This is to certify that the

thesis entitled

A Computer Based
Biofeedback Training System

presented by

Juan Carlos Esteva

has been accepted towards fulfillment
of the requirements for

Masters degree in Science
Electrical Engineering
&
Systems Science

R Hallgren
Major professor

Date May 7, 1982

A COMPUTER BASED
BIOFEEDBACK TRAINING SYSTEM

By

Juan Carlos Esteva

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Electrical Engineering
and Systems Science

1982

ABSTRACT

A COMPUTER BASED
BIOFEEDBACK TRAINING SYSTEM

By

Juan Carlos Esteva

This thesis is concerned with the development and testing of an instrumentation system to be used as the basis of a biofeedback training technique in the treatment of fecal incontinence (encopresis).

The system records, digitizes and processes human rectosphincteric responses, utilizing this information to create animated figures to be employed as the biofeedback visual pathway.

The rectosphincteric responses are detected by a pressure transducer, passed through an amplifier, digitized, and finally displayed in a comprehensive form using a T.V. monitor.

An APPLE II computer conducted the digital data processing necessary to display the animated figures, making use of high-resolution graphics.

Truly, truly, I say to you,

he who believes in me,

the works that I do shall he do also;

and greater works than these shall he do;

because I go to the Father.

--John 14:12

ACKNOWLEDGEMENTS

The author wishes to express his deep appreciation and gratitude to these people, for making this phase of his graduate work possible:

To Richard C. Hallgren, Ph.D., his major advisor, for his encouragement, support, and friendship, and, especially, for his valuable assistance in the preparation of this thesis;

To his family, Motek, Marita, and Gabo, for their understanding, encouragement, endless patience, and interest in his graduate work and academic education.

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Chapter I.

INTRODUCTION

In our rigidly toilet-trained society, fecal incontinence (encopresis) is a stigma of great magnitude. This condition of disordered motility often imposes sharp limitations on geographic and social mobility on human patients.

Presently the treatment of encopresis is generally of two types, one comprising a wide range of anti-obstipational measures, such as dieting, laxatives, enemas, and manual evacuation, and the other being psychiatric. Most authors who address the topic appear to consider simple psychological measures sufficient if the patient is willing to cooperate.

The application of psychotherapeutic techniques, like biofeedback, in the treatment and control of different bodily responses has been studies since 1967 but it was not until 1974 that biofeedback was applied in the treatment of fecal incontinence by Engel et al [1].

The Engel experiment showed that rectosphincteric responses can be brought under voluntary control in patients with chronic fecal incontinence, even when the problem was secondary to organic lesions.

It was found, while searching the literature, that some other authors had done similar experiments. Cerulli treated fifty patients with severe cases of encopresis and achieved a good response to the biofeedback training. Ninety percent of his patients learned to have almost normal bowel movements.

Wald uses the same technique but applied it to children with meningomyelocele and obtained a good clinical response with the disappearance of soiling or a greater than 75 percent improvement in the frequency of soiling.

In general, the biofeedback technique used in these experiments was to provide the patient with a feedback signal in the form of polygraph tracings that would allow him to perceive his previously unavailable physiologic response.

The work that preceded the writing of this document was intended to develop an instrumentation system that would record, digitize and process human rectosphincteric responses that will form the feedback pathway in the treatment of fecal incontinence.

The main body of this thesis deals with the description of the system and the experiment protocol developed.

For those persons unfamiliar with either medical and engineering terms, a glossary of terms used in this thesis is provided.

Chapter II.

LITERATURE SURVEY

2.1 Biofeedback

2.1.1 Definition

Biofeedback can be defined as the use of monitoring instruments to detect and amplify signals provided by some selected physiologic processes in order to make previously unavailable physiologic information accessible to the subject's consciousness. The subject is thus able to learn voluntary control over autonomically regulated body functions.

2.1.2 Historical Background

Since the time of Plato a dichotomy has been maintain between "reason" on the one hand and "emotions" on the other. Associated with "reason" are the voluntary responses of the skeletal muscles, while "emotions" are related to the presumably involuntary glandular and visceral responses. This conception has persisted, in one form or another, to the present time. Learning processes, which have been studied by psychologists and physiologists since the latter part of the nineteenth century, have been divided into two kinds: one is the classical or Pavlovian conditioning, and the other is the operant or instrumental conditioning.

In classical conditioning (which is thought to be involuntary) a stimulus or signal is identified, such that when it is presented, it will elicit a reliable and consistent response from a subject. Such a signal is called an unconditioned stimulus (US), and the response it elicits is called an unconditioned response (UR). A second signal, one that neither elicits nor inhibits the UR, is then identified; it is termed the conditioned stimulus (CS). In a typical experiment, the CS is presented along with an innate US (such as food), which normally elicits a particular innate UR (such as salivation). After several such pairings, or associations, the CS can be seen to elicit the same UR as the US. The CR's are mediated by the autonomic nervous system (ANS), as well as by the somatic nervous system (SNS).

Most human learning is not acquired through classical conditioning; it is acquired through operant conditioning. The analysis of operant conditioning begins with a response (R). The goal of operant conditioning is to change the frequency and/or the probability of occurrence of R.

Once the operant level, or base rate, of R is determined, the investigator then modified the situation so that whenever R occurs, it always will be followed by a consequence, or reinforcer, which is salient to the subject. If the reinforcer is positive (rewarding), the frequency and the probability of occurrence of R will increase; if the reinforcer is negative (punishment), the frequency and probability of occurrence of R will decrease.

The possibilities of learning are limited in classical conditioning, as the US and UR must have a natural, direct relationship to begin with. In operant conditioning, on the other hand, the reinforcer strengthens any immediately preceding response.

These assumptions have coalesced into the point of view that operant conditioning is possible only for skeletal responses mediated by the central nervous system (CNS). Conversely, classical conditioning is the only procedure available for the "inferior" visceral, emotional, and presumably involuntary responses mediated by the ANS.

Recently, an abundance of data (Barber et al [2], Kimmel [3]) pertinent to these assumptions has appeared, all of which demonstrate that the traditional view concerning the ANS is fallacious. Kimmel (1967), in a review of recent research on this topic, concluded: "The autonomically mediated responses can be changed by operant training procedures." (Page 344)

2.1.3 The Biofeedback Paradigm

The concept of biofeedback involves an organism placed in a closed feedback-loop where information concerning one or more of his bodily processes is continually made known to him. This system is illustrated in Figure 1. When the organism possesses such information about a bodily process, he can learn to control the function.

Thus, biofeedback techniques are based on the principle that certain responses are made when informational feedback is received by an organism. These responses are adjusted, corrected, and modified as feedback is continually received until a determination is made that a final goal has been achieved.

2.1.4 Clinical Applications of Biofeeback Training

Several studies have shown that the clinical application of biofeedback training has profound implications for a variety of disorders.

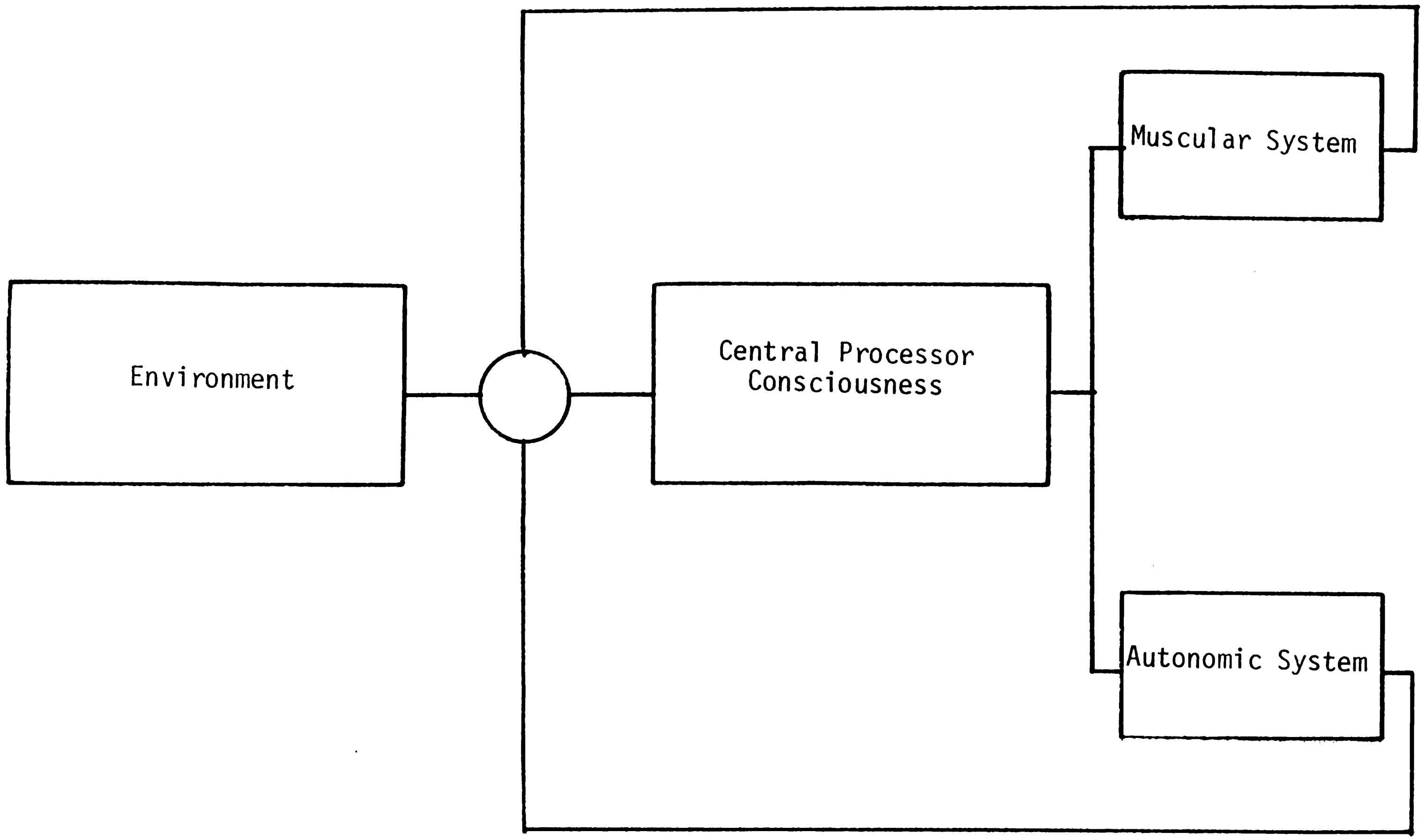


Figure 1. Closed-loop Biofeedback System

Among the responses already studied are heart rate and heart rhythm [4,5,6]; blood pressure [3,5]; muscle spasm; vascular tone; skin temperature and/or peripheral blood flow; and sweat gland activity. General references to these studies are given in the bibliography [2].

An example of such studies are those done by Blanchard et al [7], in which patients have been taught to modify heart rate (HR) through operant conditioning (or biofeedback training); Table 1 presents a summary.

2.2 Physiological Background

2.2.1 Gross Anatomy of Anorectum

The perineal region, or perineum, includes two parts, the anal and the urogenital regions. The former (Figure 2) includes the area between the tip of the coccyx and an approximately transverse line passing in front of the anal canal, between it and the urethra in the male and the vagina in the female. The roof of the anal region, separating it from the pelvis, is the pelvic diaphragm, formed by the levator ani and coccygeous muscles.

Rectum: The rectum varies in length from 12 to 15 centimeters. Its cephalad limit is indefinite, and its caudal border lies at the junction at which the mucous membrane of the rectum blends into the anal canal (anorectal line). The portion of the rectum which lies caudal to the perineal portion is supported by all the muscles of the anorectal region, namely the coccygeous, rectococcygeous, levator ani and external sphincter.

Anus: The anus measures 2 to 4 centimeters in diameter when distended. It is surrounded by the internal anal sphincter; and as the

Table 1. Summary of Studies Using Biofeedback of Heart Rate [7]

Authors	Clinical Response	No. of Subjects	Frequency Duration Treatment	Training Procedure	Concurrent Other Treatment	Results: Bioelectric Response	Results: Clinical Response	Experimental Design: Type of Design	Experimental Design: Quality of Control Procedures
Weiss & Engel [4]	Premature ventricular contractions (PVC)	8	22 to 53 sessions of 17 min per day.	Training in HR control using binary feedback: speeding, slowing, alternate speeding and slowing, maintain HR within range (direct feedback of PVC occurrence), fadeout of feedback.	None		Decreases in PVC rate in 5/8 within treatment; decreases in PVC rate in 4/8 at independent check from 10 - 20/min to 1/min.	Systematic case study with 7 replications.	Long base line by history; no base line sessions; follow-up in all cases.
Engel & Bleecker [5]	PVC	1	16 daily sessions of 17 min.	Control using binary feedback taught for 4 sessions each; slowing, speeding, alteration, maintain HR in range.	None		Decrease in treatment of PVC rate: 15/min to 1/min.	Systematic case study	Long base line by history plus 2 base line sessions; follow-up.
Engel & Bleecker [5]	Supraventricular tachycardia & PAT	1	26 daily sessions of 17 min.	Training in HR slowing	None	In-session decrease of 2/6 BPM.	Base line HR-116 BPM; final session HR-105 BPM: follow-up HR-60-75 BPM; no PATs reported.	Systematic case study	Base line by history; 1 base line session, 5 follow-up sessions.
Engel & Bleecker [5]	Sinus tachycardia	1	21 daily sessions of 17 min.	Training in HR slowing (12) & fadeout of feedback (9).	None	In-session decreases of 3 to 4 BPM.	Decrease in treatment of HR from 86 to 68 BPM.	Systematic case study	Base line by history; no base line sessions; no tachycardia in sessions.
Engel & Bleecker [5]	Paroxysmal atrial tachycardia (PAT) and episodic sinus tachycardia	1	40 daily sessions of 17 min.	Training in HR control; HR slowing (20 sessions); HR speeding (10); alteration (10).	Diazepam 5 mg. tid	Little learning of slowing, speeding by 15-20 BPM.	No data on clinical response during treatment no report of PAT for 9 mo after treatment.	Anecdotal case report	Base line by history; no in-session base line; no in-session data on clinical response.
Scott et al [6]	Sinus tachycardia	2	(1) 53, 20-min sessions 2/day (2) 30 20 min sessions day.	(1) Training in HR slowing using two shaping procedures. (2) Training in HR slowing using one shaping procedure.	None		(1) Base line HR-89, no decrease in 26 sessions, then decrease to 72 BPM in 18 sessions. (2) Base line HR-96, decrease to 78 BPM.	Controlled single-subject experiment, A-B-A	Stable base line established in session; return to base line in treatment.
Bleecker & Engel [5]	Wolff-Parkinson-White syndrome (conduction disorders).	1	Unspecified No. of daily sessions 17 mins.	Patient trained to slow HR, speed & slow, then direct feedback of W-P-W beats.	None	Learned alternation	Patient learned to produce WPM or normal beats at will and to increase normal conduction; no overall lasting clinical effects noted.	Anecdotal case report	Base line by history; no systematic data on clinical response; no base line sessions.
Prigatano and Johnson	Approach to feared object (spider)	26	2, 60-min sessions	Experimental & control subjects pretested: experimental subjects trained to hold HR constant while viewing picture of spiders.	None	Experimental subjects did not learn HR control.	No difference between experimental & control subjects at post-treatment test of fear.	Controlled group outcome study	Controls matched on pretest, received 2 sessions of tracking task.

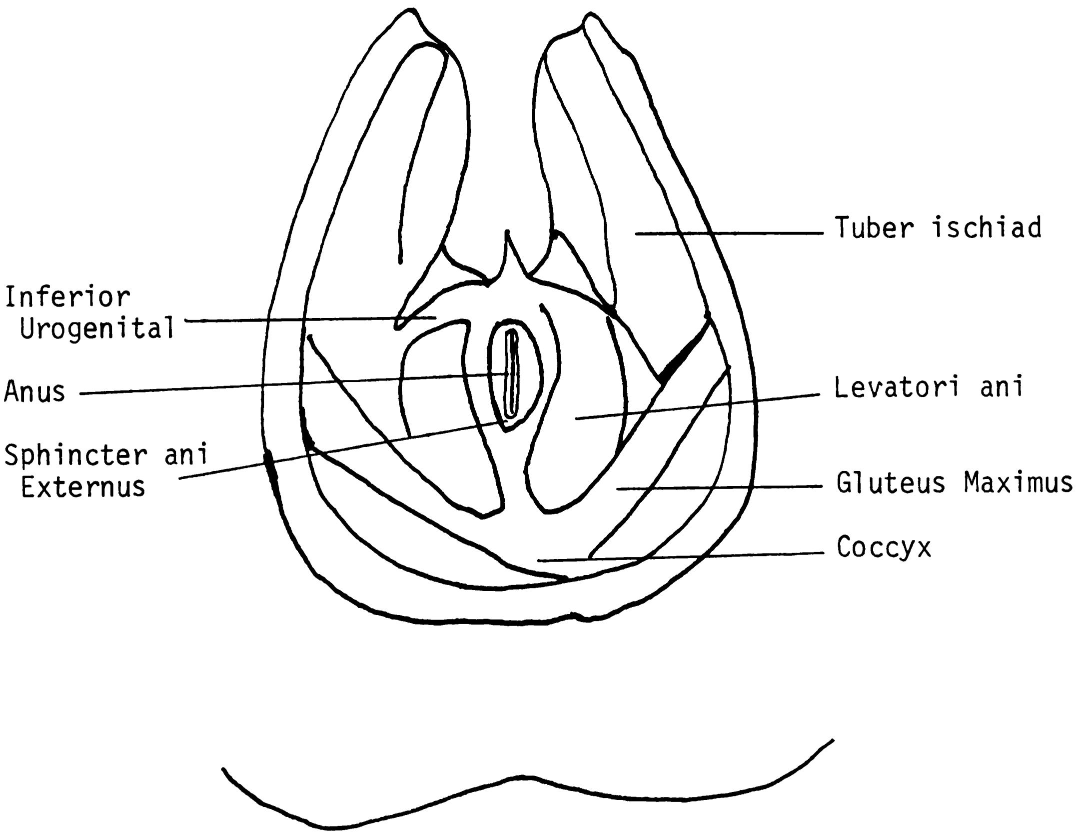


Figure 2. Muscles of the Anal Region (Perineum)

anal canal makes its exit through the pelvic diaphraghm, it is surrounded by the external anal sphincter (Figure 3).

The internal anal sphincter is a circular muscle which is continuous with the inner, circular layer of smooth muscle of the anal region. In its normal, resting state the internal sphincter is strongly contracted. Since this sphincter is smooth muscle, it is autonomically innervated. Parasympathetic stimulation relaxes it, and sympathetic stimulation contracts it. Relaxation of the internal anal sphincter is a necessary condition for the occurrence of defecation.

The external anal sphincter surrounds the internal sphincter and extends beyond it to form the terminal muscle of the anal canal. In its normal, resting state the external sphincter is slightly contracted. It is innervated by the somatic nervous system. Relaxation of this sphincter is necessary for defecation to occur, while its contracture is necessary to preserve continence. Stimulation of the nerves produces contraction, and inhibition produces relaxation. The internal anal sphincter is innervated by autonomic nerves, and the external sphincter is amenable to voluntary control.

2.2.2 Mechanisms of Continence

Fecal continence refers to the ability to retain bowel contents until evacuation becomes convenient. This includes the recognition and differential control of the passage of solids, liquids, and gases. Thus, continence requires an intact nervous reflex arc and a functioning motor component capable of retaining material. Normally, defecation is under cortical control and can be suppressed at will; and conscious differential recognition can be made of the three physical states of the bowel contents.

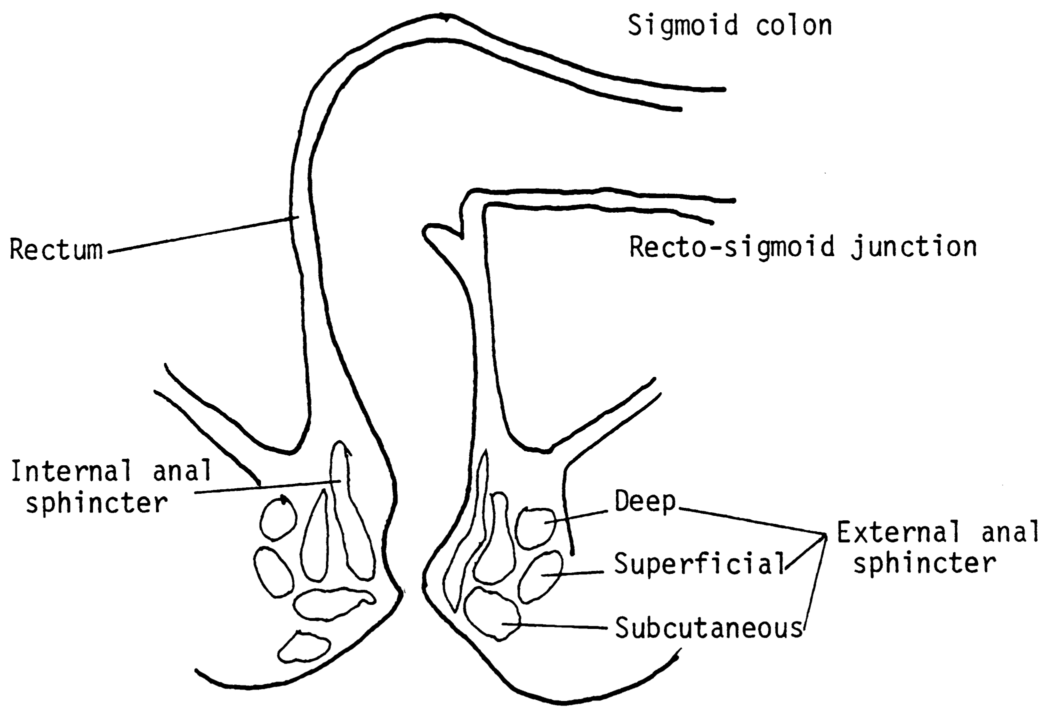


Figure 3. Internal and External Sphincters

Three basic mechanisms (Figure 4) are involved in the maintenance of continence: the sensory stimulation by intraluminal contents, reservoir action of the colon, and sphincteric contractions. Recto-sphincteric reflexes play an important role in this regard.

2.2.2.1 Reservoir Continence

The rectum usually contains little or no material except shortly before defecation, at which time feces are propelled into the rectum. The rectum serves a twofold role in preserving continence. It acts as a compliant reservoir for intestinal contents, and also as the sensory receptor organ for rectosphincteric reflexes. Reservoir continence refers to plastic adaptation (compliance) of the colon and can be totally sufficient even in the absence of anal sphincters. This reservoir function plays a more important role in the prolonged retention of feces than the sphincters, since the external sphincter fatigues after brief contraction (less than one minute). Rectal sensory receptors apparently increase in concentration in a caudad direction, since smaller volumes of distention are required to elicit sensation or to initiate rectosphincteric reflexes as distention progresses caudally. Evidence is conflicting as to whether these receptors are in rectal mucosa or the muscle wall.

2.2.2.2 Sphincter Continence

Like the rectum, the anal sphincters subserve two functions in preserving continence. The constant tone of the anal sphincters (especially the internal sphincter) closes the anal orifice and may serve to impede the rectum in amounts insufficient to distend it. This is a reflex

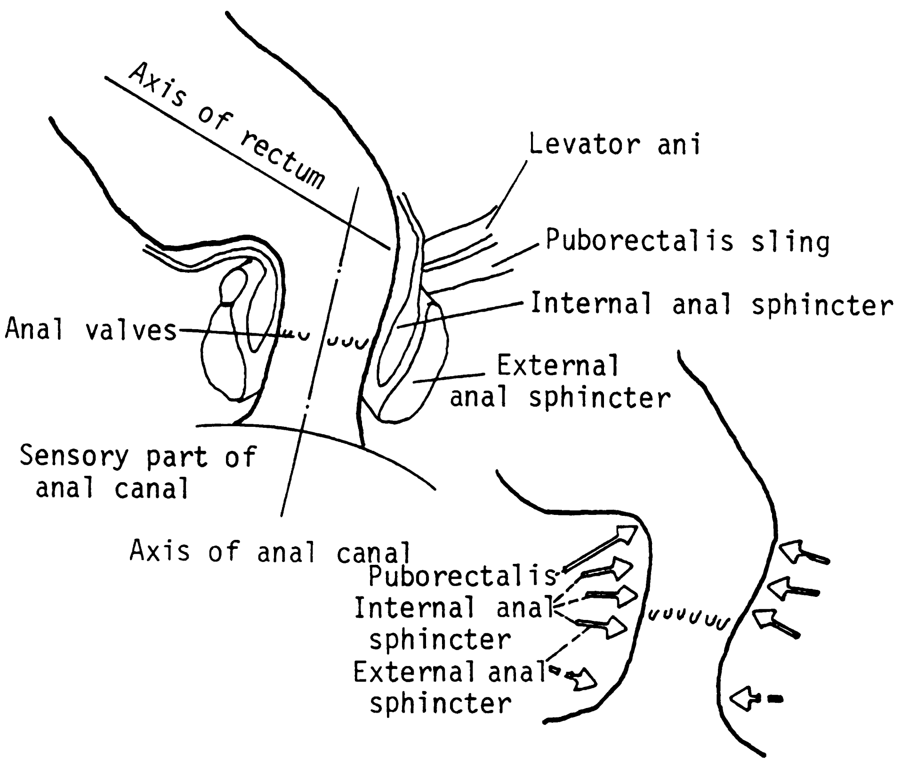


Figure 4. Diagram of Sagittal Section through Anal Canal and Lower Rectum To Demonstrate Factors Involved in Anal Continence. [Arrows in outline diagrams at right represent forces involved. (From Duthie,20)].

phenomenon without a voluntary component. The internal sphincter appears primarily concerned with the control over flatus and liquid stool.

The external sphincter, by its voluntary contraction when rectal fullness is sensed, or by reflex contraction when the rectum is distended, may facilitate continence. The external sphincter reflexly develops increased tone under circumstances that threaten continence, as when intraabdominal (and intrarectal) pressure is increased during weight-lifting or coughing. Since the external sphincter fatigues with less than a minute of voluntary contraction and also reflexly contracts only briefly even with prolonged rectal distention, its role in maintaining continence is an emergency mechanism effective only briefly. This mechanism can be effective because feces, entering the rectum, stimulate a very transient rectal contraction lasting a few seconds. There is concomitant contraction of the external sphincter which outlasts the rectal contraction. The greater the rectal distention, the greater is the force of sphincter contraction, although the duration of sphincter contraction remains unchanged. Removing the rectum destroys this reflex, although the external sphincter and its motor supply remain intact, as demonstrated by normal voluntary contraction.

In summary, the maintenance of continence is a complex and poorly understood phenomenon relying largely on reflex mechanisms and on the threatening stimulus. Rectal pressures, folds, and valves keep this area relatively free of intestinal contents. When material enters the rectum in amounts insufficient to distend it, continence is maintained by the "locking" effect or resistance of the tonically contracted internal sphincter. Increased intraabdominal pressure (produced by coughing, straining, and lifting) does not expel the material, because it activates the flutter-valve mechanism that tends to keep the anal canal closed and thus avoids stimulation of anal mucosa and conscious awareness of threatening incontinence. When contents enter the rectum sufficiently to distend it, and intraluminal pressure increases, the internal sphincter relaxes momentarily; this permits stimulation of the sensitive anal mucosa, but simultaneous external sphincter contraction prevents soiling. The warning signals from the anal receptors allow voluntary contractions to act as a further retentive force, and this, with the compliant adaptation of the rectum, permits a reversal of the pressure differential to the normal resting state. The adaptation of the rectum to its new volume and the removal of anal sensory stimulation also afford relief from discomfort.

2.2.3 Pathophysiology of Defecation

Most of our understanding of human disturbances in defecation derives from the perceptive observations of Hurst, whose balloon and radiographic studies of the pelvic colon and rectum clearly showed that the rectum could adapt in a plastic manner to increasing pressure or bolus size without triggering off a defecatory reflex. He distinguished between defecatory disturbances due to problems in the colon above the rectum and those due to rectal defects. As a general rule, patients with disturbances in defecation either have a rectal ampulla empty of feces--implicating the pelvic colon as the source of the difficulty--or chronically full of feces--focusing attention on the rectum itself as the cause of the trouble. Socially acceptable behavior requires that normal persons must often inhibit defecatory impulses as soon as they occur; this inhibition is effected by voluntary contraction of the external anal sphincter and by voluntary elevation of the pelvic floor. It is probable that the rectum adapts to the magnitude of the pressure increase which initiated the reflex, and it can be demonstrated that a large pressure increase will be necessary subsequently to cause the rectal sensors to fire off. Continuous inhibition of these reflexes over a period of months or years is probably a principle mechanism for the development of rectal constipation.

Another disturbance is fecal incontinence or encopresis. As a rule, encopresis is defined in the literature as repeated, involuntary evacuation of feces in the clothes without there being any gross explanatory cause. Isolated mishaps are thus not included.

A typical feature of this syndrome is that the child refuses to use a pot or toilet or that it repeatedly postpones the use of these facilities. Usually, the consistence of the feces is normal.

In those cases in which the patient completely refuses to use the toilet, all the feces are passed into the clothes, usually daily and with the usual amount, consistence, and caliber; this mostly occurs among very small children. Among children aged 6 - 12 years, refusal to use the toilet is said to be due to deep-seated mental disturbances which are very difficult to deal with.

Other children do most of their defecation on the toilet but pass a small stool into their clothes each day. Kanner (1953) calls this partial encopresis. In these cases, too, the feces are of normal consistence. These children state that they experience the urge to defecate but are prevented from going to the toilet by haste, by fear of the dark, by not daring to ask permission to leave the classroom, etc.

Even though encopretic children may protest that they cannot control their bowel function, many of them have symptom-free periods of varying length, when it is to their advantage. They commonly hide their soiled clothes behind furniture, etc., according to these authors when a parent has scolded them or made them feel ashamed.

Encopresis does occur among psychotic adults or among those who are seriously retarded, especially if they have severe organic lesions in the brain. Otherwise, encopresis appears to be extremely rare among adults.

In general, methods of treatment for encopresis have varied with the alleged cause of the symptom. Mostly, it has been considered either as an obstruction or as a psychiatric problem. Believers in the former cause have emptied the large intestine with laxatives, enemas, suppositories, or manual evacuation. Believers in the latter cause advocate psychological or psychiatric treatment, possibly combined with other measures.

2.3 Advances in Biofeedback Conditioning for Encopresis

2.3.1 Motility Recordings

The anorectal area does not readily lend itself to the methods usually employed for the study of the more proximal portion of the colon, such as direct observation of the exposed viscera of animals or persons under anesthesia, fluoroscopic examination, or routine pressure recordings by balloons, or open-tipped tubes lying passively in this area.

Manometric recordings of lower bowel motility have also been difficult to interpret because this segment frequently displays no spontaneous activity for periods as long as six (6) hours. Attempts to stimulate normal activity have been met with inconsistent results, and the activity observed has not been clearly related to this segment's primary function, defecation.

Schuster et al [9] describes an internal anal sphincteric response that can be elicited at will, is regularly reproducible, and is analogous to the physiological concomitants of defecation. This response is essentially that reported in 1877 by Gowers [10], who found that insufflation of air into the rectum produces relaxation of the internal anal sphincter.

Schuster et al [11] has designed an investigation to define, in the human, the normal physiology of the sphincter response, the neural pathways involved, and the effect of various disorders of bowel function upon this response. The apparatus used to measure sphincter function consisted of a balloon assembly attached via polyethylene tubes to Sanborn's differential pressure transducer and a direct-writing electrical recorder. See Figure 5.

There are, however, two major limitations to this method. First, measurements are obtained only from the internal sphincter. This is a serious drawback, since the anal sphincter is composed of two parts, the internal and the external sphincters. Second, this technique requires that the recording device must be held in place manually.

Schuster et al [12] extended the investigation to permit simultaneous recordings from both internal and external anal sphincters. The apparatus used to measure sphincter function consisted of a hollow steel cylinder 22 mm in outer diameter, 21.5 mm in inner diameter, and 10 cm long, surrounded by two balloons which created two separated compartments, which recorded separately from the internal and external sphincter. See Figure 6. With this technique, it can be shown that rectal distention produces simultaneous internal sphincter relaxation and external sphincter contraction.

2.3.2 Operant Conditioning Biofeedback

Since Miller [13] reported the results of operant conditioning of visceral responses in the curarized rats, others have used biofeedback to control different bodily responses. The application of biofeedback techniques in treating fecal incontinence was first described by Engel et al [1] in 1974. He described the means by which six patients with severe fecal incontinence and manometric evidence of external sphincter impairment were taught to produce external sphincter relaxation. These responses were induced by rectal distention. The feedback was provided to the patient by permitting him to watch the polygraph tracings of his sphincteric responses as they were being recorded. Verbal reinforcement was also used at the beginning of the process, then gradually diminished. During follow-up periods, four of the patients remained completely continent, and the other two showed definite improvement. The Engel experiment showed that recto-sphincteric responses can be brought under voluntary control in patients with chronic fecal incontinence, even when the problem is secondary to organic lesions. Engel [14] showed that although the recto-sphincteric reflexes are neurally mediated responses of the anal sphincters to rectal distention, these responses can be brought under voluntary control. This study was done on a patient who complained of chronic severe fecal incontinence (about five years) of solid stools following rectal surgery. This patient was first trained to

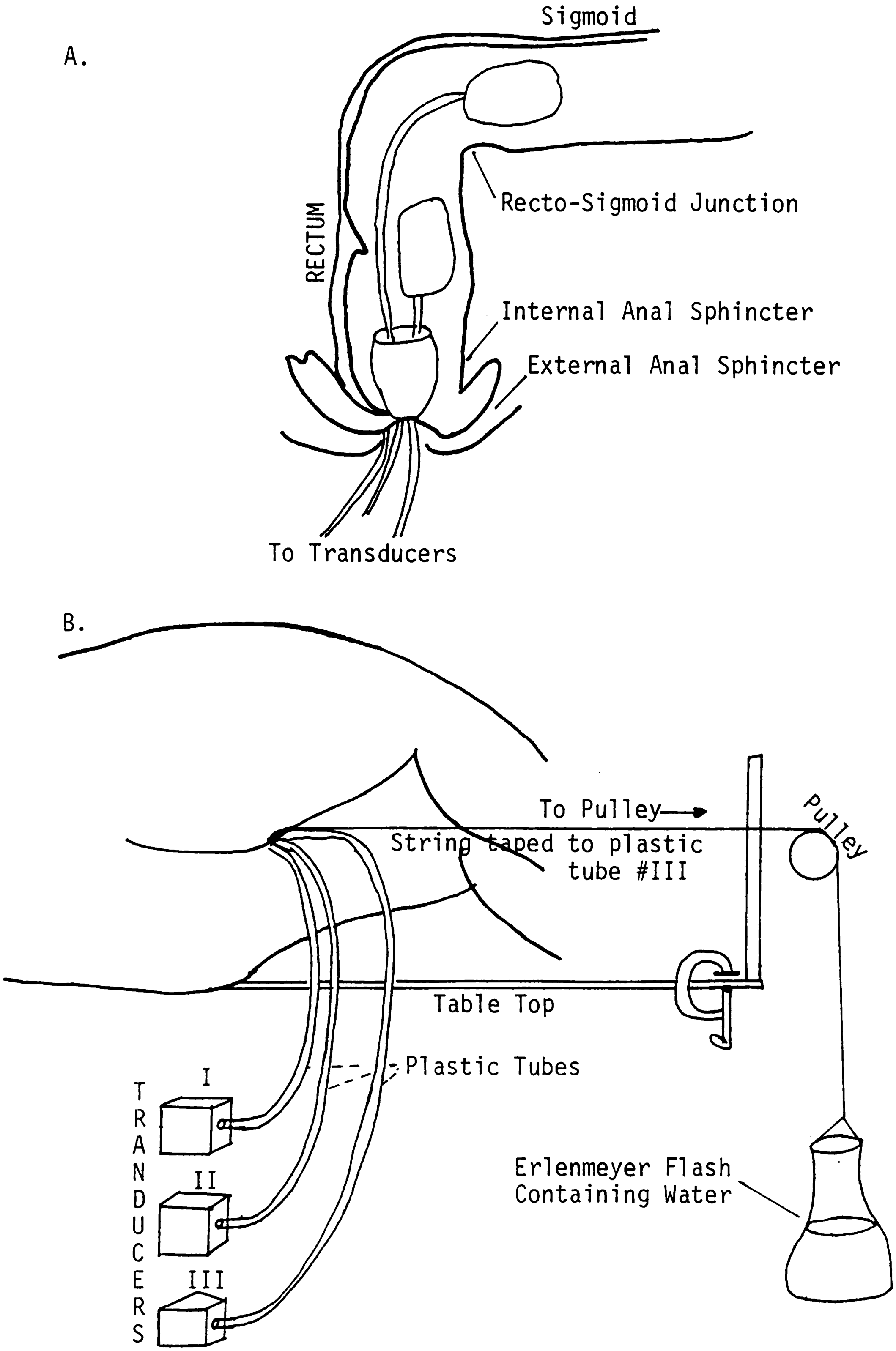


Figure 5. Schematic Diagram of Recording Technique.
[A. Balloons in situ without weight attached to caudad tube.]
[B. Counterweight traction applied to caudad tube.]

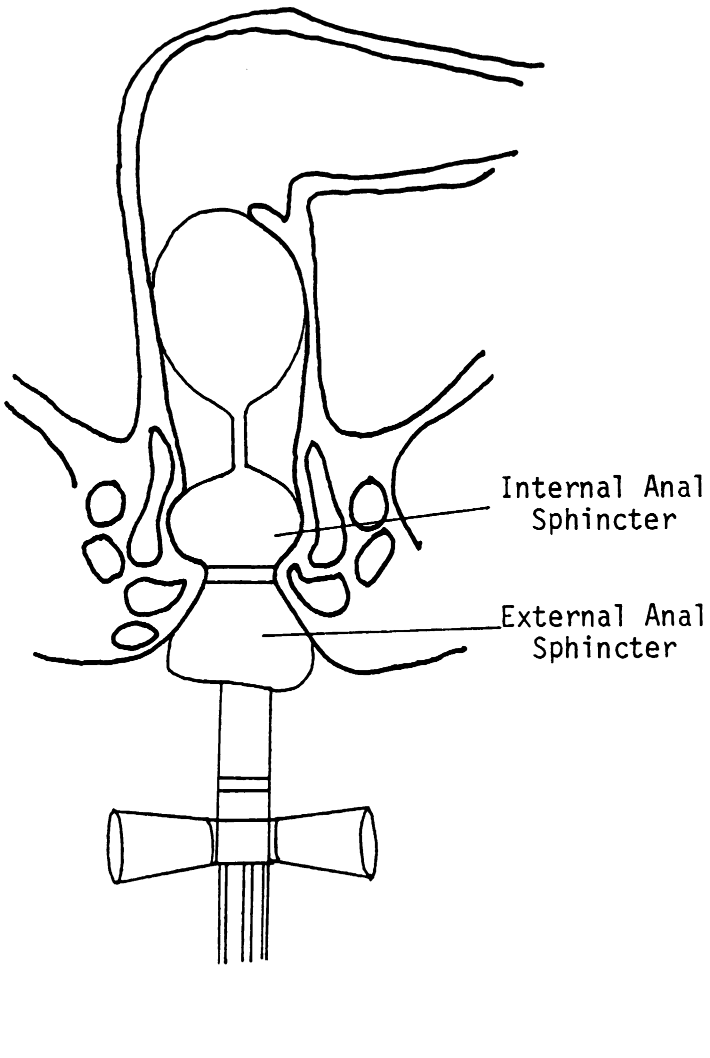


Figure 6. Measurement Device for Internal and External Sphincters.

relax her internal sphincter and was subsequently trained to contract her external anal sphincter. Following internal sphincter training she began to have normal bowel movements; following external sphincter training, she became continent. The feedback used was in the form of polygraph tracings.

Cerulli et al [15] treated fifty patients with severe daily fecal incontinence through biofeedback techniques. The training made use of a three-balloon system (as the one described by Schuster [12]) connected to a physiograph. Twenty-four patients had incontinence associated with previous anorectal surgery, while eleven had had spinal surgery. Patients were taught to develop reflex transient contraction of the external sphincter in response to rectal distention. The physiograph provided the feedback to the patient. Forty-five patients achieved a good response to biofeedback training, as evidenced by disappearance of incontinence or by a decrease in frequency of incontinence by 90 percent.

Olness et al [16] described how fifty children and adolescents who had severe fecal incontinence associated with either imperforate anus surgery in infancy or longstanding functional constipation were given biofeedback training for the purpose of achieving analsphincter control. The feedback was in the form of oscilloscope tracings which the children learned to produce by contracting small air-filled balloons positioned at the internal and external anal sphincters. Forty-seven of these patients learned to have voluntary bowel movements, and thirty eliminated soiling accidents.

Wald [17] reported on fourteen children, aged 5 to 17 years, with meningomyelocele and significant fecal soiling who underwent anorectal manometry using a three-balloon system connected to a physiograph. On the basis of manometric criteria, eight patients were taught to contract the external anal sphincter or nearby gluteal muscles in response to various volumes of rectal distention. Four of the eight patients who were treated with biofeedback had a good clinical response with disappearance of soiling or a greater than 75 percent improvement in the frequency of soiling. The feedback was in the form of physiographic tracings.

Chapter III.

SYSTEM ORGANIZATION

3.1 Characteristics of the System

The developed system obtains, analyzes, and feeds back human sphincter responses. The basic feature of this system is related to the treatment of fecal incontinence (encopresis) by operant conditioning through the use of a biofeedback system.

This biofeedback system is composed of four different parts, which are: 1) the pressure measurement device, 2) the data acquisition stage, 3) the data analysis, 4) the graphic generation and visual feedback path. A block diagram of the system is shown in Figure 7.

The pressure response of the external sphincter is detected by a two-balloon system, as the one described in Chapter II, connected through a pressure transducer to an amplifier. The amplified signal is then routed to an A/D converter which transforms the analog voltage into a binary representation. This binary representation is analyzed by an Apple II minicomputer and then used to generate the animated figures employed as the biofeedback path.

3.2 The pressure measurement device.

The pressure measurement device is formed of two different components, the balloons and the pressure transducer.

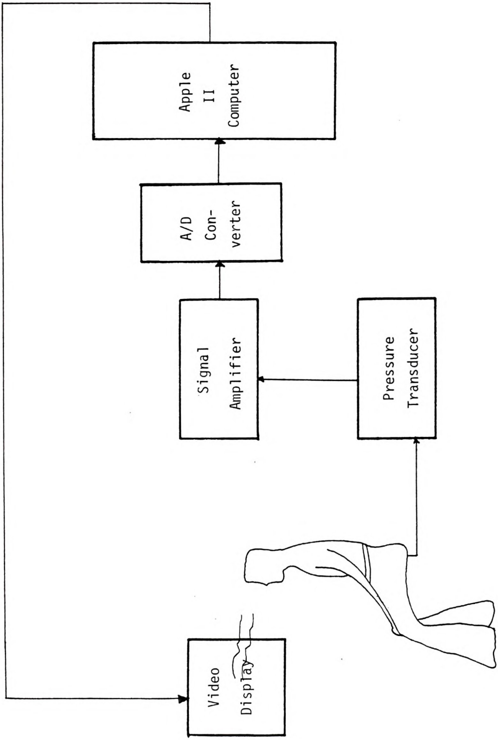


Figure 7. Biofeedback System

The balloons were selected using two different criteria. One was size, volume, and capacity required for the patient; and the other was cost and availability. Based on these two requirements, the triple lumen/double balloon (Blakemore tube, Inmed Corporation, 2950 Pacific Drive, Norcross, Georgia 30071) was chosen. Figure 8 shows the chosen balloon. The first balloon is intended for insertion into the anus at approximately the location of the inernal sphincter; the second balloon is to be positioned at the location of the external sphincter. See Figure 9.

The pressure transducer is a Statham model P23AC, and the following are the specifications provided by the manufacturer: excitation voltage of 12 volts, input resistance of 314 ohms, output resistance of 314 ohms. A 10^5 ohms resistor simulates a pressure of 16.50 cm Hg, and a 1.5×10^5 ohms resistor simulates a pressure of 11.0 cm Hg. The transducer is a strain-sensitive device in which resistance wire elements are arranged in the form of a wheatstone bridge.

Because of the lack of a pressure/voltage response curve given by the manufacturer, it was necessary to develop one. Two different methods were used, the first being a bivariate curve fitting conducted on a Texas Instruments TI59 desk calculator (Applied Statistics Module, Texas Instruments Incorporated, Dallas, Texas). The second one used experimental data to generate an approximate curve equation. The experimental data was obtained by a series of measurements of the output voltage of the pressure transducer due to a known pressure.
The equation of the pressure/voltage response is:

$$P = a \exp(-bR)$$

where P is the pressure in mm Hg, R is the resistance in ohms, and a and

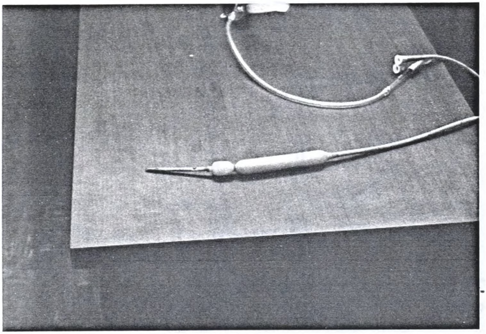


Figure 8. Triple Lumen/Double Balloon

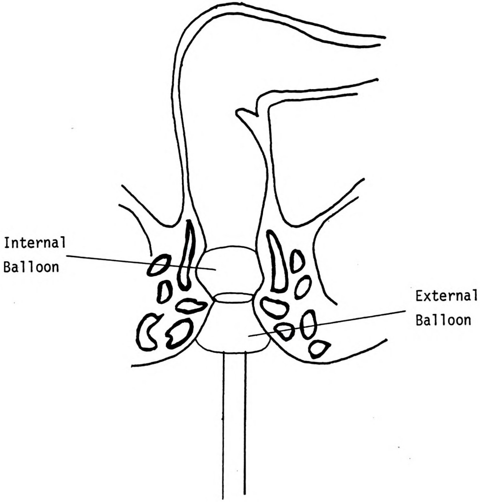


Figure 9. Schematic Diagram of Recording Technique

b are constants to be determined. Substituting the set of experimental data into this equation, a pair of equations with two unknowns was obtained. The system was solved, yielding the following equation:

$$P = 371.25 \exp (8.1\times10^{-3}R)$$

Both methods gave very similar results, which are tabulated in Table 2. Table 3 provides the output voltage of the pressure transducer as a function of the input pressure. Figure 10 shows the pressure transducer.

3.3 Data Acquisition

Data acquisition is handled by means of a high sensitivity amplifier and an A/D converter. The input signal to the amplifier may vary depending on the sphincteric response elicited by the mode of the anorectal muscles. Table 4 shows the sphincteric muscles' responses. The amplifier was designed to have a zero voltage output when the pressure input was less than 5 mm Hg and a maximum voltage output when the pressure input was 30 mm Hg.

The data sheets of the AD571 show that if a nominal full scale of 10.24 volts is desired, the less significant bit has a magnitude of 9.76 m volts. Considering these factors, the gain of the amplifier was obtained as follows:

$$\text{Gain} = \frac{\text{Vout}}{\text{Vin}} = \frac{10.24}{6.78\times10^{-3}} = 15103$$

A standard differential amplifier stage and a non-inverter amplifier stage were used to realize the desired voltage gain. The combina-

Table 2. Approximated Transducer Response

* The last two values of resistance are given by the specification sheets of the P23AC pressure transducer.

Pressure mm Hg	R K-ohms
1	729.640547
5	531.172433
10	445.690969
15	395.696869
20	360.221305
25	332.704319
30	310.221305
40	274.74574
50	247.228755
60	224.745741
70	205.736623
80	189.270176
90	174.745741
100	161.733191
110	150 (G)
165	100 (G)

Table 3. Output Voltage of the Pressure Transducer

Pressure mm Hg	Voltage in m volts
1	0.005
5	0.045
10	0.100
15	0.296
20	0.400
25	0.560
30	0.678

Table 4. Sphincteric Muscles Responses Depending on the Mode of the Anorectal Muscles

Mode	Internal Sphincter	External Sphincter
Normal	Strongly contracted (10 mm Hg)	Slightly contracted (less than 5 mm Hg)
Defecation	Relaxation (-40 mm Hg)	Relaxation (almost 0 mm Hg)
Continence	---	Contracted (5 to 30 mm Hg)

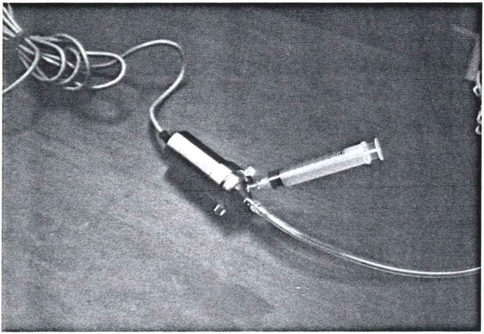


Figure 10. Pressure Transducer

tion of resistor values shown in Figure 11 provided the desired gain factor.

The off-set nulling control of the CA3140T is used to calibrate the output gain of the amplifier once the balloons are inflated.

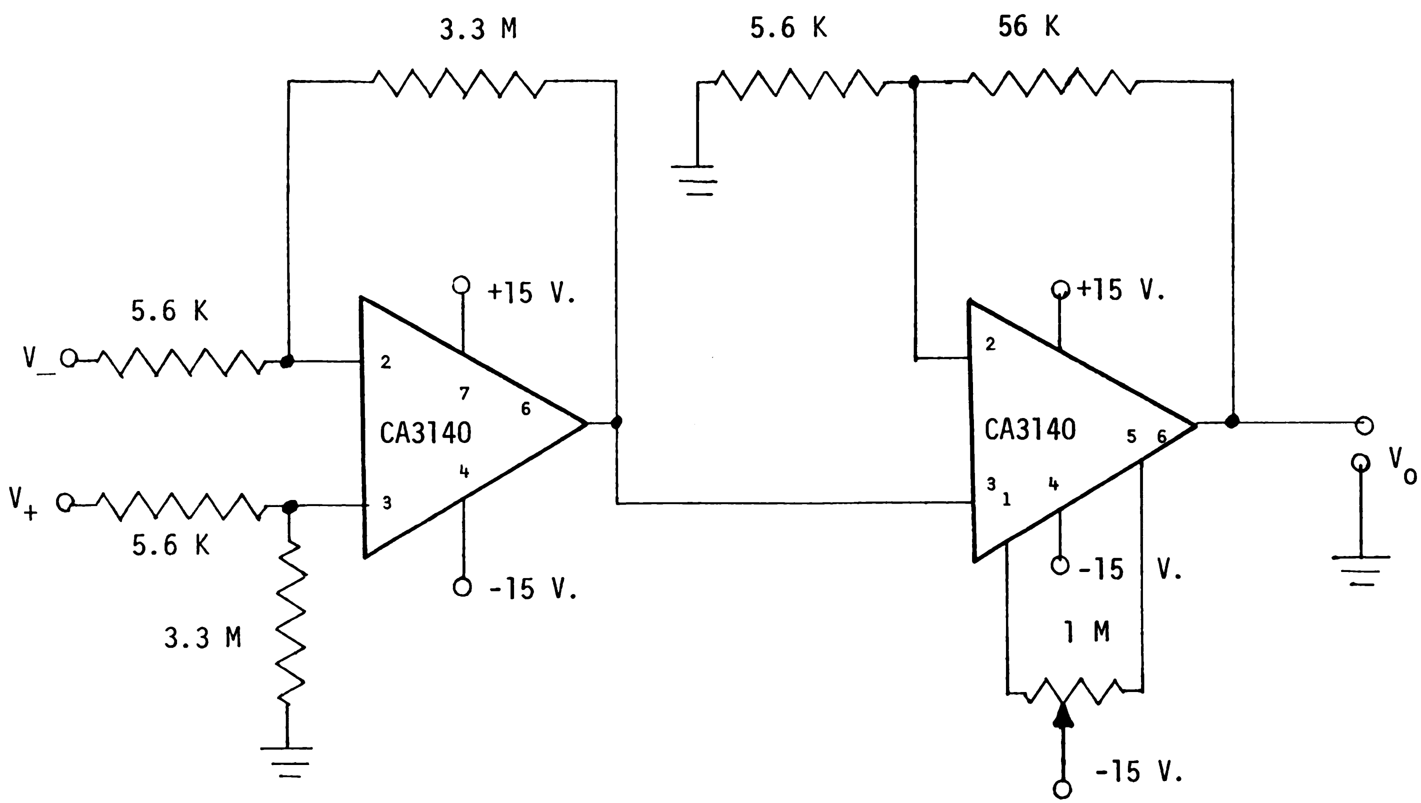
Hallgren [18] designed a high speed A/D converter for the APPLE II computer which was modified to be used in this project. Figure 12 shows the modified A/D converter circuit diagram.

The AD571 is a ten-bit successive approximation A/D converter consisting of a DAC, voltage reference, resistors, clock comparator, and output buffers. The AD571 will accept analog inputs of 0 to +10 volts (unipolar) or ± 5 volts (bipolar). Unipolar was used in this design. All data and control lines were isolated through the 74LS36AN a hex-non inverting three state buffers. The AD571 has a conversion time of 25 microsec, thus making it theoretically possible to sample at rates up to 40,000 samples/sec. The APPLE II execution time, however, reduces the sampling rate to only 10,000 samples/sec.

The MC14013B flip-flops were used to latch the three bit address, which determined the analog signal that was to be digitized, as well as to provide a strobe pulse to the A/D converter, indicating when the conversion cycle begins.

The APPLE II, being an eight-bit machine, requires the ten bits from the A/D converter to be read in two steps. The data ready (DATA RDY) line from the AD571 signals the APPLE II that the conversion cycle has finished and that the data is available to be picked up. Thus, the APPLE II transfers the two most significant bits, followed by the eight least significant bits, from the A/D converter to memory.

The software portion of the A/D converter is handled using a machine



*All resistors are in ohms

Figure 11. High Sensitivity Amplifier

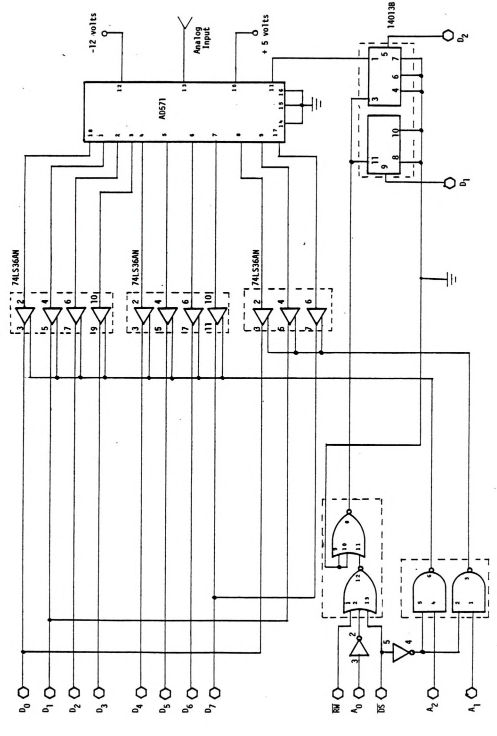


Figure 12. High Speed A/D Converter Circuit Diagram

language subroutine which provided high speed transfer of data from the A/D converter to memory. Figure 13 shows the flow chart of the machine language subroutine used to digitize the pressure response of the external sphincter, and a listing of the subroutine can be found in Appendix A. This subroutine is used in several programs that will be described later. Its main function is to transfer the data from the A/D converter to the memory of the APPLE II, allowing other programs to make use of the digitized information. The subroutine is named READER.

3.4 Data Analysis and Graphics Generation

As can be seen in Chapter II, feedback in past experiments has been provided by showing the pressure response of the sphincters on an oscilloscope or a polygraph. The APPLE II personal computer supplies three different modes of displaying information on the video display to which it is connected; these are: Text, Low-Resolution Graphics, High-Resolution Graphics. The use of the computer facilitates the generation of animated figures, which are more attractive for the patient than the usual tracings.

Once the digitized data is stored in the memory of the APPLE II, it can be used by different programs either to analyze it or to generate various kinds of dynamic displays.

The data analysis is done by two different programs written in APPLESOFT Basic. One of them is used to equate the input voltage to the computer equal to zero, which is called CALIBRATION. The other is used

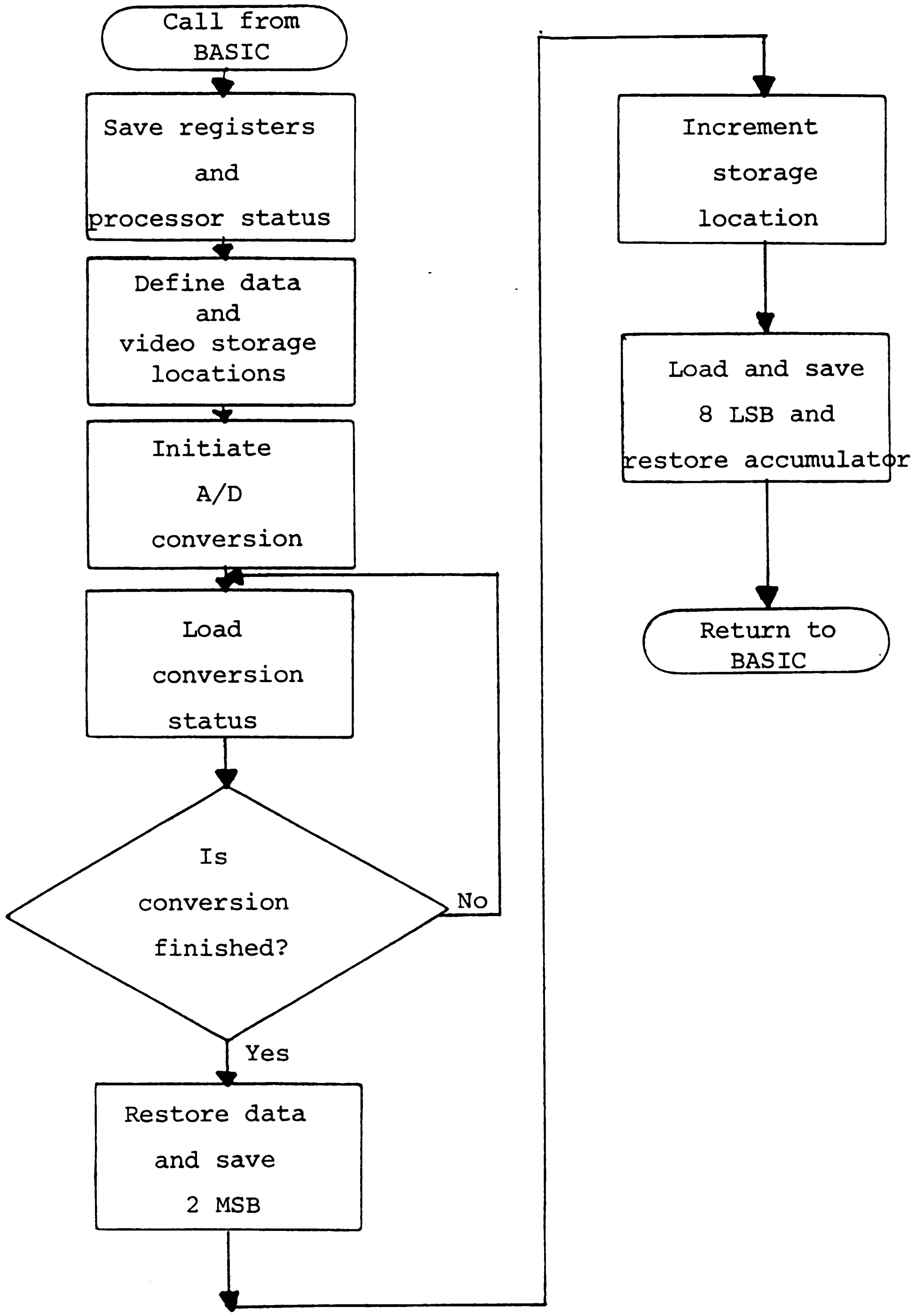


Figure 13. Flow Chart for the Machine Language Program to Digitize Sphincteric Muscle Response (READER)

in the diagnostic phase of the system to find out whether the patient is likely to have a successful training regimen. Figures 14 and 15 show the flow chart diagrams of these programs, and they are listed in Appendix B (CALIBRATION) and in Appendix C (PRESSURE).

Graphics generation is accomplished by four different programs, three of them written in APPLESOFT Basic and the last in Machine language. All four generate animated graphic displays, the three written in APPLESOFT making use of the subroutine READER. Figures 16, 17, and 18 show the flow chart diagrams for the APPLESOFT Basic programs. Program listings are in Appendices D (SQUARE), E (COLOR LINE), and F (GLASS). The program SQUARE displays a vertical bar that grows, depending on the pressure exerted by the muscle on the pressure transducer. Figure 19 shows the shape displayed by the program SQUARE. COLOR LINE displays a horizontal line that grows and changes colors, depending on the pressure exerted. See Figure 20. Program GLASS displays an empty glass which can be filled, according to the pressure exerted. See Figure 21.

The program written in machine language (EXACT) is the fastest and most accurate of the four programs. It displays two lines, one vertical, which is the pressure reference set by the researcher, and one horizontal, which is a sampling of the pressure exerted by the patient. Figure 22 shows the flow chart diagram for the machine language program EXACT; it is listed in Appendix G. EXACT is used in two different phases of the training program, as will be explained in Chapter IV. Figure 23 shows the shape displayed by the program.

All programs provide the capability to sample sphincteric responses only when either the patient or the researcher request them.

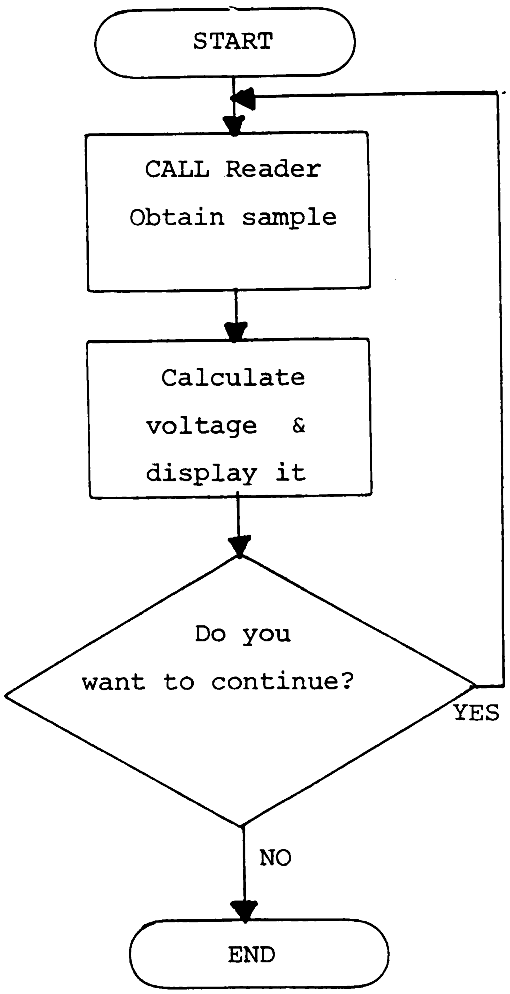


Figure 14. Flow Chart for Applesoft Basic Program to Calibrate Input (CALIBRATION)

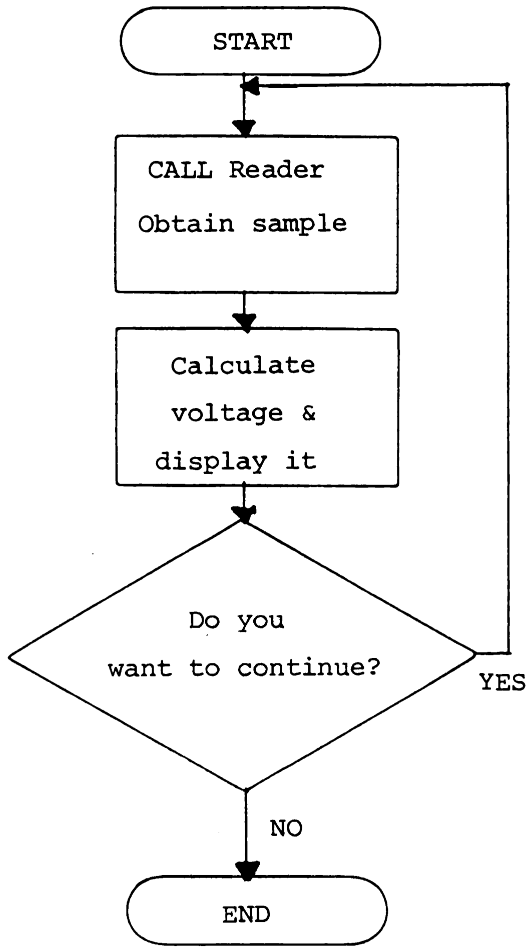


Figure 15. Flow Chart for Applesoft Basic Program to Diagnostic Initial Response (PRESSURE)

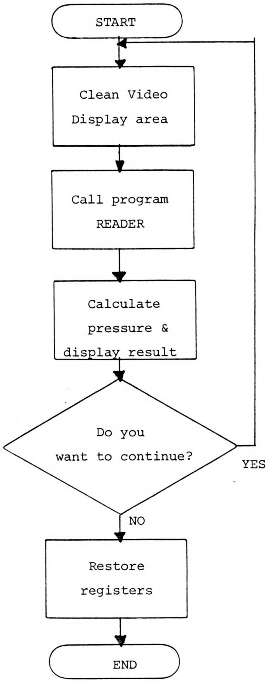


Figure 16. Flow Chart for Applesoft Basic Program that Displays a Square (SQUARE)

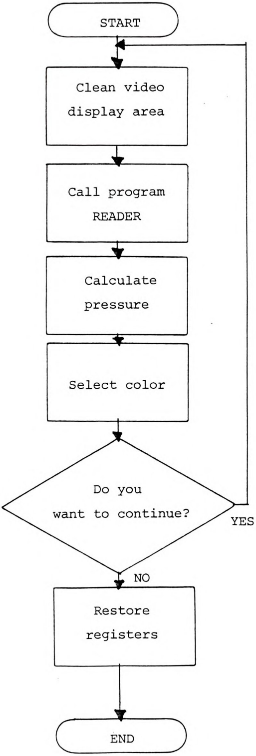


Figure 17. Flow Chart for Applesoft Basic Program that Displays a Color Line (COLORLINE)

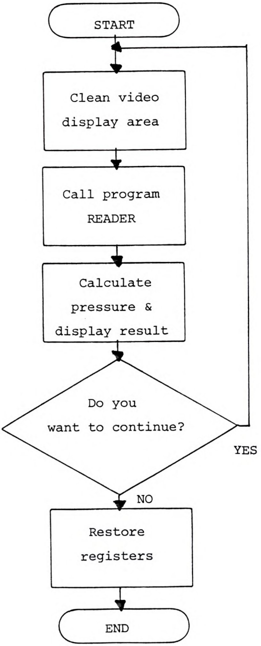


Figure 18. Flow Chart for Applesoft Basic Program that Displays a Glass (GLASS)

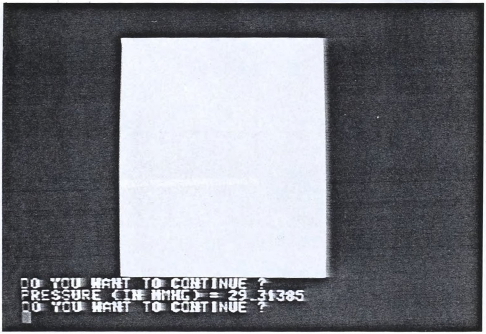


Figure 19. Shape Displayed by the Program SQUARE

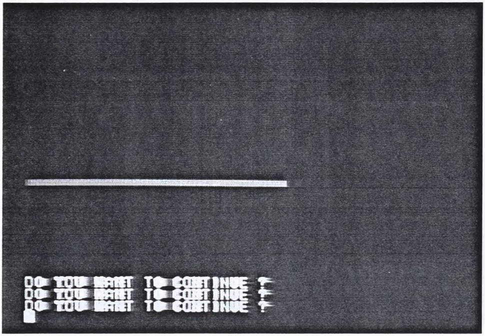


Figure 20. Shape Displayed by the Program COLORLINE

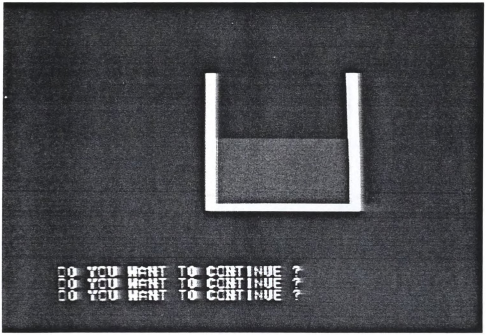


Figure 21. Shape Displayed by the Program GLASS

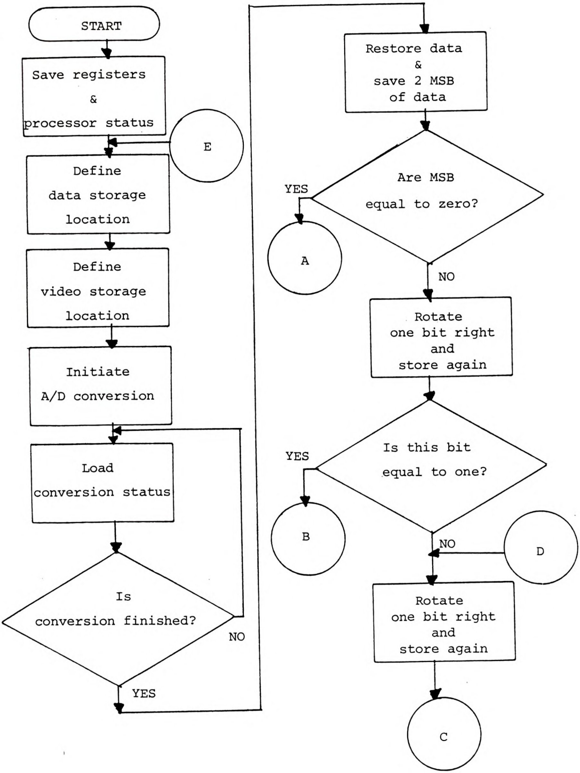


Figure 22. Flow Chart for Machine Language Program with High Speed and Accuracy (EXACT)

Figure 22, cont'd.

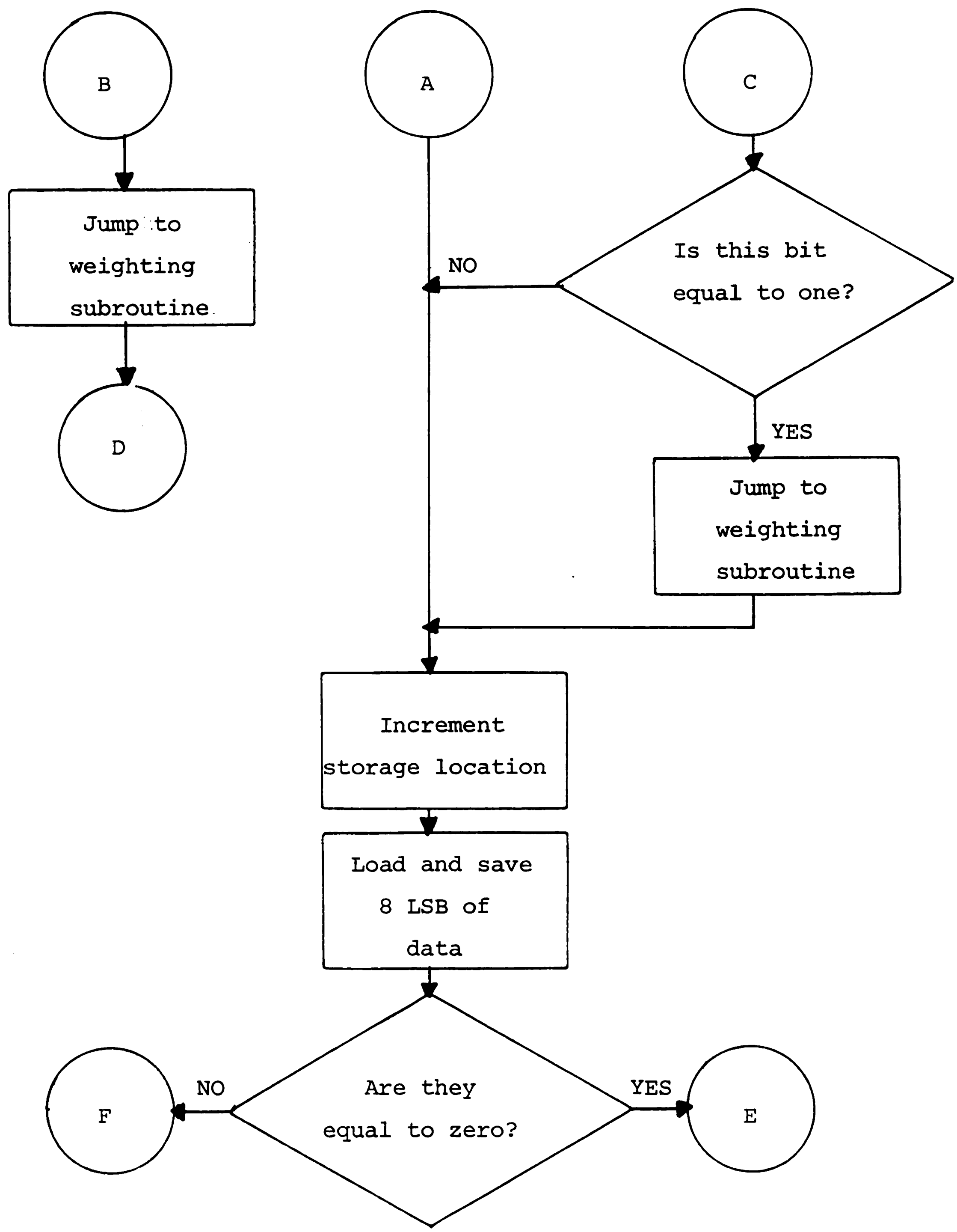


Figure 22, cont'd.

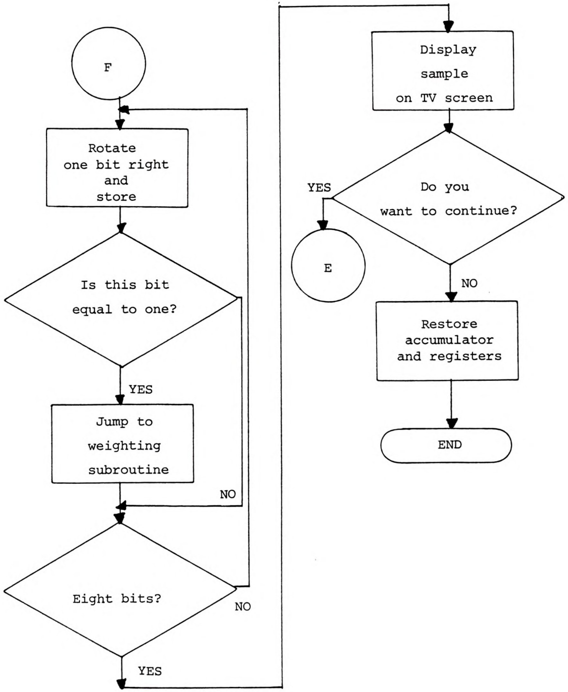
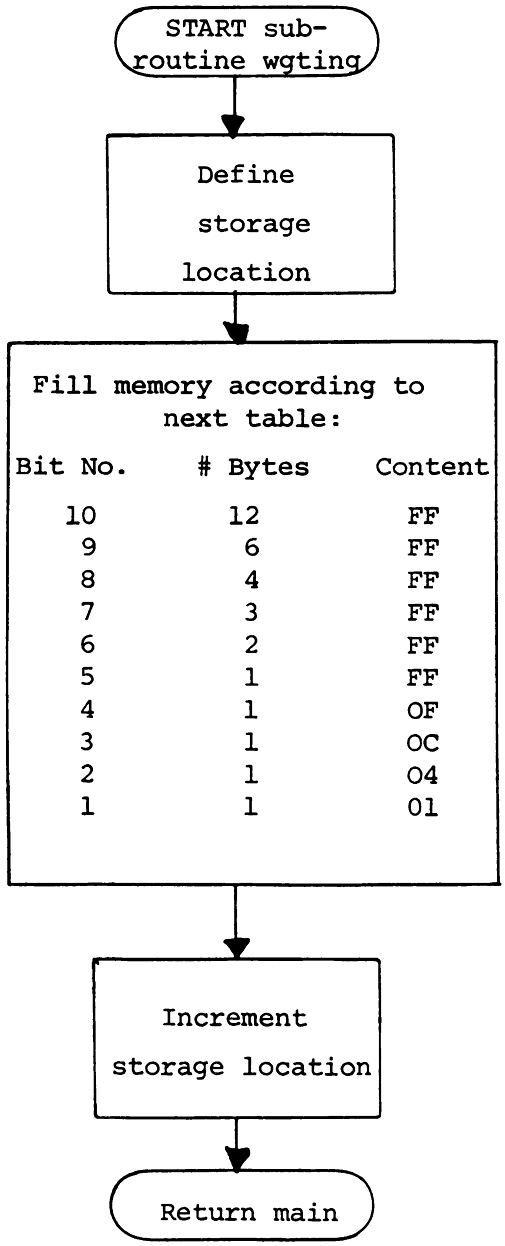


Figure 22, cont'd.



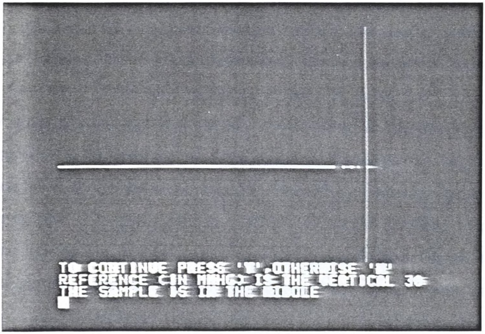


Figure 23. Shape Displayed by Program EXACT

Chapter IV.

EXPERIMENTATION PROTOCOL

A computer-based biofeedback control system was developed to help in the treatment of fecal incontinence by operant conditioning.

All patients are intended to go through a series of three phases of training. Phase 1 is a diagnostic procedure during which the severity of impairment of rectosphincteric reflexes is objectively determined. For this purpose, a three balloon arrangement, as the one described in Chapter III, is inserted into the rectum. The first two balloons are positioned at approximately the location of the internal and external sphincters. The third balloon, called the rectal balloon, is positioned above the double balloons, at a level of approximately 10 cm above the anal margin. The balloon situated at the location of the external sphincter is connected to a pressure transducer (described in Chapter III, Section 3.2), and the electrical output of this device is amplified and sampled by the APPLE II. In normal subjects, momentary inflation of the rectal balloon causes a reflex contraction of the external sphincter. This contraction produces a variation in the output of the pressure transducer so that the program PRESSURE can provide the researcher with the value of pressure exerted. The magnitude of the pressure provides the researcher with knowledge of the patient's ability to reach a normal response level. The minimum pressure required is 5 mm Hg.

After the diagnostic studies are completed and before training studies are initiated, it is important for the researcher to explain in detail to each patient capable of understanding, the nature of the normal rectosphincteric reflex and the way in which his response differs from normal.

During Phase 2, the initial stage of training, instantaneous feedback, obtained by a two balloon system, is provided to the patient by allowing him to watch the figures displayed on the T.V. monitor. Four different programs are used in this phase, SQUARE, COLOR LINE, GLASS, and EXACT. The program EXACT should be used to set goals for the patient to reach in every session. Each program supplies a different figure and information referent to pressure. During this stage of training the patient is verbally reinforced: he is praised for every normal response obtained and encouraged to modify an abnormal response.

Phase 3 is the final stage of training, and its goals are twofold. First, the patient is trained to refine his sphincteric response; i.e., to approximate the amplitude of a normal sphincteric response and to synchronize sphincteric responses so that the external-sphincter contraction occurs simultaneously with the internal-sphincter relaxation. This refinement of motor control is accomplished through verbal reinforcement in conjunction with the very accurate feedback representation provided by the program EXACT. The second goal of Phase 3 is to wean the patient from any dependency on the system. In this stage of training the visual feedback is periodically withheld, so that the patient is unable to see the displayed shapes.

After a series of trials the patient is permitted to observe his performance.

Each laboratory session comprises about two hours, sufficient to allow the patient to have an average of fifty (50) training trials. Figure 24 shows a block diagram of the system protocol.

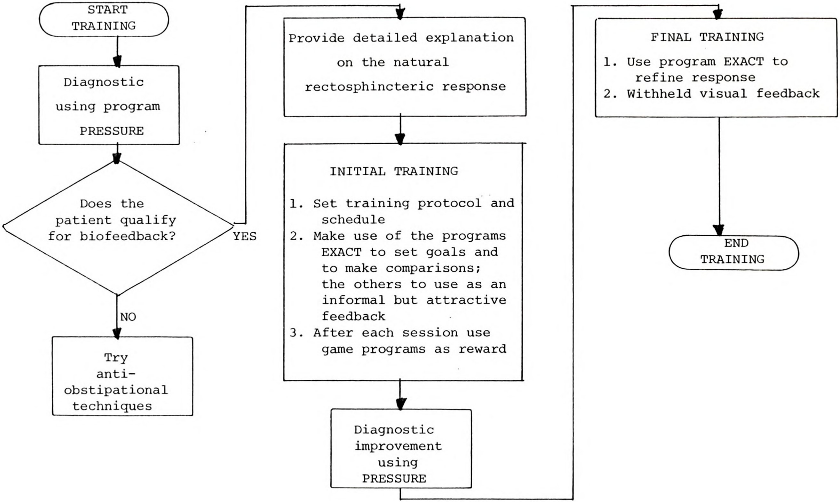


Figure 24. Biofeedback Control System

Chapter V.

RESULTS AND CONCLUSIONS

Although the system has not been tested on a patient at the time of this writing, a trial was conducted on a voluntary normal subject. This subject was placed in his right lateral position, and the Blakemore double balloon was inserted into the rectum. One of the balloons was positioned to a level of 5 cm from the anal margin, and the other was positioned at the external sphincter. Polyethylene tubing from the second balloon led to the P23AC pressure transducer. Three recordings were obtained:

1) in the resting state
2) during balloon distention of the rectum
3) during voluntary contraction of the anal sphincters.

The following results were obtained:

A) During the resting state without stimulation (no air in the rectal balloon), a steady base line with respiratory excursions was recorded from the external sphincter balloon.

B) Transient distensions of the rectum (lasting 2 - 5 seconds) resulted from introducing approximately 50 cc of air in the rectal balloon and produced an abrupt increase in pressure in the external sphincter balloon. This pressure rise in the external balloon varied from 5 mm Hg to 30 mm Hg in amplitude (average of 15 mm Hg) and 2 - 5 seconds in duration (average of 3 seconds).

C) Intermittent distentions produced a pressure rise which was no higher (average of 6 mm Hg, range 2 - 15 mm Hg), although more prolonged (average 9 seconds, range 5 - 22 seconds) than with transient distention.

D) Threshhold. The minimal amount of air required in the rectal balloon to elicit a recognizable pressure change was 15 cc.

E) Voluntary contraction of the anal sphincter resulted in a rise in pressure in the external sphincter balloon.

F) Voluntary contraction of gluteal muscles resulted in an abrupt rise in pressure in the external sphincter balloon.

A comparison test was done to verify which feedback, the oscilloscope tracings or the animated graphics, was more attractive for the subject. The test was performed with five different subjects, ranging in age from two to 32 years. In all cases the animated graphics were selected. The system was readily used by the novice subject. Even though the equipment underwent extremely limited testing, the highly favorable responses obtained provide enough evidence about the promising potential for its use in an actual clinical setting.

During the experimentation three minor problems were found. The first occurred when the balloons leaked, necessitating frequent running of the program to calibrate the system (CALIBRATION). This problem can be overcome by obtaining a better quality balloon.

The second problem was noted when the uncalibrated input voltage went to the negative side, resulting in the output not being a true representation of the input. To overcome this problem it will be necessary either to construct a zero crossing detector or to use the analog input of the A/D converter as bipolar.

Third, voluntary contraction of the gluteal muscles produced an increase of pressure in the balloon. To overcome this problem, if the patient is unable to cooperate in controlling this contraction (i.e., not contracting these muscles), the balloon system must be reconfigured.

Because the training requires insertion of an anal probe device, which may cause discomfort (and in some cases, pain), it should be emphasized that other appropriate therapeutic methods should be tried before the patient is referred for biofeedback training. Biofeedback training is not recommended as the preferred initial therapy for very young children (under two years of age) because of their difficulty in understanding the procedure and acting as cooperating participants.

The computer-based biofeedback system is economical both to produce and to operate; it is readily used by a novice operator and by a subject. Because people in general already have close familiarity with visual media (particularly television), patients are expected to respond easily and positively to the color computer animated graphics. For all of these reasons, the system shows very favorable potential as an alternative therapeutic modality in the treatment of patients with encopresis.

Glossary of Medical Terms

Glossary of Medical Terms

The following are the medical terms and their descriptions which are used throughout this thesis. See [19] for bibliographic reference.

caudal: inferior or, in the case of quadruped, posterior.

cephalad: in a direction toward the head or the anterior pole.

encopresis: involuntary passage of feces.

flatus: expired air; gas in the stomach or intestine; eructation.

intraluminal intratubal: within any tube.

manometric: related to a manometry.

manometry: measurement of pressure of gases by means of an instrument (manometer).

meningomyelocele: a protrusion of the membranes and spinal cord through a defect in the vertebral column.

motility: the power of spontaneous movement.

nervous system: the system of tissues which coordinates an animal's various activities with each other and with external events by means of nervous impulses conducted rapidly from part to part via nerves.

The nervous system can be divided into two parts.

The Central Nervous System (CNS), consisting of brain and spinal cord, stores and processes information and sends messages to muscles and glands.

The Peripherial Nervous System, consisting of 12 pairs of cranial nerves arising in and near the medulla oblongata of the brain and the 31 pairs of spinal nerves arising at intervals from the spinal cord, carries messages to and from the central nervous system.

The Autonomic Nervous System, normally considered part of the peripherial nervous system, controls involuntary actions such as heartbeat and digestion. It is divisible into two complimentary

parts: the sympathetic system prepares the body for "fight or flight," and the parasympathetic system controls the body's vegetative functions. Most internal organs are innervated by both parts.

obstipation: intestinal obstruction; severe constipation.

pathology: the medical science and practice that deals with all aspects of disease, but with special reference to the essential nature, the causes and development of abnormal conditions, as well as the structural and functional changes that result from the disease processes.

psycotherapeutic: psycotherapy. Treatment of mental disease based primarily upon verbal or non-verbal communication with the patient, in contrast to treatments utilizing chemical and physical measures.

rectophincteric: the sphincter muscles action over the rectum.

sphincter: an accumulation of muscular circular fibers or specially arranged oblique fibers, the function of which is to reduce partially or totally the lumen of a tube, the orifice of an organ, or the cavity of a viscus.

Glossary of Engineering Terms

Glossary of Engineering Terms

Analog: Analog measurements, as opposed to digital measurements, use a continuously variable physical quantity (such as length, voltage, or resistance) to represent values. Digital measurements use precise, limited quantities (such as presence or absence of voltages or magnetic fields) to represent values.

A/D Converter: System employed to convert an analog input to a digital output.

AND: A binary function which is "on" if and only if all of its inputs are "on."

BASIC: Acronym for "Beginner's All-Purpose Symbolic Instruction Code." BASIC is a higher-level language, similar in structure to FORTRAN but somewhat easier to learn. It was invented by Kemney and Kurtz at Dartmouth College in 1963 and has proved to be the most popular language for personal computers.

Binary: A number system with two digits, "Ø" and "1," with each digit in a binary number representing a power of two. Most digital computers are binary, deep down inside. A binary signal is easily expressed by the presence or absence of something, such as an electrical potential or a magnetic field.

Binary Function: An operation performed by an electronic circuit which has one or more inputs and only one output. All inputs and outputs are binary signals, See AND OR, and Exclusive-OR.

Bit: A <u>B</u>inary dig<u>IT</u>. The smallest amount of information which a computer can hold. A single bit specifies a single value: "Ø" or "1." Bits can be grouped to form larger values (see Byte and Nybble).

Byte: A basic unit of measure of a computer's memory. A byte usually comprises eight bits. Thus, it can have a value from Ø to 255. Each character in the ASCII can be represented in one byte. The Apple's memory locations are all one byte, and the Apple's addresses of these locations consist of two bytes.

Class A Amplifier: Method of operation for the amplifier in which the collector output current flows for the full 360° of the input

signal, without any part of the signal being cut off.

Class AB Amplifier: The collector output current flows between 180° to 360°, or one-half of full input cycle.

Data (datum): Information of any type.

Display: As a noun: any sort of output device for a computer, usually a video screen. As a verb: to place information on such a screen.

Flip Flop: Digital electronic circuit that has a "memory."

Format: As a noun: the physical form in which something appears. As a verb: to specify such a form.

Graphic: Visible as a distinct, recognizable shape or color.

Graphics: A system to display graphic items or a collection of such items.

Hardware: The physical parts of a computer.

Hexadecimal: A number system which uses the ten digits Ø through 9 and the six letters A through F to represent values in base 16. Each hexadecimal digit in a hexadecimal number represents a power of 16. In this manual, all hexadecimal numbers are preceded by a dollar sign ($).

High-level Language: A language which is more intelligible to humans than it is to machines.

Hz (Hertz): Cycles per second. A bicycle wheel which makes two revolutions in one second is running at 2Hz. The Apple's microprocessor runs at 1,023,000Hz.

Input: As a noun: data which flows from the outside world into the computer. As a verb: to obtain data from the outside world.

Input/Output (I/O): The software of hardware which exchanges data with the outside world.

Instruction: The smallest portion of a program that a computer can execute. In 65Ø2 machine language, an instruction comprises one, two, or three bytes; in a higher-level language, instructions may be many characters long.

Integrated circuit: A small (less than the size of a fingernail and about as thin) wafer of a glassy material (usually silicon) into which has been etched an electronic circuit. A single IC can contain from ten to ten thousand discrete electronic components. ICs are usually housed in DIPs (see above), and the term IC is sometimes used to refer to both the circuit and its package.

Interface: An exchange of information between one thing and another, or the mechanisms which make such an exchange possible.

Interpreter: A program, usually written in machine language, which understands and executes a higher-level language.

Interrupt: A physical effect which causes the computer to jump to a special interrupt-handling subroutine. When the interrupt has been taken care of, the computer resumes execution of the interrupted program with no noticeable change. Interrupts are used to signal the computer that a particular device wants attention.

Machine language: The lowest level language which a computer understands. Machine languages are usually binary in nature. Instructions in machine language are single-byte opcodes sometimes followed by various operands.

Memory address: A memory address is a two-byte value which selects a single memory location out of the memory map. Memory addresses in the Apple are stored with their low-order bytes first, followed by their high-order bytes.

Memory location: The smallest subdivision of the memory map to which the computer can refer. Each memory location has associated with it a unique address and a certain value. Memory locations on the Apple comprise one byte each.

Microprocessor: An integrated circuit which understands and executes machine language programs.

Mnemonic: An acronym (or any other symbol) used in the place of something more difficult to remember. In Assembly Language, each machine language opcode is given a three letter mnemonic (for example, the opcode $6Ø is given the mnemonic RTS, meaning "ReTurn from Subroutine").

OR: A binary function whose value is "on" if at least one of its inputs are "on."

Peripheral: Something attached to the computer which is not part of the computer itself. Most peripherals are input and/or output devices.

Personal Computer: A computer with memory, languages, and peripherals which are well-suited for use in a home, office, or school.

Pinout: A description of the fuction of each pin on an IC, often presented in the form of a diagram.

Program: A sequence of instructions which describes a process.

Software: The programs which give the hardware something to do.

Subroutine: A segment of a program which can be executed by a single call. Subroutines are used to perform the smallest sequence of instructions at many different places in one program.

Transducer: A detector-transducer stage, which detects the physical variable and performs either a mechanical or an electrical transformation to convert the signal into a more usalbe form.

Wheatstone bridge: A bridge circuit formed of four terminals, two for input voltage and two for output. It is normally used for the comparison and measurement of resistances.

APPENDICES

```
8E66-   8D E9 8E    STA   $8EE9
8E69-   8E EA 8E    STX   $8EEA
8E6C-   8C EB 8E    STY   $8EEB
8E6F-   08          PHP
8E70-   EA          NOP
8E71-   EA          NOP
8E72-   EA          NOP
8E73-   EA          NOP
8E74-   A9 05       LDA   #$05
8E76-   8D F1 C0    STA   $C0F1
8E79-   A9 04       LDA   #$04
8E7B-   8D F1 C0    STA   $C0F1
8E7E-   AD F2 C0    LDA   $C0F2
8E81-   2A          ROL
8E82-   B0 FA       BCS   $8E7E
8E84-   6A          ROR
8E85-   29 03       AND   #$03
8E87-   8D 00 8F    STA   $8F00
8E8A-   EA          NOP
8E8B-   EA          NOP
8E8C-   AD F4 C0    LDA   $C0F4
8E8F-   8D 01 8F    STA   $8F01
8E92-   EA          NOP
8E93-   EA          NOP
8E94-   AD E9 8E    LDA   $8EE9
8E97-   AE EA 8E    LDX   $8EEA
8E9A-   AC EB 8E    LDY   $8EEB
8E9D-   28          PLP
```

Appendix A Machine Language Subroutine to Transfer Data [READER]

```
10  PRINT "THIS PROGRAM HELP YOU TO SET"
20  PRINT "YOUR CALIBRATION VALUE = 0  "
25  CALL 36454
30 V1 =  PEEK (36608):V2 =  PEEK (36609)
50 VREF = ((V1 * 256) + V2) / 100
60  PRINT "VREF = ";VREF
70  PRINT "DO YOU WANT TO CONTINUE ?"
75  PRINT "IF YES PRESS 'Y',OTHERWISE PRESS 'N' ": GET A$
80  IF A$ = "Y" THEN  GOTO 25
90  PRINT "CALIBRATION FINISHED "
100  END

]
```

Appendix B Apple Soft Basic to Calibrate [CALIBRATION]

```
10  PRINT "THIS PROGRAM ALLOW YOU TO OBTAIN THE    "
20  PRINT "VALUE OF THE SAMPLE PRESSURE            "
25  CALL 36454
27  CALL  - 922
29  CALL  - 922
30 V1 =  PEEK (36608):V2 =  PEEK (36609)
50 VREF = ((V1 * 256) + V2) / 100
55 P = ( - 285.31921 * VREF) + 3231.89
57 POT =  - 0.0081093022 * P
58 PRES = 371.25 * ( EXP (POT))
59  PRINT "PRESSURE (IN MMHG) = ";PRES
60  CALL  - 922
70  PRINT "DO YOU WANT TO CONTINUE ?"
75  PRINT "IF YES PRESS 'Y',OTHERWISE PRESS 'N' ": GET A$
80  IF A$ = "Y" THEN  CALL  - 936: GOTO 25
85  CALL  - 936
90  PRINT "SAMPLING FINISHED"
100  END

]
```

Appendix C Apple Soft Basic to Diagnostic Initial Response [PRESSURE]

```
10  PRINT "INICIO DE ENTRENAMIENTO"
20  FOR X = 1 TO 3000
30  NEXT X
40  CALL  - 936
50  CALL 36454
60 V1 =  PEEK (36608):V2 =  PEEK (36609)
70 VREF = ((V1 * 256) + V2) / 25
71 VV = VREF / 4
72 R = ( - 285.31921 * VV) + 3231.89
73 POT =  - 0.0081093022 * R
75 PRES = 371.25 * ( EXP (POT))
80  GR : COLOR= 7
90  FOR J = 0 TO VREF
100  HLIN 10,30 AT J
110  NEXT J
115  PRINT "PRESSURE (IN MMHG) = ";PRES
120  PRINT "DO YOU WANT TO CONTINUE ?": GET AN$
130  IF AN$ = "Y" THEN  GOTO 50
140  PRINT "THE SESSION HAS FINISHED"
145  TEXT : HOME
150  END

]
```

Appendix D Apple Soft Basic Display Program [SQUARE]

```
3  TEXT : HOME
10  PRINT "INICIO DE ENTRENAMIENTO"
20  FOR X = 1 TO 3000
30  NEXT X
40  CALL  - 936
50  CALL 36454
60 V1 =  PEEK (36608):V2 =  PEEK (36609)
70 VREF = ((V1 * 256) + V2) / 30
80  GR : COLOR= J
90  FOR J = 0 TO VREF
100  HLIN 0,J AT 24
110  NEXT J
120  PRINT "DO YOU WANT TO CONTINUE ?": GET AN$
130  IF AN$ = "Y" THEN  GOTO 50
140  PRINT "THE SESSION HAS FINISHED"
145  TEXT : HOME
150  END

]
```

Appendix E Apple Soft Basic Display Program [COLORLINE]

```
10  GR
15  COLOR= 7
20  HLIN 15,30 AT 30
30  VLIN 30,8 AT 15
50  VLIN 30,8 AT 30
90  CALL 36454
95 V1 =  PEEK (36608):V2 =  PEEK (36609)
100 VREF = ((V1 * 256) + V2) / 50
110  FOR J = 0 TO VREF
120  COLOR= 9
130  HLIN 16,29 AT 29 - J
140  NEXT J
150  PRINT "DO YOU WANT TO CONTINUE ?": GET AN$
160  IF AN$ = "N" THEN  GOTO 250
170  FOR J = 0 TO VREF
180  COLOR= 0
190  HLIN 16,29 AT 29 - J
200  NEXT J
210  GOTO 90
250  TEXT : HOME
255  CALL  - 936
260  PRINT "THE SESSION HAS FINISHED"
270  END

]
```

Appendix F Apple Soft Basic Display Program [GLASS]

```
5  FOR T = 1 TO 20
10  PRINT "@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@"
20  HTAB 9: VTAB (12): PRINT "BIOFEEDBACK TRAINNING"
30  VTAB (24): PRINT "@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@"
40  NEXT T
50  TEXT
60  HOME : TEXT
70  PRINT "THE PROGRAM IS CLEANNING"
80  PRINT "   THE VIDEO STORAGE    "
90  PRINT "          AREA          "
100  CALL 36368
150  HOME : TEXT
160  PRINT "THE VIDEO STORAGE AREA IS CLEAN"
170  PRINT "THE FOLLOWING INFORMATION IS"
180  PRINT "THE AVAILABLE PRESSURE REFERENCES : "
190  PRINT "      5MMHG IS EQUAL TO 1  "
200  PRINT "     10MMHG IS EQUAL TO 2  "
210  PRINT "     15MMHG IS EQUAL TO 3  "
220  PRINT "     20MMHG IS EQUAL TO 4  "
230  PRINT "     25MMHG IS EQUAL TO 5  "
240  PRINT "     30MMHG IS EQUAL TO 6  "
250  INPUT "WHICH IS YOUR SELECTION ?";PR
260  IF PR > 6 OR PR < 1 THEN  GOTO 170
265  HGR
270  IF PR = 1 THEN  GOTO 350
280  IF PR = 2 THEN  GOTO 400
290  IF PR = 3 THEN  GOTO 450
300  IF PR = 4 THEN  GOTO 500
310  IF PR = 5 THEN  GOTO 550
320  IF PR = 6 THEN  GOTO 600
350  HCOLOR= 2
355  HPLOT 176,0 TO 176,159
360  GOTO 650
400  HCOLOR= 2
405  HPLOT 196,0 TO 196,159
410  GOTO 650
450  HCOLOR= 6
455  HPLOT 200,0 TO 200,159
460  GOTO 650
500  HCOLOR= 3
505  HPLOT 210,0 TO 210,159
510  GOTO 650
550  HCOLOR= 7
555  HPLOT 218,0 TO 218,159
560  GOTO 650
600  HCOLOR= 5
605  HPLOT 223,0 TO 223,159
610  GOTO 650
650  POKE 49239,2: POKE 49235,2: POKE 49236,2: POKE 49232,2
655  PRINT "TO CONTINUE PRESS 'Y',OTHERWISE 'N' "
657 S = PR * 5
660  PRINT "REFERENCE (IN MMHG) IS THE VERTICAL ";S
670  PRINT "THE SAMPLE IS IN THE MIDDLE"
680  CALL 35994
690  POKE 49233,2: POKE 49236,2
695  HOME : TEXT
700  PRINT "THE EXPERIMENT HAS FINISHED"
710  END
```

Appendix G Machine Language to show an Exact Representation [EXACT]

(Page 1 of 6)

Appendix G, cont'd.

```
8C9A-   8D 09 8E    STA   $8E09
8C9D-   8E 0A 8E    STX   $8E0A
8CA0-   8C 0B 8E    STY   $8E0B
8CA3-   08          PHP
8CA4-   EA          NOP
8CA5-   A9 01       LDA   #$01
8CA7-   8D F0 8E    STA   $8EF0
8CAA-   A9 02       LDA   #$02
8CAC-   8D F1 8E    STA   $8EF1
8CAF-   A9 03       LDA   #$03
8CB1-   8D F2 8E    STA   $8EF2
8CB4-   A9 04       LDA   #$04
8CB6-   8D F3 8E    STA   $8EF3
8CB9-   A9 06       LDA   #$06
8CBB-   8D F4 8E    STA   $8EF4
8CBE-   A9 0C       LDA   #$0C
8CC0-   8D F5 8E    STA   $8EF5
8CC3-   A9 08       LDA   #$08
8CC5-   8D F6 8E    STA   $8EF6
8CC8-   A9 0F       LDA   #$0F
8CCA-   8D F7 8E    STA   $8EF7
8CCD-   A9 FF       LDA   #$FF
8CCF-   8D F8 8E    STA   $8EF8
8CD2-   A9 00       LDA   #$00
8CD4-   8D F9 8E    STA   $8EF9
8CD7-   EA          NOP
8CD8-   A9 00       LDA   #$00
8CDA-   85 0A       STA   $0A
8CDC-   A9 8F       LDA   #$8F
8CDE-   85 0B       STA   $0B
8CE0-   EA          NOP
8CE1-   A9 28       LDA   #$28
8CE3-   85 0C       STA   $0C
8CE5-   A9 22       LDA   #$22
8CE7-   85 0D       STA   $0D
8CE9-   EA          NOP
8CEA-   AC F9 8E    LDY   $8EF9
8CED-   EA          NOP
8CEE-   20 DD FB    JSR   $FBDD
8CF1-   20 0C FD    JSR   $FD0C
8CF4-   C9 D9       CMP   #$D9
8CF6-   F0 14       BEQ   $8D0C
8CF8-   20 DD FB    JSR   $FBDD
8CFB-   20 DD FB    JSR   $FBDD
8CFE-   20 DD FB    JSR   $FBDD
8D01-   AD 09 8E    LDA   $8E09
8D04-   AE 0A 8E    LDX   $8E0A
8D07-   AC 0B 8E    LDY   $8E0B
8D0A-   28          PLP
8D0B-   60          RTS
8D0C-   20 F3 8D    JSR   $8DF3
8D0F-   EA          NOP
8D10-   A2 20       LDX   #$20
8D12-   A9 00       LDA   #$00
8D14-   20 E1 8D    JSR   $8DE1
8D17-   20 F3 8D    JSR   $8DF3
8D1A-   EA          NOP
8D1B-   EA          NOP
8D1C-   EA          NOP
8D1D-   EA          NOP
*
```

Appendix G   Machine Language to Show an Exact Representation [EXACT] (Page 2 of 6)

Appendix G, cont'd.

```
        EA           NOP
8D1E-   EA           NOP
8D1F-   EA           NOP
8D20-   EA           NOP
8D21-   EA           NOP
8D22-   EA           NOP
8D23-   EA           NOP
8D24-   EA           NOP
8D25-   AC F9 8E     LDY   $8EF9
8D28-   A9 05        LDA   #$05
8D2A-   8D F1 C0     STA   $C0F1
8D2D-   A9 04        LDA   #$04
8D2F-   8D F1 C0     STA   $C0F1
8D32-   AD F2 C0     LDA   $C0F2
8D35-   2A           ROL
8D36-   B0 FA        BCS   $8D32
8D38-   6A           ROR
8D39-   29 03        AND   #$03
8D3B-   91 0A        STA   ($0A),Y
8D3D-   C9 00        CMP   #$00
8D3F-   F0 1E        BEQ   $8D5F
8D41-   B1 0A        LDA   ($0A),Y
8D43-   6A           ROR
8D44-   91 0A        STA   ($0A),Y
8D46-   90 09        BCC   $8D51
8D48-   AE F4 8E     LDX   $8EF4
8D4B-   AD F8 8E     LDA   $8EF8
8D4E-   20 E1 8D     JSR   $8DE1
8D51-   B1 0A        LDA   ($0A),Y
8D53-   6A           ROR
8D54-   90 09        BCC   $8D5F
8D56-   AE F5 8E     LDX   $8EF5
8D59-   AD F8 8E     LDA   $8EF8
8D5C-   20 E1 8D     JSR   $8DE1
8D5F-   A6 0A        LDX   $0A
8D61-   E8           INX
8D62-   86 0A        STX   $0A
8D64-   AD F4 C0     LDA   $C0F4
8D67-   91 0A        STA   ($0A),Y
8D69-   C9 00        CMP   #$00
8D6B-   F0 70        BEQ   $8DDD
8D6D-   20 FC 8D     JSR   $8DFC
8D70-   90 09        BCC   $8D7B
8D72-   AE F3 8E     LDX   $8EF3
8D75-   AD F8 8E     LDA   $8EF8
8D78-   20 E1 8D     JSR   $8DE1
8D7B-   20 FC 8D     JSR   $8DFC
8D7E-   90 09        BCC   $8D89
8D80-   AE F2 8E     LDX   $8EF2
8D83-   AD F8 8E     LDA   $8EF8
8D86-   20 E1 8D     JSR   $8DE1
8D89-   20 FC 8D     JSR   $8DFC
8D8C-   90 09        BCC   $8D97
8D8E-   AE F1 8E     LDX   $8EF1
8D91-   AD F8 8E     LDA   $8EF8
8D94-   20 E1 8D     JSR   $8DE1
8D97-   20 FC 8D     JSR   $8DFC
8D9A-   90 09        BCC   $8DA5
8D9C-   AE F0 8E     LDX   $8EF0
8D9F-   AD F8 8E     LDA   $8EF8
*
```

Appendix G Machine Language to Show an Exact Representation [EXACT] (Page 3 of 6)

Appendix G, cont'd.

```
8D9F-   AD F8 8E    LDA   $8EF8
8DA2-   20 E1 8D    JSR   $8DE1
8DA5-   20 FC 8D    JSR   $8DFC
8DA8-   90 09       BCC   $8DB3
8DAA-   AE F0 8E    LDX   $8EF0
8DAD-   AD F7 8E    LDA   $8EF7
8DB0-   20 E1 8D    JSR   $8DE1
8DB3-   20 FC 8D    JSR   $8DFC
8DB6-   90 09       BCC   $8DC1
8DB8-   AE F0 8E    LDX   $8EF0
8DBB-   AD F6 8E    LDA   $8EF6
8DBE-   20 E1 8D    JSR   $8DE1
8DC1-   20 FC 8D    JSR   $8DFC
8DC4-   90 09       BCC   $8DCF
8DC6-   AE F0 8E    LDX   $8EF0
8DC9-   AD F3 8E    LDA   $8EF3
8DCC-   20 E1 8D    JSR   $8DE1
8DCF-   20 FC 8D    JSR   $8DFC
8DD2-   90 09       BCC   $8DDD
8DD4-   AE F0 8E    LDX   $8EF0
8DD7-   AD F0 8E    LDA   $8EF0
8DDA-   20 E1 8D    JSR   $8DE1
8DDD-   EA          NOP
8DDE-   4C ED 8C    JMP   $8CED
8DE1-   A0 00       LDY   #$00
8DE3-   91 0C       STA   ($0C),Y
8DE5-   E0 00       CPX   #$00
8DE7-   F0 09       BEQ   $8DF2
8DE9-   CA          DEX
8DEA-   A4 0C       LDY   $0C
8DEC-   C8          INY
8DED-   84 0C       STY   $0C
8DEF-   4C E1 8D    JMP   $8DE1
8DF2-   60          RTS
8DF3-   A9 28       LDA   #$28
8DF5-   85 0C       STA   $0C
8DF7-   A9 22       LDA   #$22
8DF9-   85 0D       STA   $0D
8DFB-   60          RTS
8DFC-   A0 00       LDY   #$00
8DFE-   B1 0A       LDA   ($0A),Y
8E00-   2A          ROL
8E01-   91 0A       STA   ($0A),Y
8E03-   60          RTS
8E04-   00          BRK
8E05-   00          BRK
8E06-   00          BRK
8E07-   00          BRK
8E08-   00          BRK
8E09-   8C 9D 9A    STY   $9A9D
8E0C-   00          BRK
8E0D-   00          BRK
8E0E-   00          BRK
8E0F-   00          BRK
8E10-   8D E9 8E    STA   $8EE9
8E13-   8E EA 8E    STX   $8EEA
8E16-   8C EB 8E    STY   $8EEB
8E19-   08          PHP
8E1A-   EA          NOP
8E1B-   EA          NOP
*
```

Appendix G Machine Language to Show an Exact Representation [EXACT] (Page 4 of 6)

Appendix G, cont'd.

```
8E1C-   A9 00       LDA   #$00
8E1E-   85 0C       STA   $0C
8E20-   A9 20       LDA   #$20
8E22-   85 0D       STA   $0D
8E24-   A9 FF       LDA   #$FF
8E26-   8D EC 8E    STA   $8EEC
8E29-   A9 3F       LDA   #$3F
8E2B-   8D ED 8E    STA   $8EED
8E2E-   EA          NOP
8E2F-   EA          NOP
8E30-   A9 00       LDA   #$00
8E32-   A2 00       LDX   #$00
8E34-   81 0C       STA   ($0C,X)
8E36-   A4 0C       LDY   $0C
8E38-   C8          INY
8E39-   84 0C       STY   $0C
8E3B-   D0 F3       BNE   $8E30
8E3D-   A4 0D       LDY   $0D
8E3F-   C8          INY
8E40-   84 0D       STY   $0D
8E42-   AD ED 8E    LDA   $8EED
8E45-   C5 0D       CMP   $0D
8E47-   D0 E7       BNE   $8E30
8E49-   AD E9 8E    LDA   $8EE9
8E4C-   AE EA 8E    LDX   $8EEA
8E4F-   AC EB 8E    LDY   $8EEB
8E52-   28          PLP
8E53-   60          RTS
8E54-   00          BRK
8E55-   00          BRK
```

Appendix G Machine Language to Show an Exact Representation [EXACT] (Page 5 of 6)

Appendix G, cont'd.

```
8E10-   8D E9 8E    STA   $8EE9
8E13-   8E EA 8E    STX   $8EEA
8E16-   8C EB 8E    STY   $8EEB
8E19-   08          PHP
8E1A-   EA          NOP
8E1B-   EA          NOP
8E1C-   A9 00       LDA   #$00
8E1E-   85 0C       STA   $0C
8E20-   A9 20       LDA   #$20
8E22-   85 0D       STA   $0D
8E24-   A9 FF       LDA   #$FF
8E26-   8D EC 8E    STA   $8EEC
8E29-   A9 3F       LDA   #$3F
8E2B-   8D ED 8E    STA   $8EED
8E2E-   EA          NOP
8E2F-   EA          NOP
8E30-   A9 00       LDA   #$00
8E32-   A2 00       LDX   #$00
8E34-   81 0C       STA   ($0C,X)
8E36-   A4 0C       LDY   $0C
8E38-   C8          INY
8E39-   84 0C       STY   $0C
8E3B-   D0 F3       BNE   $8E30
8E3D-   A4 0D       LDY   $0D
8E3F-   C8          INY
8E40-   84 0D       STY   $0D
8E42-   AD ED 8E    LDA   $8EED
8E45-   C5 0D       CMP   $0D
8E47-   D0 E7       BNE   $8E30
8E49-   AD E9 8E    LDA   $8EE9
8E4C-   AE EA 8E    LDX   $8EEA
8E4F-   AC EB 8E    LDY   $8EEB
8E52-   28          PLP
8E53-   60          RTS
```

Appendix G Machine Language to show an Exact Representation [EXACT] (Page 6 of 6)

```
3  TEXT : HOME
10  PRINT "THIS PROGRAM WILL GIVE YOU ALL THE      "
11  PRINT "INFORMATION NEEDED TO EXECUTE A         "
12  PRINT "BIOFEEDBACK TRAINNING SESSION           "
15  FOR X = 1 TO 2500
17  NEXT X
20  CALL  - 936
22  CALL  - 922
24  CALL  - 922
25  CALL  - 936: PRINT "THE SYSTEM CONSIST ON THREE DIFFERENT  "
26  PRINT "SUB-SYSTEMS, WHICH ARE :                "
27  PRINT "                                        "
28  PRINT "CALIBRATION  (TO ZERO THE INPUT).             "
29  PRINT "DISPLAY      (TO RUN THE SESSION).            "
30  PRINT "PRESSURE     (TO OBTAIN PRESSURE).            "
31  CALL  - 922
32  PRINT "TO RUN THEM MAKE USE OF THE FIRST LETTER"
33  CALL  - 922
34  CALL  - 922
35  INPUT "WHICH IS YOUR SELECTION ? ";SEL$
37  IF SEL$ = "C" THEN  GOTO 50
39  IF SEL$ = "D" THEN  GOTO 100
40  IF SEL$ = "P" THEN  GOTO 200
42  CALL  - 936
44  PRINT "INVALID CODE. YOU MUST USE 'C','D',OR 'P'"
45  CALL  - 936
47  PRINT "TRY AGAIN ": GOTO 35
50  PRINT " YOU MUST TYPE :          "
55  PRINT "      BLOAD LECTOR($8E66) "
56  PRINT "      LOAD CALIBRATION    "
57  PRINT "      RUN                 "
60  PRINT "DO YOU WANT TO CONTINUE ?": GET AN$
62  IF AN$ = "Y" THEN  GOTO 25
63  GOTO 250
100  PRINT " YOU MUST TYPE :          "
102  PRINT "      BLOAD COMPLETO($8C9A) "
104  PRINT "      BLOAD BLANCO($8E10)   "
106  PRINT "      LOAD BASICO3          "
108  PRINT "      RUN                   "
110  PRINT "DO YOU WANT TO CONTINUE ? ": GET AN$
112  IF AN$ = "Y" THEN  GOTO 25
114  GOTO 250
200  PRINT " YOU MUST TYPE :           "
202  PRINT "      BLOAD LECTOR($8E66)  "
204  PRINT "      LOAD PRESSURE        "
206  PRINT "      RUN                  "
208  PRINT "DO YOU WANT TO CONTINUE ?": GET AN$
210  IF AN$ = "Y" THEN  GOTO 25
220  GOTO 250
250  PRINT "END OF THE PROGRAM "
260  END
```

Appendix H Systems Manager [HELLO]

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