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To the Graduate Council:

I am submitting herewith a thesis written by Dawna E. Johnson entitled "Acoustic Reflex Testing with Neonates." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Audiology.

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ACOUSTIC REFLEX TESTING
WITH NEONATES

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Dawna E. Johnson

June 1982

DEDICATION

My son, keep thy father's commandment, and forsake not the law of thy mother:
Bind them continually upon thine heart and tie them about thy neck.
When thou goest, it shall lead thee; when thou sleepest, it shall keep thee; and when thou awakest, it shall talk with thee.
For the commandment is a lamp; and the law is a light; and reproofs of instruction are the way of life:

Proverbs 6: 20-23

This thesis is dedicated to my parents, Charles and Elizabeth Johnson. From them I learned things no book or classroom could ever teach me. Without their love and support I would not be who I am. I thank God continually for allowing me to be one of their children.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Allan O. Diefendorf, committee chairman, for his guidance and support throughout the preparation of this thesis. He made quite a few rough spots easier to bear and provided help beyond what was required.

Appreciation is extended to Robert Moore, committee member, for first discussing my topic with me and for his special help in all procedures involving the hospital. Also, thanks go to Jane Moore for her moral support and encouragement.

Thanks go to Charles J. Ferrell and Samuel B. Burchfield, committee members, for the advice, corrections, and modifications they provided for this thesis.

Sincere appreciation is extended to Sehas, Inc. for the use of an Amplaid 702 Acoustic Impedance Meter. Their cooperation was of significant help in this study.

Thanks go to Phil Williams from the Electronics Shop in the Department of Audiology and Speech Pathology. He was always willing to answer questions and try to perform "miracles" with the equipment.

The author is grateful to Debbie Smith for her help during testing. More importantly, though, thanks are extended for her encouragement, faith, and friendship.

ABSTRACT

The purpose of this investigation was to examine acoustic reflex thresholds in neonates under conditions that would optimize elicitation of the reflex. Use of hand held equipment and oscilloscopic display of eliciting stimuli and compliance changes were intended to provide an approach in which obscuring concomitants would be minimized. A secondary purpose was to obtain SPAR results for all infants who exhibited responses to all activating stimuli.

Tympanograms were obtained bilaterally for 10 infants from nine to 55 hours post-birth. Acoustic reflexes were then evaluated unilaterally with stimuli of 500, 1000, and 2000 Hz pure tones and white noise utilizing a probe tone of 220 Hz. Thresholds for acoustic reflexes were recorded from the compliance change meter of an impedance bridge and an oscilloscope. Two observers independently judged reflexes from the instruments while a third judge reported behavioral responses from the infants. Acoustic reflex thresholds were determined according to a pre-determined set of criteria.

Results indicated acoustic reflex thresholds for all stimuli in 60% of all ears tested utilizing visual observation of the compliance change meter of the impedance bridge and 50% of all ears utilizing oscillographic display. Of the remaining infants, two exhibited absent reflexes to all stimuli, and two exhibited absent reflexes only at 2000 Hz. A comparison between the oscilloscope and the impedance results indicated slightly fewer questionable responses for the oscilloscope.

However, one infant displayed absent reflexes to all pure tone stimuli when viewed on the oscilloscope but present to those stimuli when recorded from the impedance bridge. SPAR results were obtained for 60% of the infants.

Advantages and disadvantages were noted for use of oscillographic display of reflex responses. The oscillographic display allowed the observer to judge reflex responses in relation to each other as well as to the onset of the activating stimuli. This additional information may increase the accuracy of the measurement. In addition, the oscilloscope can be adjusted so that it is more sensitive to compliance changes in the ear.

There is a disadvantage to added sensitivity, however, in that the oscilloscope is also more sensitive to movements from the infant and/or the investigator holding the equipment. This disadvantage may be alleviated by the use of filters.

The results of this investigation indicate that is is possible to obtain fairly accurate reflex thresholds with neonates. Although the method for eliciting acoustic reflexes with neonates is not complete at present, the procedures utilized in this investigation may aid in the development of a standardized clinical procedure for use with the neonatal population.

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CHAPTER I

INTRODUCTION

The importance of early identification of hearing loss has gained increasing support among professionals working with infants and children. Central to this support is that language input and language development are lost to the hearing impaired child until his/her disability is diagnosed and proper remediation procedures undertaken (Goldstein and Tate, 1971; Downs, 1977). Downs (1977) suggests that the psychological and social ramifications resulting from hearing loss could be partially alleviated by early identification. Friedlander (1975) stated that

> systematic early identification of children who are known to suffer developmental disability, or who have a high risk of doing so, is potentially the single most powerful means at hand for reducing the impact of exceptionality--on the individual child, on the family and on the community and society at large.

The efforts of professionals involved in treatment and habilitation of hearing impairment can begin only after proper identification has been made. The earlier this can be done the earlier the process for reducing the impact of exceptionality can begin.

For the earliest possible identification of hearing loss, procedures should begin in the hospital nursery soon after the infant is born. Goldstein and Tate (1971) point out

> this is the only situation or time when all babies (except those born outside hospital facilities) are available for testing. A child who is not tested in a hospital nursery may not be tested again until his auditory impairment becomes obvious to the family or to the school.

Goldstein and Tate (1971) have suggested several factors which must be considered in the planning of any procedure to evaluate hearing in a neonatal population. One factor is the identification of mild and moderate hearing losses. Procedures which present acoustic stimuli at high intensities and evaluate behavioral responses (e.g., Downs and Sterritt, 1967) are likely to miss all but severe and profound hearing losses.

Another factor is unilateral hearing losses. Procedures which present stimuli binaurally (Downs and Sterritt, 1967; Simmons and Russ, 1974) leave unilateral hearing losses undetected. Such losses may not be uncovered until the child reaches school age.

One procedure which has been used in the assessment of auditory function with infants is impedance measurement. This measurement includes both tympanometry and acoustic reflex testing.

Tympanometry measures the compliance of the tympanic membrane as a function of changes in air pressure in the external auditory canal. This measurement provides an assessment of the tympanic membrane's mobility, the condition of the ossicular chain and the air pressure of the middle ear (Harford, 1980). Studies of tympanometry with infants (Keith, 1973; Keith, 1975; Margolis and Popelka, 1975) have stated that although slightly different from adult norms, middle ear pressure and compliance are essentially normal within a few hours after birth.

Acoustic reflex testing provides information about the peripheral and central auditory mechanisms. The contraction of the stapedius muscles occurs bilaterally as a result of high intensity acoustic stimulation at either ear. When eliciting the contralateral acoustic reflex (see Figure 1), the opposite ear is stimulated with a sound of sufficient intensity

> and electrical impulses from the sensory cells in the cochlea pass via the primary acoustic neuron to the ventral cochlear nucleus. From the ventral cochlear nucleus the electrical impulses are transmitted through a second neuron to the region of the medial superior olive. A third neuron connects the medial superior olive to the medial part of the contralateral facial motor nucleus. A fourth neuron transmits the electric impulses from the facial motor nucleus to the contralateral stapedius muscle (Djupesland, 1980).

As a result of this pathway, acoustic reflex measurements provide information about the status of the middle ear, cochlea, cranial nerve VII, and cranial nerve VIII.

The pure tone stimulus intensity at which the acoustic reflex can first be detected ranges from 75-95 dB HTL for normal hearing individuals with an average value of approximately 85 dB HTL (Peterson and Lidén, 1972; Deutsch, 1972). The average intensity required for broad band or white noise is approximately 15-20 dB less (Peterson and Lidén, 1972; Deutsch, 1972). The difference between acoustic reflex thresholds for pure tones and broad band or white noise is often referred to as the noise-tone difference (NTD) (Hall, 1980).

Utilizing the relationship between acoustic reflex thresholds for pure tone and noise signals, Niemeyer and Sesterhenn (1974) proposed the concept of predicting hearing loss from the acoustic reflex. They reported that the NTD for individuals with sensory neural hearing losses is smaller than it is for individuals with normal hearing. From this, they developed a formula for calculating hearing threshold based on differences between acoustic reflex thresholds (ART) for pure tones and noise signals. In their formula:

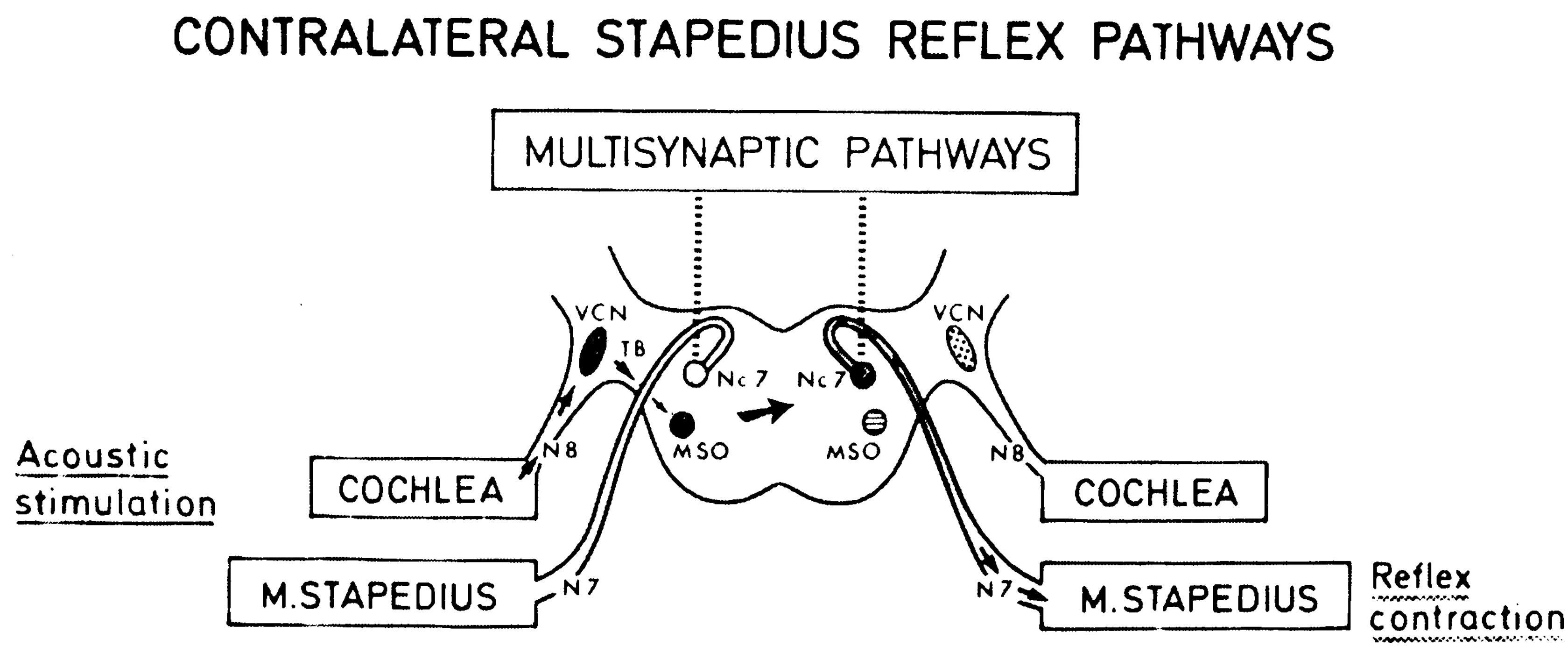

Figure 1. Schematic diagram over contralateral stapedius reflex pathways, based on experimental work in rabbits (Borg, 1973). N8, acoustic nerve; VCN, ventral cochlear nucleus; TR, trapezoid body; MSO, medial superior olive; N7, facial nerve.

Source: Djupesland (1980).

hearing threshold = ART tones - (2.5)(dl 2)

where "hearing threshold" represents the mean threshold for 500, 1000, 2000, and 4000 Hz pure tones; "ART tones" represents the mean acoustic reflex threshold for 500, 1000, 2000, and 4000 Hz pure tones; and "dl 2" represents the difference between "ART tones" and the acoustic reflex threshold for white noise. Niemeyer and Sesterhenn modified the formula to use high and low pass noise in place of white noise to improve predictions of sloping hearing losses.

Niemeyer and Sesterhenn (1974) reported that predictions using this method were within ± 20 dB of actual hearing threshold. Keith (1977), reporting on the use of the Niemeyer and Sesterhenn method, stated that only 80% of predictions were within ± 20 dB, with most errors resulting in false-positive predictions of hearing loss in normal individuals or over-estimation of hearing loss.

In 1974, Jerger et al. developed another technique for determining hearing threshold from the acoustic reflex. Their method, Sensitivity Prediction from the Acoustic Reflex, or SPAR, also uses differences between acoustic reflex thresholds for pure tones and noise in its calculations. In this method, the individual's acoustic reflex thresholds for 500, 1000, and 2000 Hz pure tones are averaged and the acoustic reflex threshold for broad band noise is subtracted from this value. A correction factor which has been biologically obtained for the specific impedance bridge is added to obtain an NTD. The correction factor is determined by first obtaining pure tone reflex thresholds from 10 normal hearing adults (20-30 years old) and averaging the values. Broad band noise thresholds for the same subjects are obtained and averaged. The broad band noise reflex average is subtracted from the pure tone average to obtain the NTD for the specific impedance bridge. This NTD is subtracted from the original Jerger (1974a) norm of 25 dB to provide the correction factor. The NTD is interpreted according to a set of criteria and combined with the absolute threshold for broad band noise (Table 1). This process results in a prediction of hearing loss that falls within one of three categories (Table 2). Hall (1978) reported that the SPAR accurately predicts hearing loss over 50% of the time, with serious errors occurring in less than 10% of cases. Moderate errors occur most often and are usually false-positive predictions where hearing level is actually better than what is predicted.

The accuracy of the SPAR and other methods for predicting hearing loss from acoustic reflexes are affected by a variety of factors. These include degree of loss, middle ear disorders, central auditory disorders, and chronological age.

The accuracy of both the SPAR and the Niemeyer and Sesterhenn methods is greater in persons with normal hearing or severe to profound sensory neural losses. Errors occur most often in mild or moderate losses (Keith, 1977). In addition, middle ear disorders usually result in elevated or absent acoustic reflexes (Jerger et al., 1974b) as do eighth nerve lesions (Jerger et al., 1974b).

Hall (1980) investigated the effect of chronologic age on acoustic reflex thresholds. In general, the data showed that "the accuracy of hearing prediction methods based on the NTD, such as the SPAR technique, tends to diminish as a function of age." With an N of 537 subjects

TABLE 1

THE 1974 SPAR CRITERIA FOR PREDICTION OF HEARING LOSS[a]

NTD	BBN,[b] dB SPL	Prediction
≥20	Anywhere	Normal
15-19	<80	Normal
15-19	>80	Mild-moderate
10-14	Anywhere	Mild-moderate
<10	<90	Mild-moderate
<10	>90	Severe
Reflexes not observed		Profound

[a]From Jerger et al., 1974a.

[b]BBN = broad band noise.

Source: Hall (1980).

TABLE 2

CRITERIA FOR CATEGORIZING DEGREE OF LOSS ACCORDING TO THE SPAR METHODS[a]

Category	Criteria
Normal	PTA[b] less than 20 dB HL[b]
Mild-Moderate	PTA 20-49 dB HL inclusive
Severe	PTA 50-84 dB HL inclusive
Profound	PTA 85 dB HL or more

[a]Modified from Jerger et al., 1974a.

[b]PTA = pure tone average for 1000, 2000, and 4000 Hz; HL = hearing level.

Source: Hall (1980).

between one and 20 years of age, SPAR was found to be most accurate in the one- to five-year-old age group (Hall, 1980).

The literature concerning the Niemeyer and Sesterhenn and SPAR methods indicates that the acoustic reflex threshold can be a fairly accurate predictor of hearing level. Acoustic reflex testing is also useful in identifying unilateral hearing loss. In addition, even though acoustic reflex testing tends to over-estimate mild to moderate hearing losses (Niemeyer and Sesterhenn, 1974; Jerger et al., 1974a; Hall, 1978), it does identify infants in that category as having some degree of hearing loss. Previous methods (Downs and Sterrit, 1967) overlooked these infants altogether.

The research also indicates that prediction methods using the acoustic reflex are more accurate with younger subjects. The evidence would, therefore, appear to provide strong support for the use of impedance measurements, specifically acoustic reflex testing, as a procedure for early identification of hearing loss. However, examination of acoustic reflex thresholds with neonates has not enjoyed success as a clinical technique.

The basic requirement for hearing level predictions from the acoustic reflex is the ability to elicit the reflex. The literature regarding acoustic reflex testing with neonates has been so clouded by conflicting information that no clear-cut parameters for eliciting the acoustic reflex have been developed for this population. Information regarding the probe frequency, the reflex eliciting stimuli, equipment arrangements, criteria for determining presence of a reflex, and procedures for optimizing elicitation have varied from one study to the next. Results from these studies have also varied considerably, leaving no clear evidence regarding the presence of the acoustic reflex or the ability to measure it accurately. The existing confusion must be alleviated before acoustic reflex testing can be used clinically with neonates. Until this is done, procedures for predicting hearing loss with the acoustic reflex will be minimized and acoustic reflex testing will remain a promising but questionable technique with neonates.

One of the conflicts regarding acoustic reflex testing with neonates relates to the probe tone frequency. Using probe tones of 220 Hz, several authors have found a very low incidence of acoustic reflexes in neonates and infants (Keith, 1973; Keith and Bench, 1978; Allred, 1974; Bennett, 1975; Weatherby and Bennett, 1979). Other authors, however, have found the percentage of acoustic reflexes elicited to be somewhat higher (Margolis and Popelka, 1975; Abahazi and Greenberg, 1977; Himelfarb et al., 1978).

The reflex eliciting stimuli used in testing neonates have also varied considerably across studies. Bennett (1975), testing infants from five to 218 hours post birth, used a Barany noise box as the contralateral stimulus. He found acoustic reflexes in only 16% of all ears tested. Weatherby and Bennett (1979) used contralateral broad band noise as the stimulus when testing newborns. They found that the intensity level of the stimulus affected responses from the infant; above 95 dB SPL behavioral startle responses obscured the acoustic reflex measurements. Several investigators have utilized pure tone signals as reflex eliciting stimuli. Keith (1973) tested newborns ranging in age from 36-151 hours post birth. Using 500 Hz and 2000 Hz pure tones, he found that reflexes were clearly present only 30% of the time and measurements were often contaminated by behavioral responses. Allred (1974), utilizing pure tone stimuli of 500, 1000, 2000, and 4000 Hz, found the optimum stimulus frequency for eliciting an acoustic reflex to be 500 Hz followed by 1000 Hz when testing infants between 25 and 50 hours post birth. Himelfarb et al. (1978) tested newborns between eight and 96 hours post birth. They also found 500 Hz to yield the highest percentage of reflex responses when compared with 1000, 2000, and 4000 Hz. When wide band noise was used as a stimulus by Himelfarb, median thresholds were slightly lower when compared to the tonal stimuli.

Abahazi and Greenberg (1977) used stimuli of 500, 1000, 2000 Hz pure tones, low-pass, high-pass, and white noise to elicit reflexes in infants from one month to one year of age. They found that noise required less intensity than pure tones to elicit reflexes from infants. Of the pure tone stimuli, 500 Hz required the greatest intensity for elicitation of reflexes. In addition, the authors found that the intensity required to elicit acoustic reflexes decreased as age increased.

Equipment arrangements also vary from one study to another. Different investigators lay the infant over an earphone and insert the probe tip contralaterally (Keith, 1973, Keith and Bench, 1975). Others hold the earphone and/or probe tip by hand (Himelfarb et al., 1978; Allred, 1974). These variations may have some effect on behavioral concomitants which mask acoustic reflex responses and could, in part, account for differences that have been reported in the literature.

Furthermore, investigators do not appear to have any standardized criteria for determining the presence or absence of the acoustic reflex.

Some denote the acoustic reflex by deflections of the compliance needle on the measuring equipment (Keith, 1973; Keith and Bench, 1978; Abahazi and Greenberg, 1977). Even within this reported literature, there is no evidence of criteria by which the amount of needle deflection required to denote an acoustic reflex has been determined. Other investigators use some type of strip chart, x/y recorder, or oscillographic representation in the determination of acoustic reflexes (Margolis and Popelka, 1975; Himelfarb et al., 1978; Weatherby and Bennett, 1979; Bennett, 1975). Himelfarb et al. (1978) attributed the inability of investigators to elicit acoustic reflexes in newborns, at least partially, to the sole use of visual observation of the VU meter's needle deflection. They felt that such a procedure would miss small muscle contractions.

The potential of acoustic reflex testing as a means of assessing infant hearing sensitivity has remained clouded by the confusion surrounding its measurement. As long as investigators question the normal development of the acoustic reflex and whether it can be reliably measured, it remains uncertain whether this technique will ever become a clinically useful tool with this population.

The purpose of this investigation is to examine the acoustic reflex threshold in neonates under conditions that will optimize elicitation. Use of hand-held equipment and oscillographic display of eliciting stimuli and compliance changes may provide an approach in which obscuring concomitants are minimized.

CHAPTER II

REVIEW OF THE LITERATURE

> The acoustic reflex is of particular importance in the diagnosis of conductive deficiencies. Although the absence of a stapedius muscle reflex does not necessarily indicate a hearing loss, its presence can be positive evidence of an intact neural and conductive mechanism (Bennett, 1975).

Acoustic reflex measurements have been used in the determination of middle ear pathologies, sensory neural hearing loss, recruitment, cranial nerves VII and VIII pathologies, and central lesions. The use of this measurement with primarily adult populations has been well documented (Niemeyer and Sesterhenn, 1972; Jerger et al., 1974a; Jerger et al., 1974b; Hall, 1978; Jerger and Hayes, 1980). Acoustic reflex measurements have also been used as a method of assessment of infants (Keith, 1973; Keith and Bench, 1978; Bennett, 1975; Margolis and Popelka, 1978; Abahazi and Greenberg, 1978).

Keith (1973) examined 40 normal infants from 36 to 151 hours old. Equipment was set up so that an earphone was placed in a bed of foam rubber in the mattress of a crib. The infant was placed with one ear over the earphone. The speaker and microphone were in a chrome box taped to a yardstick and placed over the crib approximately above the infant's head. An airtight seal was obtained in the exposed ear and measurements of compliance, tympanometry, and acoustic reflexes were performed. Acoustic reflex measurements were performed with stimuli of 500 and 2000 Hz at 100 dB HTL and a probe tone of 220 Hz. Presence of reflexes were determined by viewing the deflections of the needle on the balance meter of the impedance bridge. Presence of behavioral responses to tones were also recorded. Keith found that only 30% of the stimulus presentations produced clear acoustic reflexes; 44% resulted in behavioral responses and 26% produced no responses. He reported that acoustic reflexes may have been present in the 44% behavioral responses but movement obscured the measurement. Additionally, Keith stated that cases where both behavioral and acoustic reflex responses were absent may have been a result of the deep sleep state of the infants.

In a later study, Keith and Bench (1978) concluded that the existence of behavioral movement artifacts prohibits the accurate detection of the acoustic reflex in neonates. They tested 20 infants ages 18 to 192 hours with equipment arrangements the same as used in the earlier Keith (1973) study. A probe tone of 220 Hz was used and reflex eliciting stimuli consisted of a 1000 Hz pure tone, a 2600 Hz low-pass noise, and a broad band noise, all between 95 and 110 dB HL. Five presentations of each stimulus were made except when no reflex was observed after three presentations. In these cases, a new signal was presented.

During presentations, one observer watched the infant to record behavioral responses while another recorded deflections of the VU meter needle. The results revealed that over all meter readings, 5.4% were judged as apparent acoustic reflexes, 26% as indicating behavioral responses, and 68.5% as no responses. For overall behavioral responses, 53% were judged as no response, 36.7% as mild response, and 10% as generalized body movement in response to sound.

A study by Bennett (1975) also demonstrated low presence of measurable acoustic reflexes in newborns. Ninety-eight infants between five and 218 hours old were tested using a 220 Hz probe tone and a Barany noise box as contralateral stimulus. An x/y plotter recorded responses. Acoustic reflexes were present in an average of 16% of all ears tested.

Margolis and Popelka (1978) attempted to measure acoustic reflex thresholds for 14 normal infants ranging in age from 55 to 132 days. Stimuli consisted of 500, 1000, 2000, and 4000 Hz pure tones and wide band noise. Some infants were held by the mother during testing and others were laid in a crib. The probe assembly was hand-held by an investigator during testing and the earphone was hand-held at the infant's ear or wedged between the infant's head and mother's shoulder or the crib mattress. "The acoustic reflex threshold was taken to be the lowest level that consistently resulted in a change in acoustic conductance or acoustic susceptance as observed visually on the oscilloscope" (Margolis and Popelka, 1978). The authors found acoustic reflex thresholds for at least two stimuli from 16 ears of 10 infants.

Abahazi and Greenberg (1978) examined acoustic reflex thresholds on normal infants between one month and one year of age. A probe tone of 220 Hz was utilized with reflex activating stimuli of 500, 1000, and 2000 Hz pure tones, low-pass, high-pass, and white noise.

> Acoustic presentations of approximately one-sec duration began at approximately 70 dB SPL and ascended in 5 dB steps until the reflex was obtained for two of three presentations. The ascending method was used to reduce the possibility of startle responses. Acoustic reflex thresholds were determined by a deflection of at least one unit on the impedance device's

compliance change meter set at the R sensitivity setting in response to signal presentation.

Results revealed that noise required less intensity than pure tones to elicit an acoustic reflex and that 500 Hz required the greatest intensity of all stimuli tested. Furthermore, the intensity required to elicit an acoustic reflex was found to decrease as age increased. Only 21% of the infants tested exhibited acoustic reflexes to the three pure tones and three noises. However, approximately 57% produced responses to at least one stimulus. The authors concluded that several test sessions may be required to obtain an accurate assessment with this method. In addition, they stated that the accuracy of the measurement could be increased by using strip chart recordings of the acoustic reflex.

Using 21 normal neonates between eight and 96 hours post birth, Himelfarb et al. (1978) measured acoustic reflexes at a probe tone of 220 Hz and stimuli of 500, 1000, 2000, and 4000 Hz pure tones and broad band noise. Measurements were made using an acoustic admittance meter for which outputs were filtered and sent to one channel of a two-channel strip chart recorder. One ear of the subject was positioned on an earphone surrounded by foam rubber while a probe tip was hand-held in the contralateral ear. An ascending method was used to determine threshold.

The authors recorded acoustic reflexes to at least one stimulus in 88% of the ears tested. The highest percentage occurred at 500 Hz with systematic decreases as frequency increased. Median thresholds for broad band noise were slightly lower when compared to the tonal stimuli. They also found that the median reflex thresholds in neonates were higher than those of older subjects for all of the stimuli.

In summary, there are several areas of acoustic reflex testing with neonates and infants in which there has been conflicting information. These are:

1. Probe tone frequency;
2. Reflex eliciting stimuli;
3. Equipment arrangement;
4. Procedure;
5. Criteria for determination of presence of acoustic reflexes.

These conflicts have led to confusion regarding the presence of the acoustic reflex in neonates and the ability to measure it clinically. Thus, although acoustic reflex testing may be an excellent tool for neonatal hearing assessment, its clinical usefulness remains questionable.

CHAPTER III

METHODOLOGY

The purpose of this investigation was to evaluate acoustic reflex thresholds in neonates. Use of hand-held equipment and oscillographic display of output were intended to minimize obscuring concomitants and optimize elicitation of the acoustic reflex threshold. A secondary purpose was to analyze threshold results using the SPAR techniques (Jerger et al., 1974a) in order to examine the utility of the technique with a neonatal population.

A. SUBJECTS

Subjects consisted of 10 neonates between nine and 55 hours post birth obtained from the newborn nursery at The University of Tennessee Memorial Research Hospital. Infants were required to meet the following criteria:

1. No family history of hearing loss since childhood;
2. No Rubella during pregnancy;
3. Birthweight of greater than 1500 grams (3.3 pounds);
4. No congenital craniofacial malformation;
5. Bilirubin count below 12 mg/100 ml;
6. Five-minute APGAR ratings of six or above;
7. Normal findings on physical examination by a physician.

Examination of medical files and conversations with the infants' parents were used to ensure that all infants met the criteria.

B. STIMULI AND INSTRUMENTATION

Test Environment

Infants were tested in quiet rooms (≃45-48 dBA) adjacent to the main ward of the newborn nursery. All infants were brought to the rooms in their cribs and remained in them during the entire test procedure. The only occupants of the test rooms were the examiners and the infants.

Infants were tested within one to two hours after feeding. As a result, the infants were either sleeping or quietly awake when they arrived for testing.

Stimuli

A probe tone of 220 Hz was used. Intensity of the probe tone was set at 85 dB SPL. Stimuli were varied across the parameters of 500, 1000, and 2000 Hz pure tones and white noise. The maximum intensity for the stimuli was set at 110 dB HTL for the pure tones and 110 dB SPL for white noise. An ascending method was used to determine the reflex threshold.

Instrumentation

An Amplaid Acoustic Impedance meter (model 702) was used to perform impedance measurements. The output of the impedance meter was monitored on a two-channel oscilloscope (Tektronix 5103N) (see Figure 2).

Channel one of the oscilloscope monitored the compliance changes in the ear. It was set at a sensitivity of .1 volts/division. Channel

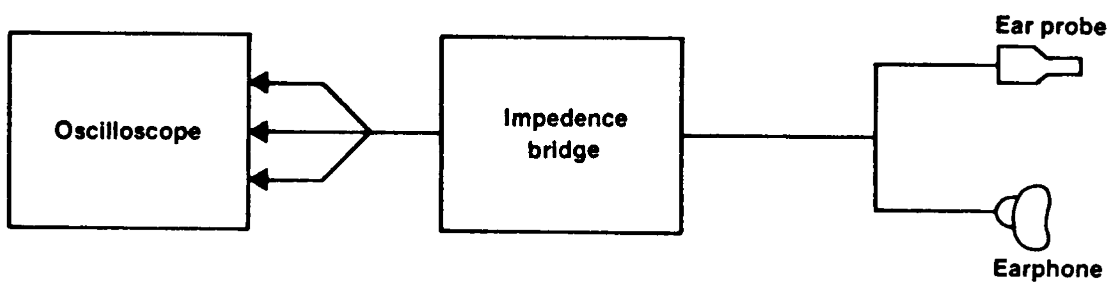

Figure 2. Schematic of instrumentation.

two monitored the waveform relative to the acoustic stimulus. It was set at a sensitivity of 2 volts/division. The speed at which the display crossed the screen was set at .5 seconds/division.

Calibration

The impedance bridge was calibrated using a Bruel and Kjaer 159 Audiometer Calibrator. A two-cc coupler was placed over the microphone for calibration of the probe tone and the earphone of the impedance bridge was used in calibration of the stimuli. Calibration checks were performed at the beginning of each daily test session and following testing of the tenth infant.

Biological calibration for the SPAR test (Jerger et al., 1974a) was carried out on 10 normal-hearing young adults (20-30 years of age). Pure tone reflex thresholds were obtained at 500, 1000, and 2000 Hz for each of the individuals and the values were averaged. Broad band reflex thresholds were also obtained and averaged. The broad band reflex average was subtracted from the pure tone average to obtain the NTD for the Amplaid 702 impedance bridge. This value was subtracted from the Jerger norm of 25 dB to provide the correction factor to be used in calculating SPAR results for the neonates. Separate correction factors were determined for reflex thresholds obtained from the compliance change needle of the impedance bridge and reflex thresholds obtained from the oscilloscope.

Procedure

Each infant was arranged comfortably in his/her crib so that one ear was exposed. A probe tip was placed in that ear to obtain a hermetic seal. Due to the small size of the ear canal, it was often necessary to re-position the probe to avoid pushing it against the wall of the ear canal. Tympanometric measurements were carried out at pressures from +200 to -200 mm H_2O. The probe tip was then removed, inserted in the contralateral ear, and the procedure repeated.

After tympanograms had been obtained bilaterally, an earphone was held at the ear contralateral to the probe tip. Care was taken to avoid collapsing the ear canal with the earphone. Placement was checked frequently during testing to ensure an open canal.

For the majority of infants tested, two investigators were required to hold the probe and earphone in place. This arrangement reduced chances of collapsed canal at the earphone ear and positioning of the probe against the canal wall. It also minimized discomfort to the infant, thus reducing extraneous movement.

Acoustic reflex measurements were carried out at the earphone ear. The ear on which testing was performed was counterbalanced among the 10 subjects.

In searching for the acoustic reflex threshold, each trial consisted of three presentations of the stimulus at a given intensity level within a five-second time period. Intensity of stimuli was increased in five-dB steps until the reflex produced:

1. A change in acoustic compliance as observed visually on the oscilloscope; and
2. A deflection of the compliance change meter needle on the impedance bridge.

It was necessary for these responses to be time-locked to the stimulus presentation in order for them to be judged a reflex.

The events were recorded independently by two judges. The judge watching the compliance change needle of the impedance bridge presented the stimuli to the infant's ear. He was required to make a decision regarding presence of a reflex immediately upon presentation of the reflex stimulus. The judge watching the oscilloscope waited until all three presentations had been made during a trial and made a decision based on observation of a hard copy of the stimulus presentations and compliance changes in the ear.

The following criteria were utilized by both judges in determination of the acoustic reflex threshold:

1. Positive reflex threshold. Reflex time-locked to stimulus presentation judged to be present on two of three stimulus presentations in two successive trials.
2. Questionable reflex threshold. Reflex time-locked to stimulus presentation judged to be present on one of three stimulus presentations in two successive trials.
3. Absent reflex threshold. Reflex judged to be absent in all stimulus presentations.

While the two judges were recording output from the equipment, a third judge reported behavioral responses of the infant during testing. If the infant was crying, moving excessively, or sucking vigorously, testing was suspended briefly until the infant returned to a quiet state.

CHAPTER IV

RESULTS

Ten infants were seen in the newborn nursery at The University of Tennessee Memorial Research Hospital. Tympanometric measurements were obtained bilaterally on each infant. Acoustic reflex measurements were obtained unilaterally on each infant for stimuli of 500, 1000, and 2000 Hz pure tones and white noise with a probe tone of 220 Hz. Acoustic reflex thresholds were measured independently with an oscilloscope and the compliance change meter of an impedance bridge. Individual reflex thresholds for each infant recorded by both instruments are shown in Table 3.

Data analysis consisted of a comparison between acoustic reflex thresholds (positive and questionable) for each of the activating stimuli as recorded by both instruments. Means and ranges of acoustic reflex thresholds were also determined for each of the activating stimuli. SPAR results were determined for all infants who responded to all activating stimuli.

Tympanometry

Tympanometric measurements were successfully completed bilaterally for all 10 infants (20 ears). Peaks at positive pressures ranging from +25 to +100 mm H_2O were recorded in nine ears. One infant exhibited normal pressure (0 mm H_2O) at the left ear when testing began. During the test procedures, however, pressure at the left ear changed to a peak at +100 mm H_2O. Negative pressure peaking at -100 mm H_2O was observed

TABLE 3

ACOUSTIC REFLEX THRESHOLDS IN dB HTL (RE: ANSI 1969) FOR PURE TONES AND dB SPL (RE: 0.0002 μ bor) FOR WHITE NOISE (WN) RECORDED FOR EACH SUBJECT ON THE IMPEDANCE BRIDGE AND OSCILLOSCOPE

			Stimulus Condition							
			Bridge				Oscilloscope			
Subject	Gestation Age (weeks)	Post Birth Age (hours)	500	1000	2000	White Noise	500	1000	2000	White Noise
1	39	37	110	110	105	90	---	---	---	90
2	39	55	110	110	---	100	110	110	---	100
3	39	43	---	---	---	---	---	---	---	---
4	38	36	---	---	---	---	---	---	---	---
5	40	13	105	110	105	100	110	110	110	100
6	40	36	110?	105	110	110	110	105	110	110
7	41-44	17	110	110?	110?	105	110	110?	110	105
8	42	9	110	110?	---	110	110	110?	---	110
9	38	25	105	105	95	90	105	105	95	90
10	41	47	105	110?	100	100	100	110	100	100

in one ear. The remaining 10 ears peaked at ambient pressure throughout testing (Figure 3).

Acoustic Reflexes

Acoustic reflex measurements were performed unilaterally on each of the 10 infants. Positive acoustic reflex thresholds to the four activating stimuli were obtained from five (50%) of the 10 infants. By combining positive and questionable reflex results, acoustic reflex thresholds for the four activating stimuli were obtained from six (60%) of the 10 infants. Of the remaining four infants, two (20%) had absent reflexes at 2000 Hz only and two (20%) had absent reflexes to all stimuli (Table 3).

A comparison was made between positive and questionable responses obtained on both the impedance bridge (Figure 4) and the oscilloscope (Figure 5). For both instruments, most positive responses were obtained for white noise and 500 Hz pure tone stimuli. These results are in agreement with results found by Himelfarb et al. (1978). Fewest positive responses were obtained for 1000 and 2000 Hz pure tone stimuli. There were fewer questionable responses for the oscilloscope than the impedance bridge. It should be noted, however, that the results for the two instruments differed by only one in this case. In addition, an N of only 10 subjects causes any generalization from these results to be conservative.

One infant exhibited acoustic reflexes to pure tone stimuli that were visible on the impedance bridge but not on the oscilloscope. Combining positive and questionable acoustic reflex responses resulted in

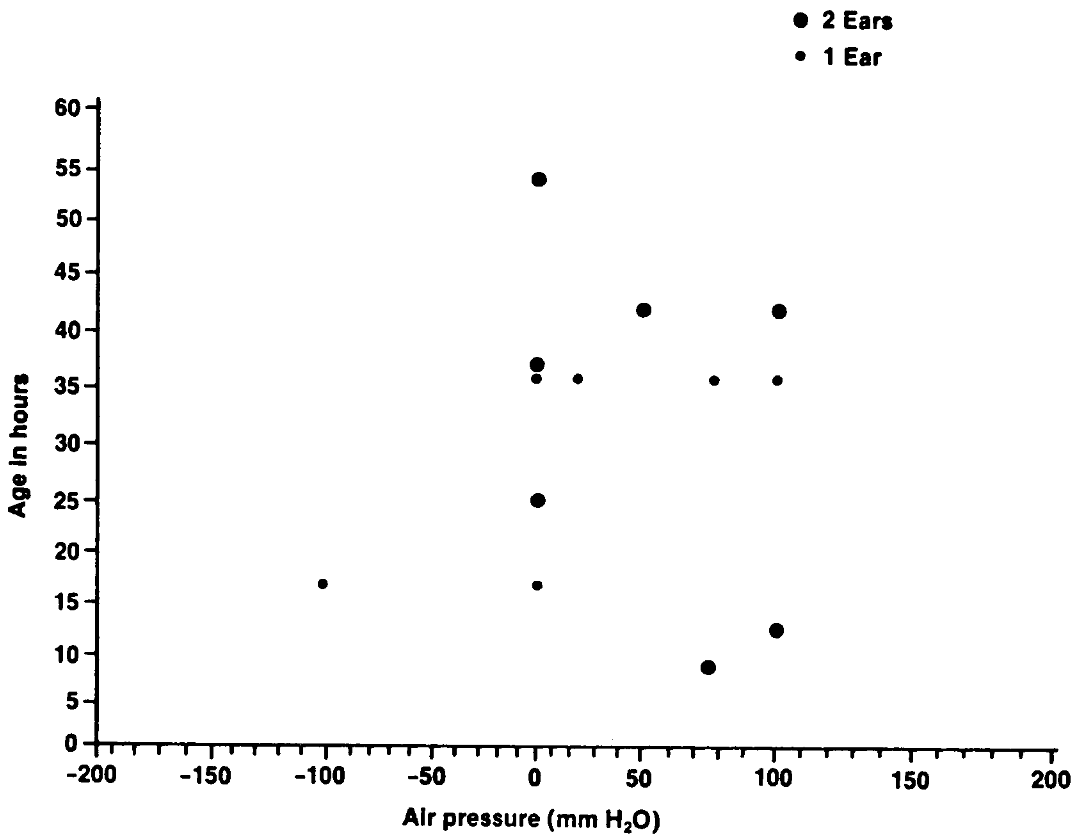

Figure 3. Middle ear pressure as a function of age in hours post birth.

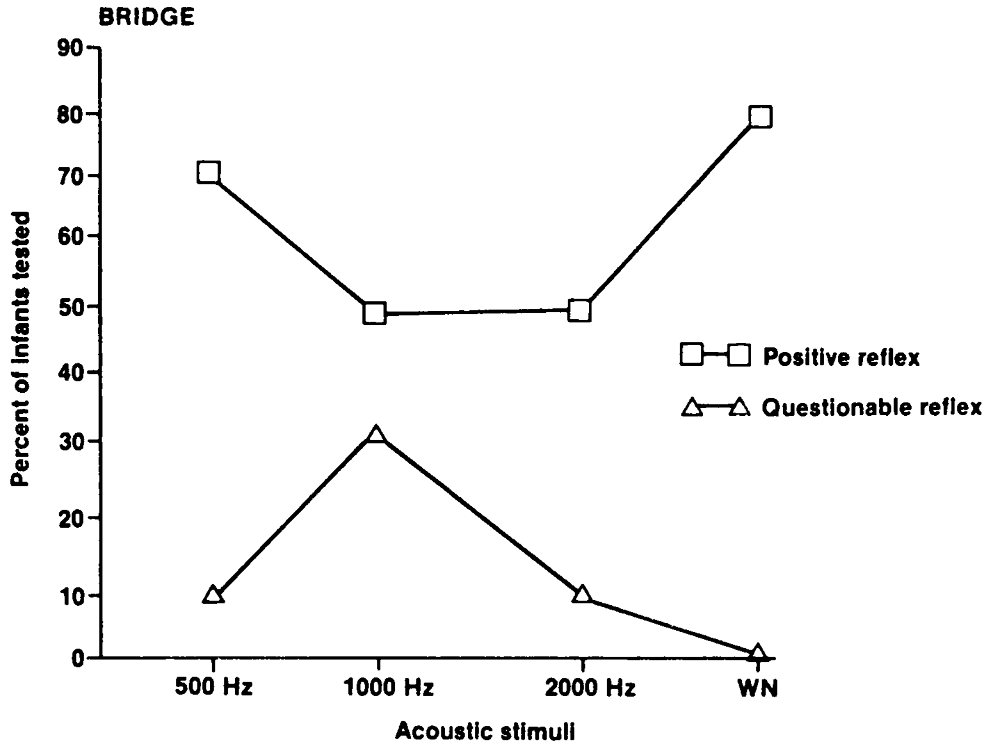

Figure 4. Percentage of positive and questionable acoustic reflex thresholds for stimuli of 500, 1000, and 2000 Hz pure tones and white noise (WN) as recorded from the impedance bridge.

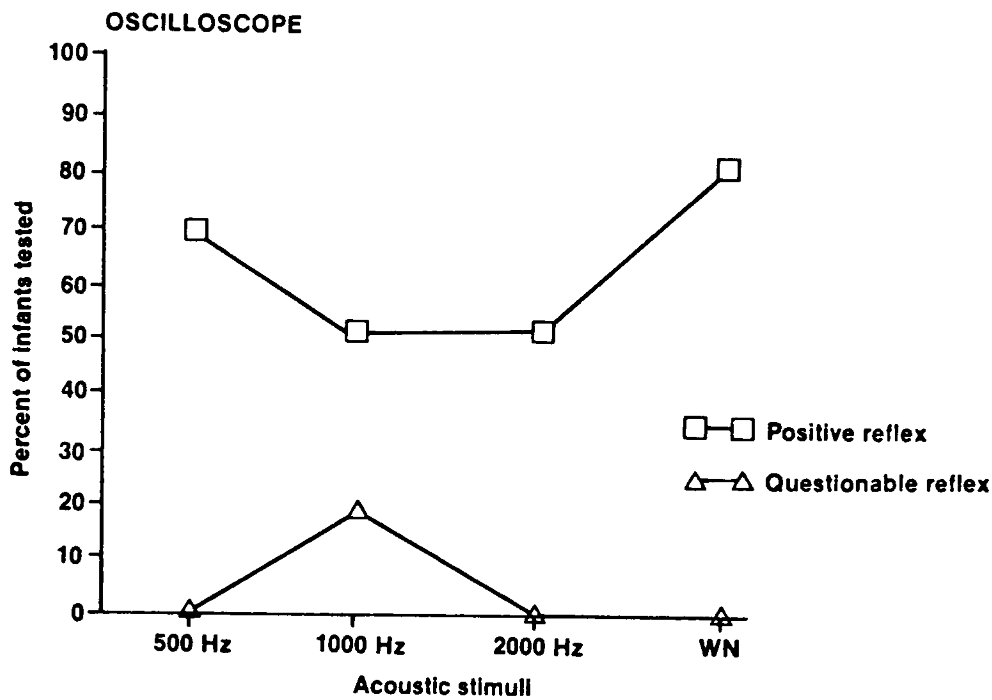

Figure 5. Percentage of positive and questionable reflex thresholds for stimuli of 500, 1000, and 2000 Hz pure tones and white noise (WN) as recorded from the oscilloscope.

a higher percentage of acoustic reflex thresholds obtained for the impedance bridge (Figure 6). Again, the reader should note the small difference between results for the two instruments, as well as the small N.

The total number of acoustic reflex thresholds obtained on the impedance bridge (Figure 6). Again, the small difference between results for the two instruments, as well as the small N, should be noted.

approximately equivalent.

The mean and range for each stimulus condition obtained on the impedance bridge are shown in Table 4. The mean and range for each stimulus condition obtained on the oscilloscope are shown in Table 5. The mean threshold for both instruments was lowest for white noise (101 dB SPL). The mean threshold for 2000 Hz followed at 104 HTL utilizing the impedance bridge and 105 dB HTL utilizing the oscilloscope. The mean thresholds for 500 and 1000 Hz were 108 dB HTL and 109 dB HTL, respectively, for both instruments.

The ranges of the acoustic reflex thresholds were the same for the impedance bridge and for the oscilloscope. Ranges were broadest for white noise (90-110 dB SPL) and the 2000 Hz pure tone signal (95-110 dB HTL). Ranges were approximately the same for the 500 Hz and 1000 Hz pure tone signals (105-110 dB HTL).

Overall, means and ranges were higher than those that have been reported for adults (Peterson and Liden, 1972; Deutsch, 1972). However, these results are in agreement with results that have been reported for infants (Himelfarb et al., 1978; Abahazi and Greenberg, 1977).

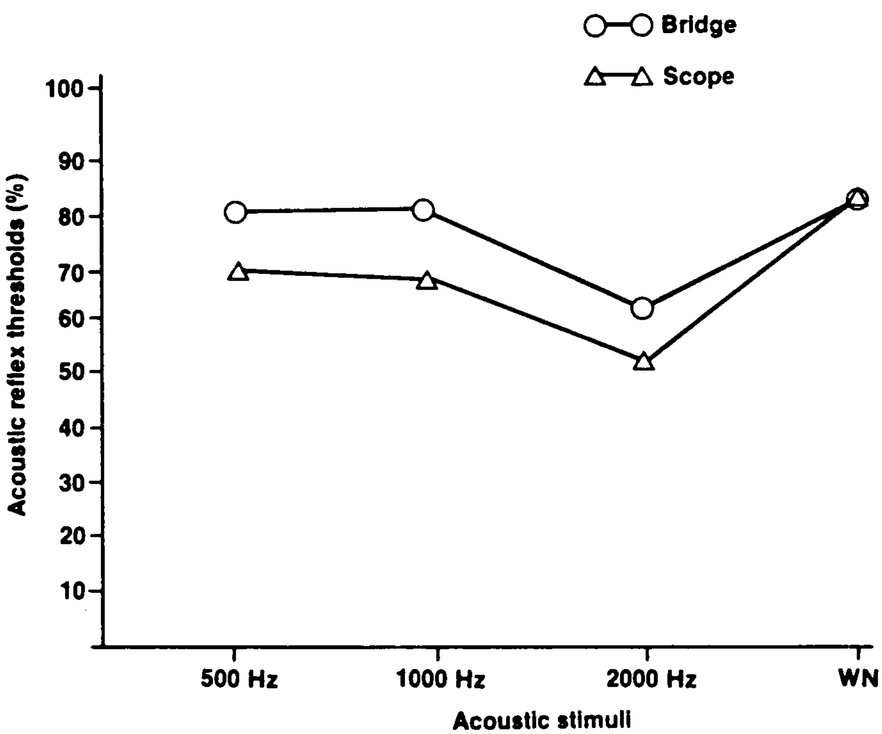

Figure 6. Percent of acoustic reflex thresholds obtained for stimuli of 500, 1000, and 2000 Hz pure tones and white noise (WN) as recorded on the impedance bridge and the oscilloscope.

TABLE 4

MEAN AND RANGE OF ART'S[a] RECORDED ON IMPEDANCE BRIDGE IN dB HTL (RE: ANSI 1969) FOR PURE TONES AND dB SPL (RE: 0.0002 μ bor) FOR WN WHILE USING A PROBE TONE OF 220 Hz AT STIMULUS FREQUENCIES OF 500, 1000, AND 2000 Hz AND WN

Stimulus Frequency	Number of Ears Tested	Number of Questionable ART's	Number of Positive ART's	Total ART's	Mean Threshold	Range
500 Hz	10	1	7	8	108	105-110
1000 Hz	10	3	5	8	109	105-110
2000 Hz	10	1	5	6	104	95-110
WN	10	0	8	8	101	90-110

[a]ART = acoustic reflex threshold.

TABLE 5

MEAN AND RANGE OF ART'S RECORDED ON OSCILLOSCOPE IN dB HTL (RE: ANSI 1969) FOR PURE TONES AND dB SPL (RE: 0.0002 μ bor) FOR WN WHILE USING A PROBE TONE OF 220 Hz AT STIMULUS FREQUENCIES OF 500, 1000, AND 2000 Hz AND WN

Stimulus Frequency	Number of Ears Tested	Number of Questionable ART's	Number of Positive ART's	Total ART's	Mean Threshold	Range
500 Hz	10	0	7	7	108	105-110
1000 Hz	10	2	5	7	109	105-110
2000 Hz	10	0	5	5	105	95-110
WN	10	0	8	8	101	90-110

Prior to testing, it was assumed that the oscilloscope would aid in the detection of reflex thresholds because it could be made sensitive to small compliance changes resulting from the acoustic reflex. During testing, it was observed that this was, in fact, true. However, the oscilloscope was also sensitive to small movements from the infant and/or the investigators holding the equipment.

SPAR

By combining positive and questionable reflex thresholds, SPAR results were obtained from the impedance bridge for six (60%) of the 10 infants and from the oscilloscope for five (50%) of the 10 infants. Because results for the two instruments were essentially the same, the data will be collapsed and reported together. For five of the infants, SPAR results showed hearing to be within normal limits. Results for one infant showed hearing to be borderline normal/mild to moderate hearing loss. This infant was the one for whom the point of maximum compliance changed from 0 mm H_2O to +100 mm H_2O during testing.

The infant for whom SPAR results were obtained from the bridge but not from the oscilloscope had hearing within normal limits. SPAR was not performed with the oscilloscope results because of insufficient data.

SPAR results could not be obtained from either instrument for the four (40%) remaining infants due to lack of data. Two (20%) of the infants had no reflex responses at 2000 Hz on either instrument, and two (20%) infants had no reflex responses to any of the activating stimuli.

The percentage of SPAR results obtained in this investigation is higher than obtained by Abahazi and Greenberg (1977). They reported acoustic reflex measurements for 62 infants and were able to obtain acoustic reflex thresholds for all activating stimuli on only 37% of the infants tested. The remaining 63% exhibited acoustic reflex thresholds to some but not all of the activating stimuli. SPAR was carried out for the infants responding to all stimuli. Results showed hearing to be within normal limits for all of the infants tested.

CHAPTER V

DISCUSSION

The purpose of this investigation was to examine acoustic reflex thresholds in neonates under conditions that would optimize elicitation of the reflex. The use of hand-held equipment and oscillographic display of compliance changes in the ear were intended to minimize concomitants that might obscure the acoustic reflex. Additionally, tympanograms were obtained bilaterally for each infant to provide information about the middle ear system.

Tympanometric measurements indicated peaks at positive pressure for nine (45%) ears, negative pressure for one ear (5%), and ambient pressure for 10 ears (50%). McCandless and Allred (1978) suggest that "positive pressures may be due to the reflexive pumping action produced by infantile sucking motion which forces air into the middle ear cavity via the Eustachian tube." In the present investigation, the majority of infants were sucking on pacifiers during all or part of the test procedure. The pacifiers, which were used to keep the infants resting quietly, may account for the large number of positive pressure peaks noted.

Of the five infants (nine ears) exhibiting positive pressure, two had absent reflexes for all stimuli, one had absent reflexes at 2000 Hz, and two had positive or questionable reflexes for all stimuli. This data is not sufficient to argue for a relationship between positive pressure and absent reflexes.

The literature (Schwartz and Schwartz, 1978; Paradise et al., 1976) reports that tympanograms alone are a poor indicator of the condition of the middle ear in infants. Schwartz and Schwartz (1978) reported that, in a group of infants below six months of age, 80% of ears with confirmed middle ear effusions produced normal tympanograms. However, acoustic reflexes were absent in 100% of the ears. It is possible that the tympanograms displayed by the infants in this investigation who exhibited absent reflexes are misleading. Any generalization based on the tympanometric findings should, therefore, be made with caution.

With acoustic reflex testing, 60% of the infants in this investigation exhibited acoustic reflex thresholds to all activating stimuli, and 20% exhibited acoustic reflex thresholds for all but one activating stimulus. This total of 80% of infants exhibiting reflex thresholds is much higher than results obtained by Keith (1973) or Bennett (1975). In addition, a 60% response rate for all activating stimuli is higher than has been reported elsewhere when a 220 Hz probe tone is used (Margolis and Popelka, 1978; Abahazi and Greenberg, 1978; Himelfarb et al., 1978). The high percentage of reflex thresholds obtained in this investigation provide support for the assumption that it may be test conditions and procedures rather than an absent reflex which have been responsible for poor results when testing neonates.

Among the procedures used in this investigation which were intended to elicit a high percentage of acoustic reflex responses was the use of hand-held equipment. This was intended to minimize discomfort for the infants, as well as reduce movement artifacts. During testing, it was found that two investigators were required to hold the probe tip and the earphone in a comfortable position for the infant. Placement of the earphone in a bed of foam rubber or a hole in the crib bottom (Keith, 1973; Himelfarb et al., 1978) would resolve the need for the second individual to hold equipment and would not result in excessive movement from the infant. It is important, however, to have someone holding the probe tip. Adjustments were often necessary to keep the probe tip away from the canal wall of the infant's ear. A slight movement of the probe tip by the individual holding it was usually all that was required to correct the problem. In addition, the investigator holding the probe tip was often able to quiet the infant fairly quickly if he/she became restless or agitated.

Oscillographic display of the onset of stimuli and compliance changes was another procedure intended to increase the percentage of acoustic reflex thresholds obtained. There were positive and negative aspects to the use of an oscilloscope for recording acoustic reflex thresholds. As mentioned earlier, the sensitivity setting of the oscillographic recording made it sensitive to movements from the infant and/or the investigator holding equipment, as well as to small compliance changes in the ear. Margolis and Popelka (1975) addressed this problem by reducing the sensitivity setting of the oscilloscope. However, reducing the sensitivity defeats, in part, the purpose of using an oscilloscope. A better solution might be to use filters to reduce extraneous ambient noise. This procedure has been used elsewhere with infants and adults (Robinette, 1975; Himelfarb et al., 1978).

In addition to its sensitivity, the oscilloscope was used to provide a fixed copy for the investigator. The fixed copy allowed the investigator to judge reflex responses in relation to each other, as well as to the onset of the activating stimuli. This is in contrast to the investigator watching needle deflection on the impedance bridge. The investigator watching the bridge was required to make decisions regarding presence of an acoustic reflex immediately upon onset of the activating stimulus.

In this investigation, the results may not be an accurate depiction of the advantage that can be gained by using a hard copy for judging reflex responses. The close agreement between the two instruments may be a result of several factors which include the experience of the investigator judging needle deflections and the particular impedance bridge used. These factors cannot be held constant across all test situations. Therefore, a hard copy is a valuable tool in the accurate assessment of acoustic reflex thresholds in neonates.

The oscilloscope is not the only means of producing a hard copy. The literature reports on the use of x/y plotters (Bennett, 1975) and strip chart recordings (Himelfarb et al., 1978). Any measure which allows the investigator to review the reflex response in relation to other responses and the onset of the activating signal may increase the accuracy of the measurement. The advantage of the oscilloscope is in its ability to provide greater degrees of sensitivity for recording responses.

The absence of an acoustic reflex threshold for all activating stimuli was found for two infants. The fact that only two infants exhibited these results and that the infants were tested in succession may be of some consideration in examining the possible factors involved.

It is possible that there was some equipment malfunction of which investigators were unaware. It is also possible that the probe tip was against the canal wall or some other substance in the external canal. There may have been some middle ear pathology in both infants which tympanometry did not accurately identify. The positive pressure exhibited by both infants might also have been the cause. The absent reflexes might be explained by an insufficiently developed neurological system (Keith and Bench, 1978).

A further explanation for absent and even questionable reflex responses is related to the stimulus intensity. In this investigation, the upper limit for intensity of activating stimuli was set at 110 dB HTL for pure tones and 110 dB SPL for white noise. This is the level at which slightly more than half of the reflex thresholds were obtained. It is possible that the acoustic reflex thresholds in some infants were at higher intensity levels for the probe tone and activating stimuli that were used.

At present, all of the explanations regarding the absent reflexes are speculation, however. Further examination under the same conditions is required to determine whether the results from these infants are caused by any of the number of explanations postulated here or from some factor not yet discovered.

Obtaining SPAR results for six (60%) infants indicates promise for the use of acoustic reflex testing in predicting hearing threshold for neonates. Before such testing can be truly accurate, however, it will be necessary for clinicians to be able to obtain quick, accurate acoustic reflex thresholds for all required activating stimuli on the majority of infants tested. Once the normative data for neonates has been clearly established, more accurate predictions of abnormality can be made. This is especially important for determining the correction factor for the SPAR test. In this investigation, as well as the investigation by Abahazi and Greenberg (1978), correction factors were based on data from young normal-hearing adults. One must be careful in interpreting results from two such differing populations.

Therefore, prediction of hearing thresholds using acoustic reflex thresholds is still a goal for the neonatal population. Use of hand-held equipment and oscillographic display in carefully administered impedance tests may be the aid that is needed to expedite the process.

The results of this investigation indicate that it is possible to obtain fairly accurate acoustic reflex thresholds with neonates. This is especially promising in regard to future use of procedures for predicting hearing loss from the acoustic reflex. The procedure for eliciting acoustic reflexes with neonates is clearly not complete at present. However, careful examination and planning of procedures as discussed in this thesis may aid in the development of a standardized clinical procedure that can be used with the neonatal population.

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