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The Effects of Ear Canal Pressure Variation on Distortion Product Otoacoustic Emissions

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THESIS APPROVAL

The abstract and thesis of Jodi L. Head for the Master of Science in Speech Communication: Speech and Hearing Science were presented April 28, 1995, and accepted by the thesis committee and the department.

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ABSTRACT

An abstract of the thesis of Jodi L. Head for the Master of Science in Speech Communication: Speech and Hearing Science presented April 28, 1995.

Title: The Effects of Ear Canal Pressure Variation on Distortion Product Otoacoustic Emissions.

The middle ear system is a vital component in the propagation mechanism of otoacoustic emissions. As such, investigation of the effect of variation in middle ear impedance on the measurement of emissions is warranted.

Distortion product otoacoustic emissions (DPOAEs) have gained recognition as a means of gaining frequency specific information on auditory function. As the effects of changes in middle ear impedance will vary as a function of frequency, a clear definition of the relationship between middle ear impedance and DPOAE amplitude across the frequency spectrum is needed.

Twenty adults (ages 20-37) with normal hearing and normal middle ear function were selected as subjects. Commercially available equipment (Virtual 330) was used to measure the DPOAEs on all subjects. The unit was modified to change canal pressure by coupling the probe to the pressure pump of a clinical acoustic immittance system. One ear from each subject was randomly selected for measurement and each subject was tested under five pressure conditions: +200, 0, -200, -300, -400 daPa. The mean frequency of the f1/f2 tone pairs swept from 500 to 8000 Hz.

Results indicate that changes in ear canal pressure can effect the amplitude of DPOAEs. Alteration of ear canal pressure resulted in decreased emission amplitude. This effect was found to differ as a function of eliciting frequency with the greatest reduction in amplitude with the mean of the primaries at 500 Hz. Less variation was noted across the ear canal pressures with the higher frequency stimuli. These results are consistent with previous findings reported regarding the effects of impedance changes on spontaneous and transiently evoked otoacoustic emissions.

THE EFFECTS OF EAR CANAL PRESSURE VARIATION ON DISTORTION PRODUCT OTOACOUSTIC EMISSIONS

by

JODI L. HEAD

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CHAPTER I

INTRODUCTION

Otoacoustic emissions (OAEs) are measurable sounds in the ear canal emitted by the cochlea. Electromotile properties of the cochlea's outer hair cells are thought to be responsible for the generation of the emitted sound (Brownell, 1990; Glattke & Kujawa, 1991; Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993). Some emissions, spontaneous otoacoustic emissions (SOAEs), are not associated with acoustic stimulation while others, evoked otoacoustic emissions, (EOAEs), are responses to acoustical stimuli. EOAEs can be elicited by clicks, (transiently evoked, TEOAEs) tones (stimulus-frequency, SFOAEs), or pairs of tones (distortion product, DPOAEs).

Click-evoked emissions were first observed by Kemp (1978). Commercially-available instrumentation now allows quick and easy measurement of these. Recent investigations suggest the use of distortion products as a means of gaining frequency specific information on auditory function (Chery-Croze, Moulin, & Collet, 1993; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin & Martin, 1990). DPOAEs are measurable in essentially all ears with normal hearing sensitivity (Glattke & Kujawa, 1991; Kemp, Bray, Alexander, & Brown 1986; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993). A decrease in emission amplitude is reported in ears with pure-tone thresholds between 15 and 50 dB HL (Glattke & Kujawa 1991). DPOAEs have been reported to be absent in impaired ears with pure-tone thresholds in excess of 40-55 dB HL (Glattke & Kujawa, 1991; Lonsbury-Martin & Martin, 1990). This elevation or absence may have utility in the identification of cochlear hearing loss.

Once emissions are generated within the cochlea the sound travels through the middle ear cavity to the external ear canal. The participation of the middle ear system in the transmission of emissions makes it necessary to investigate the effects of variations in middle ear impedance on the amplitude of the emission. Changes in impedance associated with normal pressure variation or with such common ailments as otitis media where the immittance of the middle ear is altered, could inhibit the propagation of the emission. Thus, the emission measurement could falsely suggest the presence of cochlear hearing loss if deleterious effects of middle ear pressure variations are not accounted for.

Schloth and Zwicker (1983) found the effect of increased middle ear impedance due to changes in middle ear pressure inhibited the recording of SOAEs. A more recent study by Naeve, Margolis, Levine, and Fournier (1992) reported a similar effect on TEOAEs concluding that both positive and negative changes in air pressure reduce the amplitude of TEOAEs by 3-6 dB. Little research; however, is available documenting the effects of alteration of middle ear impedance on DPOAEs. As the effects of changes in middle ear impedance will vary as a function of frequency, this study was undertaken to define the relationship between middle ear impedance and DPOAE amplitude across the frequency spectrum.

CHAPTER II

REVIEW OF THE LITERATURE

DISCOVERY OF OTOACOUSTIC EMISSIONS

In 1978, Kemp presented transient acoustic stimuli to the ear and recorded sound emitted in response to the stimulation. The recorded response was found to have unique acoustical properties. The original sound source was a series of clicks with a broadband signal, whereas the recorded response had specific frequency characteristics (Glattke & Kujawa, 1991). Responses were recorded with a time delay of approximately six milliseconds. Glattke and Kujawa make reference to this long delay as "sufficient time for sound to travel more than 6 feet" based on 1,100 feet per second as the speed of sound traveling in air. Wit, Langevoort, and Ritsma (1981) called this phenomenon the "Kemp echo." However, this description of the phenomenon is of questionable accuracy as a mere reflection of the original sound presentation from the surface of the tympanic membrane would be evident within one millisecond. Glattke and Kujawa describe the differences between Kemp's original stimulation and the recorded response as "somewhat like shouting 'hello' in a canyon and hearing a reply that not only is different from the utterance, but that begins after an unusually long delay and persists for a prolonged time" (p. 29).

Although Kemp's findings were not readily accepted when first reported (Probst, Lonsbury-Martin, & Martin, 1991) the existence of energy within the cochlea had been considered as early as 1948 when Gold conducted a study of the physical processes within the cochlea. Gold described the cochlea as an active mechanism where an applied stimulus triggers the release of energy. The cochlear microphonic effect, originally described by Davis, Derbyshire, Lurie, and Saul in 1934, and later supported by Wever, Bray, and Lawrence (1940), occurs when stimuli presented to the cochlea results in a measurable oscillatory electrical potential. Gold found it "unlikely" that the cochlear microphonic was due solely to a passive conversion of energy. The oscillatory potential was too great to account for the damping which Gold believed must be present within the cochlea.

Gold's work examined the cochlea's resonating properties, the known size and density of the basilar membrane and the surrounding liquid, making an estimation as to the least amount of viscous damping which must be present. The calculated amount of damping was inconsistent with observation, in that sound introduced to the system maintained sufficient energy to be measured outside the cochlea. He thus proposed the 'regeneration hypothesis' which suggested that additional energy is supplied from an electromechanical action which counteracts the damping effect. Gold also examined the observation by Gersuni and Volokhov (1936) that the reverse of the cochlear microphonic exists, thus creating a feedback channel within the cochlea.

Gold's findings were later supported by Von Bekesy (1951), who measured dc potentials at different points along the cochlear partition. A potential difference was found indicating the presence of current flow. Von Bekesy thus concluded that the existence of the potential difference "makes it probable that continuous chemical processes are going on in the inner ear" (p. 576).

Accumulating evidence suggests that OAEs are indeed the result of an active mechanism within the cochlea (Brownell, 1990; Glattke & Kujawa, 1991; Lonsbury-Martin & Martin, 1989). In order for evoked emissions to be recorded several events must take place. The stimuli presented to the ear must travel from the sound source through the external canal, vibrate the tympanic membrane, and traverse the ossicular chain within the middle ear space to the cochlea. The vibration of the cochlear partition causes vibration of the cochlear fluid. An active process establishes a new traveling wave which propagates back through the ossicular chain and reaches the tympanic membrane. The motion of the tympanic membrane produces a new sound which is recordable in the external canal.

The exact site of origin of emissions is still under examination. However, recent studies report the outer hair cells as having electromotile capabilities, which according to Brownell (1990), "appear to be responsible for the cochlea's ability to generate sound" (p. 82). The movement of the outer hair cells are thought to be responsible for the production of the reverse traveling wave within the cochlear fluids (Lonsbury-Martin & Martin, 1989). Studies in which outer hair cell damage was found to broaden the frequency tuning of the traveling wave and reduce its sensitivity support the view that outer hair cells act as a cochlear amplifier (Brownell, 1990; Lonsbury-Martin, McCoy, Whitehead, & Martin 1993).

DISTORTION PRODUCT OTOACOUSTIC EMISSIONS

According to Von Bekesy (1960), distortion products have been observed in the auditory system for over a century with research conducted by Helmholtz as early as 1885. Helmholtz theorized that the middle ear was responsible for the nonlinear processing within the ear. Later investigation disputed this theory (Von Bekesy, 1960; Wever, Bray, & Lawrence 1940). Examinations of middle ear mechanics found distortion products to be generated in the middle ear only as a byproduct of saturation of the middle ear system (Hall, 1972). Goldstein (1967) proposed that distortion products are generated within the cochlea. His work, attributing the cochlea as the source of the nonlinear production has gained widespread acceptance (Gaskill & Brown 1990; Hall, 1972; Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993; Roede, Harris, Probst, & Xu 1993).

Distortion products can be elicited by the simultaneous presentation of two pure-tones. The two tones can be referred to as f1 and f2. The cubic difference distortion product (2f1-f2; f2>f1), is reported as the most prominent in the human auditory system (Lasky, Perlman, & Hecox, 1992; Martin, Probst, & Lonsbury-Martin, 1990; Smurzynski, Leonard, Kim, Lafreniere, & Jung, 1990). DPOAE amplitudes are generally quite low. Lonsbury-Martin, McCoy, Whitehead, and Martin (1993) report the common practice of acceptance to be that DPOAE amplitude need only be in excess of 3 dB above the sampled noise floor to be considered valid.

Distortion product otoacoustic emissions have gained recognition as a means of gaining frequency specific information on auditory function (Chery-Croze, Moulin, & Collet, 1993; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin & Martin, 1990). They are generally analyzed according to one of two methods. One method is the response growth, or input/output function. This method is generally recorded over a 60 dB stimulus range (Lonsbury-Martin & Martin, 1990). The input/output function can provide information about detection "threshold," dynamic range, and growth slope (Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993).

The second method, which is most commonly used, is the DPOAE "audiogram." This method maintains a constant level of the stimulus while the frequencies of the primary tones are changed. This allows for frequency specificity of the emission testing (Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993).

CLINICAL FINDINGS

Distortion product otoacoustic emissions are measurable in essentially all ears with normal hearing sensitivity (Glattke & Kujawa, 1991; Kemp, Bray, Alexander, & Brown 1986; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin, McCoy, Whitehead & Martin, 1993). Smurzynski, Leonard, Kim, Lafreniere, and Jung (1990) tested DPOAEs in normal and impaired adult ears and found good correlation between pure-tone thresholds and DPOAEs.

Some discrepancy is noted as to the relationship between pure-tone sensitivity and recordable DPOAEs in the impaired ear. Glattke and Kujawa (1991) reported a decrease in DPOAE amplitude if pure-tone thresholds were between 15 and 50 dB HL. They reported the emissions to be absent if pure-tone thresholds were in excess of 50 dB HL. Lonsbury-Martin and Martin (1990) generally support this finding in reporting DPOAEs as unrecordable in subjects with pure-tone thresholds in excess of 45-55 dB HL. Gaskill and Brown (1990) reported DPOAEs as unrecordable in subjects with pure-tone thresholds in excess of 20 dB HL; however, the study is thought to have been influenced by instrumentation limitations leading to excessive noise floor contamination.

Scholth and Zwicker (1983) found the effect of increased middle ear impedance due to changes in ear canal pressure inhibited the recording of spontaneous otoacoustic emissions. Naeve, Margolis, Levine, and Fournier (1992) reported a similar effect on transient evoked otoacoustic emissions, concluding that TEOAEs are reduced by 3-6 dB as a result of both positive and negative pressure changes. Trine, Hirsch, and Margolis (1993) reported the reduction of TEOAE amplitude as a result of pressure variation to be greatest in the low frequencies.

Several other variables can effect the recording of DPOAEs including the frequency ratio of the two primary tones used to elicit the emissions. Kemp, Bray, Alexander, and Brown (1986) suggest that the frequency ratio (f2/f1) of the two primaries yields the greatest response at a ratio of 1.25. Harris, Lonsbury-Martin, Stagner, Coats, and Martin (1989) suggest a ratio of 1.22 as most effective. More recent investigations suggest a ratio of 1.21 to yield the greatest response (Franklin, McCoy, Martin, & Lonsbury-Martin 1992; Gaskill & Brown, 1990; Roede, Harris, Probst, & Xu, 1993).

The presentation level of the primary tones used to elicit DPOAEs can also effect the recording of emissions. Lonsbury-Martin and Martin (1990) suggest a 65-85 dB SPL presentation level for optimal recording. Franklin, McCoy, Martin, and Lonsbury-Martin (1992) indicate that although emission amplitude increases with increase of stimulus presentation, a 55 dB SPL signal yields recordable emissions. The study also indicated that the amplitude of the primary tones, when varied from 55 to 75 dB SPL, had little influence on test/retest reliability.

Many studies have been conducted to assess the test/retest reliability of DPOAE testing. Roede, Harris, Probst, and Xu (1993) measured DPOAEs of 12 subjects over a period of 6 weeks. They found relatively stable conditions, with the most variability reported in the high frequencies between 6.0 and 8.0 kHz. Some variability was also noted in the low frequencies below 1.0 kHz. This was attributed to the influence of noise in this frequency region. Franklin, McCoy, Martin, and Lonsbury-Martin (1992) assessed both short-term and long-term repeatability. The short-term testing took place over a period of 4 days, while the long-term testing took place over a period of 4 weeks. Although their findings did suggest some variability between tests, overall reliability was considered excellent.

CLINICAL UTILITY

Otoacoustic emissions allow for objective noninvasive measurement of cochlear function (Glattke & Kujawa, 1991; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993). Emissions can be recorded quickly and with relative ease of measurement. Lonsbury-Martin, McCoy, Whitehead, and Martin (1993) attribute the growing recognition of OAE testing to the ability to isolate cochlear function without neural involvement.

Due to the noninvasive nature and objective measurement of OAEs, researchers emphasize the usefulness of OAE testing in the pediatric population (Glattke & Kujawa, 1991; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin & Martin, 1990). Franklin, McCoy, Martin, and Lonsbury-Martin (1992) suggest the usefulness of DPOAE testing in cases where high frequency monitoring is necessary, as with individuals exposed to excessive noise or ototoxic agents.

While OAE measurements provide information regarding cochlear function, attention must be given to the role of the middle ear system in the propagation of emissions. As the effects of changes in middle ear impedance will vary as a function of frequency, a clear definition of the relationship between middle ear impedance and DPOAE amplitude across the frequency spectrum is needed.

CHAPTER III

METHODS

SUBJECTS

Twenty adults (6 male, 14 female; ages 20-37) were included in the study. One ear was tested from each subject. The test ear was selected at random with 12 right ears and 8 left ears included in the data collection. Subjects were recruited from among students at Portland State University.

Each candidate was required to meet the following criteria in order to participate in the study: 1) no evidence of physical abnormality to either ear; 2) pure-tone air conduction thresholds of less than or equal to 15 dB HL at .25, .5, 1, 2, 3, 4, 6, and 8 kHz in both ears; 3) pure-tone bone conduction thresholds within 5 dB of air conduction thresholds; 4) tympanometric peaks (using a 226 Hz probe tone) within $\pm$15 daPa of ambient pressure.

INSTRUMENTATION

Commercially available equipment (Virtual 330) was used to measure the DPOAEs on all subjects. The primary tones used to elicit emissions were delivered via a probe tip inserted into the ear canal. A microphone housed within the probe recorded emissions in the canal.

The noise floor was plotted as well as the emission level. External noise present in the ear canal was reduced using a time averaging technique. Time averaging was set for 16; therefore, 16 acquisitions were made and averaged for each data point plotted. The artifact reject level was set at 10 dB SPL to avoid contamination with high noise level intervals during the test. The reject count was set for 4 retries. If the artifact reject tolerance level was exceeded, the measurement was repeated 4 times and the measurement with the best signal-to-noise ratio was plotted.

An adjustment to the standard probe of the Virtual 330 was made in order to allow for the variation of air pressure within the ear canal (see Figure 1). The tone transducers are housed in a tubephone that is acoustically

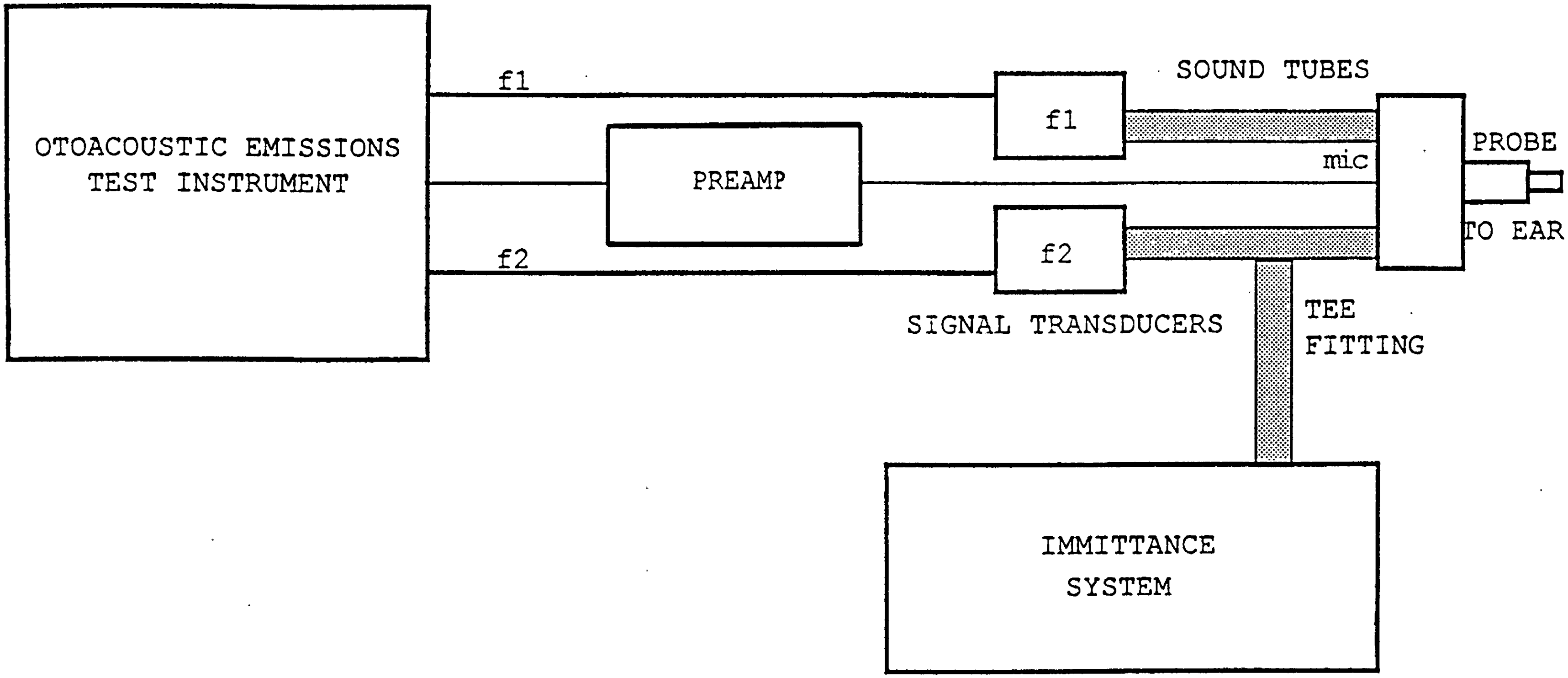

Figure 1. Schematic drawing of probe assembly.

coupled to the probe through a large diameter, flexible tubing. This tubing was severed and a "tee" fitting was inserted in-line with the tubing. The perpendicular branch of the tee fitting was connected by tubing to a manual air-setting system fitted with a pressure transducer and readout. The air-setting system was used to manually adjust the air pressure within the ear canal for each pressure condition tested. The Virtual 330 was controlled via a Macintosh CI computer.

TEST ADMINISTRATION

Subjects were tested in a sound booth at Oregon Health Sciences University. Each subject was seated comfortably in a chair throughout the testing. Test ears were examined otoscopically to ensure the canal was free of cerumen and to determine canal size for proper probe tip selection.

A probe tip was inserted into the test ear and an air-tight seal obtained. Two tones were presented simultaneously and the resulting emission was recorded at the frequency of the cubic difference distortion product

(2f1-f2). The ratio of the f2 to f1 eliciting tones were held constant at 1.21 as this has been suggested as the ratio to yield to greatest response (Franklin, McCoy, Martin, & Lonsbury-Martin, 1992; Gaskill & Brown, 1990; Roede, Harris, Probst, & Xu, 1993). The mean frequency of the f1/f2 tone pairs ranged from 500 to 8000 Hz in 1/5 octave steps. The primary tones were presented at 75 dB SPL under five pressure conditions: 200, 0, -200, -300, and -400 daPa. Ear canal pressures were set manually prior to each trace.

CHAPTER IV

RESULTS

Raw data were analyzed using the Minitab Statistical Program. The primary tones ranged from 500 to 8000 Hz in 1/5 octave steps resulting in 25 eliciting tone pairs. For the purpose of this study, specific responses included in the data analysis were obtained using low frequency ($f1=.45$ kHz, $f2=.55$ kHz; mean=500 Hz), middle frequency ($f1=1.82$ kHz, $f2=2.21$ kHz; mean=2000 Hz), and high frequency ($f1=7.28$ kHz, $f2=8.81$ kHz; mean=8000 Hz) tone pairs at each of the five pressure conditions: 200, 0, -200, -300, and -400 daPa. This resulted in 15 data points per subject (300 data points total).

LOW FREQUENCY TONE PAIR

Figure 2 displays the mean and standard deviation of the data obtained for the low frequency ($\bar{X}$=500 Hz) tone pair. The highest DPOAE amplitude was measured at 0 daPa (mean=13.25 dB SPL, standard deviation=6.22). Changes in ear canal pressure from ambient pressure resulted in decreased emission amplitude. The lowest DPOAE amplitude was measured at 200 daPa (mean=4.45 dB SPL, s.d.=8.30). The remaining three pressure conditions yielded decreased DPOAE amplitude as compared to the measurement at 0 daPa (-200 daPa: mean=4.50 dB SPL, s.d.=9.05; -300 daPa: mean=6.35 dB SPL, s.d.=8.798; -400 daPa: mean=5.25 dB SPL, s.d.=7.806).

Analysis of variance with amplitude as the dependent variable and pressure as the independent variable was computed. The results shown in Table 1 reveal a significant main effect across the pressure variable. Post-hoc analysis using Tukey's pairwise comparisons revealed significant differences between the +200 daPa and 0 daPa conditions, the -200 daPa and 0 daPa conditions, and the -400 daPa and 0 daPa conditions (see Table 2). No other significant differences among pressures were revealed.

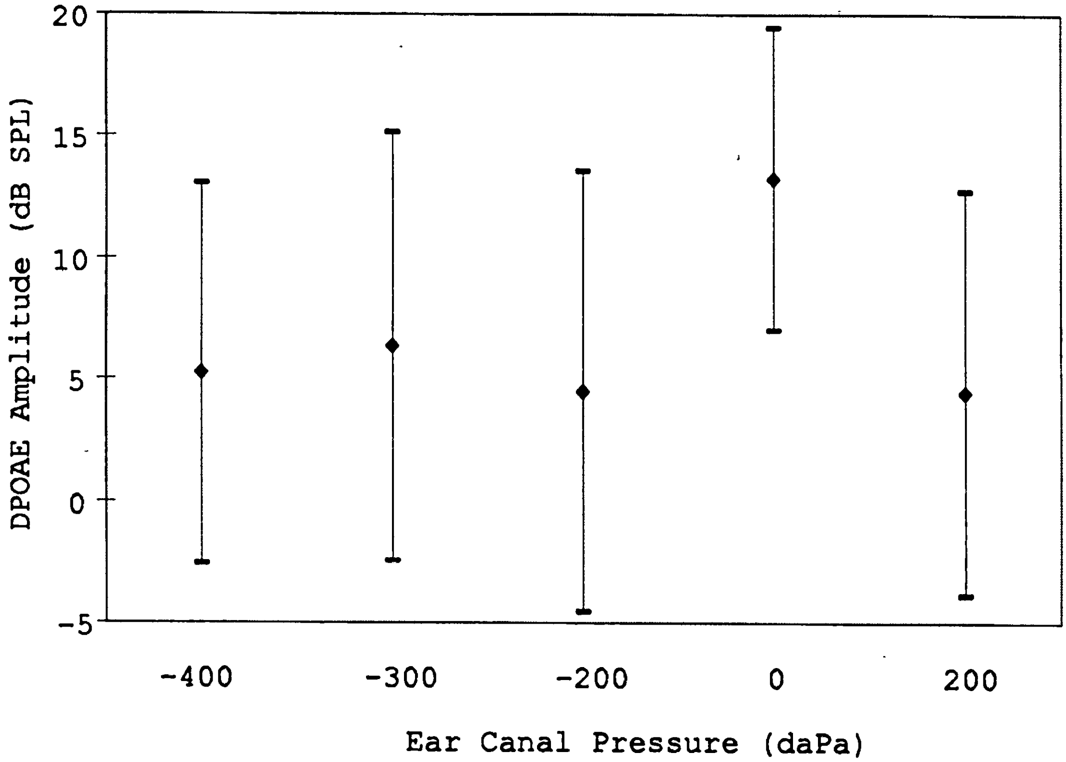

Figure 2. Means and standard deviations for the low frequency (500 Hz) tone pair.

Table 1

Anova Table for Emissions Recorded with the Low Frequency (500 Hz) Tone Pair

Source	df	SS	MS	F	p
Pressure	4.0	1100.2	275.1	4.2	0.004
Error	95.0	6232.0	65.6		
Total	99.0	7332.2			

Table 2

Tukey's Pairwise Comparisons for the Low Frequency (500 Hz) Tone Pair

	-400	-300	-200	0
-300	-8.218 6.018			
-200	-6.368 7.868	-5.268 8.968		
0	-15.118* -0.882	-14.018 0.218	-15.868* -1.632	
200	-6.318 7.918	-5.218 9.018	-7.068 7.168	1.682* 15.918

*p<.05.

MIDDLE FREQUENCY TONE PAIR

Figure 3 displays the mean and standard deviation of the data obtained for the middle frequency ($\overline{X}$=2000 Hz) tone pair. The highest DPOAE amplitude was measured at 0 daPa (mean=7.00 dB SPL, s.d.=4.34). The lowest DPOAE amplitude was measured at +200 daPa (mean=-.55 dB SPL, s.d.=8.90). The remaining pressure conditions yielded lower DPOAE amplitude as compared to the 0 daPa condition (-200 daPa: mean=4.00 dB SPL, s.d.=6.245; -300 daPa: mean=3.50 dB SPL, standard deviation=8.75; -400 daPa: mean=.05 dB SPL, s.d.=11.180).

Analysis of variance with amplitude as the dependent variable and pressure as the independent variable was computed. As seen with the low frequency tone pair, this tone pair also revealed a significant main effect for the pressure variable (see Table 3). Post-hoc analysis using Tukey's pairwise comparisons revealed significant differences between the +200 daPa and 0 daPa conditions and the -400 daPa and 0 daPa conditions (see Table 4). No other significant differences among pressures were revealed.

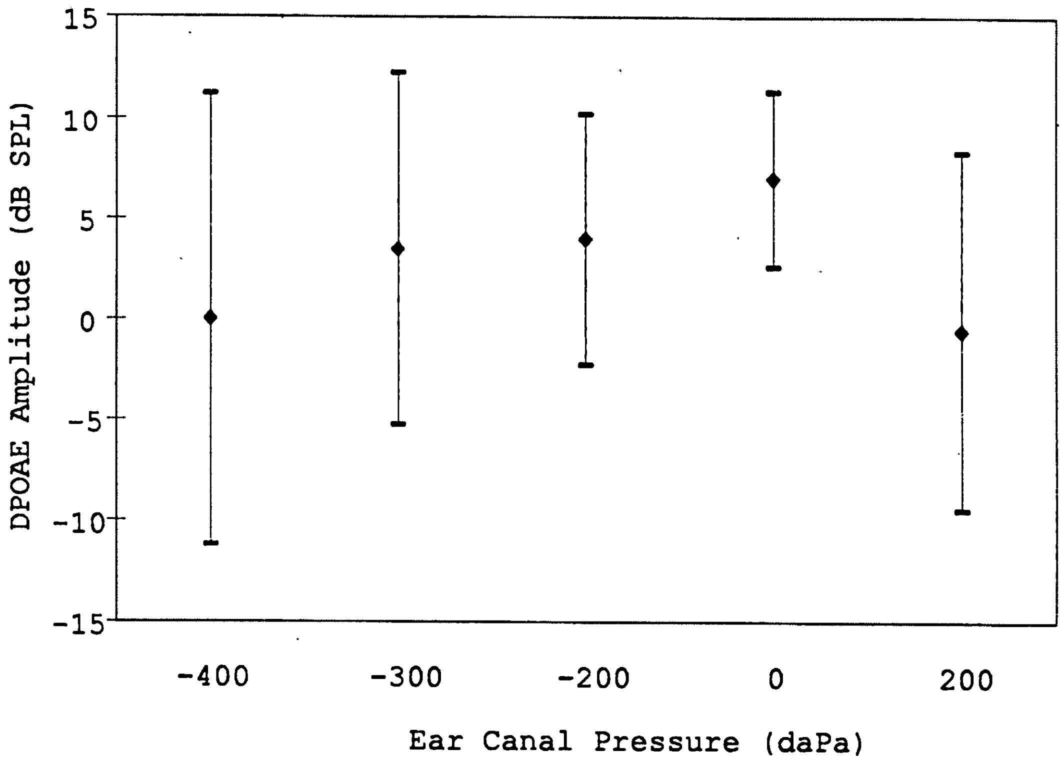

Figure 3. Means and standard deviations for the middle frequency (2000 Hz) tone pair.

Table 3

<u>Anova Table for Emissions Recorded with the Middle Frequency (2000 Hz) Tone Pair</u>

Source	df	SS	MS	F	p
Pressure	4.0	767.1	191.8	2.8	0.029
Error	95.0	6435.9	67.7		
Total	99.0	7203.0			

Table 4

Tukey's Pairwise Comparisons for the Middle Frequency (2000 Hz) Tone Pair

	-400	-300	-200	0
-300	-8.617 1.717			
-200	-9.117 1.217	-5.667 4.667		
0	-12.117* -1.783	-8.667 1.667	-8.167 2.167	
200	-4.567 5.767	-1.117 9.217	-0.617 9.717	2.383* 12.717

*p<.05.

HIGH FREQUENCY TONE PAIR

Figure 4 displays the mean and standard deviation of the data obtained for the high frequency ($\bar{X}$=8000 Hz) tone pair. Minimal differences in DPOAE amplitude were noted as ear canal pressure deviated from ambient pressure. At 0 daPa, the mean amplitude was -3.25 dB SPL with a standard deviation of 7.144. At 200 daPa, the mean DPOAE amplitude was -4.20 dB SPL with a standard deviation of 9.457. At -200 daPa, the mean amplitude was -3.20 dB SPL with a standard deviation of 5.681. At -300 daPa, the mean amplitude was -4.85 dB SPL with a standard deviation of 6.167. At -400 daPa, the mean amplitude was -6.70 dB SPL with a standard deviation of 9.820. Analysis of variance was computed (see Table 5). No significant effects were noted across the pressure variable.

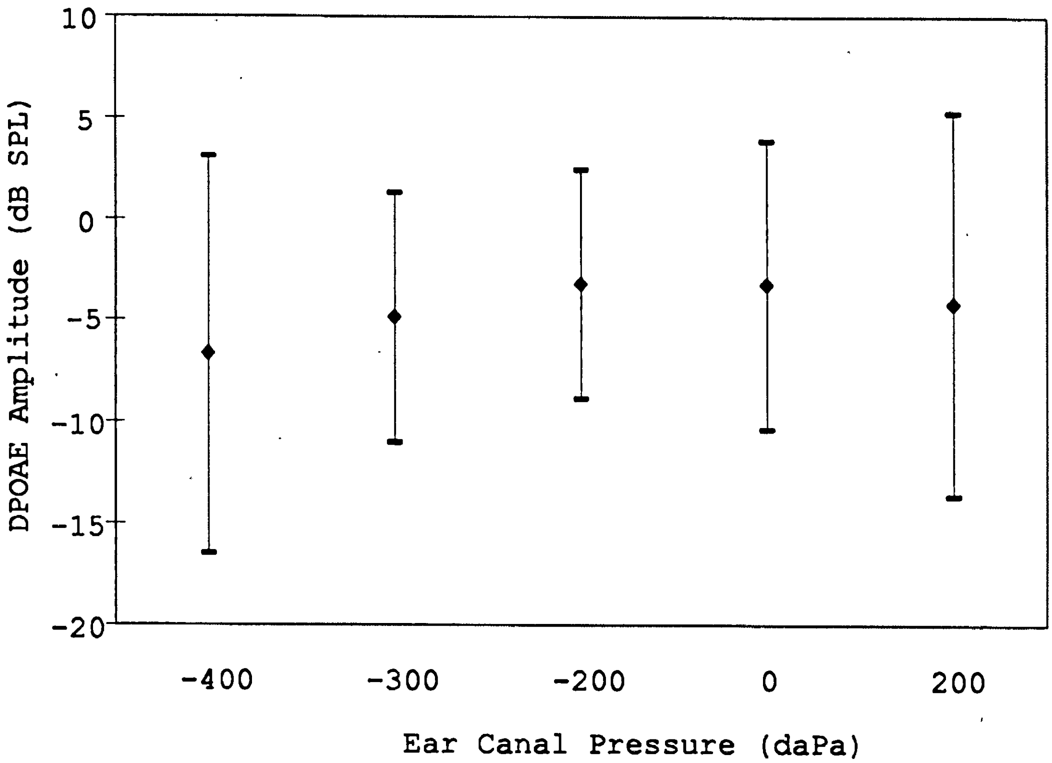

Figure 4. Means and standard deviations for the high frequency (8000 Hz) tone pair.

Table 5

Anova Table for Emissions Recorded with the High Frequency (8000 Hz) Tone Pair

Source	df	SS	MS	F	p
Pressure	4.0	165.7	41.4	0.7	0.611
Error	95.0	5836.9	61.4		
Total	99.0	6002.6			

CHAPTER V

DISCUSSION

The purpose of this study was to define the relationship between middle ear impedance and DPOAE amplitude across the frequency spectrum. The results indicated that changes in ear canal pressure can effect the amplitude of DPOAEs. Alteration of ear canal pressure resulted in decreased emission amplitude. This effect was found to differ as a function of eliciting frequency with the greatest reduction in amplitude with the mean of the primaries at 500 Hz. Less variation was noted across the ear canal pressures with the higher frequency stimuli.

The results are consistent with previous findings reported regarding the effects of impedance changes on SOAEs and TEOAEs. Schloth and Zwicker (1983) found the effect of increased middle ear impedance due to changes in middle ear pressure inhibited the recording of SOAEs. Naeve, Margolis, Levine, and Fournier (1992) reported a similar effect on TEOAEs, concluding that TEOAEs are reduced by 3-6 dB as a result of both positive and negative pressure changes. Trine, Hirsch, and Margolis (1993) reported the reduction of TEOAE amplitude as a result of pressure variation to be greatest in the low frequencies.

The observed decrease in low frequency DPOAE amplitude, as ear canal pressure deviated from ambient pressure, was the expected outcome given earlier descriptions of low frequency energy transmission through a stiffness dominated system (Naeve, Margolis, Levine, & Fournier, 1992; Shanks, 1984). Deviation of ear canal pressure from ambient pressure causes the tympanic membrane and the ossicular chain to be displaced thus increasing the stiffness of the middle ear system and inhibiting transmission of low frequency energy (Trine, Hirsch, & Margolis, 1993).

OAEs allow for objective noninvasive measurement of cochlear function (Glattke & Kujawa, 1991; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993). Given the noninvasive nature, the relative ease of recording, and the objectivity of measurement, OAEs have gained recognition as a useful screening method (Glattke & Kujawa, 1991; Lonsbury-Martin & Martin, 1990). DPOAEs are suggested as a means of gaining frequency specific information on auditory function (Chery-Croze, Moulin, & Collet, 1993; Lasky, Perlman, & Hecox, 1992; Lonsbury-Martin & Martin, 1990).

It is evident in the examination of the data collected for this study that the middle ear system does influence the propagation of emissions. It is therefore critical that middle ear function be fully documented prior to the measurement of DPOAEs. The implication of the findings is that DPOAE measurements could falsely indicate the presence of cochlear hearing loss if middle ear pressure variation is not adequately identified and controlled.

FURTHER RESEARCH

For this study, test ears had resting middle ear pressure of ± 15 daPa. Further research is warranted to determine if similar effects would be evident if measured in reference to peak pressure, i.e., if a test ear had abnormal middle ear pressure would the amplitude of DPOAEs be effected if pressure was equalized/recorded within 15 daPa of peak pressure? The significance of such information is obvious in light of the observation that tympanometric peak pressure can vary from ambient in a clinical population. This is particularly true when considering the pediatric age group.

The test protocol for this study included maintaining the amplitude of the eliciting stimuli while the frequency of the primary tones varied. An expansion of this research could be conducted in which the amplitude of the eliciting stimuli varies, thus generating a response growth or input/output function. The input/output function allows for information to be obtained regarding detection threshold, dynamic range and growth slope and may possibly allow the detection of more subtle influences on the recording of DPOAEs. The significance of the input/output function as a diagnostic tool is not well defined. However, Norton and Stover (1994) and Probst, Lonsbury-Martin, and Martin (1991) review a number of studies which suggest an expanding role for the input/output function in differentiating various auditory pathologies. As an example, Naeve, Margolis, Levine, and Fournier (1992) reported that the input/output function flattened out as ear canal pressure varied from ambient. It is possible that the input/output slope could serve as an indicator for differentiating conductive from cochlear causes of reduced DPOAE amplitude.

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