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Abstract

The parameters influencing the respiratory pattern at or near the threshold for hearing were studied in hearing impaired and normal hearing subjects. A semiautomatic system was designed to process the data. Results indicated that thresholds for pure tones could be estimated better on the inspiration phase of the breathing cycle and that duration of the cycle was more precise than amplitude. An ascending mode of presentation was as satisfactory as the random and better than the descending methods; a 250 millisecond tone was as effective as longer tones. Estimation of thresholds were not as successful with hearing impaired as with normal hearing children; however, an accurate estimate could be made if the breathing cycle approximated a sine wave. A method based on visually apparent changes in the cycle as recorded on the strip chart was at least as accurate as the semiautomated system. A condition of visual distraction elevated auditory threshold; thresholds in the second stage of natural sleep or in sparine induced sleep were essentially similar to thresholds in the waking state. (Author/JD)

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May 31, 1969

DEPARTMENT OF
HEALTH, EDUCATION AND WELFARE

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Department of Health, Education, and Welfare

U.S. Office of Education
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Principal Investigator - Clyde L. Rousey, Ph.D.

Summary

The patient whose speech and language output is minimal or non-existent may be so functioning because of peripheral deafness, central deafness, mental retardation, emotional disturbance, specific neurological deficits or a combination of these diagnostic categories. Many of these patients cannot voluntarily give a direct indication of their capacity to hear.

Several indirect methods for determining auditory thresholds in nonresponding subjects are in use at the present time. The two most widely used emphasize electrodermal and electroencephalic responses. Despite references dating back to 1913, the use of respiratory change as an indirect indication of auditory threshold has only recently begun to receive serious investigation.

The purpose of this research project was to investigate further the parameters which influence the respiratory pattern at or near the threshold for hearing. A semi-automatic system was designed to facilitate processing of the data. Then, experiments were conducted using this instrumentation. A wide range of subjects, some with normal hearing and some who were hearing impaired, were utilized. The hypothesis was that auditory stimuli presented at or near threshold would significantly alter the breathing cycle. The results of this research project may be summarized as follows:

(1) Thresholds for pure tones can be estimated better when presented on the inspiration rather than the expiration phase of the breathing cycle. When numerical values are used, duration of the individual breathing cycle is a more precise way of estimating threshold than use of the amplitude portion of the cycle.

(2) In terms of allowing estimation of threshold, an ascending mode of presentation is as satisfactory as the random method. Both of these modes are more satisfactory then the descending method. For this research, the ascending method was used.

(3) For purposes of estimating auditory thresholds by changes in respiration, a 250 millisecond tone is as effective as tones of longer duration.

(4) Estimation of thresholds on hearing impaired children using all data were not as successful as with children whose hearing was normal.

(5) However, an accurate estimate of hearing in both normal and hearing impaired children can be made if the breathing cycle approximates a sine wave.

(6) A clinical method based on visually apparent changes in the respiratory cycle as recorded on the strip chart can be used with an accuracy equivalent to, and in some cases better than found by the use of the semi-automated system.

(7) A condition of visual distraction while listening to tones was shown to elevate auditory threshold. The inference was made that the phenomenon of change in respiration at or near threshold is likely to be affected by cortical activity. Whether the subject sits or reclines during the testing session seems irrelevant.

(8) Thresholds estimated by the visual inspection of the strip chart during the second stage of natural sleep seem to produce essentially similar thresholds to what is given in the waking state. Thresholds estimated in approximately the same state of sleep after administration of sparine show similar or in a few cases slightly elevated thresholds as compared to those given in the waking state.

Future research, it appears, can be concentrated on study of the phenomenon of altered breathing at an individual's auditory threshold in specific neurological states such as cerebral palsy. Further investigation is also warranted of the efficacy of the clinical method which this study devised. To this end, study of the effects of the different stages of sleep on auditory threshold might produce evidence related to the effect of cortical influences on auditory threshold. Study could also be done estimating thresholds in infants at an early age as indicated by their respiratory patterns. Appropriate follow-up would determine the usefulness of the respiratory technique in measuring auditory threshold in the neonate. Finally, the respiratory technique would appear to have potential use for experimenters using animals. It possibly could replace the present necessary, but tedious, conditioning procedures in animal studies.

Acknowledgments

Completion of any research project necessarily involves assistance of many people and often many institutions. This project has been no exception! Though the conduct of the experiment and the resulting conclusions are solely the experimenter's responsibility, he is grateful for the assistance of the Superintendent of the State School for the Deaf, Dr. Stanley Roth, the Superintendent of the Kansas Neurological Institute, Mr. Leonard W. Lavis and the students and patients of these institutions who served as subjects. In addition, grateful acknowledgment is hereby extended to Dr. C.P. Goetzinger and Dr. Rollie Houchins who consulted and worked with the experimenter during the course of the research. The Bio-medical Laboratory of the Menninger Foundation contributed in an innovative way to the design of the electronics used in this research. Several years before the grant was awarded, during the course of several pilot projects, the experimenter had the wise counsel and advice of Dr. Gardner Murphy--then Head of the Research Department of the Menninger Foundation, and Mr. Charles Synder--a staff member. In the latter phase of the research the experimenter was aided in an incalcuable way by his wife, Carol Rousey, who worked on a part time basis on the project. Administrative support and guidance was provided by Mr. Roger Hoffmaster. Throughout the course of the experiment, Nell Levy, Lawrence Shriberg, Delores Lebbert, Martha Dodson and Marianne Eger served at various times as research assistants. I am indebted for the competent secretarial help o Berni Flaherty, Patricia Brown and Carol Graham.

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INDIRECT ASSESSMENT OF HEARING SENSITIVITY BY CHANGES IN RESPIRATION

Chapter I

Introduction

Professional areas such as speech pathology, audiology and psychology are somewhat dependent upon behavioral symptomatology for differential evaluation of children who have multiple problems. The patient whose speech and language output is minimal or non-existent may not be functioning adequately because of peripheral deafness, central deafness, mental retardation, emotional disturbance, specific neurological deficits or a combination of these diagnostic categories. One of the first items which should be ruled out is if the patient does or does not respond to sound. Children are many times placed in inappropriate treatments because they do not have measurable speech and language output. Deaf children are at times inadvertently placed in programs for retarded children. Conversely, normally hearing but emotionally disturbed youngsters at times are found in programs for the deaf. Thus, through misdiagnosis the child vegetates in an inappropriate treatment program.

Many of these patients cannot voluntarily give a direct indication of their capacity to hear. Several indirect methods for determining auditory thresholds in nonresponding subjects are in use at the present time. The two most widely used are electrodermal responses and electroencephalic responses. These procedures or variations thereof are designed to circumvent the problem of requiring an overt response from a patient. However, they present special problems, such as the use of electric shock with EDR conditioning procedures, and the complex instrumentation needed for obtaining electroencephalic responses. A method, which would be easy to administer and free of the special difficulties noted above plus having the capability of determining thresholds with at least the validity of the present indirect methods, would be an important contribution to auditory testing. It is to that end that the present study was directed.

Chapter II

Review of the Literature

Section 1: Prior Research Relating Respiration to Auditory Sensitivity

As early as 1913, Canestrini is reported to have noted that the breathing of sleeping infants becomes slower and shallower in the presence of musical tones. He also is reported to have noted that auditory stimuli intense enough to awaken the baby increased respiration rates and that a pistol shot evoked an immediate increase in the amplitude of respiration. In 1934, Stubbs, recording changes in respiration with the pneumograph on 75 infants under 10 days of age, reported that responses to pure tone stimulation were observed in almost all infants at a 75 to 80 dB intensity level.

Davis, et al. (1955), presented a 1000 Hz tone of 120, 90 and 70 dB via earphones to subjects who in general responded by "...an increase in amplitude of breathing..." (page 34). Because the amplitude measurement of the respiratory response varied more than the duration measurement, the authors concluded there was a certain amount of independence in the two phenomenon. In a discussion of the duration of the breathing cycle, the researchers noted that "duration is believed to be determined by the Hering-Breuer reflex initiated by heightened intra-alveolar pressure." (page 38).

Although their study was concerned with other stimuli in addition to auditory stimuli, they concluded:

> "Repetition of a stimulus diminishes most elements of the response, though at different rates, but increases the respiratory responses to a 90 dB stimulus. The pattern of response is changed, therefore, by a stimulus repetition (page 69).
>
> "...There are some interaction effects between repetition and intensity, most conspicuous in the fact that repetition of the 120 dB stimulus decreases the respiratory response, while the repetition of the lower intensities increases it." (page 69).

In the years 1961, 1962, and 1963, Rosenau published reports dealing with what he called a sleep hearing test--"Die Schlafbeschallung." His 1962 article seems to be the most comprehensive of the reports. In his experiments, subjects were asleep in an experimental room with a low ambient noise level. Respiration was measured by means of a girdle-pneumograph connected by a plastic hose to a drum graph in an adjoining room. The sound stimulus used was a tone generated from a loud speaker hanging fifty centimeters above the child's head. Sound pressure levels used with the child ranged from 43 dB to 97 dB. The durations of the stimuli in these experiments were from 250 to 500 milliseconds.

Rosenau noted that with normal hearing children a sound stimulus of high intensity caused an inconstant change in the respiratory pattern. At medium sound intensities (sound-pressure level not specified), responses were characterized by irregularities such as are shown in Illustrations 1 and 2 below.

Illustration 1

The Respiratory Pattern Following Sound Stimulation
from Rosenau (page 198, 1962)

(Break in line indicates onset of tone).

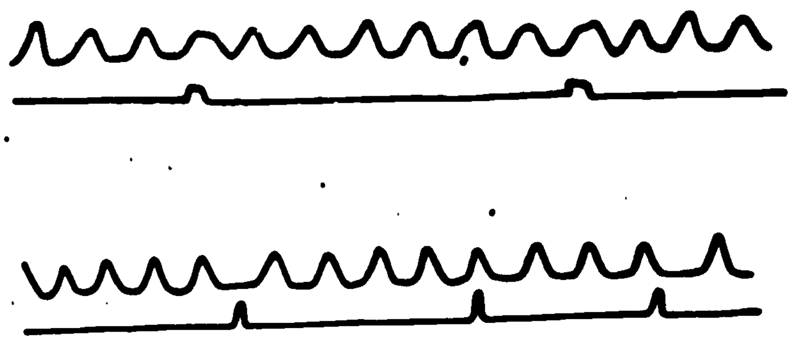
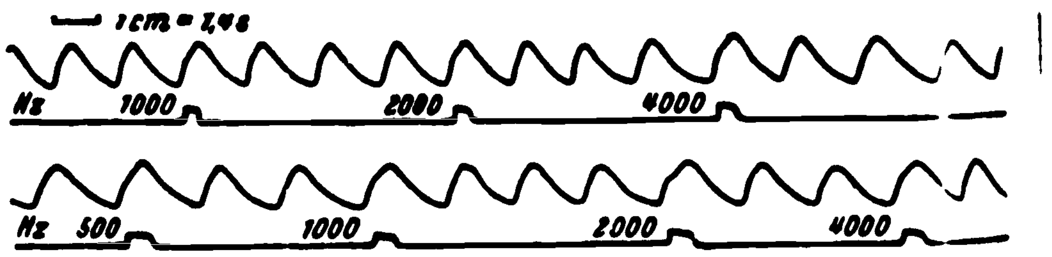


Illustration 2

The Respiratory Pattern Following Sound Stimulation
from Rosenau (page 198, 1962)

(Break in line indicates onset of tone).



In general, the sinusoidal excursions are marked by a flattening of the peak or valley of the expiratory curve or a distortion in the breathing pattern characterized by a notch on the inspiratory part of the curve.

Rosenau conducted four experiments to test the efficacy of his "Die Schlafbeschallung." The four experimental groups included: 1) normal hearing children with healthy ears; 2) normal hearing children with artificially induced deafness as a result of plugging their ears with paraffin-saturated gelatin; 3) children with audiometrically determined organic hearing impairment, and 4) children with verified total deafness.

Children with normal hearing showed "a mean reaction threshold of 53 dB to 60 dB in all frequencies..." (page 201). In the totally deaf group, Rosenau reported that no respiration changes could be observed except at 125 Hz with a sound intensity of 97 dB. He felt that this response was due to tactile stimulation resulting from the high intensity.

Rosenau (1962) also investigated the effects of sound stimuli upon breathing during sleep. He reported that "There is a significant change in respiration with a normal hearing child at sound intensities above 50 to 60 dB, which according to our experience up until now (so far), operates almost independently from how deep the sleep is--the deepness of the sleep has almost no effect on the change in respiration brought on by the sound stimulus." (page 37). In addition, he found noise to be superior to pure tones for eliciting responses.

Wagner (1963) modified the sleep audiometry method as proposed by Rosenau. He utilized electronic instrumentation (a psychogalvanometer) to record the respiratory excursions and the effects of the stimuli. He felt that the technique was developed to the point where medical technicians could perform the necessary operations.

Suzuki, et al. (1964), noted three changes in respiration which indicated possible auditory responses. These included 1) "changes in rate or deepness of respiration, that is, becoming fast or slower in its rate or becoming deeper or shallower in its amplitude," (page 918); 2) "decrease in regularity of respiratory movement which lasts 20 to 30 seconds after auditory stimulation," (page 919) and 3) "appearance of sudden deep inspiration." (page 918).

Suzuki stimulated his subjects at intensity levels ranging from 30 dB to 80 dB. The subjects were 45 full-term newborn infants ranging in age from 5 hours to 7 days whose parents were characterized by an absence of hearing problems in their case histories. At the lower intensity levels, he did not observe any consistent changes in respiration as related to the stimuli. However, at 70 dB and 80 dB levels there was a marked increase in the incidence of sudden inspiration.

Goldie and Green (1961) felt that "frequently a change from thoracic to abdominal breathing, or vice versa, denoted more clearly than the electroencephalograph alone a change in the level of consciousness." (page 581). They felt that "A consistent change in mode of respiration during sleep as a response to sound stimulus could be used as objective evidence as to the site of the lesion in deaf children, and may be of value in distinguishing deafness from mental deficiency." (page 581). Exactly how the site of the lesion could be ascertained from a change in respiration was never clearly spelled out.

Fisch (1965), quoting Davis (1964), reiterated that respiratory changes may be a sensitive indicator of hearing. However, he felt that there were still many technical problems to be considered with reference to clinical applicability.

In 1964, Rousey, et al., published in the American professional literature the first of a series of papers relating changes in respiration to levels of pure tone stimuli. In this initial research, ten subjects ranging in age from 14 to 17 years comprised the sample. Each subject received ten presentations at intensity levels from 100 dB through -20 dB as noted on the audiometer (calibrated to ASA 1951 standards). Electrical measurements allowed the inferential extension of the lower limit of the audiometer to -20 decibels. The hypothesis was that there would be a significant lengthening of the respiratory cycle at the point of threshold. Computation of changes in respiration was carried out by two methods. In Method 1, the length of the subject's breathing cycle during tonal stimulation was compared to the average length of the breathing cycle when no tone was present. The obtained scores for each of the ten presentations for each stimulus level were computed and a median score computed to represent the central tendency of the reactions. The second method utilized a percentage of change figure. The duration of the breathing cycle during tonal stimulation was subtracted from the duration of the preceding cycle. The difference was divided by the aforementioned preceding cycle and multiplied by 100. Thus, a percentage of change score was obtained and again a median response was determined for each group of stimuli at each intensity level. Utilizing Method 1, five of the ten subjects showed the greatest slowing of breathing during presentations of pure tones within plus or minus 10 decibels of their threshold obtained by conventional procedures. Using Method 2, four subjects showed the greatest median score within plus or minus 10 decibels of the criterion threshold.

In a later study, Poole, Goetzinger and Rousey (1966) investigated the test-retest reliability of respiration thresholds at 1000 Hz and compared the results with voluntary thresholds obtained in the same subjects. The sample consisted of 36 young adults with normal hearing. Stimuli were presented to the subjects at six different sound-pressure levels, i.e. 69 dB, 37 dB, 28 dB, 23 dB, 19 dB and 12 dB. There were five tonal presentations at each sound-pressure level for each subject. A median breathing cycle duration during tonal stimulation was computed for each subject at each sound pressure level. These breathing cycle durations during tonal stimulation were compared to the duration of breathing cycles in the absence of tonal stimulation at each presentation level. The results of the experiment showed 1) excellent test-retest reliability for the respiration thresholds; 2) the respiration thresholds agreed with the voluntary thresholds and 3) the duration of the breathing cycle increased as the tonal stimuli decreased in intensity.

Rousey and Reitz (1967) reported on the changes in respiration to visual and auditory stimuli. The greatest slowing in respiration occurred when the subject's auditory threshold was reached. However, a consistent relationship between respiratory pattern and visual threshold was not found.

Teel, et al. (1967), reported on the estimation of thresholds by changes in respiration with a group of deaf subjects. Ninety-four deaf children, 7 to 21 years of age, were studied. Ninety-four percent of the group gave respiratory thresholds within plus or minus 15 dB of auditory thresholds which were determined by standard audiometric procedures.

Brooks and Gieschen (1968) studied 30 adults ranging in age from 16 to 20 years who had hearing thresholds between 10 dB and 55 dB at 4000 Hz re: ISO 1964 standards. Seventy percent of the 30 subjects were found to have respiratory threshold measurements within plus or minus 5 dB of their clinically predetermined threshold. All of the subjects came within plus or minus 10 dB of their previously determined clinical thresholds. Estimation of threshold from the clinical record was accomplished by methods similar to the ones previously discussed by Poole, et al. (1966) and Teel, et al. (1967).

In all of the studies appearing since 1964, measurement of thresholds has been laboriously computed by hand. In general, the experimenters had measured from peak to peak or valley to valley of the respiration curve unless some jiggle in the respiration curve was present. In that case the measurement was to the initial jiggle. No attempt was made to measure the amplitude inasmuch as this was not initially calibrated.

Section 2: Theoretical Explanations for the Phenomena of Changes in Respiration Following Auditory Stimulation

A. Neurological Explanations

Oberholzer and Tofani (1960) provide the most comprehensive neurological discussion of changes in respiration relevant to the present discussion. With reference to a particular area which controls respiration, they write:

> "Today, it is customary to separate a primary respiratory center in the reticular substance of the medulla and pons from the superimposed or secondary respiratory centers in the mesencephalon and diencephalon, as also from the spinal effector centers in the spinal cord." (page 1111).

These authors noted with reference to experiments on animals that portions of the higher brain stem and of the cortex can affect the respiratory curve. Specifically, they note:

> "From the interthalamic commissure and from the lateral thalamus--lateral, ventral and caudal to the perifornical and activating region--an electrical stimulus always causes a reduction in the respiratory frequency. With the stimulation of the interthalamic commissure, this is, for the most part, caused by a lengthening of the duration of inspiration. With the stimulation of the lateral hypothalamus, both phases, the inspiratory and the expiratory, are generally lengthened, and the respiratory amplitude is often reduced." (page 1113).

With reference to cortical and cerebellar influence in respiratory activity, they write:

> "Most easily obtained (in the cat)[1] through cortical stimulation is a respiratory inhibition, with a decrease in the depth of inspiration and a prolongation of expiration. (page 1115).
>
> "In man, for the most part, stimulation of the cortex results in an inhibition of respiration, for example, from the orbital face of the frontal lobe (30)[2], from the anterior end of the island of Reil (150)[3], and from the columna fornicis (176).[4]" (page 1115).

The work of these authors lends support to the notion that while the phenomenon of respiration itself is a complex issue, nevertheless the probability does exist for there being some belief that it not only can be influenced by but also can be controlled by cortical centers. Such a possibility is of major significance in determining auditory thresholds and relating them to the neurological level of the patient.

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1 Present investigators' insert

2 In the original article, (30) referred to the following reference: Brookhart, J.M. Am. J. Physiol. 129:709, 1940.

3 In the original article, (150) referred to the following reference: Penfield, W. and T. Rasmussen. The Cerebral Cortex of Man. New York: Macmillan, 1950.

4 In the original article, (176) referred to the following reference: Segundo, J.P., R. Arana, E. Migliaro, J.E. Villar, A. Garcia Guelfi and E. Garcia Austf. J. Neurophysiol. 18:96, 1955.

Other authors in their study of animals have also noted the possibility for alterations in the respiratory pattern being obtained from cortical levels.

Smith (1938) in his animal studies concluded:

> "The presence in the cat, dog and monkey of cortical areas possessing similar cytoarchitectural structure and yielding similar physiological responses, suggests the existence of a fundamental plan for the cortical control of respiration in the general scheme of cerebral cortical evolution." (page 68).

Thus, Kaada, et al. (1949), concluded from their study of monkeys that "From temporal pole blood pressure alterations and respiratory inhibition were obtained." And further, "With these optimal parameters similar vascular and respiratory responses were obtained from a continuous stretch of cortex extending through the anterior insula, the posterior orbital surface of the frontal lobe, the subcallosal region to the rostral limbic gyrus and also including basal olfactory structures (uncus, limen insulae, anterior perforated space)." (page 356).

B. Psychological Explanations

Freud (1958), in his discussion of dreams, notes that when we fall asleep our plan is never completely realized. He writes:

> "We cannot keep stimuli completely away from our sense organs nor can we completely suspend the excitability of our sense organs. The fact that a fairly powerful stimulus will awaken us at any time is evidence that 'even in sleep the soul is in constant contact with the extra-corporeal world'." (page 23).

Later Freud quotes Burdach, the physiologist, to underline the notion that hearing continues during sleep.

> "In sleep the mind isolates itself from the external world and withdraws from its own periphery...Nevertheless connection is not broken off entirely. If we could not hear or feel while we were actually asleep, but only after we had woken up, it would be impossible to wake us at all...The persistence of sensation is proved even more clearly by the fact that what rouses us is not always the mere sensory strength

of an impression but its psychical context: a sleeping man is not aroused by an indifferent word, but if he is called by name he wakes ..thus the mind in sleep distinguishes between sensations..." (page 53).

A position implicating attention and breathing was discussed by Woodworth (1938). He wrote:

"Another clear correlation is that between momentary attention and partial or complete inhibition of breathing. Sudden stimuli will make the subject 'catch his breath.' If he is listening to a faint sound, arrested breathing eliminates disturbing respiratory sound..." (page 260).

One theoretical model which may be used to explain the changes in respiration is the orienting reflex. Broadly stated, the orienting reflex may be thought of as variation in the sensory, motor and integrative systems of the body in response to external change or stimulation. As such, the reflex occurs so long as each succeeding stimulus changes. The orienting reflex is extinguished when an identical stimulus is repeated. There is one exception to this latter rule which is of some importance for our speculation about the present results. Specifically, Sokolov (1960, 1962), suggests that for an orienting response to be extinguished, a neuronal model of the stimulus must be present. Further, he suggests that stimuli close to an individual's threshold are believed not capable of setting up a neuronal model. Thus, the present experiments would conclude that repeated sound stimulation above threshold would result in the extinguishing of the orienting reflex because no neuronal model of the stimulus was present.

However, Sokolov (1963) himself considers alterations of the respiratory rhythm as a manifestation of the defense reflex. He differentiates this from the orienting reflex as follows:

"The defense and orientation reflexes are similar in that they bring into operation generalized reactions and are not limited to any given analyzer depending on the nature of the stimulus. On the other hand, they differ in their ultimate object, this being the establishment of contact with the stimulus in the case of the latter and the breaking away from, or limitation of, the activity of the stimulus in the case of the former.

"The defense reflex (general defense reflex of the body) can appear in two forms, active and passive. The passive defense reflex takes the form of complete immobilization of the animal. The active defense reflex is expressed by behavior directed to the removal of or escape from the destructive agent." (page 14).

Other incidental findings regarding the orienting response have been reported by McDonald, et al. (1964) and Lynn (1966). McDonald, et al. (1964) reported that respiration failed to show a different orienting response to sound between the drowsy and awake state. Lynn, (1966), in discussing the differences between the orientation reaction and the startle (defensive) reaction, notes that "Autonomic components of this reaction (the defensive reaction) include a pause in respiration..." (page 9).

Section 3: Animal Studies

Instrumentation

Two studies have been reported measuring respiration in the rat. In one instance, Eisman (1965) implanted a thermocouple in the nose of the rat. This allowed the rat to be unrestrained and undisturbed by the measuring process. Mundl (1965) employed a transducer using a strain gauge fitted over the animal's back in both restrained and unrestrained situations. These experimentalists did not concern themselves with measurement of hearing threshold.

Specific Experiments

Corbeille and Baldes (1929) studied respiratory responses to acoustic stimulation in intact and decerebrate animals. No control was made of intensity of sound in their studies and the sounds were presumably quite loud. Their specific findings were summarized by them as follows:

> "In frogs, prolonged oscillator tones caused a decrease in the respiratory rate, while short, repeated stimuli or the sound of an alarm clock bell caused an increase in rate. Decerebrate frogs gave the same reactions as intact frogs." (page 489).

In the mammalian forms (rabbit, cats and dogs) studied, acoustic stimulation was accompanied by an increase in the respiratory rate, a shortening of the individual's respiration, whether the stimulus was a prolonged sound or a series of short sounds. After the period of stimulation, the respirations again increased in length. The immediate effect of beginning or of ending a stimulus was positive in only 25 to 30 percent of the experiments, and then consisted either of an increase or of a decrease of the time of the respiration in progress. A large number of tests was made on decerebrate rabbits, and again the respiratory reflex in these animals was the same in direction and extent as in the intact animals. Shliafer (1960), using tones from a sound generator varying from 1000 to 2000 Hz at a level of 75 to 80 dB concluded:

> (1) "An orienting reaction with changes in the respiratory and cardiac rates was noted in fully grown rats in response to auditory stimulation. In young rats there was no orienting reaction to a sound in the early post-natal period. These exhibited mainly a very definite respiratory reaction, less frequently a cardiac or motor reaction." (page 1346).

Golodov (1959) studied the respiratory reaction to loud sound of four dogs. Though he found individual differences between his dogs in their reaction, in general there was an increase in the depth of respiration. The results were interpreted in terms of the Russians' work in the orienting reflex, and the response of the animals to loud sound as reflected through their respiration was labeled as a defense reaction. Anderson and Wedenberg (1965) cite a 1929 study by Upton in which experiments on tonal discrimination "used a method in which the response to the test tones consisted (sic) in an increased regularity in the respiratory cycles of the guinea pig, which had been conditioned with shock-terminated tone." (page 376).

Chapter III

Results

The research grant outlined a series of experiments and procedures designed to specify the parameters of the phenomenon of changes in breathing at thresholds of hearing. They may be summarized as follows. Because all previous experiments (Rousey, et al. (1964), Rousey and Reitz (1967), Poole, et al. (1966) and Teel, et al. (1967) had used hand measurements which required a great expenditure of time, the first goal of the research was to design an automated process which would shorten the length of time involved in analyzing the data. Following the construction of this equipment, the research proposed to investigate some parameters of the phenomenon of changes in breathing at the threshold of hearing. These parameters included the questions as to whether the stimuli should be presented at the beginning of expiration or inspiration, whether variations in the duration of stimulus tone affected the respiratory cycle at threshold differently, the number of presentations of stimuli needed to produce the phenomenon, the variation in terms of intervals between presentation of stimuli which would enhance the disturbance in respiration, and the application of the knowledge obtained to testing of children with known hearing losses and/or organic problems which might interfere with their learning capacity. During the course of the experiment, study of the variation of intervals between presentation of stimuli was omitted because data suggested alternate experiments would be more valuable. These experiments centered on developing visual criteria for estimating threshold and studying the relationship between auditory stimulation and respiratory patterns during natural and drug induced sleep. In the following pages, we shall summarize the step-by-step process which was undertaken during the research program.

Section 1: Construction of the Equipment

This phase of the research produced some unanticipated delays because of a shortage in obtaining necessary electronic apparatus. This shortage was occasioned by the war in Viet Nam. However, after this was overcome, we were able to construct a piece of equipment which we felt answered the needs of the research. This phase of the research is described in the following excerpt of an article by Hartzell, et al. (1969) which was accepted for publication in the near future by the Journal of Psychophysiology.

In the following pages, a semi-automatic system is described which allows determination of the auditory threshold on the basis of changes in the respiratory signal. The system performs three major functions: 1) recording the respiration signal; 2) data processing; and 3) stimulus programming. This system was designed and constructed in mid-1967 at a cost of $6000 for equipment and material.

Recording

The respiratory signal is recorded on a single channel (mechanics for electronics model M2/760) strip chart recorder.[5] This record is used as both a display and a permanent record of the raw data.

A mercury tube strain gauge wrapped around the thorax generates the signal. The mercury tube is the active arm of a bridge circuit. A single mercury strain gauge as used in this experiment obviously does not reflect volume flow or allow differentiation between thoracic and abdominal breathing. However, knowledge of these parameters is not necessary in the present instance where we are primarily interested in the aspect of duration (time) of the breathing cycle. An event marker on the edge of the strip chart records duration and temporal location of the stimulus. An event marker signal, originating in the data processor, is superimposed on the respiratory signal at the beginning of inspiration and the beginning of expiration. With the superimposed marker and the location of the stimulus marked on the strip chart, the record contains all of the information needed to determine the auditory threshold. Without data processing capabilities, the strip chart must be measured by manual techniques that are time consuming and prone to error.

Data Processor

The data processor's function is to extract four pieces of information from each respiratory cycle. These bits of information are the duration of inspiration, duration of expiration, and the amplitudes of these two periods. This information is printed out on a multichannel printer (Clary Model 7000) to facilitate the final data handling. Each row on the printout contains an identification number and the duration and amplitude for a half-cycle of the respiration signal.

To obtain a duration and amplitude measurement for each half cycle, the beginning of inspiration (the negative peak of the signal) and the beginning of expiration (the positive peak) must be located each time they occur. Only the detection of the beginning of expiration,

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[5]All system components supplied by commercial manufacturers are noted in the text. Manufacturer and model number are given the first time a component is mentioned. All remaining circuitry is laboratory designed. Circuitry and/or suggested improvements are available upon request.

the approximate positive peak, will be discussed. The negative peak is determined in the same manner.

Peak Detector

The respiratory signal from the strain gauge is filtered by a low pass filter with a passband below 5 Hz--this is to remove any EKG signal that may be present and to reduce the effects of small body movement artifacts. The filtered signal is applied to the signal input of a voltage comparator. At the same time, the signal is applied to a positive peak reading memory circuit. (See Figure 1). During inspiration the signal is going positive and the peak reading memory tracks it. The output from the peak reading memory is then delayed by a phase shift network. The delayed signal is applied to the reference input of the comparator. When the positive peak is reached, the peak reading memory holds this voltage on the reference input of the comparator. The small difference in amplitude of the two signals produced by the delay of the reference signal keeps the comparator output in a zero, or false state. As the signal starts negative at the beginning of expiration, the signal input of the comparator goes negative with respect to the reference input (the peak amplitude). This reversed input voltage relationship causes the comparator to change to the true state, thus locating the beginning of expiration. The signals produced by the comparators at the beginning of inspiration and expiration are used to initiate duration measurements, stimulus presentation, amplitude measurements and are superimposed on the respiration signal on the strip chart recorder.

Peak detection, by comparing the maximum amplitude of a wave front with the continuously changing wave, is plagued with problems, i.e., flat topped waves, noise, signal saturation, and signal dropout. These variations produce large timing inaccuracies in the peak detection. In the system described, the maximum range of signal produced by respiration falls well within the working limits of the peak detector, eliminating signal saturation or dropout as a source of error. Noise is the most difficult problem to overcome. In this system, a low pass filter is used to reduce the effects of noise on peak detection. Hysteresis in the comparator further reduces the effects of noise. The remaining major problem is flat topped input signals. This does not present a problem when respiration is the signal source. The shape of the respiration wave is generally flat at the end of expiration. However, there is a corner on the wave from at the beginning of inspiration and the beginning of expiration. This corner produces a fast rate of change on the input of the comparator causing it to change state very close to the actual beginning of inspiration or expiration. The small delay results in an acceptable timing error when it is noted that for a given subject the respiration wave form has a relative constant shape. The timing error produced by this type of peak detection thus remains nearly constant.

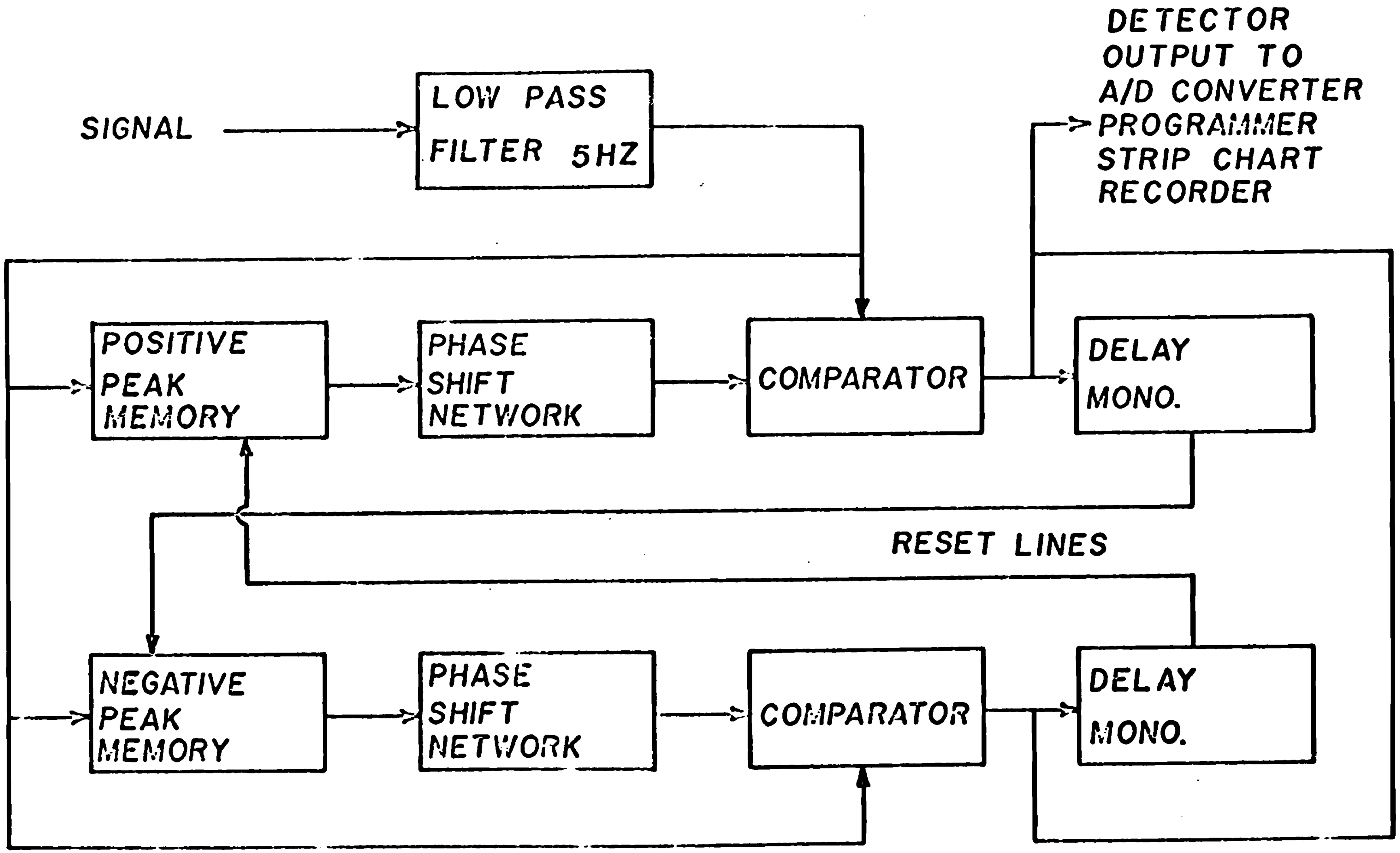

FIGURE I. PEAK DETECTOR

The output of the comparator is also used to start a delay multivibrator. At the conclusion of the delay period, the negative peak reading memory is reset. This allows the negative peak memory to track the incoming negative going signal. When the negative peak (the beginning of inspiration) is detected, a delay period is started. At its conclusion the positive peak memory is reset. Cross coupling of the reset signals alternately reset the peak memories and allows them to track to their next incoming peak. (See Figure 2 for data processor timing sequence). Delay of the reset signal is required to allow data sampling to be completed before a memory is reset. The system will handle respiration rates from .1 to 3 Hz without losing the timing sequence.

Duration Measurement

The basic hypothesis states that for determining the auditory threshold from the changes in respiration patterns, the duration of a respiratory cycle increases more near threshold when an auditory stimulus is presented than for levels above or below threshold.

The duration of each half-cycle of the respiratory signal is measured by a digital clock (Figure 3). The output of the peak detectors is used to start the clock. The clock times until the next peak is detected. At that time the information in the clock is transferred to a storage register. After data transfer, the clock is reset to zero and starts timing the period of the next half-cycle of respiration. The storage register output is applied to the printer. Thus, each time the print command is generated, the duration of the half-cycle period is printed out.

Amplitude Measurement

We are measuring amplitude as well as duration of the half-cycle periods of the respiration wave to determine if variations in amplitude may be used as an indicator of the auditory threshold.

Figure 4 is a block diagram of the amplitude measurement section of the data processor. To follow the sequence of events, assume the system is running, a negative peak (inspiration) is held in memory, and a positive peak is reached (end of inspiration). The outputs from the two peak reading memories are applied to the differential inputs of an analog to digital converter (Fairchild Instruments Digital Voltmeter, Model 7140). The difference in amplitude of the applied signals to the A/D converter is the relative amplitude of the just completed inspiration period. As expiration begins, the positive peak of the wave form is detected. This initiates data sampling by the A/D converter (refer to Figure 1). The output of the A/C converter, the amplitude of inspiration, is applied to the printer. At the completion of the A/D's sampling period, a sample complete pulse is

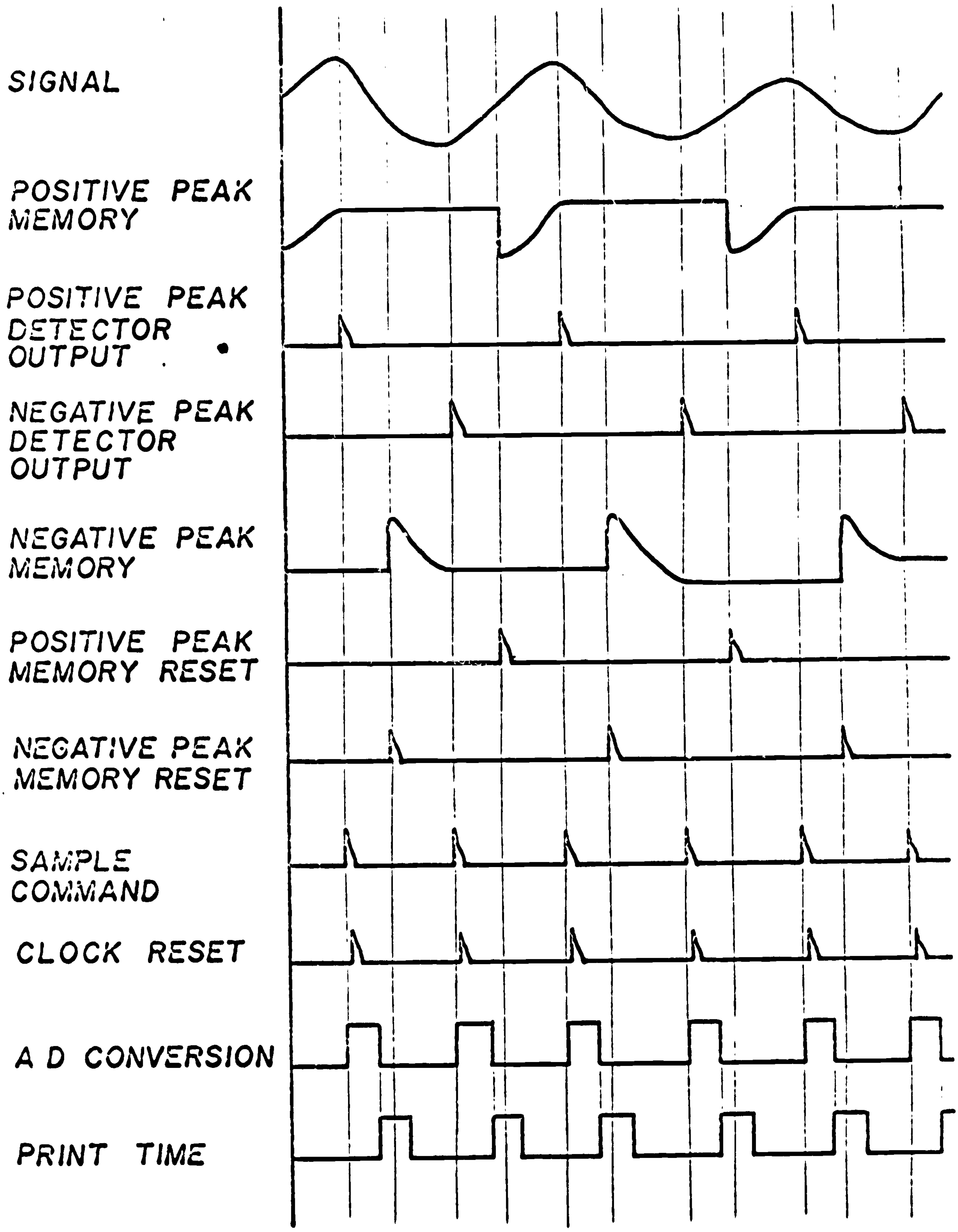

FIGURE 2.

DATA PROCESSOR TIMING SEQUENCE

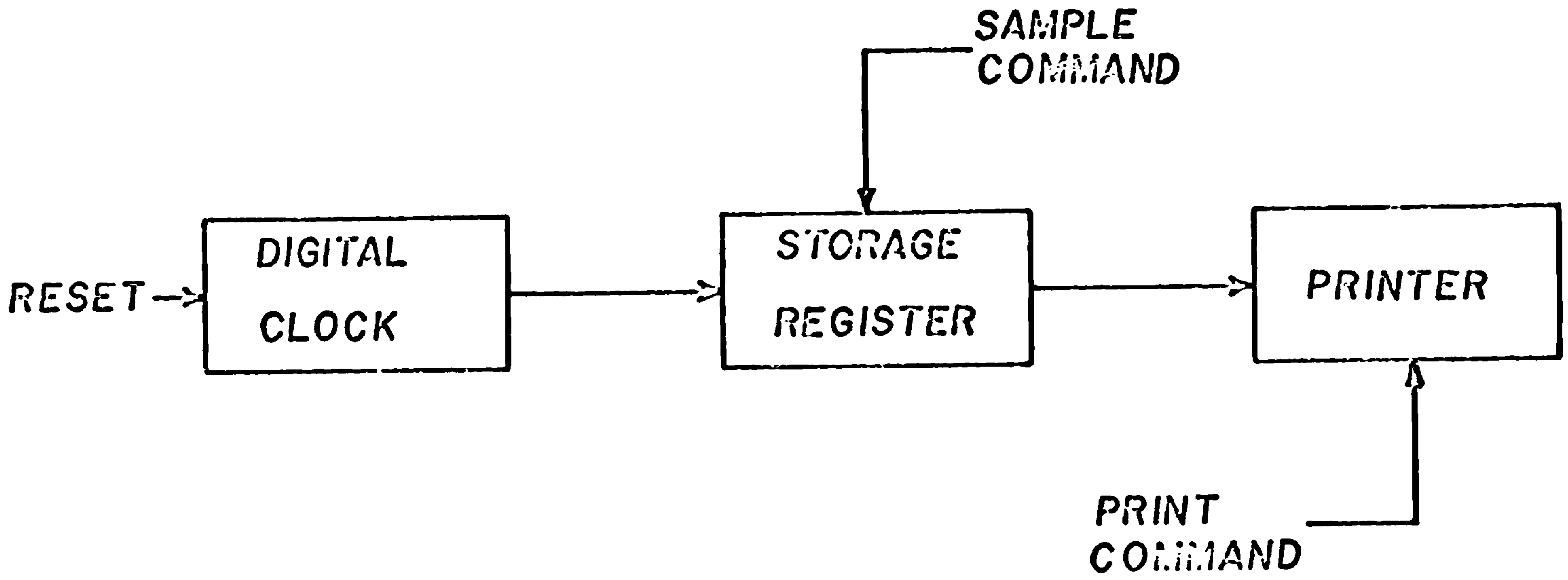

FIGURE 3. DURATION MEASURMENT

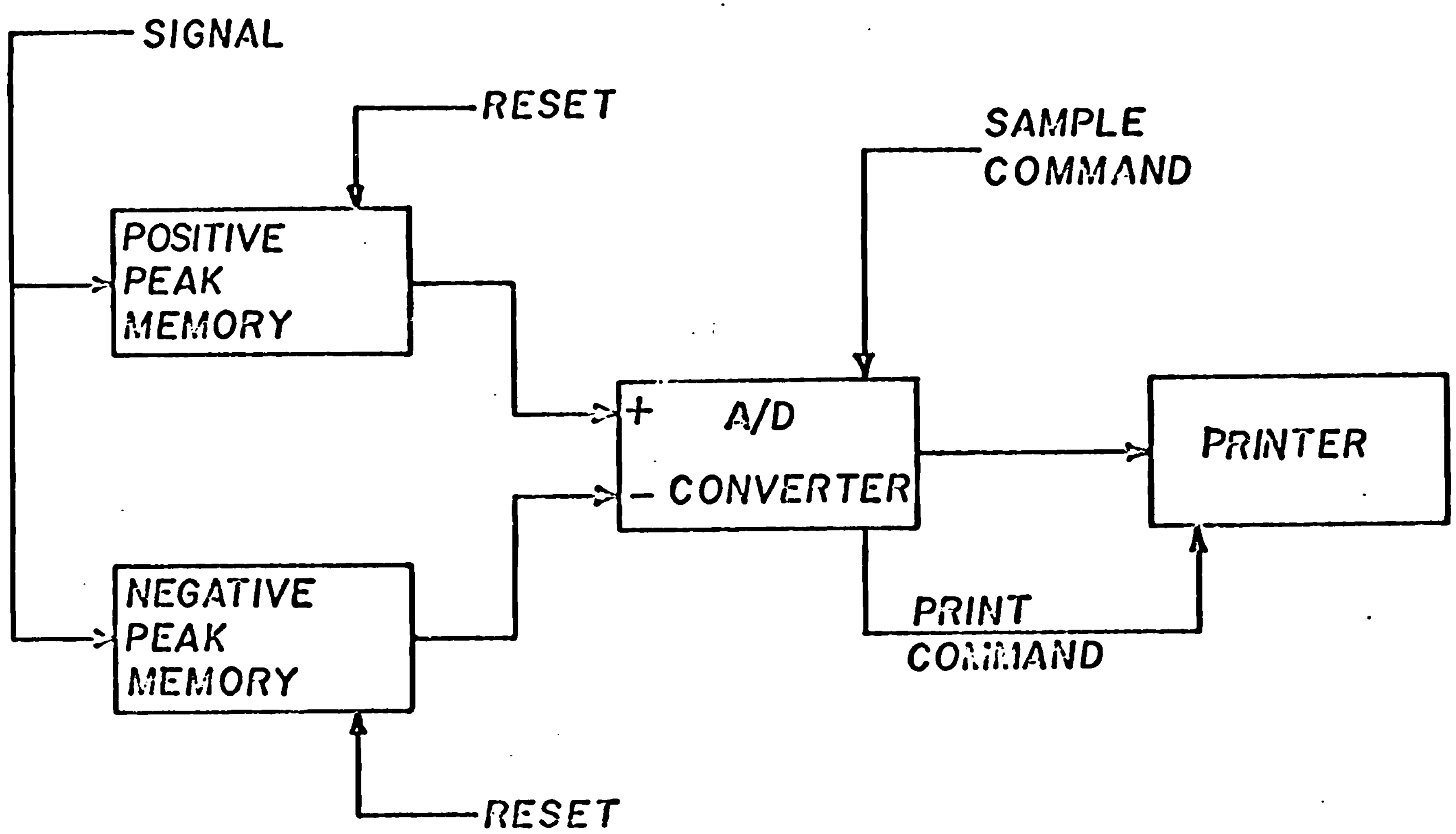

FIGURE 4. AMPLITUDE MEASURMENT

generated. This pulse is used as a print command pulse for the printer, thus printing out the amplitude of the half-cycle period, the duration of that period which is being applied to the printer and the identification number.

The peak detection at the beginning of expiration initiates the delayed reset signal for the negative peak memory. When the negative peak is detected at the beginning of inspiration, the data sampling, printout, reset sequence is repeated. Thus, the amplitude of alternate half-cycle periods is measured.

Identification Number

The identification number printed with each data sample is derived from a sequential counter. Each time a stimulus is presented, the counter advances one digit. Several data samples are taken between each stimulus presentation, the number of samples being dependent upon the program sequence. The data samples between each stimulus all have the same identification number. Each time a new identification number appears in the printout, a new stimulus has been presented. Thus, the dB level of each stimulus may be identified. The two data samples following the first print of an identification number are the durations and amplitudes used in the final determination of the auditory threshold.

Stimulus Programmer

Stimulus programming is the remaining function to be performed by the system. The programmer (Figure 5) is controlled by a manually operated enable switch and the outputs of the peak detectors. The enable switch presets the control circuits and selects the beginning of inspiration or expiration as the starting point of the programming sequence.

When the enable switch is set and peak is detected, a delay timer[6] is started. This delays the onset of the stimulus for a preselected time (0 to 10 seconds) after the peak is detected. At the end of the delay period, the stimulus is initiated. A duration timer turns on the audiometer (Beltone, Model 15/C, modified for remote on/off control) for a pre-selected time.

The stimulus level is controlled by the adjustable drum programmer (Sealectro Corp. Model 91-3867-001). It switches the appropriate values of attenuation into the output line of the audiometer in accordance with a pre-selected program. Normally, the drum

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[6] The delay timer has been incorporated to allow for investigation of the effects of changing the starting point of the stimulus with respect to the beginning of inspiration or expiration in determining the auditory threshold.

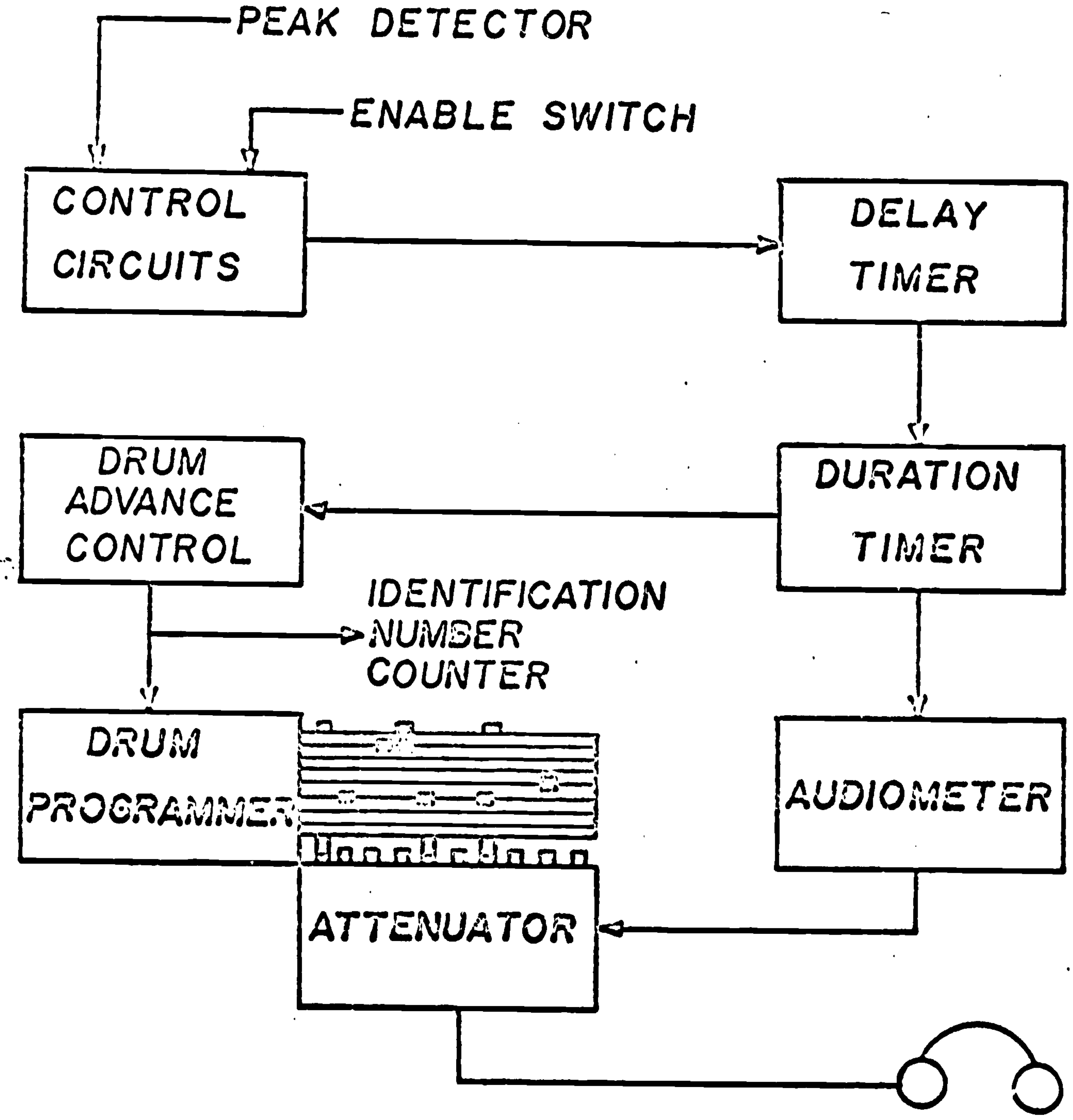


FIGURE 5. PROGRAMMER

advances to a new position after each stimulus presentation. A preset counter, part of the drum advance control, makes it possible to hold the drum in any position for up to five presentations to a stimulus level before the drum is allowed to advance. The drum is field adjustable; thus a wide choice of program sequences may be easily selected. Twenty-four stimulus levels are used, no signal and -10 to +100 dB in five dB steps, re: .0002 dynes/cm^2.

Figure 6 shows a picture of the equipment as it stands in the experimental room. It demonstrates how it was placed relative to the audiometer.

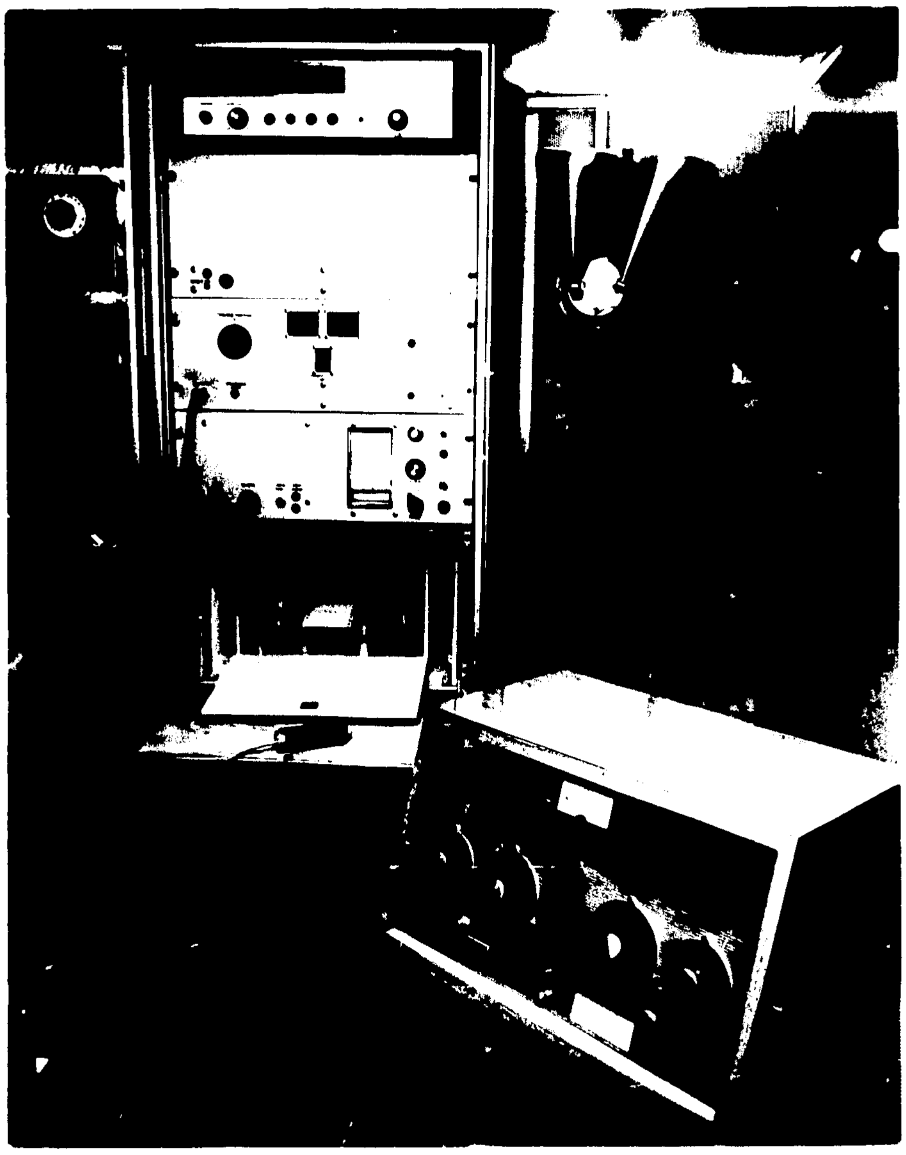


Figure 6. Equipment Used in Experiment

Figure 7 shows how the typical subject looks wearing the strain gauge and earphones. Figure 8 shows the basic components used in this research to determine respiration thresholds. Following construction of this apparatus, we embarked on a series of experiments which we hoped would allow us to circumvent the necessity for laborious hand measurements.

Figure 7. Typical Subject Shown in Reclining Position Wearing Strain Gauge (White Belt) and Earphones

Section 2: The Experiments

Procedure

All of the experiments were conducted with the previously

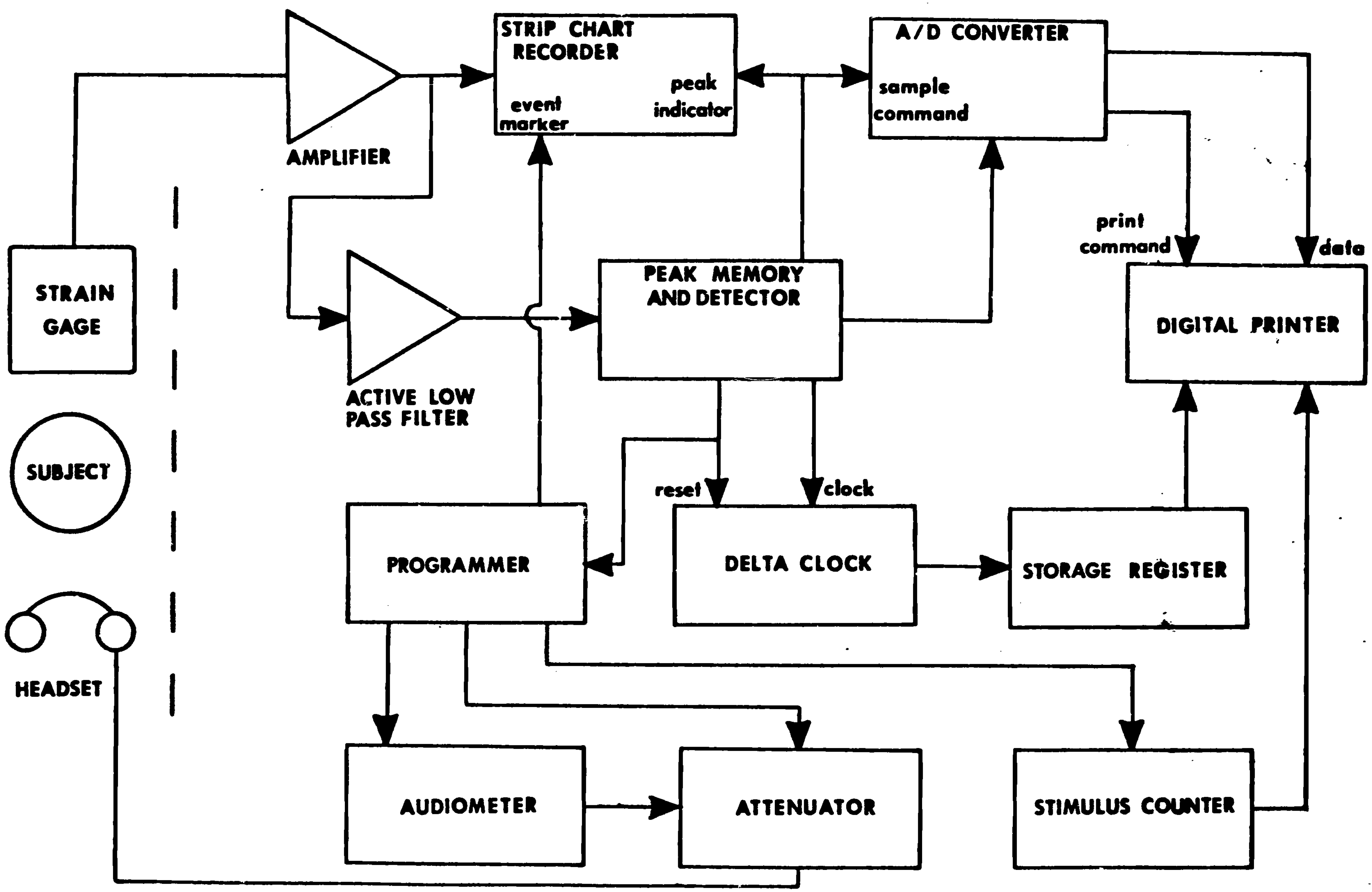


FIGURE 8. BLOCK DIAGRAM OF BASIC COMPONENTS IN THE EXPERIMENT

described apparatus. All data collection, with the exception of data on children from the Kansas School for the Deaf and the Kansas Neurological Institute was obtained in a series 1200 IAC Soundproof Suite. A Beltone 15C audiometer (calibrated to ASA 1951 standards) was used as the source of the auditory stimulus.

In general, the frequency of 1000 Hz was used as the stimulus tone. However, at the Kansas Neurological Institute and the Kansas School for the Deaf, other frequencies were used because of the nature of the hearing loss in the population. These frequencies included 250 Hz, 500 Hz, 2000 Hz and 4000 Hz. The experiment failed to show any differences between frequencies in terms of effect on the respiratory cycle. Hence, the results section does not differentiate between frequencies.

Rise time for the 250 Hz signal varied from 120 milliseconds at a setting of 10 dB re: the audiometer setting to 140 milliseconds at 100 dB re: the audiometer setting. Decay time for the 250 Hz tone varied from 60 milliseconds at 10 dB re: the audiometer setting to 140 milliseconds at 100 dB re: the audiometer setting.

The 500 Hz rise time varied from 100 milliseconds at 10 dB re: the audiometer setting to 120 milliseconds at 100 dB re: the audiometer setting. Decay time varied from 60 milliseconds at 10 dB re: the audiometer setting to 140 milliseconds at 100 dB re: the audiometer setting.

At 1000 Hz, rise time varied from 100 milliseconds at 10 dB re: the audiometer setting to 120 milliseconds at 100 dB re: the audiometer setting. Decay time varied from 50 milliseconds at 10 dB re: the audiometer setting to 120 milliseconds at 100 dB re: the audiometer setting.

At 2000 Hz, rise time varied from 100 milliseconds at 10 dB re: the audiometer setting to 120 milliseconds at 100 dB re: the audiometer setting. Decay time varied from 40 milliseconds at 10 dB re: the audiometer setting to 60 milliseconds at 100 dB re: the audiometer setting.

At 4000 Hz, the rise time varied from 60 milliseconds at 10 dB re: the audiometer setting to 120 milliseconds at 100 dB re: the audiometer setting. Decay time varied from 40 milliseconds at 10 dB re: the audiometer setting to 80 milliseconds at 100 dB re: the audiometer setting.

For the experiment at the Kansas School for the Deaf, located at Olathe, Kansas, and the Kansas Neurological Institute in Topeka, Kansas, the programming and data processing equipment and the audiometer were moved to the appropriate institutions and were set up in a two-room sound treated suite.

As each subject entered the experimental situation, a mercury-in-rubber strain gauge was fastened around the upper part of the body at the xiphoid process and the earphones were positioned comfortably. With the subject in a comfortable reclining position, he was told that there would be a series of sounds and that he was not to respond, but rather just lie as quietly as possible and listen. At the end of each testing session, a threshold was obtained from each subject in the traditional manner. This was compared to the respiration threshold.

Respiration thresholds were obtained from data contained in the computer print out. Figure 9 presents a section of the computer print out. The first three numbers beginning at the left indicate the stimulus number, the next 0 is a blank number which never contains data,

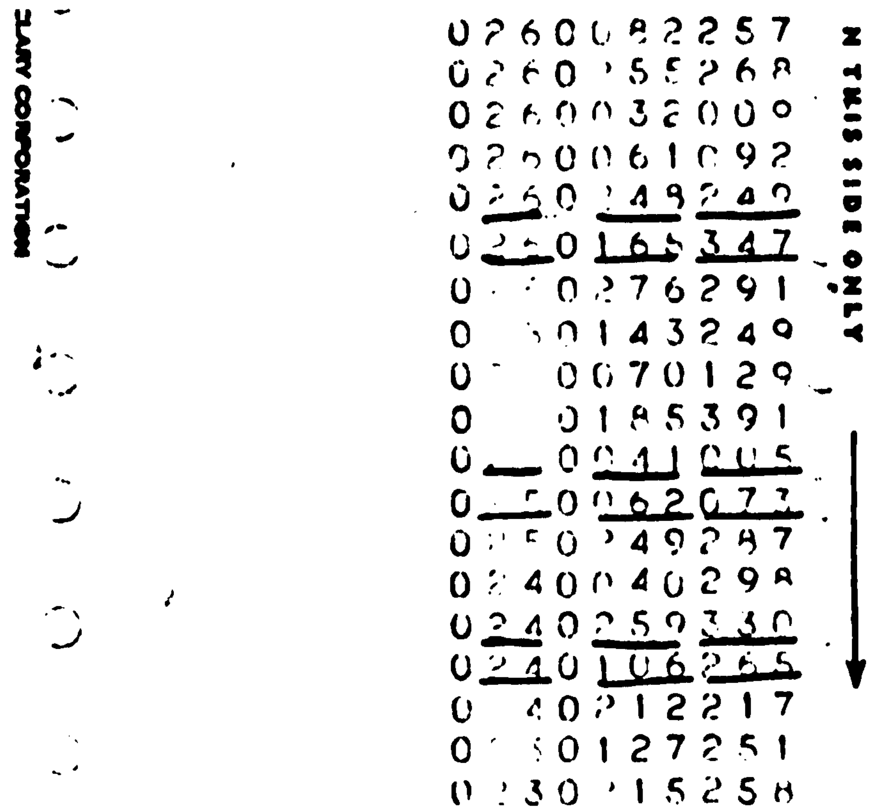


Figure 9. A Sample of the Computer Print Out

the next three numbers give the duration of the first half of the breathing cycle, and the final three numbers give the amplitude of the first half of the breathing cycle. The numbers for the second half of the breathing cycle appear immediately above the first set of figures. Thus, in Figure 9 the fourth line from the bottom (0240106265) is translated as follows. The stimulus number is 024, the number 0 is an extra number not used, the numbers 106 indicate the first half of the duration of the respiration cycle and the number 265 indicates the amplitude of the first half of the breathing cycle. The line of data immediately above gives the other half of the breathing cycle. The numbers were recorded on a data sheet, added together manually and a final duration and amplitude score was obtained. The initial assumption was that threshold would be reflected for the stimulus presentation number where the duration was the greatest and the amplitude the least.

Subjects

In its entirety, data from 174 subjects were used in the experiment. Table 1 shows the distribution by sex and age for each of the following experiments. With the exception of the children from the Kansas Neurological Institute, there were no known neurological abnormalities present in any of the children.

Experiment 1: Effect of Presentation of Tone on Inspiration and Expiration

In our first experiment, we presented a tone of one second duration to the subjects at the beginning of inspiration and expiration. However, inadvertent movement at times during stimulus presentation spoiled the responses. Thus, although we tested some twenty subjects when the stimuli were presented randomly on inspiration and some nineteen subjects when the stimuli were presented randomly on expiration, inadvertent movements by many of the subjects prevented us from using all of the subjects which were tested. The score printed by the computer could not take into account and make adjustments for any extraneous movements. Accordingly, we picked seven subjects in each group who had the least number of extraneous and unforeseen movements during the presentation of the stimulus. In each of these seven records, ten or fewer extraneous movements occurred. In the remaining subjects there were larger numbers of inadvertent movements.

The basic question explored in this experiment was whether threshold could be estimated better by presenting the tone at the beginning of inspiration or the beginning of expiration. We were also interested in determining whether the amplitude of the breathing cycle could be used to estimate threshold as effectively as duration. Because the material was presented in a random, but programmed fashion three successive times, we were also able to study the question of how many presentations of stimuli should be used. Each program contained 48 presentations of stimuli. These 48 presentations were composed of two presentations at each 5dB intensity level from -10 through 100 dB (ASA). In each series an X condition was also presented. X was always a blank presentation.

With reference to the question of whether presenting the tone during inspiration or expiration produced differing estimates of threshold, we may compare the results presented in Tables 2 and 3. The results are based on three presentations of the program, i.e. six presentations at each intensity level. When the parameter of duration of the breathing cycle is considered, a closer estimate of threshold is obtained when the tone is presented on the beginning of inspiration than expiration. Use of the criteria of least amplitude shows a greater number of close estimates of threshold

TABLE 1

DISTRIBUTION OF SUBJECTS AS TO NUMBER, AGE AND SEX

	Number of Subjects Male	Median Age	Age Range	Number of Subjects Female	Median Age	Age Range
Experiment 1	5	17	15 - 45	9	21	15 - 40
Experiment 2	4	17.5	17 - 48	11	33	21 - 40
Experiment 3	30	9.5	7 - 35	51	34	23 - 64
Experiment 4	12	13	11 - 18	15	14	12 - 17
Experiment 5	All subjects were used who were in Experiments 1, 2, 3, 4,and 7.					
Experiment 6	All subjects were used who were in Experiments 1, 2, 3, 4, and 7.					
Experiment 7	6	23	20 - 32	11	33	22 - 55
Experiment 8	16	23	9 - 52	4	9.5	6 - 20

TABLE 2

ESTIMATION OF THRESHOLD BY PRESENTATION OF STIMULUS AT BEGINNING OF INSPIRATION

Subject	Conventional Test	Estimated Threshold by Changes in Respiration on the Basis of Longest Duration	Estimated Threshold by Changes in Respiration on the Basis of Least Amplitude
1	-10	5	10
2	10	5	15
3	-5	-10	50
4	-5	65	10
5	-5	0	-5
6	-5	-5	100
7	-10	-5	85

TABLE 3

ESTIMATION OF THRESHOLD BY PRESENTATION OF STIMULUS AT BEGINNING OF EXPIRATION

Subject	Threshold by Conventional Test	Estimated Threshold by Changes in Respiration on the Basis of Longest Duration	Estimated Threshold by Changes in Respiration on the Basis of Least Amplitude
1	-10	-5	15
2	-10	15	65
3	-10	5	5
4	-10	15	45
5	-10	X	45
6	-10	25	45
7	-10	25	80

in the group receiving the tone on inspiration. However, the dimension of amplitude fails to be as sensitive as duration as an indirect indicator of threshold.

When the same dimensions, i.e. duration and amplitude, are studied for each of the three successive presentations of the program, duration clearly appears to be a better way of estimating threshold. The data for this inference is presented in Tables 4 and 5. It is also clear that presentation of the program once is more effective in allowing threshold estimation than continued presentation of the program. As we shall see in a later experiment (See Experiment 6), amplitude proves helpful as a visual indicator of threshold.

Experiment 2: Determination of Method of Stimulus Presentation--Ascending, Descending or Random

On the basis of the previous experiment which suggested that for best estimation of threshold the tone should be presented twice during inspiration, we studied next, methods of presentation. Indirect threshold estimations were made solely on the basis of longest duration of a breathing cycle.

In standard clinical audiometric testing, the descending-ascending technique (Carhart-Jerger, 1959) is preferred. However, this technique is not appropriate when an involuntary threshold is sought. To this end we compared thresholds which were obtained during ascending, descending and random tonal presentations.

Fifteen subjects were randomly assigned to three groups of five each. The test frequency, a 1000 cycle tone of one second duration, was presented monaurally. The testing conditions were the same as in the first experiment. Group 1 was tested using the ascending method, Group 2 the descending method and Group 3 the random method. For the ascending and descending methods, each series of stimuli was presented twice. For the random method, a total of two stimuli were presented at each test level from -10 to 100 dB. The data are summarized in Table 6.

It is clear from the table that the ascending and random methods produced a closer estimation of threshold. However, extraneous movement during presentation of the stimuli seemed to be present more during the random than the ascending presentations. Accordingly, we decided to use the ascending method in the following experiment.

Experiment 3: Duration of the Stimulus

Having decided on the basis of the previous experiment that the tones should be presented in an ascending manner during the inspiration phase of breathing, we next investigated the possible effects of

TABLE 4

ESTIMATION OF THRESHOLD DURING THREE PRESENTATIONS OF THE PROGRAM
FOR THE
INSPIRATION GROUP

		Estimated Threshold by Changes in Respiration on the Basis of Longest Duration			Estimated Threshold by Changes in Respiration on the Basis of Least Amplitude		
Subject	Actual Threshold	Program 1	Program 2	Program 3	Program 1	Program 2	Program 3
1	-10	-10	90	55	50	0	-5
2	10	0	5	95	-5	0	40
3	-5	-10	35	40	50	75	80
4	-5	10	90	65	-5	10	35
5	-5	0	60	0	-5	65	40
6	-5	-5	60	10	100	35	100
7	-10	-5	75	60	40	85	20

TABLE 5

ESTIMATION OF THRESHOLD DURING THREE PRESENTATIONS OF THE PROGRAM
FOR THE
EXPIRATION GROUP

Subject	Actual Threshold	Estimated Threshold by Changes in Respiration on the Basis of Longest Duration			Estimated Threshold by Changes in Respiration on the Basis of Least Amplitude		
		Program 1	Program 2	Program 3	Program 1	Program 2	Program 3
1	-10	5	15	5	30	15	85
2	-10	5	30	10	65	45	0
3	-10	0	20	40	55	60	5
4	-10	25	50	15	90	45	X
5	-10	0	X	20	65	40	50
6	-10	55	X	25	0	35	20
7	-10	X	25	90	80	80	55

TABLE 6

THRESHOLDS OBTAINED USING THE ASCENDING, DESCENDING AND RANDOM METHODS OF STIMULUS PRESENTATION

Subject	1	2	3	4	5
		GROUP 1			
		Ascending			
Actual	45	-5	-5	0	0
Estimated	50	5	10	5	-5
		GROUP 2			
		Descending			
Actual	0	-10	0	-10	0
Estimated	70	70	65	25	X
		GROUP 3			
		Random			
Actual	-10	-5	-10	-5	-5
Estimated	70	-5	-10	10	-5

varying the duration of the tone. It is to be expected that the thresholds for a tone of more than one second in duration will be different than the thresholds for shorter bursts of tone (Hirsh, 1952).

Our primary concern, partly because of the length of the test session, was to find the stimulus of the shortest duration which would yield adequate threshold data. Within the limitations of rise and decay time discussed on page 25, the following dial readings (in milliseconds) for duration were used: 250, 500, 750, 1000, 1500 and 2000. Table 7 shows the amount of discrepancy between estimated and actual thresholds for the six different durations of tone presentation.

It soon became apparent during our testing that a 250 millisecond duration was yielding a high degree of threshold agreement between actual and estimated thresholds. Therefore, with the exception of 1000 milliseconds, the other five duration levels were only cursorily evaluated. It will be recalled that the earlier 1000 millisecond presentations had yielded fairly close estimation of thresholds. The departure from this close level of agreement seen in the present data stems in part from the larger sample. Although the 250 millisecond presentation has some

TABLE 7

EFFECT OF STIMULUS DURATION ON ESTIMATED THRESHOLD

Tonal Duration in Milliseconds	Agree Within 5 dB	Agree Within 10 dB	Agree Within 15 dB	Agree Within 20 dB	Agree Within 25 dB	Disagree Over 25
250	17	13	3			8
500	1			1		3
750			2	1		2
1000	8	1	2	3	2	9
1500	1					4
2000	1				1	3

eight disagreements (a variance between actual and estimated threshold of over 25 dB), some 33 of the 41 subjects gave respiratory responses within 15 dB of their voluntary threshold. Each of the succeeding experiments was then executed using the ascending technique with a tonal duration of 250 milliseconds and with two presentations at each intensity level.

Experiment 4: Respiration Thresholds on Children with Impaired Hearing

Thirty-five children from the Kansas School for the Deaf were included in this study. The children ranged in age from eleven through eighteen years and the hearing loss was from moderate to profound. Since we had been testing primarily normally hearing people, we at this point were concerned about 1) how the data collection would proceed with hearing handicapped children and 2) what data would be provided in a no response situation.

Careful examination of the data from Table 8 indicates that the relationship between actual and estimated thresholds was not as high as found with the normal hearing population.

Earlier research (Teel, et al., 1967), indicated that there was a close relationship between actual and respiratory thresholds in the deaf. The difference between the present experiment and the aforementioned one is that in Teel et al.'s experiment, five presentations of each stimulus level were randomly presented and hand measurements were made from the peak or valley nearest to the onset of the tone to the first notch in the following expiration or inspiration phase of the respiratory cycle. The apparent drop in capacity to estimate threshold by change in respiration may reflect either the penalty paid for automatizing the data or reducing the number of stimulus presentations. In the present study, we tested five subjects who gave no response via conventional audiometry. On only one subject did we obtain a result consistent with the profound loss which is inferred in a subject who gives no response. At this point, it became obvious that some unknown factor must be present in our data from the deaf population which affected our capacity to estimate threshold via our automated system. We also had some disagreements in our population with normal hearing. In the next experiment, we examined the respiratory curves to see if we could specify the unknown factors.

Experiment 5: Specification of Ideal Respiratory Pattern

We reasoned that perhaps there was an ideal respiratory pattern which might be present and which would affect our capacity to indirectly estimate threshold. Accordingly, ten records which correlated highly with conventional audiometric thresholds were compared with ten records in which the relationship was poor. Examination of these records

TABLE 8

ESTIMATED THRESHOLDS OBTAINED FROM HEARING IMPAIRED SUBJECTS

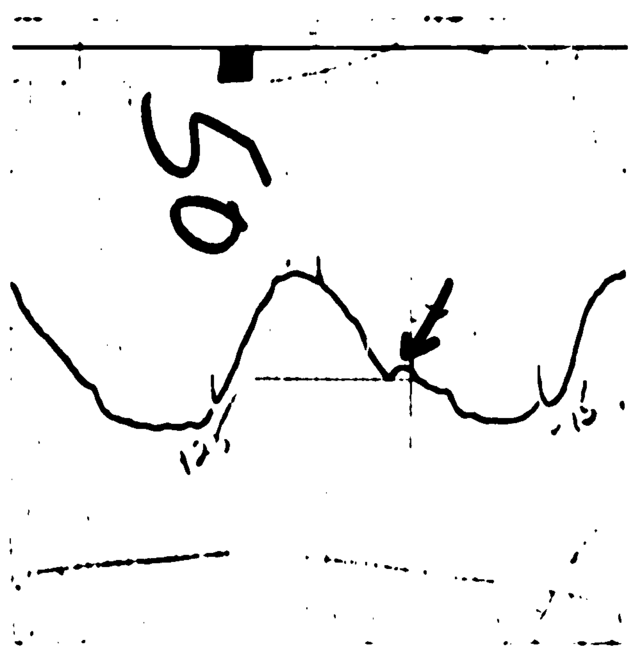
	Agree Within 5 dB	Agree Within 10 dB	Agree Within 15 dB	Agree Within 20 dB	Agree Within 25 dB	Disagree Over 25 dB
Subjects with Measured Hearing Loss	5	4	1	6	2	13
	Within 5 dB of 100	Within 10 dB of 100	Within 15 or more dB of 100			
Subjects Failing to Give Any Indication of Hearing	1		4			

suggested that certain variations were occurring in the respiratory cycles which militated against accurate threshold estimation. Accordingly, criteria were developed for judging acceptable variations in the respiratory patterns of sound. They are shown in Figure 10. Using these criteria, we rated each of the records. As shown in Table 9, when the

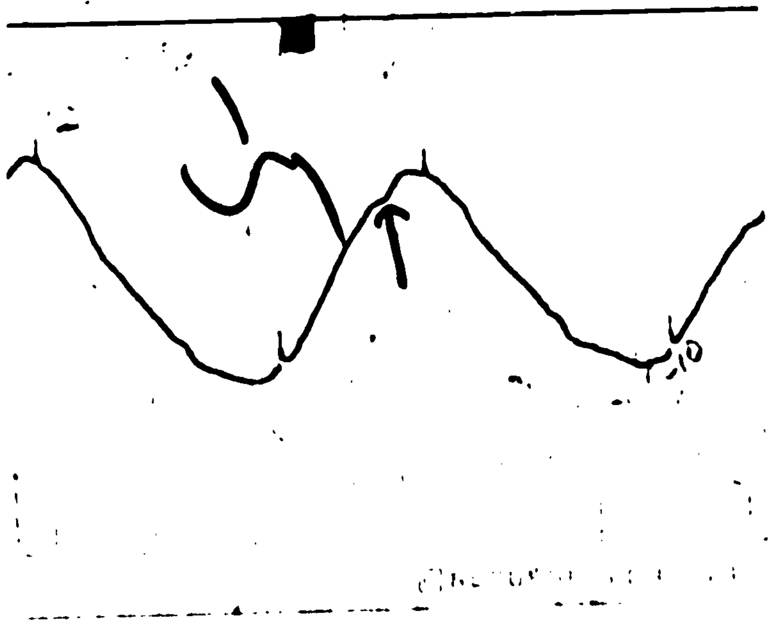
Figure 10. Criteria for Judging a Bad Cycle

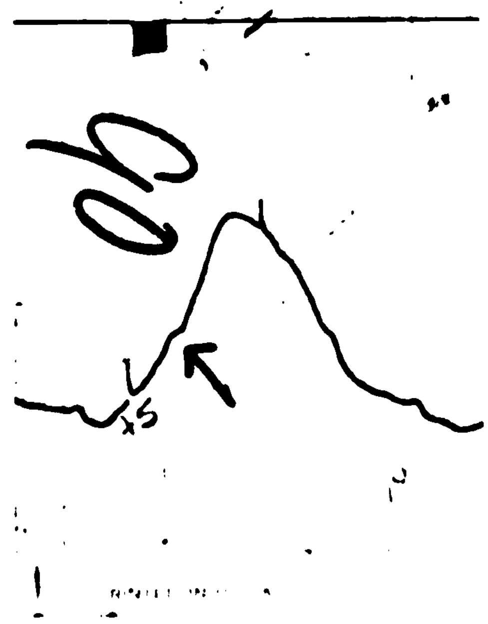
(Black box at the top of the chart indicates tone is on).
(Arrow indicates notch).

1. A notch of 7 mm. or more on expiration.

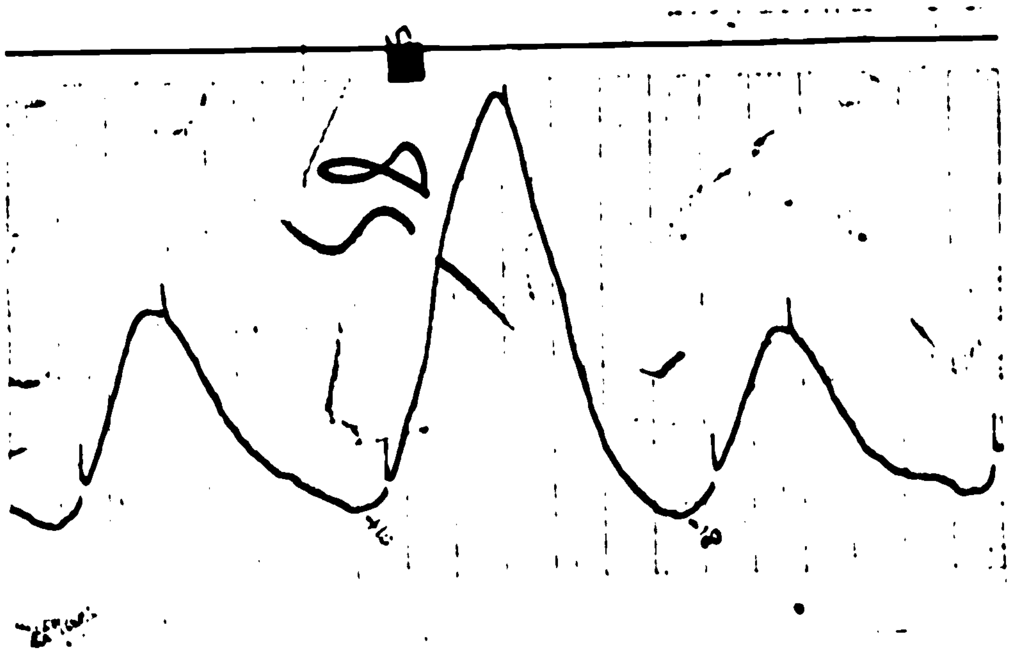


2. Any notch on inspiration.

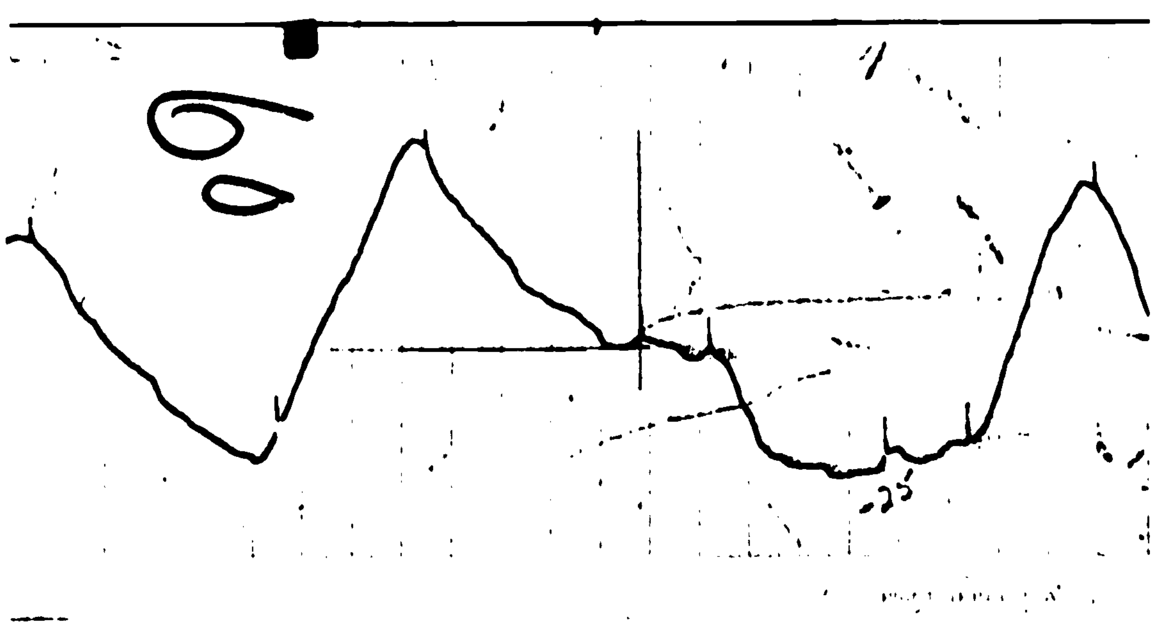




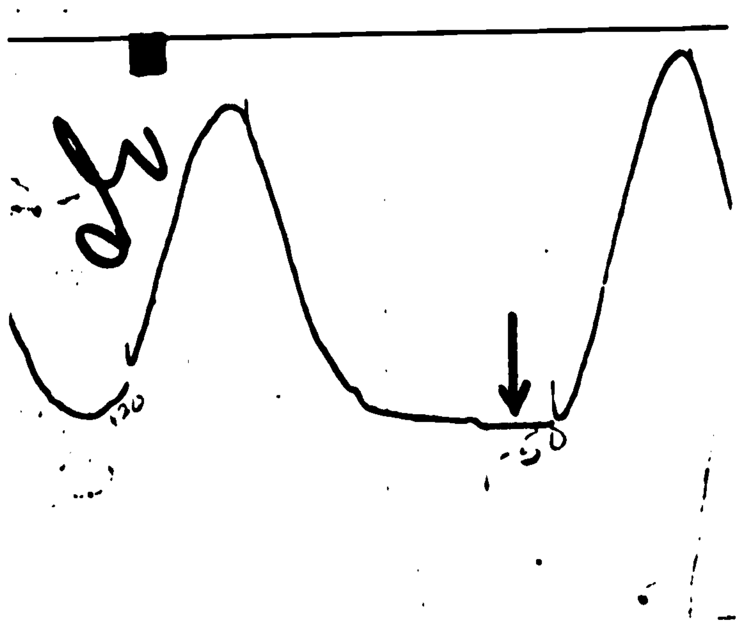
3. A marked increase of amplitude as compared with amplitude on either side. (Increase should be while tone is on).



4. A marked change in shape of curve while tone is on.



5. A flatness at bottom of cycle.



6. When top or bottom of cycle exceeds the border of strip chart and becomes flat.

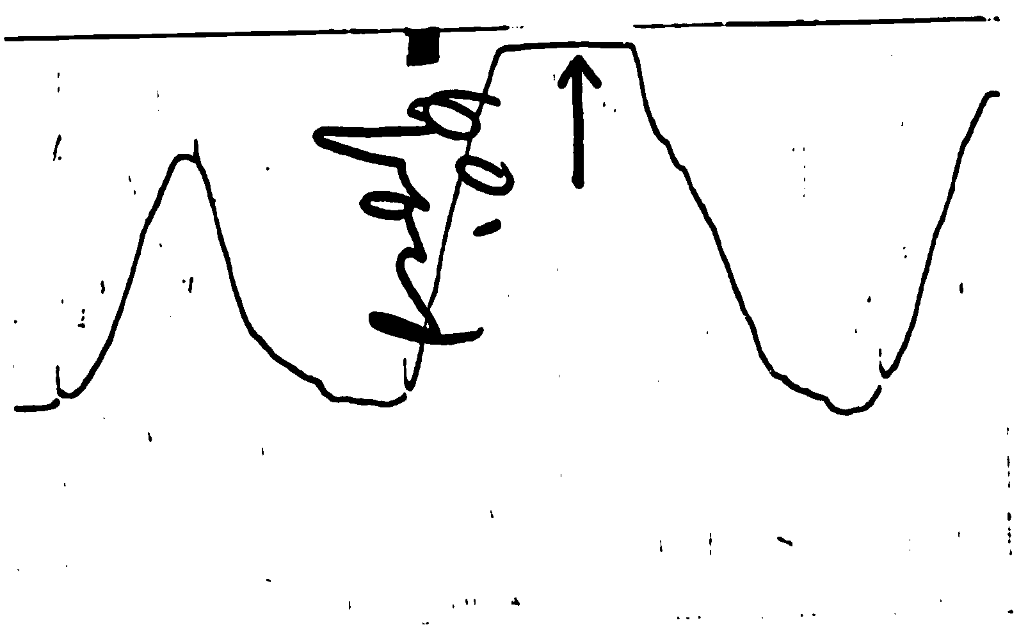


TABLE 9

AGREEMENT BETWEEN ESTIMATED AND ACTUAL THRESHOLDS COMPARED ON THE BASIS OF GOOD AND BAD CYCLES

	ARRANGEMENT OF STIMULUS PRESENTATIONS	AGREE GOOD CYCLE	DISAGREE GOOD CYCLE	AGREE BAD CYCLE	DISAGREE BAD CYCLE
NORMAL HEARING SUBJECTS	<u>Inspiration Ascending</u>				
	Stimulus Duration of .25 seconds	11		33	32
	Stimulus Duration of 1 second	12	1[3]	15	22
	Stimulus Duration of 2 seconds		1[2]	2	7
	Stimulus Duration of 1.5 seconds	1		3	6
	Stimulus Duration of .75 seconds	3		2	5
	Stimulus Duration of .50 seconds			3	7
	<u>Inspiration Descending</u>				
	Stimulus Duration of 1 second				10
	<u>Random</u>				
	Stimulus Duration of 1 second			2	6
	.25 second				2
DEAF SUBJECTS	<u>Inspiration Ascending</u>				
	Stimulus Duration of of .25 second	10		16	46

1. Agree means estimated and actual threshold are within 20 dB.
2. Actual threshold -10; estimated threshold +15.
3. Actual threshold -10; estimated threshold +20.

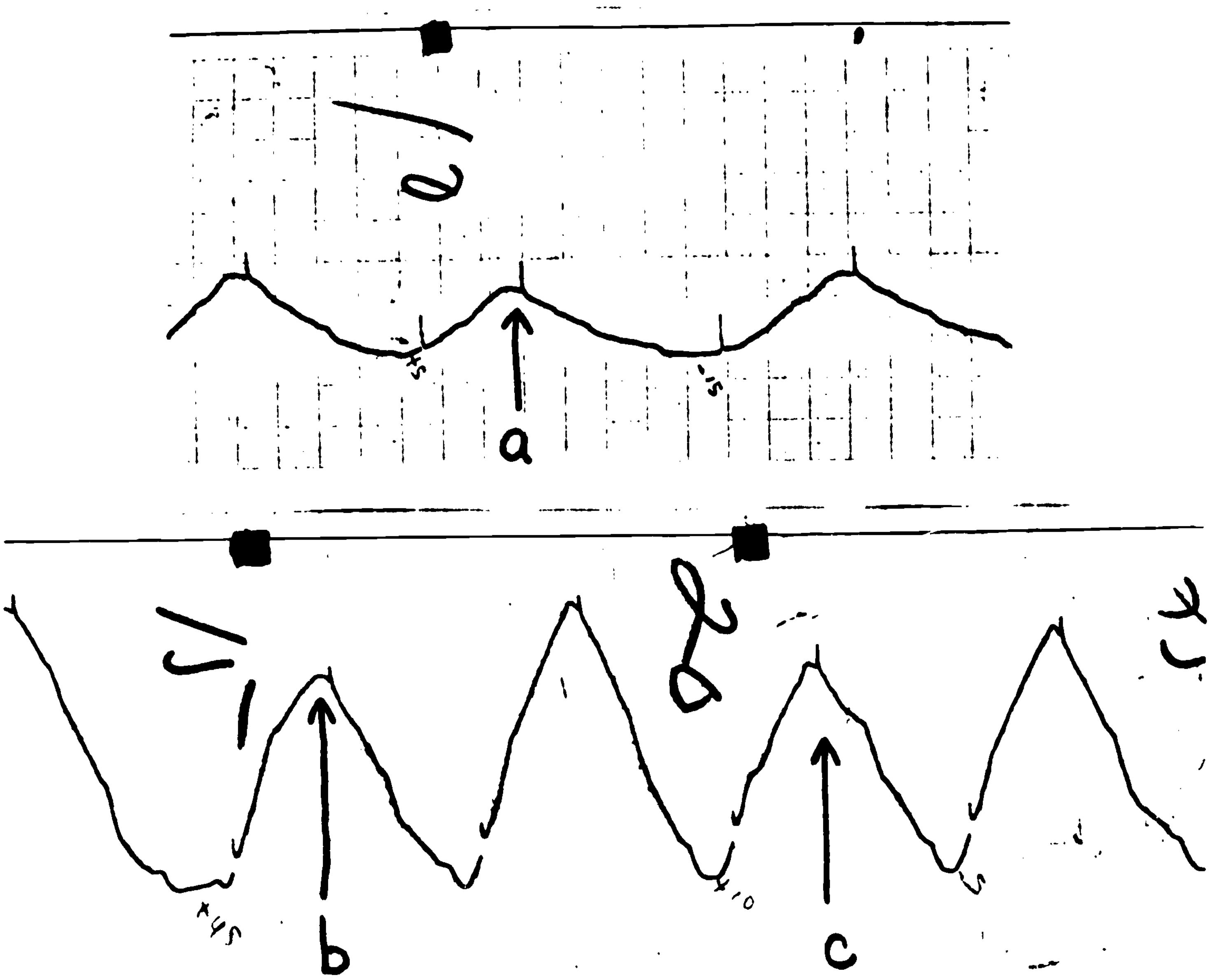
respiratory cycle is rated good, we can be quite sure that the computed threshold estimation is correct and conversely, when the respiratory cycle is rated as bad, we often, but not invariably, find the computed threshold estimation is incorrect.

Experiment 6: A Clinical Method for Visually Estimating Thresholds

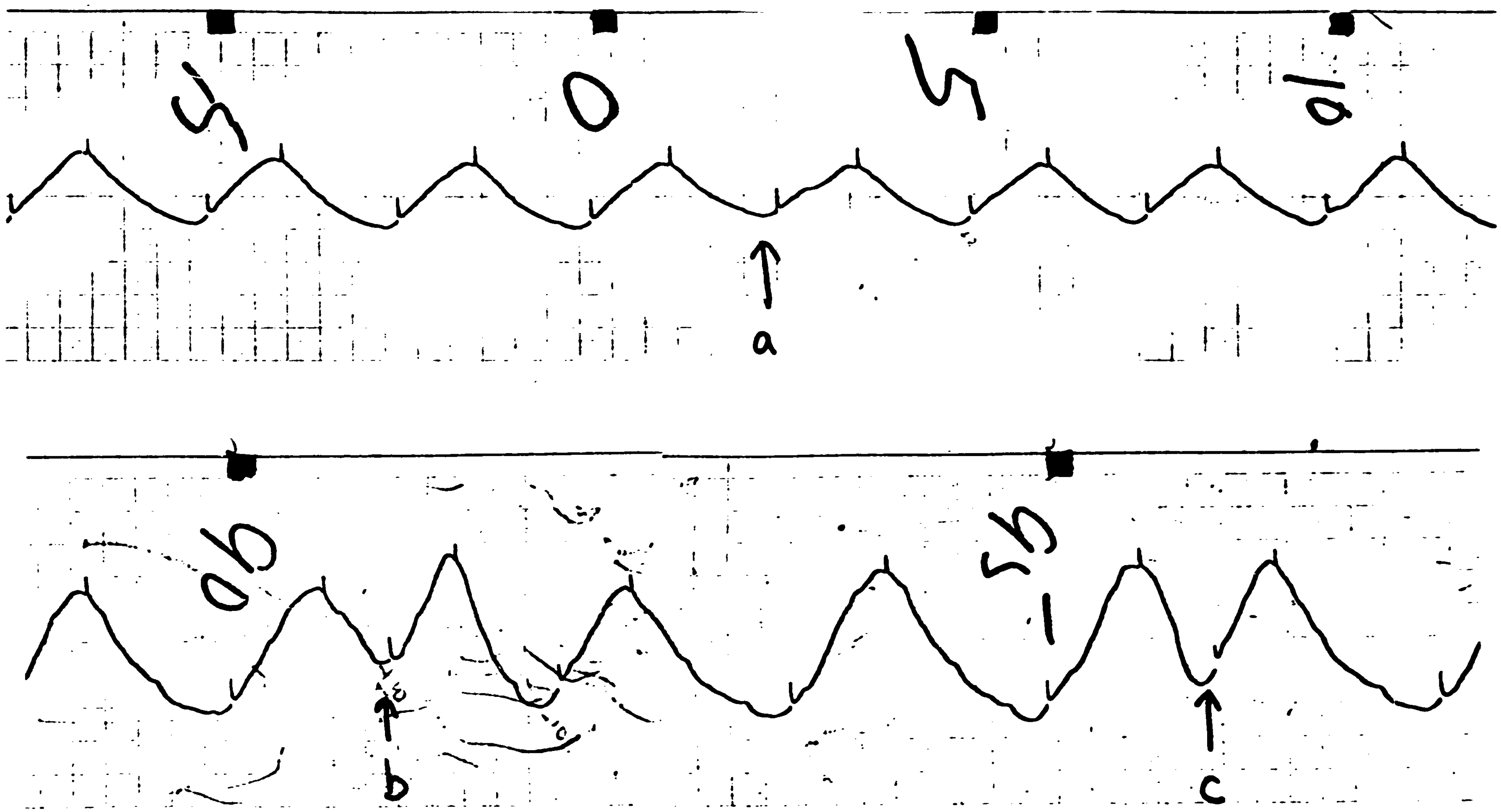
From the foregoing experiments, it became obvious that measurement of threshold by automation has several built in problems, i.e., requiring essentially normal breathing cycles and an inability to reflect a no response condition. Accordingly, we tried to establish visual criteria which would obviate the aforementioned problems. We devised the following procedures for visual examination of the respiratory curve. Adherence to these rules allows us to estimate thresholds. Following are the steps used.

1. Examine the whole record making note of the following:

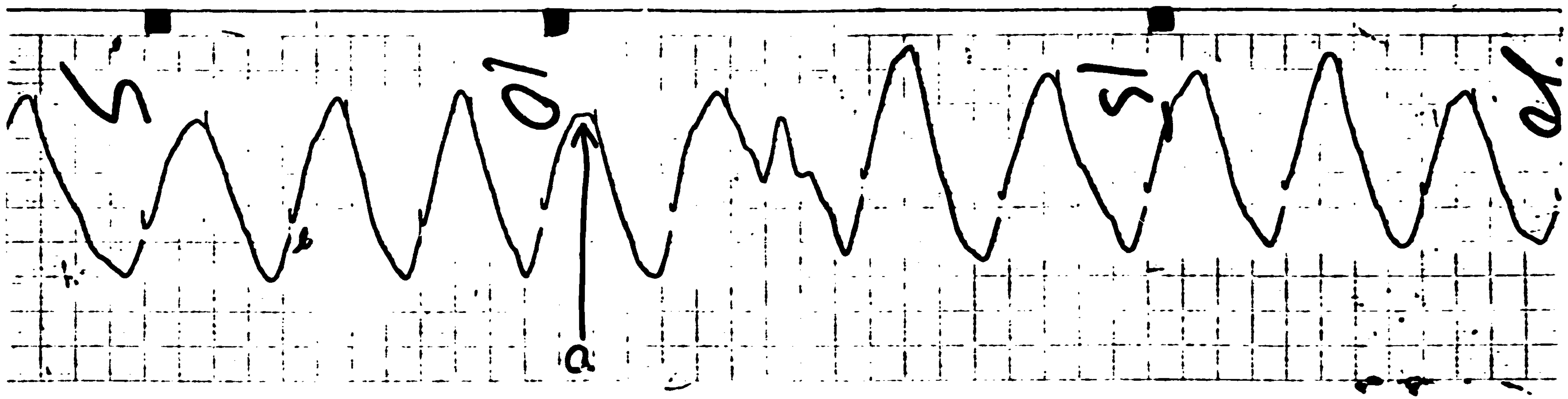
   A. Any reduction in amplitude of a cycle while the tone is being presented as compared to both the preceding and following cycles. See a, b, and c below. (The black box at the top of the chart indicates a tone of 250 milliseconds is on. Paper speed for the record was 10 mm. per second. The large hand written numbers on the chart indicate the intensity level.)



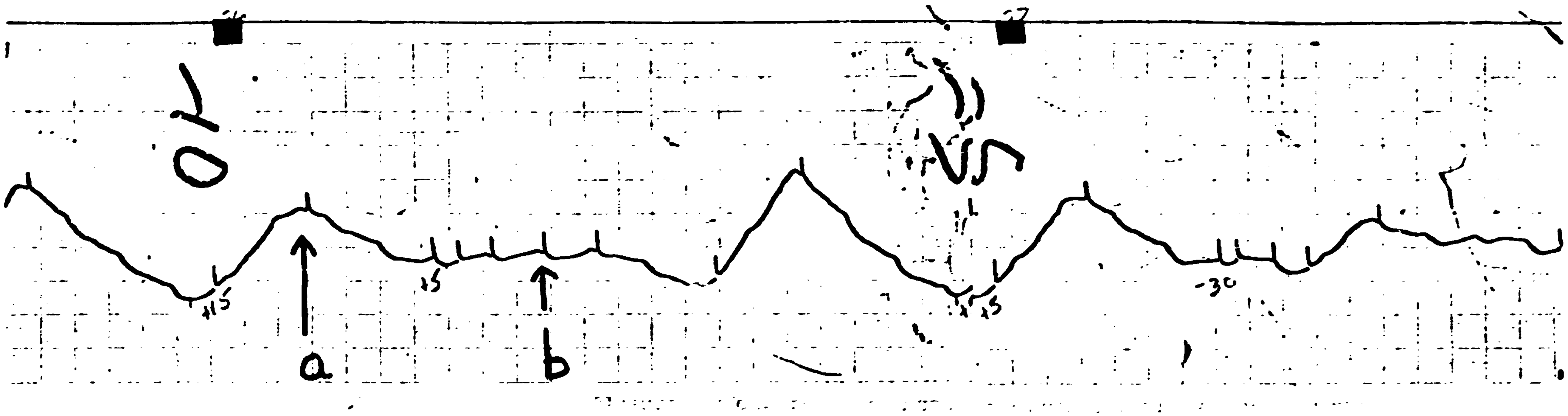
B. "Jamming" of two cycles together while the tone is presented. This jamming may be subtle or it may be very obvious. (Jamming is a compression of the width of a cycle combined with a reduction in amplitude). Jamming usually first appears at the subject's threshold level and should be taken as a true indication of threshold unless a run of reduced amplitude responses precedes or follows it. See a, b, and c below.



C. Flattening of the curve at either zenith (positive peak) or nadir (negative peak). See a below.

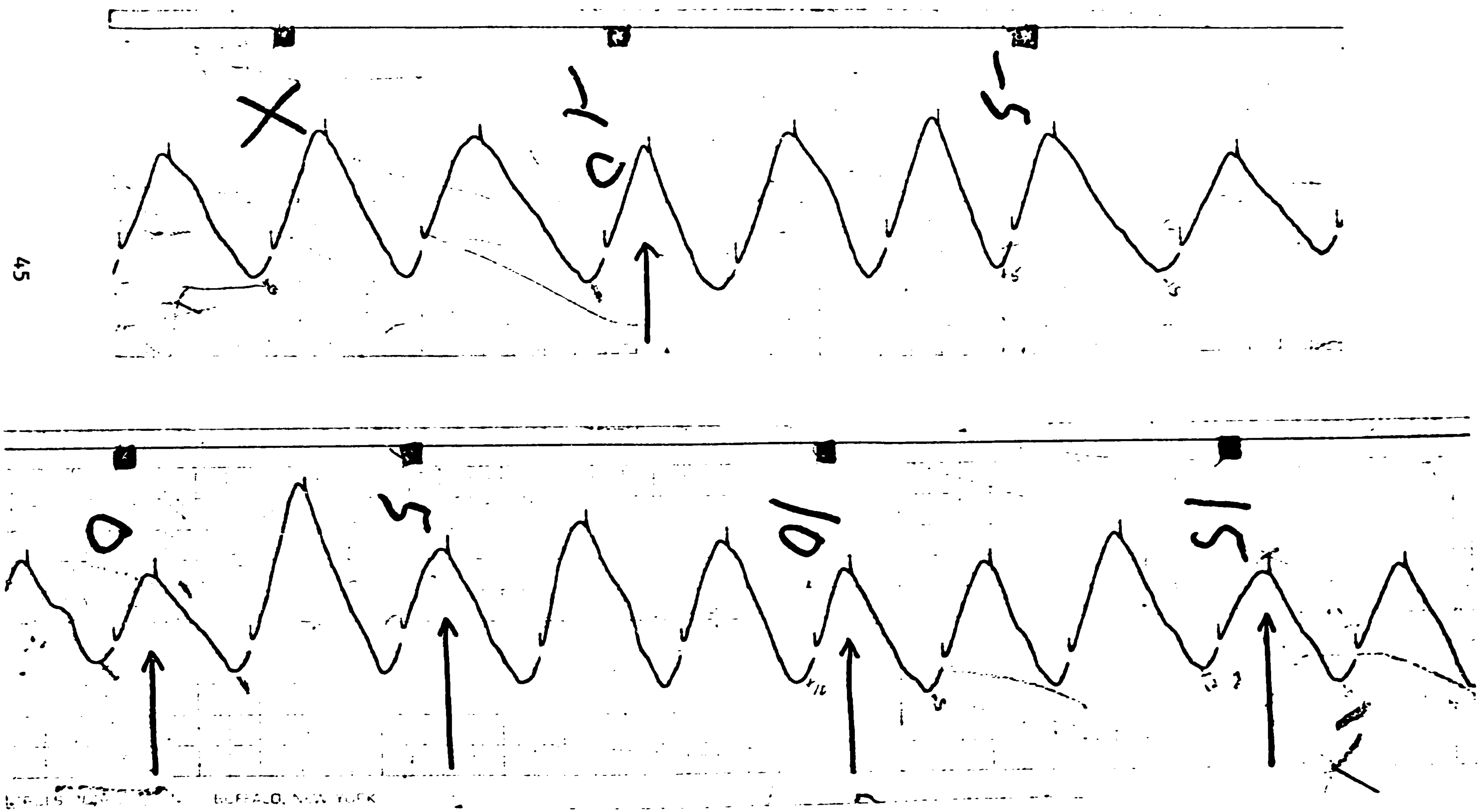


D. Any combination of the above. See a and b below.

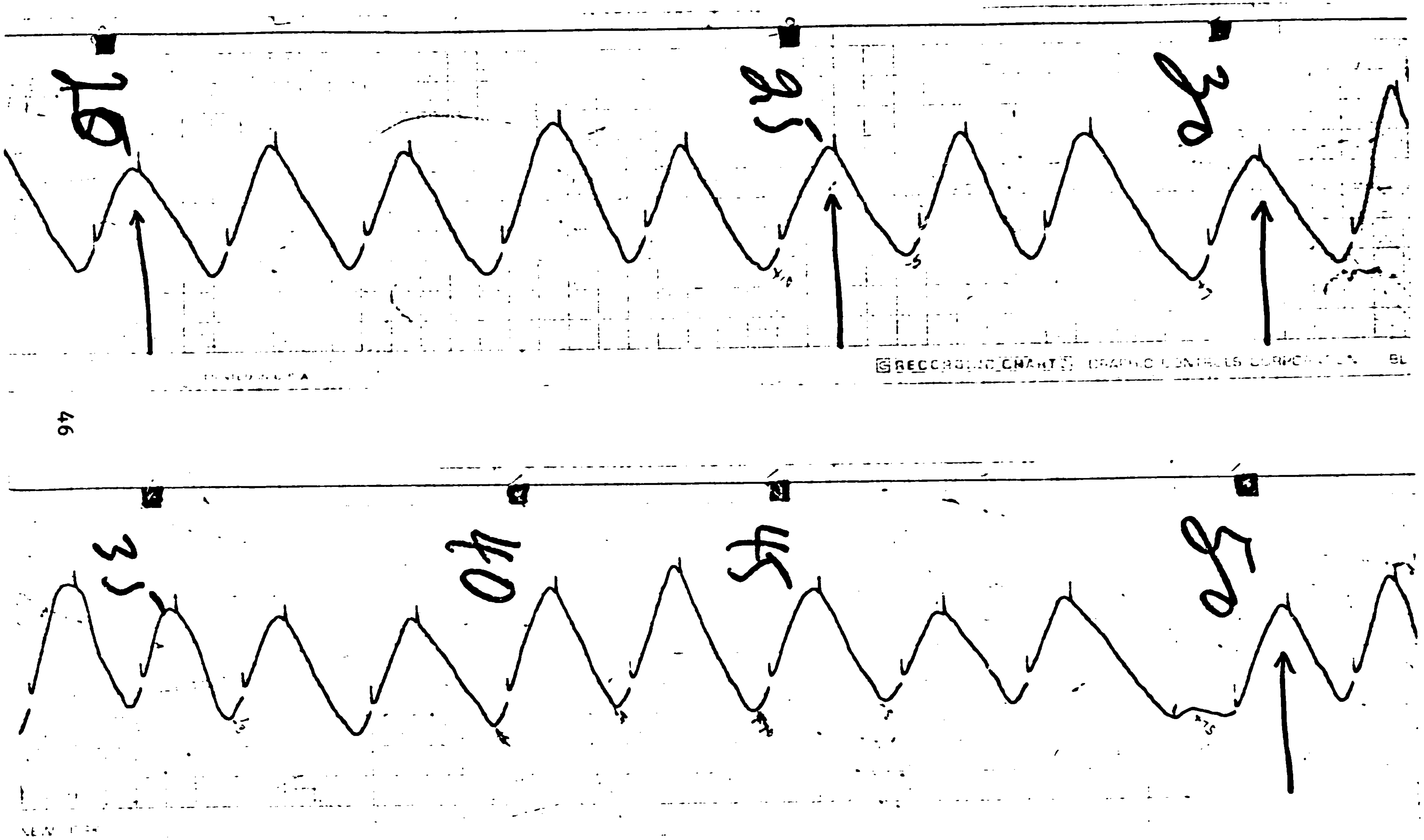


2. As an example, in the following strip chart the responses which were noted were -10 dB, 0 dB, 5 dB, 10 dB, 15 dB, 20 dB, 25 dB, 30 dB, 50 dB, 60 dB, 90 dB and 100 dB. The actual threshold obtained for the subject by conventional audiometry was -10 dB re: ASA 1951.

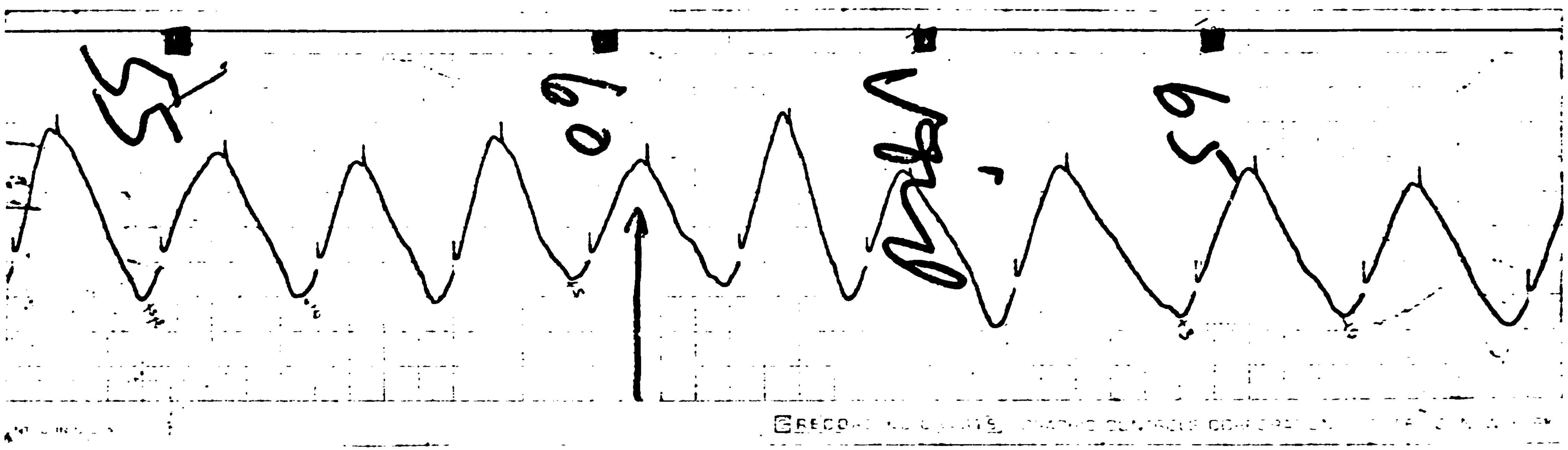
Observe the responses marked on the following strip chart. The estimated threshold would be 0 dB. Note Rule 3 following examination of this strip chart.

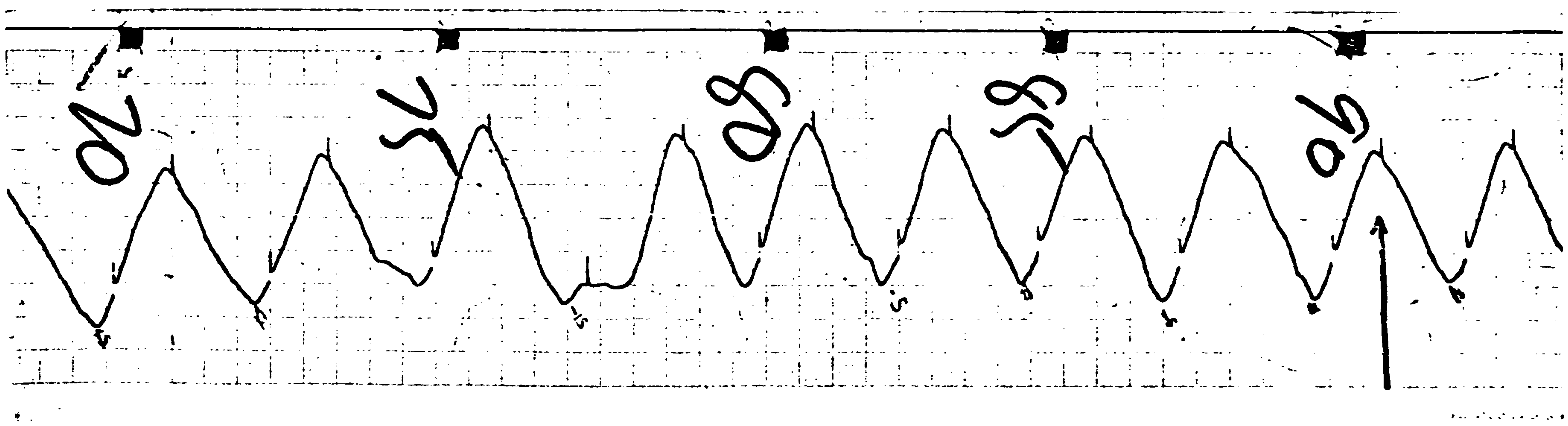


(Sample strip chart continued).

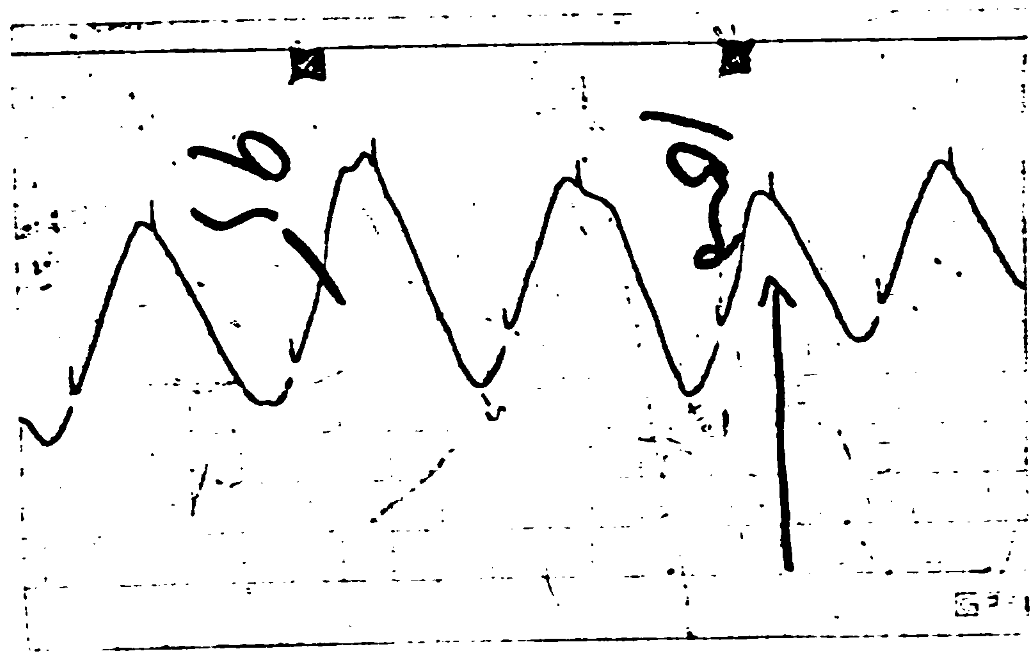


(Sample strip chart continued).



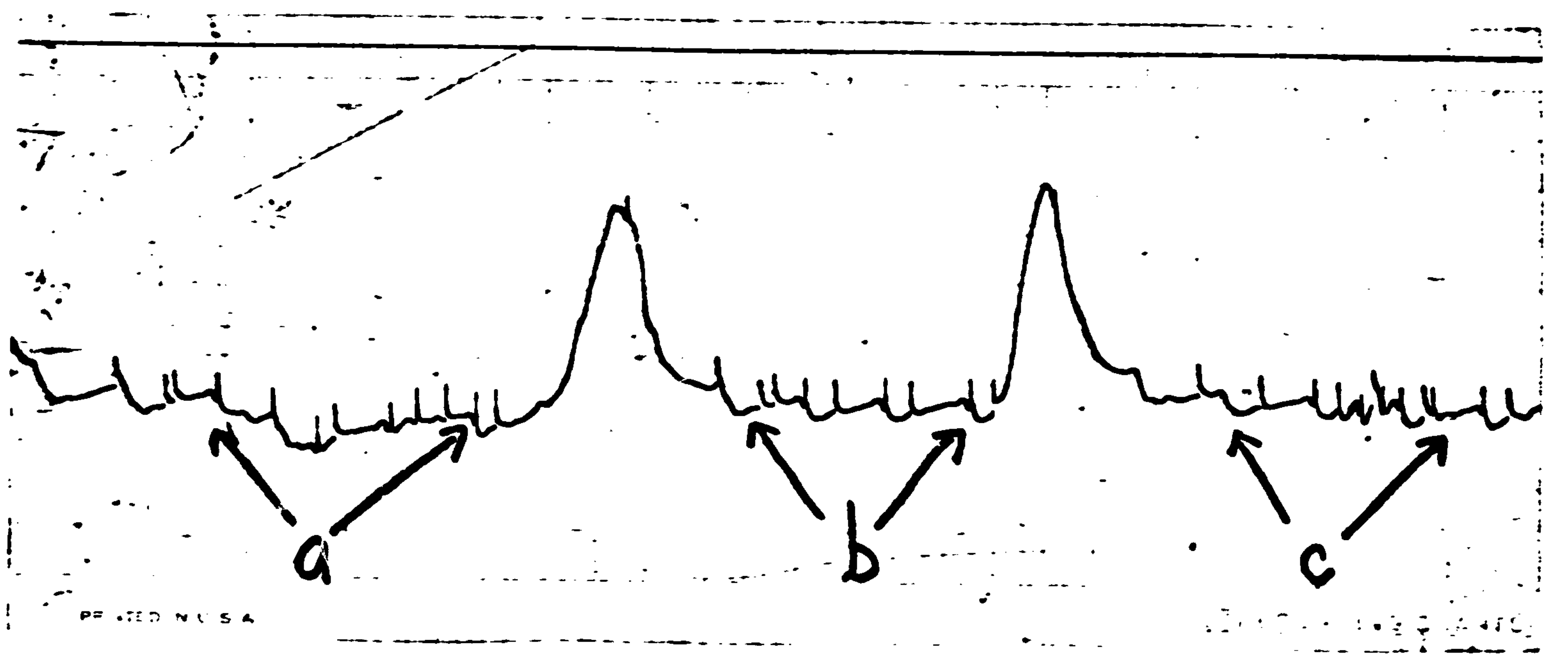


(Sample strip chart continued to end).



3. Three or more responses in a row are usually a solid indicator of threshold. The lowest number is used as the threshold. If there are no other responses except two together, this is used as a threshold. Single responses, except those of jamming, are not sure indicators of threshold.

4. A period of breath-holding, especially when the tone is not on, is highly suggestive of a hearing loss, most probably a severe loss. See a, b, and c below.



5. A no response may be indicated by

(a) no visual response
(b) a reduction in amplitude at the higher intensity levels which may be a mechanical response to vibration, or
(c) containing single responses (no two or more in succession).

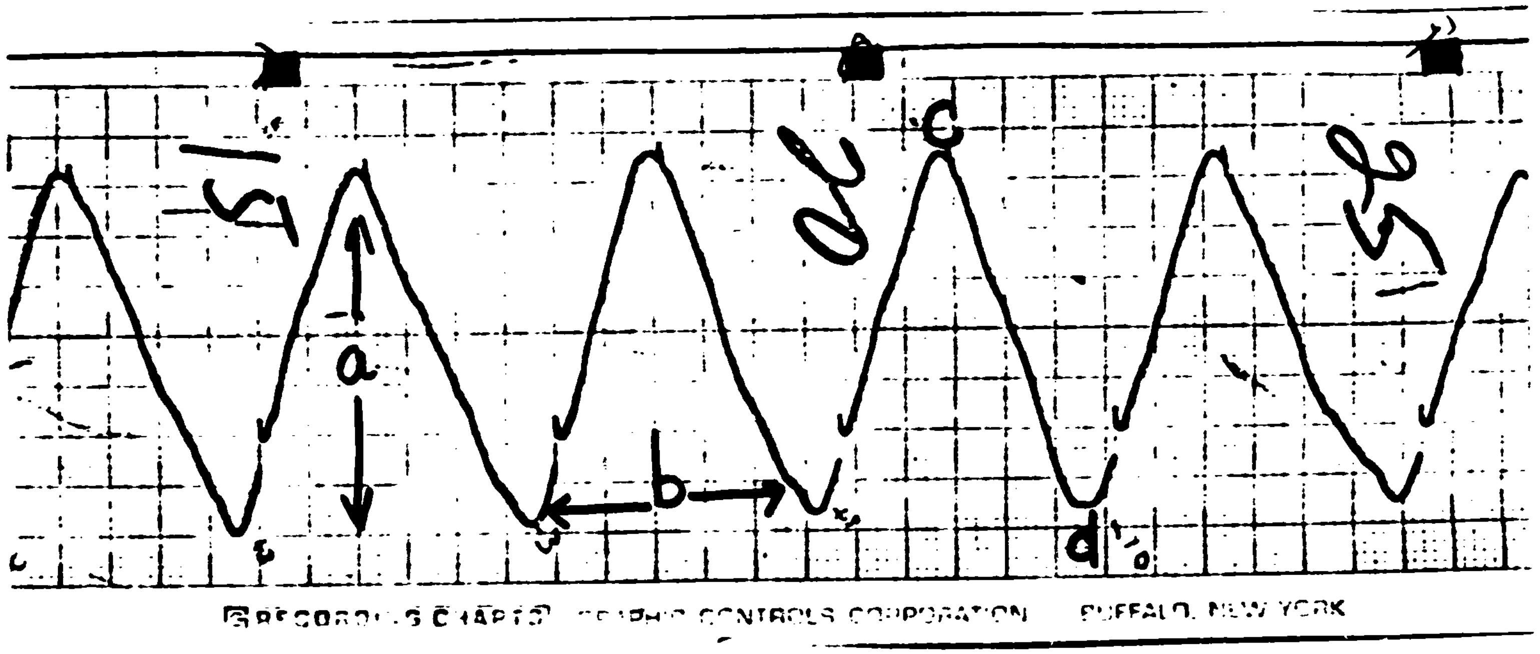
6. When there is a discrepancy between responses on the first and second group of stimulus presentations (-10 through 100 dB), the first group is usually the more accurate indication of threshold because the subject is unfamiliar with the tone presentation.

2

7. Terminology used in describing responses on the strip charts:

(a) amplitude - height of the curve as measured from a peak to a valley
(b) duration - width of the curve as measured from valley to valley
(c) zenith - positive peak
(d) nadir - negative peak

(See a, b, c, d below).



Use of these criteria now allows us to read the charts in a visual way with a high degree of accuracy. Table 10 demonstrates that 33 out of 36 subjects receiving a 250 millisecond presentation gave visual indicators of threshold within 15 dB of their voluntary threshold. Major disagreements with conventionally determined thresholds occur only once for the subjects receiving the 250 millisecond presentation. Amplitude becomes an important consideration as a visual indicator of threshold because the frequency of reduction in amplitude, rather than the specific amount, is used as a criterion. A question which arises is whether the threshold obtained by the present method is related to cortical or subcortical factors. Our attempt to shed some light on this issue is found in the next experiment.

Experiment 7: Study of Cortical vs. Subcortical: Visual Distraction Study

In order to take a look at the effect of distracting a subject and its relationship to the estimated threshold, 17 young adults were tested. The conditions for presenting the stimulus were the same as for the preceding studies. The distractor was a series of numbers flashed on the wall of the test cubicle via a Carousal slide projector. The subject was given a hand signal switch and was instructed to push the button each time an odd number was flashed on the wall. The numbers appeared at the rate of two per second. Each subject received two presentations of the stimuli at each intensity level with the distractor and two presentations of the stimuli at each intensity level without the distractor. Nine of the subjects began the experiment with the distractor condition (Condition B), and eight began in the routine manner (Condition A). As can be seen from Table 11, no order effect seems to occur. The estimated threshold by visual criteria was elevated under Condition B for 15 out of the 17 subjects. This observation received further support when it was subjected to statistical procedures. Table 12 shows the conventional level of statistical significance is reached only for the analysis between Condition A and B. No significant correlation was found between number of correct indications that an odd number was present and the amount of shift in threshold from Condition A to Condition B

It is of further interest that the subjects in this study all sat up instead of being in a reclining position. We had had no previous experience up to this point to indicate whether the estimated respiratory threshold would be affected by the posture of the subject. Analysis of the estimated auditory thresholds shows close agreement with their voluntary threshold. Table 13 summarizes the results.

Experiment 8: Auditory Thresholds During Natural and Sedated Sleep

All of the foregoing experiments had utilized subjects capable

TABLE 10

COMPARISON OF ACTUAL AND VISUALLY - READ THRESHOLDS

(Number of subjects in each category are indicated).

Arrangement of Stimulus Presentation	AGREE						DISAGREE
	Thresholds Agree	Within 5 dB	Within 10 dB	Within 15 dB	Within 20 dB	Within 25 dB	
Ascending							
Stimulus Duration of .25 seconds	14	8	7	4	1	1	1
Stimulus Duration of .50 seconds	1	1	2	1			
Stimulus Duration of .75 seconds	1	2				1	1
Stimulus Duration of 1 second	7	10	2	4			2
Stimulus Duration of 1.5 seconds	2	3					
Stimulus Duration of 2 seconds	3		1				
Hearing Loss							
Stimulus Duration of .25 seconds	11	5	9	3	4	2	1
Random							
Stimulus Duration of .25 seconds		2	1	1		1	
Descending							
Stimulus Duration of 1 second	1	1	2				1

TABLE 11

ESTIMATED THRESHOLDS FOR CONDITIONS
WITH AND WITHOUT VISUAL DISTRACTION

(A - Without Visual Distraction)
(B - With Visual Distraction)

Subject	Actual	A Estimated	B Estimated	Condition with Greater Estimated Threshold
1	-5	-5	10	B
2	-5	-10	-5	B
3	-10	-10	0	B
4	-5	5	20	B
5	-10	0	10	B
6	-10	-10	-10	
7	-10	0	60	B
8	-10	-10	0	B
	Actual	B Estimated	A Estimated	
9	-10	20	-5	B
10	-10	0	0	
11	-10	75	-10	B
12	-10	20	-5	B
13	0	40	0	B
14	0	70	0	B
15	-10	15	-10	B
16	0	15	-5	B
17	-10	5	-10	B

TABLE 12

ANALYSIS OF VARIANCE FOR CHANGE IN AUDITORY THRESHOLD BETWEEN DISTRACTION AND NO DISTRACTION CONDITIONS

Source	df	s^2	F	P
Uncorrelated A Order	1	706.3828	1.9073	.20
Error Between	15	370.3588		
TOTAL Between	16			
Correlated B Condition	1	5438.2353	19.6308	.001
A B	1	706.3827	2.5499	.20
Error Within	15	277.0255		
TOTAL Within	17			
TOTAL	33			

TABLE 13

AGREEMENT OF RESPIRATORY THRESHOLD WITH CONVENTIONAL THRESHOLD DURING TESTING WHERE SUBJECT SAT UP INSTEAD OF LYING DOWN

Subjects Sitting Up

Thresholds Agree Perfectly	Agree Within 5 dB	Agree Within 10 dB
9	4	4

of lying or sitting essentially quiet. The logical objection might be made that this procedure would be of little use for the hyperactive and untestable subject. Accordingly, we next studied the capability of estimating threshold in subjects who were in a state of natural sleep and drug induced sleep (via sparine). All drug induced sleep was conducted with the consent of the patients and under appropriate medical supervision. Both children and adults were used. Table 14 presents the results. All subjects' sleep was monitored via EEG. Thresholds were estimated for the second state of natural sleep or its apparent equivalent in the drug state.

TABLE 14

RAW DATA FOR STUDY OF EFFECT OF NATURAL SLEEP AND SEDATED SLEEP ON AUDITORY THRESHOLD

(Subjects 1-13 are from the Kansas Neurological Institute and range from mildly to severely retarded. Subjects 14-21 are adult professional persons with no known clinical symptomatology).

Subjects	Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 1 - Age 20			25 milligrams sparine administered intravenously
Frequency			
Right Ear 1000 Hz	0 dB	(1)* 35 dB	
500 Hz	0 dB	(2) -5 dB	
Left Ear 500 Hz	0 dB	(3) 15 dB	
1000 Hz	0 dB	(4) 5 dB	
Patient is considered mildly retarded.			
Subject # 2 - Age 14			25 milligrams sparine administered intravenously
Frequency			
Right Ear 1000 Hz	0 dB	(1) 30 dB	
Left Ear 1000 Hz	0 dB	(2) -5 dB	
Patient is considered moderately retarded.			

* Order of testing, i.e., (1) means 1000 Hz for the right ear was tested first, (2) means 500 Hz for the right ear was tested second and so on.

(Table 14 Continued)

Subjects	Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 3 - Age 13			
Frequency			
Right Ear 1000 Hz	0 dB	(1) 5 dB	25 milligrams sparine administered intravenously
Patient is considered moderately retarded.			
Subject # 4 - Age 9			
Frequency			
Left Ear 1000 Hz	30 dB	(1) 15 dB	25 milligrams sparine administered intravenously
500 Hz	25 dB	(2) 25 dB	
Right Ear 1000 Hz	40 dB	(3) 15 dB	
500 Hz	40 dB	(4) 20 dB	
Patient is considered mildly retarded.			
Subject # 5 - Age 12			
Frequency			
Right Ear 1000 Hz	10 dB	(1) 5 dB	25 milligrams sparine administered intravenously
Patient is considered severely retarded.			

(Table 14 Continued)

Subjects	Frequency	Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 6 - Age 19				
Left Ear	1000 Hz	10 dB	(1) 75 dB	25 milligrams sparine administered intravenously
	500 Hz	10 dB	(2) 40 dB	
Right Ear	500 Hz	10 dB	(3) 30 dB	
	1000 Hz	10 dB	(4) 30 dB	
Patient is considered moderately retarded.				
Subject # 7 - Age 7				
Right Ear	1000 Hz	Not known; Considered as deaf by all individuals in environment. Unable to be tested by conventional means.	(1) 35 dB	25 milligrams sparine administered intravenously
	500 Hz		(2) 15 dB	
	250 Hz		(3) 30 dB	
Left Ear	1000 Hz		(4) 40 dB	
	500 Hz		(5) 20 dB	
Patient is considered severely retarded.				

(Table 14 Continued)

Subjects		Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 8 - Age 6				
	Frequency			
Left Ear	750 Hz	Previous tests gave conflicting results. One examiner had felt the patient was deaf while another had felt the patient could hear.	(1) -5 dB	25 milligrams sparine administered intravenously
	1500 Hz		(2) 30 dB	
Right Ear	1500 Hz		(3) 20 dB	
	750 Hz		(4) -5 dB	
		Patient is considered severely retarded.		
Subject # 9 - Age 13				
	Frequency			
Left Ear	1000 Hz	5 dB	(1) 5 dB	25 milligrams sparine administered intravenously
	500 Hz	5 dB	(2) 10 dB	
Right Ear	2000 Hz	10 dB	(3) -5 dB	
		Patient is considered severely retarded.		

(Table 14 Continued)

Subjects		Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 10 - Age 12				
	Frequency			
Right Ear	1000 Hz	10 dB	(1) 5 dB	25 milligrams sparine administered intravenously
	2000 Hz	10 dB	(2) 15 dB	
	4000 Hz	10 dB	(3) 20 dB	
Patient is considered severely retarded.				
Subject # 11 - Age 9				
	Frequency			
Left Ear	500 Hz	Untestable because hyperactive with presentation of tones at 40 dB and above.	(1) 10 dB	25 milligrams sparine administered intravenously
	1000 Hz		(2) 10 dB	
Patient is considered severely retarded.				

(Table 14 Continued)

Subjects		Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 12 - Age 22				
	Frequency			
Left Ear	1000 Hz	Couldn't condition or test but hospital ward estimates normal hearing.	(1) 35 dB	25 milligrams sparine administered intravenously
Right Ear	500 Hz		(2) 85 dB	
Patient is considered severely retarded.				
Subject # 13 - Age 12				
	Frequency			
Left Ear	1000 Hz	0 dB	(1) 40 dB	Natural, no sedation used.
	500 Hz	0 dB	(2) 5 dB	
Right Ear	1000 Hz	0 dB	(3) -5 dB	
	500 Hz	0 dB	(4) 20 dB	
Patient is considered severely retarded.				

(Table 14 Continued)

(Professional Persons: No clinical symptoms)

Subjects	Age	Actual Threshold	2nd Stage Threshold (Read Visually)	Sleep Condition
Subject # 14	31	0 dB	5 dB	Natural
Subject # 15	42	10 dB	5 dB	Natural
Subject # 16	23	-10 dB	-5 dB	Natural
Subject # 17	28	10 dB	10 dB	Natural
Subject # 18	52	45 dB	65 dB	Natural
Subject # 19	34	0 dB	0 dB	Natural
Subject # 20	39	0 dB	25 dB	(25 milligrams sparine administered orally)
Subject # 21	38	-5 dB	5 dB	(25 milligrams sparine administered orally)

It is clear that the influence of sparine is often to elevate the patient's threshold for frequencies which are tested first. There seems to be some dimunition of the influence of the drug as the test continues. The magnitude of elevation of threshold seems to be around 30 dB. It was also our observation that in Stage II of natural sleep the normal hearing subjects frequently awoke when the intensity of the tone reached a level of 55 to 60 dB re: ASA 1951 audiometer setting. This observation is in essential agreement with Rosenau's earlier findings (1962).

Chapter IV

Conclusions and Recommendations

The purpose of the research was to investigate parameters which influenced the respiratory patterns at or near the threshold for hearing. To this end, several sequential experiments were proposed. Initially, the goal was to automate the analysis of the respiratory pattern and presentation of the stimuli. This was accomplished through the design of a semi-automatic system. Next, several experiments were conducted using this equipment. The conclusions of these experiments may be summarized as follows:

Experiment 1: Thresholds for pure tones can be estimated better when presented on inspiration than on expiration. Presentation of stimuli two times appears as effective in allowing an estimate of threshold as presentation of the stimuli six times. Use of the duration of the individual breathing cycle is a more precise way of estimating threshold than use of the amplitude.

Experiment 2: In terms of allowing estimation of threshold, an ascending mode of presentation is as satisfactory as a random method. Both of these modes are more satisfactory than the descending method.

Experiment 3: A tone of 250 milliseconds is as effective as a tone of 1000 milliseconds in terms of its effect on the respiratory cycle.

Experiment 4: Estimation of thresholds on hearing impaired children using the previously noted conditions is not as successful as it is with normal hearing children.

Experiment 5: A breathing cycle which approximates a sine wave allows one to use the computor's measurement of duration of the respiratory cycle to make an accurate estimate of hearing in both normal and hearing impaired children.

Experiment 6: A clinical method based on visually apparent changes in the respiratory cycle can be used with an accuracy equivalent to and in some cases better than found by the use of the semi-automated system.

Experiment 7: Visual distraction was shown to elevate the threshold estimated by changes in respiration. The inference was made that the phenomenon of change in respiration at threshold is likely to be a cortical phenomenon. Whether the subject sits or lies during testing seems irrelevant.

Experiment 8: Threshold estimated by the clinical method during the second stage of natural sleep seems to produce essentially similar thresholds to what is given in the waking state. Thresholds estimated in approximately this same stage of sleep after administration of sparine show essentially similar or, in a few cases, slightly elevated thresholds as compared to those given in the waking state.

Future research, it appears, can be concentrated on study of the phenomenon in specific neurological states such as occur in cerebral palsy as well as in attempting to further investigate the application of the clinical method which this study devised. To this end, study of the effects of different stages of sleep on auditory thresholds might produce evidence related to the effect of cortical influence on auditory threshold.

During the part of the study where numerical values were obtained for the duration and amplitude respiratory cycles, we discovered times when a subject would on one occasion give an essentially normal respiratory cycle (essentially a sine-wave) and then on another cycle give a distorted one. It would seem that some mathematical formula could be written to "correct" the distorted cycle and allow it to be used. While such a project was beyond the limits of the present study, future investigators may wish to follow this line of study. Study could also be done estimating thresholds of infants at an early age as indicated by their respiratory patterns. Appropriate follow-up would determine the usefulness of the respiratory technique in measuring auditory threshold in the neonatal period. Finally, the respiratory technique would appear to have potential use for experimenters using animals. It possibly could replace the present necessary but tedious conditioning procedures in animal studies.

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