1329552

Zizz, Carol Anne

SUPPRESSION OF SPONTANEOUS OTOACOUSTIC EMISSIONS

The University of Arizona M.S. 1986

University
Microfilms
International 300 N. Zeeb Road, Ann Arbor, MI 48106

SUPPRESSION OF SPONTANEOUS OTOACOUSTIC EMISSIONS

by

Carol Anne Zizz

A Thesis Submitted to the Faculty of the

DEPARTMENT OF SPEECH AND HEARING SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 8 6

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the copyright holder.

SIGNED: Carol A. Jigg

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Theodore J. Glattke
T. J. Glattke
Professor of Speech and Hearing Sciences

November 26, 1986
Date

ACKNOWLEDGMENTS

I wish to thank the five subjects who cheerfully participated in this study, as well as those who helped in calibration of equipment, and initiation of thought provoking discussions concerning this area of acoustical research. A special thank you is extended to Dr. Ted Glattke for the many helpful suggestions and countless hours spent editing to produce this final edition.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

The literature pertaining to the suppression of Spontaneous Otoacoustic Emissions (SOAEs) and SOAE Suppression Tuning Curves (STCs) lacks information about the stability of suppression effects. The objective of this study was to refine the description of SOAE STCs by obtaining replications of STCs. Ten STCs were developed for five subjects (two STCs each). For all STCs the tuning curve tip was found to be above the SOAE frequency. The STCs were similar in shape to Frequency Tuning Curves (FTCs). The average low frequency slope was 51.91 dB/octave (SD= 9.82 dB) with an average high frequency slope of 130.11 dB/octave (SD= 35.9 dB). Wider STC width was found for STCs than has been reported from studies of Psychophysical Tuning Curves (PTCs). Good correspondence was observed between FTC widths (from animal studies) and widths of the STCs found in this investigation. The results of this study were found to be in good agreement with earlier reports of SOAE suppression.

INTRODUCTION

In 1948, Gold reported that experimental observations of cochlear mechanics were not consistent with the accepted theory regarding how the ear functioned. This conclusion caused him to object to a theory of passive cochlear oscillation in response to stimulation and to postulate a "regeneration hypothesis." He argued that active electromechanical oscillation (implying an additional supply of energy) is necessary to release a chain of events to counteract the damping effect of the viscosity of the fluid within the inner ear.

It should be possible to detect Gold's proposed electro-mechanical oscillations as an acoustical event or emission resulting from a "backwards middle ear transmission" as described by Kemp (1980). The stapes would vibrate as a result of motion of fluid within the cochlea. The displacement of the stapes would be transmitted across the ossicular chain to the tympanic membrane. This would produce pressure variations that could be detected by a sensitive microphone and amplifier arrangement. Individual case reports of tonal emissions from the ear have been reported in the literature during the past 25 years (Citron, 1969; Coles, Snashell, & Stephens, 1975; Glanville, Coles, & Sullivan, 1971; Huizing & Spoor, 1973; Loebell, 1962). Defined as objective tinnitus or spontaneous otoacoustic emissions (SOAEs), these narrowband continuous signals can be detected in the ear canals of humans in the absence of known external stimulation and may be examples of the events predicted by Gold (1948).

In 1981, the first report appeared on the prevalence of SOAEs in a sample population (Zurek, 1981). Since then, normative data have been gathered in an effort to determine the prevalence of SOAEs in the general population and the distribution of SOAEs across the acoustic spectrum. The prevalence of SOAEs in adult sample populations ranges from 38 to 47 percent of subjects (Bright & Glattke, 1984; Hammel, 1983, cited in Strickland, Burns, & Tubis, 1985; Wier, Norton, & Kincaid, 1984; Zurek 1981). Strickland, Burns, & Tubis (1985) compared the prevalence of SOAEs in the adult population, as reported by Hammel (1983) and Zurek (1981), with their observations of prevalence in two groups of children. The mean age of the two comparison groups was 9 years, 6 months (Group 1) and 30 days (Group 2). They found a prevalence (40%, Group 1; 38%, Group 2) of SOAEs among children that was similar to that reported for the adults in the Hammel (1983) (cited in Strickland, Burns, & Tubis, 1985) and Zurek (1981) studies.

Research published since 1981 has revealed a correspondence between the frequencies of SOAEs and locations of cochlear pathology (Clark, Kim, Zurek, & Bohne, 1984; Zwicker & Manley 1981) as well as areas of threshold minima (regions of increased sensitivity) illustrated by microstructure audiograms (Bright, 1985). Arguments that SOAEs are a manifestation of normal cochlear function rather than evidence of subtle cochlear pathology remain open to debate and further investigation.

Although the exact location of SOAE generation has not been identified, it is generally accepted that the origin is within the cochlea. One line of evidence in support of this premise has been established through demonstrations of suppression of SOAEs (Rabinowitz & Widin 1984; Ruggero, Rich, & Freyman, 1983; Schloth & Zwicker 1983; Zurek, 1981). Suppression, first described in detail for nerve fiber responses by Sachs & Kiang (1968) is a cochlear phenomenon. The neuron response is said to manifest suppression if the discharge rate associated with a tonal signal is reduced in the presence of a second, simultaneous tone. The amount of suppression of the response to the initial pure tone signal is dependent upon the frequency and intensity of a second or suppressor tone. The most effective suppressor frequencies are located in narrow bands near the frequency of the tonal stimulus.

Suppression is not considered to be a form of cochlear or auditory nerve inhibition. Kiang (1965) tested the hypothesis of auditory nerve inhibition and reported that the suppression phenomenon continued to operate subsequent to complete lesion of the olivocochlear bundle (the efferent route of inhibition from the brainstem nuclei to the hair cells and nerve fibers of the organ of corti). Furthermore, suppression occurs with negligible latency between the onset of the suppressor and reduction of the response. There is insufficient time for transmission across a synapse to occur, even if evidence of cochlear synapses could be anatomically established.

An acoustic signal can be cancelled by a competing signal of appropriate characteristics. The relationship between a suppressor signal and a SOAE cannot, however, be explained on the basis of simple cancellation effects. In the presence of a suppressor signal, reduction of SOAE SPL is dependent upon frequency and intensity characteristics of the suppressor. The relationships between SOAE characteristics and suppressor frequencies and intensities are complex and are characteristics of other inner ear phenomena. For example, consider the usual pattern of tuning in the cochlea. The Frequency tuning curve (FTC) is a representation of the stimulus frequency-intensity combinations that will elicit a response from a single auditory neuron. The tip, or minimum, of the tuning curve occurs at the frequency that requires the least intensity of stimulation to increase the neural discharge rate above the spontaneous rate (Kiang, 1965). This is referred to as the characteristic frequency (CF) of the neuron. When plotted on logarithmic coordinates, the high frequency side of the FTC is very steep, while the low frequency side is shallower and displays a "tail" that extends far into the low-frequency region. The tip of the FTC of a neuron may be used to estimate the place of innervation of the neuron in the cochlea. This is based on two facts: (a) the mechanical frequency resolution known to occur in the cochlea; and (b) the observation that the vast majority of afferent neurons terminate on single inner hair cells.

When the level of the suppressor tone necessary to cause a specific amount of SOAE suppression is plotted as a function of the suppressor frequency, the resulting curve is called a Suppression Tuning Curve (STC), and it resembles a standard FTC. Some of the recent publications concerning SOAEs have reported SOAE suppression curves among their results (Rabinowitz & Widin 1984; Ruggero, Rich, & Freyman, 1983; Schloth & Zwicker, 1983; Zurek, 1981). Zurek (1981) reported that the suppression effect of the external tone is frequency specific, particularly in the tip region where external tones close in frequency to the SOAE are very effective suppressors. The lower frequency tones are less effective than those in close proximity to the SOAE, and there is a rapid loss of effectiveness as the frequency of the suppressor tone is increased above the STC tip. Schloth and Zwicker (1983) report that the suppression tuning curve is relatively flat for much of the frequency region below the SOAE (about 15 dB/octave), gradually steepens in a downward slope as it draws nearer to the SOAE frequency, reaches a minimum a little above the emission frequency and rises rapidly for frequencies above the STC tip. The slope of the curve above the emission frequency has been reported to be as much as 200 dB/octave. Ruggero, Rich, and Freyman (1983) described several aspects of the suppression curve that they felt were important: (a) the lowest levels of stimuli (27 and 25 dB SPL at 8.4 and 9.7 kHz) that were effective as suppressors were higher than the level of the SOAE by 9 to 11 dB; (b) several irregularities existed in the region of the minimum of the curve; (c) the most effective frequencies for suppression were 900 to 2000 Hz higher than the SOAE; and (d) the suppression curve was substantially wider than single-fiber or

Psychophysical Tuning Curves (PTCs). In 1984 Rabinowitz and Widin reported frequency-intensity functions of the tonal suppressor that were in good agreement with the earlier findings of Zurek (1981) and Schloth and Zwicker (1983). The slopes of the STCs reported by Rabinowitz & Widin (1984) were equal in steepness for suppressor frequencies above and below the region of the SOAE.

Although recent publications have reported suppression tuning curves for SOAEs, there has been no consistent application of methods or measurement criteria. Significant shifting of the frequency of the SOAE was reported to occur in several of the studies (Rabinowitz & Widin, 1984; Ruggero et al., 1983; Zurek 1981). Shifting of the frequency of an SOAE during suppression would be expected to result in an increase in the range of frequencies that are effective in producing suppression. The results would suggest poor frequency resolution in the region of the SOAE. Ruggero et al., (1983) acknowledge that their results were probably compromised by the shifting of the SOAE frequency in the presence of a suppression tone. They reported a drift of the SOAE frequency in the range of 7506-7533 Hz (mean = 7529), with a frequency drift of approximately 10 Hz during 1/2 hour measurements occurring commonly. In contrast, Zurek's (1981) STC findings were in good agreement with PTCs obtained in the same frequency region. This close correlation between the STC and PTC reported by Zurek (1981) suggests that minimal frequency shifting occurred during suppression of the SOAE. If frequency shifting of the SOAE had occurred, irregularities in the minimum of the STC, as reported by Ruggero et al., (1983) would have been expected. Rabinowitz & Widin (1984) controlled for frequency shifting by "always selecting the peak in the spectrum near the ambient SOAE frequency (rather than the magnitude at a fixed frequency)" (p. 1715). Wilson & Sutton (1981) report that this method of measurement will not cause changes in measured SOAE levels and should result in an accurate estimate of the suppression of the SOAE. A critical evaluation of STCs must include consideration of the extent of frequency shifting of the SOAE included in the development of reported STCs.

In previous research the criteria for suppression were established in terms of reduction of the amplitude of the SOAEs and ranged from 1 to 20 dB across studies. Ruggero et al., (1983) reported SOAE intensity fluctuations that were associated with suppression and which ranged from 8 to 21 dB SPL with a mean of 16 dB SPL. In addition, the studies were often of a single subject design with replication being clearly reported in the Zurek (1981) study only. A comparison of SOAE suppression curves across more than one subject with similar criteria and evidence of SOAE stability, in terms of amplitude and frequency, has yet to be presented. The result of this is a lack of definitive evidence regarding the characteristics of SOAE suppression curves.

The purpose of this study was to refine the description of suppression characteristics of SOAEs by reducing or eliminating the frequency shifting and controlling for the variability of SOAE amplitude that has been reported in earlier studies. In this way a basis for the estimation of normal SOAE STC stability may be provided and may lend support for a better understanding of cochlear mechanics.

METHOD AND PROCEDURE

Thirty-two individuals were screened as potential subjects. The first five individuals who met all selection criteria were recruited to participate in the study. Compensation ($4.00/hour) was provided for those individuals who elected to participate.

Subjects were included in the study based on the following criteria: (1) age 18 or older; (2) otoscopic observation revealed clear and unobstructed view of a healthy tympanic membrane; (3) normal auditory sensitivity (thresholds of better than 15 dB HL) across conventional audiometric test frequencies (250-8000 Hz); and (4) the presence of spontaneous otoacoustic emissions with stable emission amplitude (standard deviation of 1.5 dB or less) and less than 5 Hz change in frequency over a one hour period.

All potential subjects received a conventional pure tone audiometric evaluation to determine auditory sensitivity in the range of 250 to 8000 Hz. If the criterion of normal auditory sensitivity (threshold better than 15 dB across the frequency range) was met, the subject was then seated in a sound-treated booth. A small insert probee coupled to a Knowles EA-1842 miniature microphone and earphone was placed into one ear of the subject. A 4 cm length of teflon tubing with an inner diameter of 1.35 mm attached the microphone to the probe assembly. The microphone output was led to a low-noise amplifier and high pass filter system that attenuated the noise levels below 400 Hz by 30 dB per octave. The output of the amplifier-filter system was coupled to a Bruel and Kjaer 2033 real time spectral analyzer, and was also monitored by an oscilloscope and an amplifier-loudspeaker (see Figure 1). Sampling and averaging of the spectrum of the sounds recorded from the subject's ear canal were then completed. This technique is identical to that used by Bright (1985) and involves examination of the frequency spectrum by adjusting the spectral analyzer to sample frequency windows of 500 Hz (a resolution of 1.25 Hz per line) from a starting point at 500 Hz and extending up to 5000 Hz. A spontaneous otoacoustic emission was defined as a narrowband spectral maximum that exceeded the noise floor by 5 microvolts. The noise floor value was typically at least 10 dB below the amplitude of the emission. Following detection of a spontaneous otoacoustic emission, variability of the emission amplitude and frequency was evaluated through the use of a repeated sampling technique. A total of 30 averaged spectra, based on means of 32 samples of noise from the subject's ear canal, contributed to each baseline measurement. Sampling results were then analyzed to determine the mean, variance, and standard deviation of the SOAE amplitude and frequency. Potential subjects whose emission amplitude changes had a standard deviation of less than or equal to 1.5 dB, and whose emission frequency changes were less than 5 Hz over a period of approximately one hour, returned at a later date for further investigation.

Suppression patterns were studied during the second and third visits. During the second and third visit low and moderate intensity

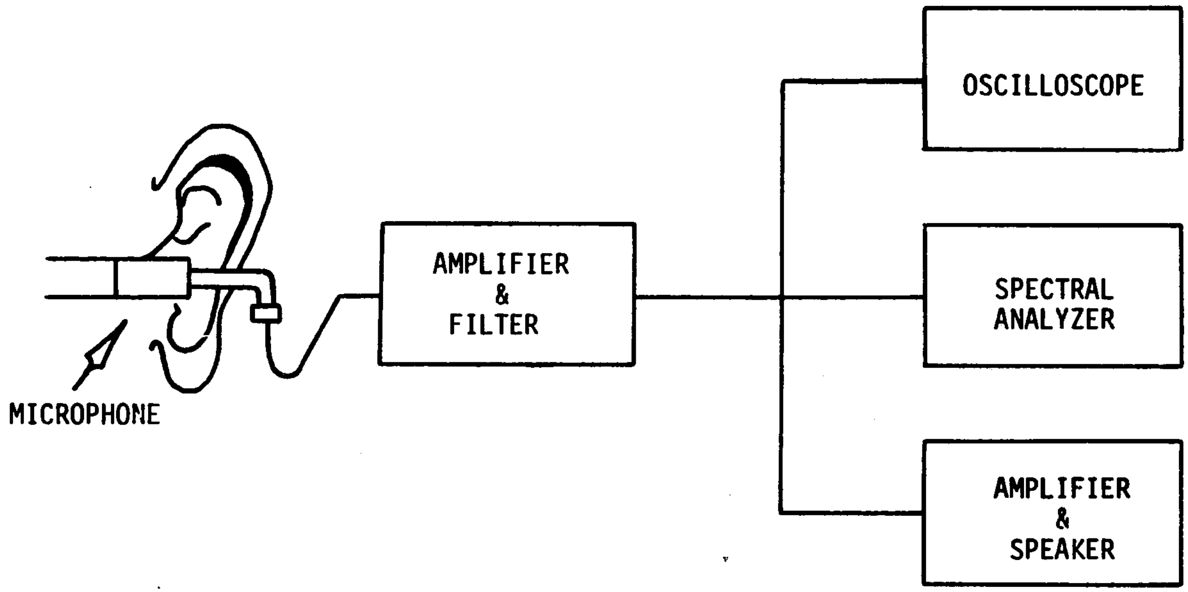

Figure 1. Schematic Illustration of Apparatus for Detecting SOAEs

external tones were generated by a function generator (Interstate High Voltage AM-FM — F46) at fixed frequency intervals (50, 40, 30, 20, 10, and 5 percent) above and below the frequency of the spontaneous emission. External signal frequencies were verified with an electronic counter (Hewlett-Packard) and visual display on the Bruel & Kjaer real time analyzer. Introduction of the external tone to the subject's ear was made via the miniature transducers coupled to the recording apparatus as described above (see Figure 2). Repeated sampling (30 means of 32 samples of noise from the subject's ear canal) of the emission using a spectral averaging technique was used to determine the amount of suppression induced by the presence of the external tone. The amplitude of the external tone was adjusted to produce a reduction of the emission by 4 dB. The SPL of the suppressor tone was limited to 70 dB SPL to insure that subjects could tolerate the stimuli. Reduction of the SOAE amplitude by 4 dB was chosen to allow for tentative comparison with previous research that has presented suppression curves with suppression criteria ranging from 3 to 10 dB (Rabinowitz & Widin, 1984; Ruggero, Rich, & Freyman, 1983; Schloth & Zwicker, 1983; Zurek, 1981). Repeated sampling (30 means of 32 samples) of the SOAE in the presence of the external suppressor tone formed the basis for determination of the mean, variance, and standard deviation of the emission sound pressure level, insuring that the 4 dB suppression criterion had been met. SPL of the SOAE was monitored before the introduction of the external tone and again after the removal of the external tone. This was done to determine if the SOAE

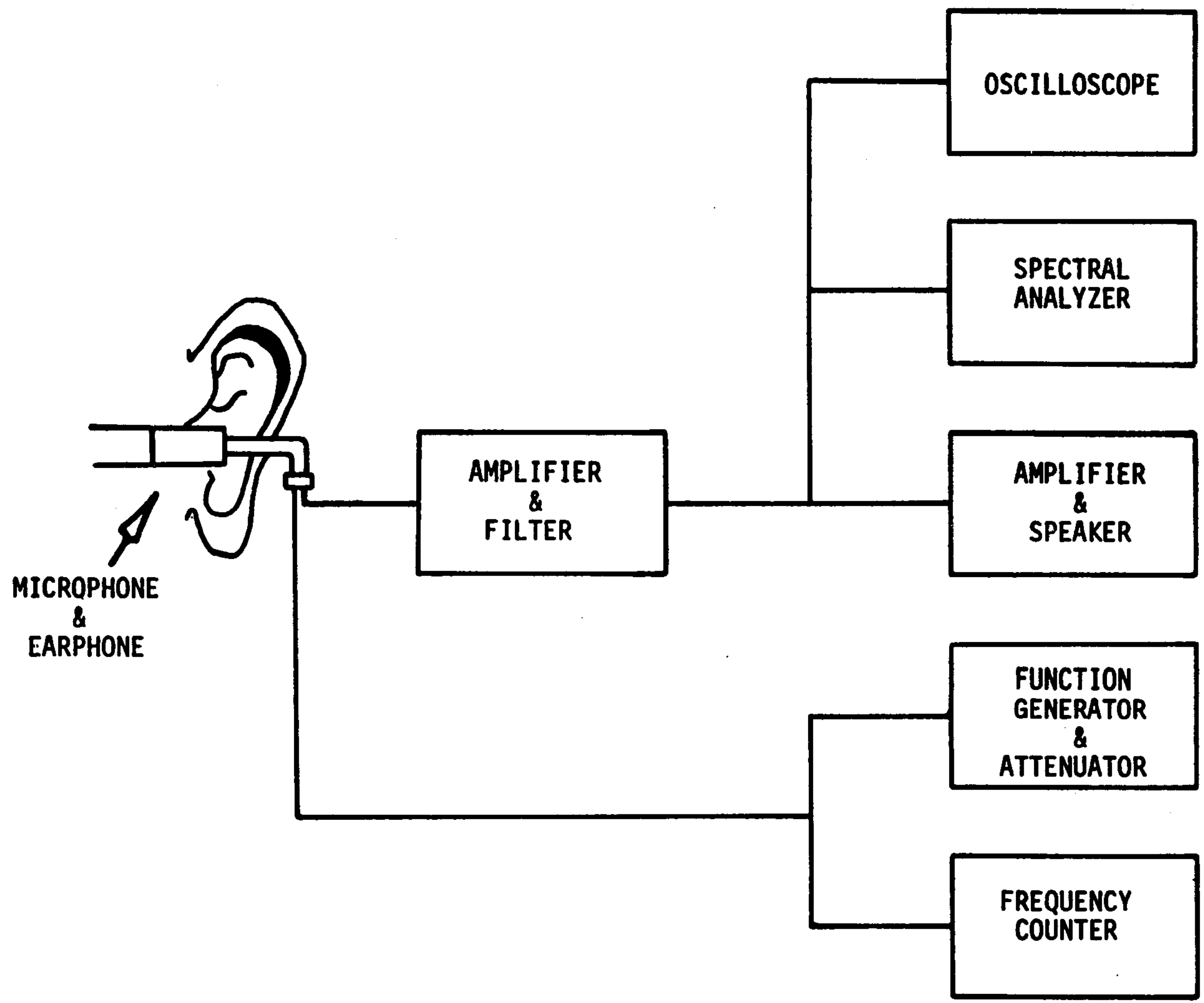

Figure 2. Schematic Illustration of Apparatus for Suppressing SOAEs

returned to its pre-suppression SPL subsequent to the suppression procedure. The entire procedure required approximately 2 and 1/2 hours. Subjects were given a 15 minute break approximately 1 and 1/2 hours following introduction of the first external suppressor tone. This was done to reduce subject fatigue, which was accompanied by an increase in low frequency noise. Based on previous investigations of SOAE suppression (Rabinowitz & Widin, 1984; Schloth & Zwicker, 1983; Zurek, 1981) a STC similar to that illustrated in Figure 3 was the expected result.

Suppression tuning curves, illustrating the various frequency intensity combinations of external tones required to produce a 4 dB reduction of the emission were developed from the raw data. The automated curve fitting procedure for analysis of Psychophysical Tuning Curves (PTCs), as described by Stelmachowicz and Jesteadt (1984), was modified in regard to STCs and used as a guideline for the analysis of the SOAE STCs. High and low frequency STC slopes (in terms of dB/octave), STC tip to tail differences, when a tail was readily identifiable, and STC Q10s (an estimate of the width of the STC tip) were identified. Q10 was estimated by dividing the SOAE frequency by the STC bandwidth at 10 dB above the STC tip. The low frequency point 10 dB above the STC tip was determined by calculating the slope of the tip to tail difference, while the high frequency point 10 dB above the STC tip was determined by using the STC high frequency slope. High and low frequency slopes were computed by determination of the SPL of the suppressor (dB re: 20 microPascals) at 10% and again at 20% above (for

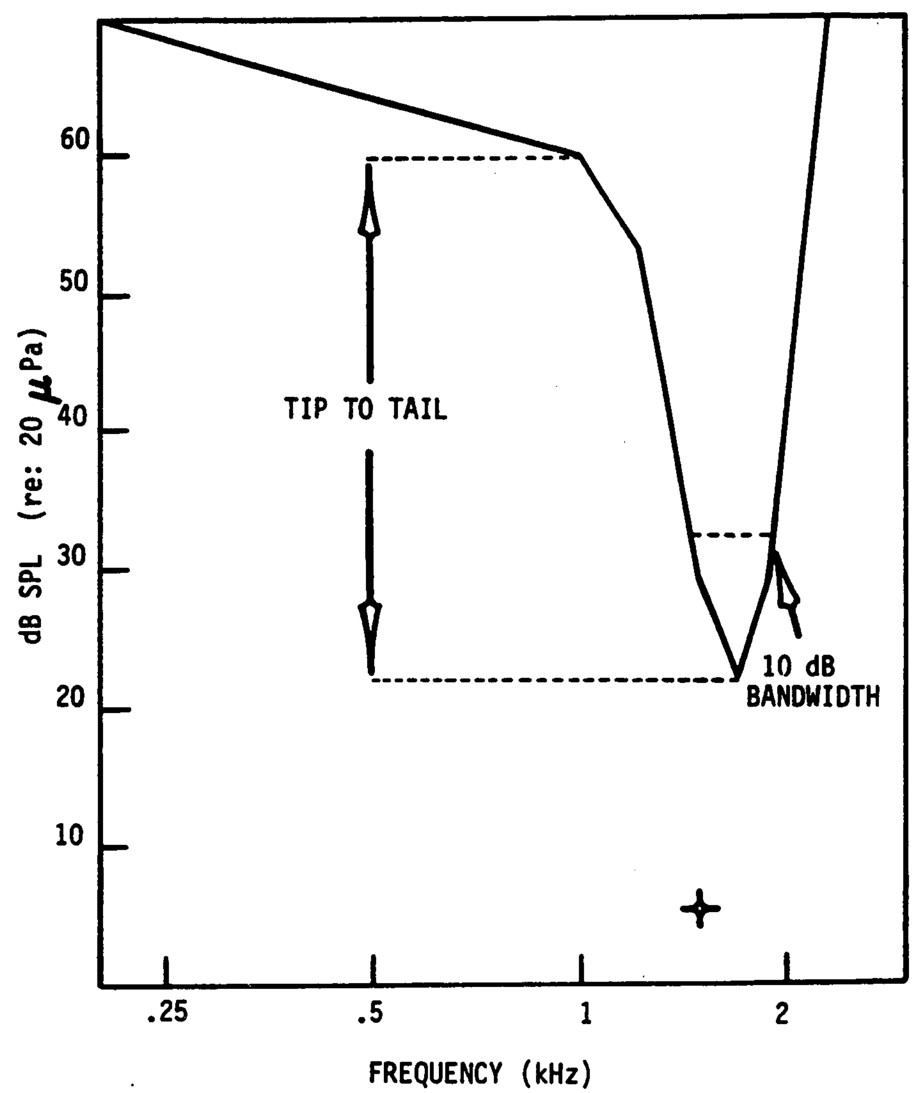

Figure 3. Idealized Illustration of a STC (Based on Suppression Findings of Rabinowitz & Widin, 1984; Schloth & Zwicker, 1983; Zurek, 1981).

✦ = SOAE Frequency at 1500 Hz.

high frequency slope) and below (for low frequency slope) the SOAE frequency and extrapolating from those data points to a full octave above or below the SOAE frequency. Tip to tail differences were defined as the difference in dB between the level of the suppressor at the STC tip and the level of the suppressor at the intersection of the two low frequency segments of the STC. These data were then compared with psychophysical and electrophysiological data already in the literature.

RESULTS

SOAEs were found to occur in 13 of the 32 individuals who were screened, resulting in a prevalence of 41 percent, and occurred in the right ear with a greater prevalence than in the left ear. SOAEs occurred in the right ear in 54% (7 of 13) of the subjects who had emissions, and in the left ear of 31% (4 of 13) of those subjects. Bilateral SOAEs occurred in 15% (2 of 13) of the subjects with emissions. Multiple emissions in one or both ears occurred for 23% (3 of 13) of the individuals. SOAE SPL ranged from -10.6 to 18.87 dB SPL and SOAEs occurred in the frequency range of 662 to 3407 Hz. Eight of the 13 subjects who exhibited SOAEs were eliminated from the study due to fluctuation of SOAE SPL, frequency shifting that exceeded the proposed criteria levels, or inability to record the SOAE reliably during suppression procedures.

All five subjects recruited to participate in the suppression study were women who ranged in age from 23 to 38 years. In all five cases the SOAE which best met selection criteria was exhibited in the right ear. Individual mean amplitudes of SOAEs ranged from 9.17 to 18.97 dB SPL, with individual standard deviations in SOAE SPL during suppression ranging from 0.55 to 1.30 dB. None of the SOAEs targeted for suppression exhibited frequency shifting during suppression procedures. Two subjects, AS and SE, exhibited multiple emissions in the ear targeted for suppression. For a detailed description of the target SOAEs of the five subjects, see Table 1.

Data obtained during suppression of the five target SOAEs were used to develop ten SOAE STCs (2 STCs per subject). The mean amount of suppression across subjects was 4.02 dB with a range of 3.94 to 4.09 dB. In general, tones below the frequency of the emission, with the exception of the tip region, were found to be much more effective than high frequency tones in suppression of the emission. As reported in earlier SOAE suppression studies, the 10 STCs from this study exhibit a gradual slope on the low frequency side of the STC while the high frequency slope is much steeper. The average low frequency slope (N = 10) was 51.91 dB/octave (range = 41.82 - 66.82 dB/octave) while the average high frequency slope (N = 10) was 130.11 dB/octave (range = 96.92 - 209.68 dB/octave). The external tone that required the least SPL to cause 4 dB of reduction of the SOAE and subsequently resulted in forming the STC tip was found to be 5% above the SOAE for all ten STCs. The reader is reminded that frequencies sampled to determine the general shape of the SOAE STC were fixed at 50, 40, 30, 20, 10, and 5 percent below the SOAE and 5, 10, 20, 30, and 40 percent above the SOAE. Therefore, the precise location of the STC tip could not be located by this procedure, but rather was inferred from the data that were obtained. It can be stated, however, that the most effective external suppression tone is located above the SOAE and very close in frequency (within 0 - 10%) to the respective SOAE. All ten STCs are characterized by the V-shape associated with tuning curves and

Table 1. Description of Subject SOAEs

Subject	Target Emission	SOAE Amplitude During Session #1	SOAE Amplitude During Session #2	Results from Session #1 Combined with Session #2
PA	1112.5 Hz	M= 10.08 dB SPL	M= 8.26 dB SPL	M= 9.17 dB SPL
		SD= 0.97 dB	SD= 0.87 dB	SD= 1.30 dB
LW	1225.0 Hz	M= 12.04 dB SPL	M= 14.15 dB SPL	M= 13.10 dB SPL
		SD= 0.52 dB	SD= 0.30 dB	SD= 1.14 dB
AS	1400.0 Hz	M= 12.85 dB SPL	M= 12.40 dB SPL	M= 12.63 dB SPL
		SD= 0.53 dB	SD= 0.88 dB	SD= 0.76 dB
AM	1400.0 Hz	M= 16.06 dB SPL	M= 14.84 dB SPL	M= 15.45 dB SPL
		SD= 0.81 dB	SD= 0.63 dB	SD= 0.95 dB
SE	1650.0 Hz	M= 19.47 dB SPL	M= 18.46 dB SPL	M= 18.97 dB SPL
		SD= 0.25 dB	SD= 0.16 dB	SD= 0.55 dB SPL

frequency specificity (see Figures 4-8). The STCs obtained from one subject, (see Figure 7) exhibited a V-shaped relative minimum in addition to the STC tip. The irregularity was located along the high frequency portion of the curve at 30% above the respective SOAE in the STC of subject AM. Zurek (1981) reports a single case of an unexpected, and as yet, unexplained "...downward dip in the..." STC "...curve at frequencies about 35% higher than the respective..." SOAE. By chance, another subject, AS (see Figure 6), presented a SOAE at 1400 Hz which was subsequently used to develop a STC. AS presented no observable SOAEs in addition to the one at 1400 Hz (also in the RE) and the subsequent STC revealed no nonmonotonicity in high or low frequency slope.

The method for analysis of high frequency slope as described in the previous section (Methods and Procedures) was followed for all but one subject's STCs. Suppression of the SOAE at frequencies greater than 10% above subject LW's SOAE was not measured because it was necessary to introduce a suppressor tone in excess of the 70 dB SPL limit described in the methods and procedure section. Therefore, LW's high frequency STC slopes were estimated from the data points located at frequencies 5% and 10% above the SOAE. For two of the five subjects, AM and SE, it was possible to suppress the emission without exceeding the 70 dB SPL limit when the suppressor frequency was 40% (approximately 1/2 octave) above the emission frequency. These two subjects also exhibited multiple SOAEs in the test ear, which may have influenced the shape of the STC by enhancing the suppressive effect of

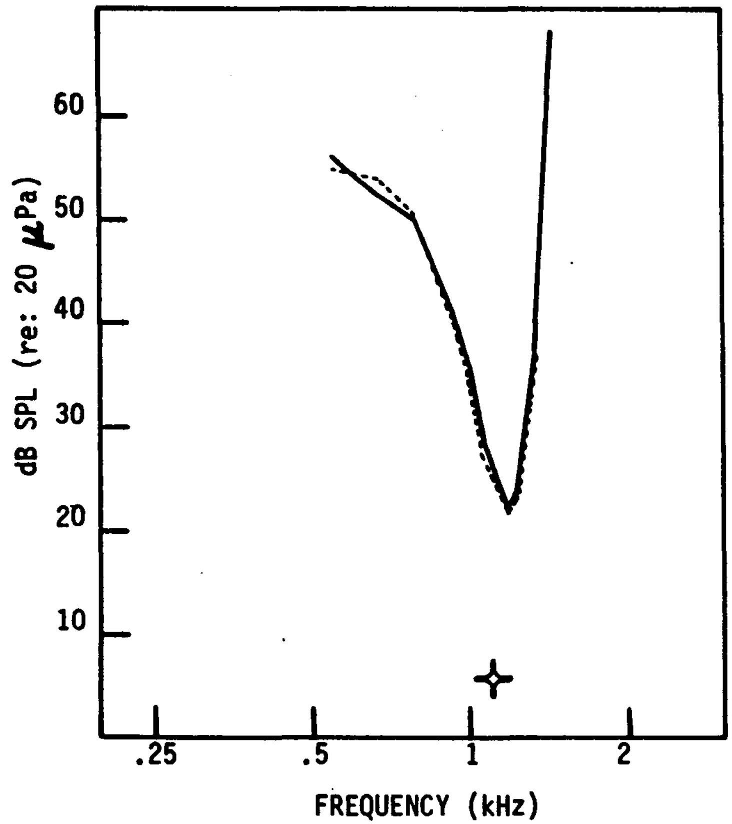

Figure 4. STC From Subject PA

✧ = SOAE at 1112.5 Hz
——— = STC #1
------- = STC #2

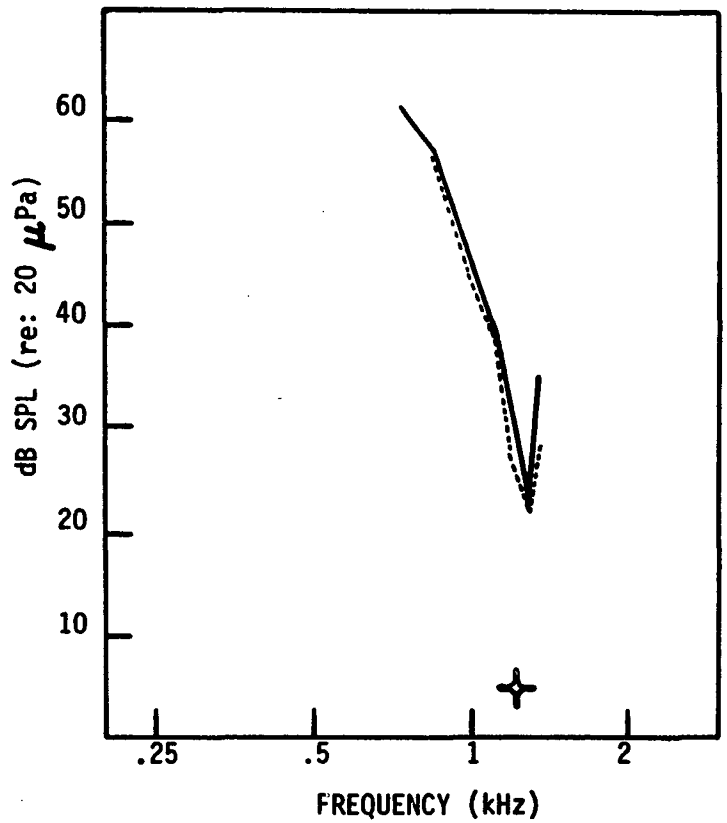

Figure 5. STC From Subject LW

✧ = SOAE at 1225 Hz
——— = STC #1
------- = STC #2

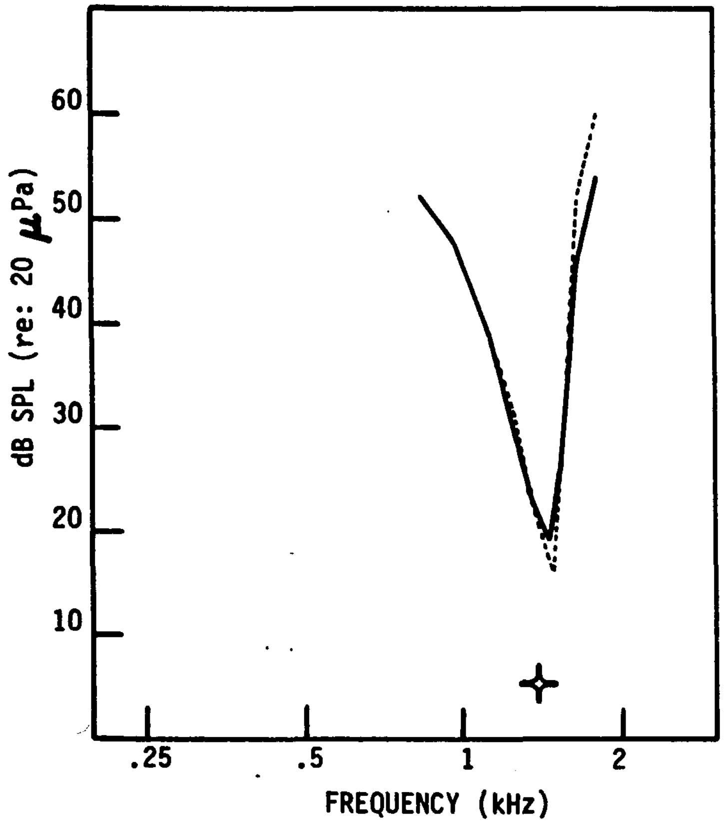

Figure 6. STC From Subject AS

 = SOAE at 1400 Hz
——— = STC #1
------- = STC #2

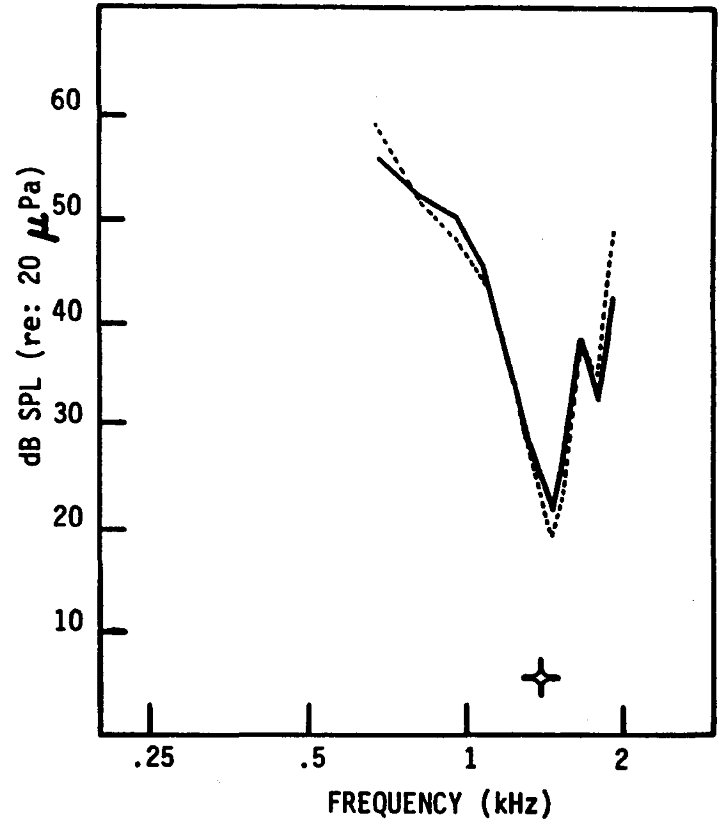

Figure 7. STC From Subject AM

 = SOAE at 1400 Hz
——— = STC #1
------- = STC #2

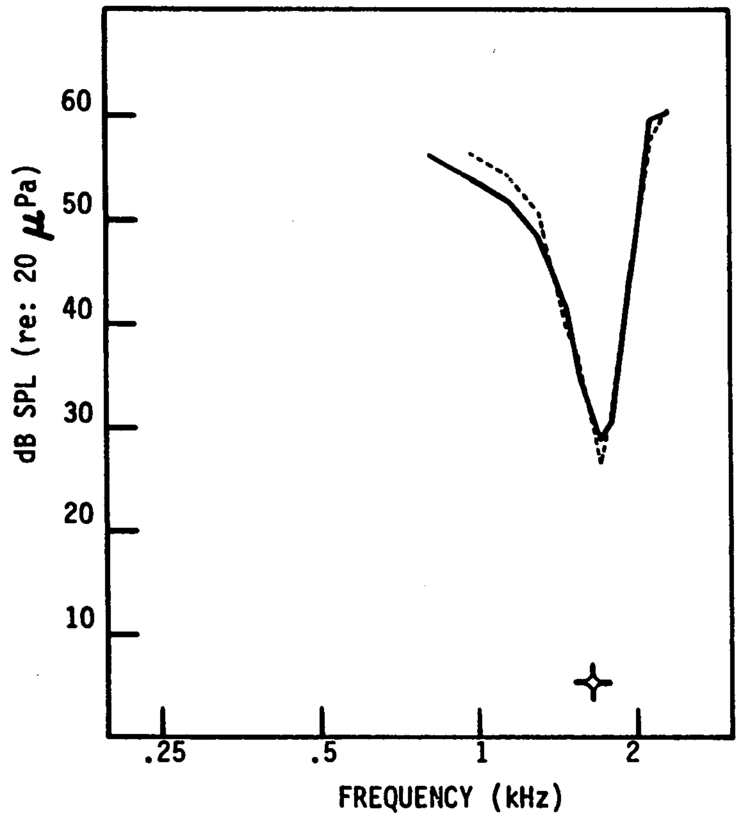

Figure 8. STC From Subject SE

= SOAE at 1650 Hz
——— = STC #1
------- = STC #2

the external tone. For the remaining two subjects, PA and AS, SPL limits of the test protocol (70 dB SPL) for suppression were reached at frequencies below the 40% data point.

Tip to tail differences ranged from 19.78 to 33.39 dB with a mean (N=10) of 28.36 dB. The STC tail was readily identifiable in the STC of only one subject, PA (see Figure 4). Therefore, the data point at a frequency 20% (SE) or 30% (PA, LW, AS, and AM) below the STC tip, as indicated by the general shape of at least one of the subject's STCs, was used to estimate the STC tail. The mean of the width of the STCs, determined by Q10 values and averaged across all subjects, was 4.95, (range = 4.07 - 6.11). The mean (N=10) and standard deviation of high and low frequency slope, tip to tail difference and Q10 values are summarized in Table 2.

Replication of the STCs for all subjects appears good. The mean difference of the SPL of the STC tip was 1.95 dB (range = .76 - 3.0) when results from trial one were compared with those from trial two for all subjects. In addition, the general shape of the STCs was retained between test sessions. High frequency slopes (N=10) reveal a mean difference of 32.82 dB/octave (range = 5.92 - 72.06; SD= 23.79) when the results from trial one were compared with the results from trial two. This finding suggests greater variability for high frequency slopes than for low frequency slopes (N=10) which reveal a mean difference of 14.15 dB/octave (range = 8.11 - 23.36; SD= 5.08). Tip to tail differences were very reliable between sessions and showed minimal variability. A comparison of tip to tail differences between trial one

Table 2. Analysis of Data From STCs

High Frequency Slope (dB/octave)	Low Frequency Slope (dB/octave)	Tip to Tail Difference (dB)	Q10
M= 130.11	M= 51.91	M= 28.36	M= 4.95
SD= 35.90	SD= 9.82	SD= 3.88	SD= 0.60

and trial two (N=10) revealed a mean difference of 2.0 dB (range = .02 - 8.07; SD = 3.07) with subject SE showing the greatest variability (individual SD = 4.04). Q10 values were reliable from session to session with a mean difference across subjects of .63 (range = .16 - 1.09; SD = .38). Individual STC results can be seen in Table 3.

Table 3. Suppression Tuning Curve (STC) Results.

Subject	Session	Low Frequency Slope	High Frequency Slope	Tip to Tail Difference	Q10
PA	1	43.71 dB/octave	122.24 dB/octave	27.23 dB	4.18
	2	51.82 dB/octave	97.76 dB/octave	28.55 dB	4.02
LW	1	47.87 dB/octave	169.85 dB/octave	33.39 dB	6.11
	2	36.63 dB/octave	97.79 dB/octave	32.98 dB	5.02
AS	1	62.47 dB/octave	163.20 dB/octave	28.56 dB	5.23
	2	49.12 dB/octave	209.68 dB/octave	28.72 dB	6.03
AM	1	67.06 dB/octave	102.74 dB/octave	28.74 dB	4.45
	2	52.65 dB/octave	117.92 dB/octave	28.72 dB	4.66
SE	1	42.82 dB/octave	114.08 dB/octave	19.78 dB	4.44
	2	66.18 dB/octave	108.16 dB/octave	27.85 dB	5.33

DISCUSSION AND CONCLUSION

The data revealed STCs similar in general shape to those reported by other authors (Rabinowitz & Widin, 1984; Schloth & Zwicker 1983; and Zurek, 1981). Low frequency suppressor tones were found to be more effective, with exception of the tip region, than high frequency suppressor tones. Low- and high-frequency slopes were similar to those reported by Rabinowitz & Widin, 1984. They report average low- and high-frequency slopes of 91 and 234 dB/octave respectively (a ratio of 1:2.6). The low- to high-frequency slope ratio found for the five STCs included in this study (low-frequency 51.91 db/octave; high-frequency 130.11 dB/octave) is approximately the same (ratio = 1:2.5).

In good agreement with the three studies cited (Rabinowitz & Widin, 1984; Schloth & Zwicker, 1983; and Zurek, 1981) the STC tip was located at the test frequency just above the SOAE (within 0 - 10%) in all cases. The V-shaped illustration of STCs with the tuning curve tip in close proximity to the target SOAE is reminiscent of FTCs and PTCs, and illustrates SOAE frequency specificity.

Stemacholwicz and Jesteadt (1983) report a mean 2000 Hz PTC Q10 of 9.3. Three earlier investigations of mean 2000 Hz PTC measures (Weber, Johnson-Davies, & Patterson, 1980; O'Loughlin & Moore, 1981; Hoekstra & Ritsma, 1977) report a range of PTC Q10 of 7.1 to 10.6 (cited in Stemacholwicz & Jesteadt, 1983). Average Q10 values for the

STCs included in this study range from 4.02 to 6.11 (mean = 4.95). Q10s obtained from the five subject's STCs of this study were smaller (indicating a wider tuning curve) than expected for PTCs. Comparison of STC Q10s with the Q10 values of FTCs was accomplished by using the findings of Kiang, Watanabe, Thomas, and Clark (1965). Although they do not report a mean FTC Q10 value, they do report a FTC Q10 range of approximately 3.0 to 7.0 at a CF of 2000 Hz. Furthermore, Kiang, et al., (1965) report that Q10 values for CF units at 2000 Hz and below are very similar. This suggests good agreement between the STC Q10 findings from this investigation and the FTC Q10 findings reported from the animal studies of Kiang, et al., (1965).

As referred to earlier, an irregularity was observed in the high frequency slope of subject AM's STC. Closer analysis of the spectrum recorded from AM suggests the possibility that the multiple SOAEs identified in AM's right ear, may have influenced the suppression effect of the external tone at 30% above the target SOAE (1400 Hz). Specifically, distortion products might be expected to be created as the result of a combination of the external tone and emissions near the frequency of the external tone. In this case, the distortion products may have included energy at frequencies below the target SOAE. Those distortion products could have introduced enhanced suppression effects when the external tone was in the region of the "notch." The absence of a nonmonotonicity in the high frequency slope of subject AS's STC who also presented an SOAE at 1400 Hz, in the absence of any observable additional SOAEs, supports this suggestion in an indirect manner.

The purpose of this study was to refine the description of SOAE STCs by suppressing the SOAEs of individuals who exhibited stable SOAE frequency and SPL. The lack of reported replication of STCs, as well as definitive measures of STC characteristics suggested the possibility of serendipitous results by earlier investigators. Good agreement between the general shape of STCs from earlier SOAE suppression studies and those developed from this investigation support the finding that STCs are indeed similar to other tuning curves (PTCs and FTCs). Furthermore, this finding lends additional evidence to the theory that the behavior of the SOAE is frequency specific. The appearance of good replication of the STCs within subjects further supports the claim that the general shape of the SOAE STC observed in this study and those of earlier investigators is indeed an accurate illustration of SOAE STCs.

In summary, one may expect that suppression of the SOAE by frequencies below the SOAE, with the exception of those frequencies very close in frequency above the SOAE, will be much more effective than frequencies above the SOAE. Suppression of the SOAE with the intention of producing a STC will result in a gradual depression in the low frequency region in conjunction with an abruptly rising high frequency slope and a STC tip located approximately 0 to 10% above the SOAE frequency. Low- to high-frequency slope ratio will be approximately 1 to 2.5. Tip to tail differences average approximately 30 dB. Q10 values will indicate a tuning curve wider than PTCs, but in good agreement with FTCs for auditory nerve fibers reported in animal studies (Kiang, Watanabe, Thomas, & Clark, 1965). Good replicability of STCs can be expected from subjects who exhibit stable emission SPL and frequency.

The findings from this investigation indicate that one of the characteristics of SOAEs is frequency specificity, supporting the argument that SOAEs manifest events in a restricted region of the inner ear in the absence of pathology at the frequency of the SOAE. The SOAE may well reflect an active biomechanical function of the cochlea and represent the additional supply of energy that Gold (1948) postulated was necessary to overcome the viscosity of the inner ear fluid.

REFERENCES

Bright, K.E. (1985). Microstructure audiograms and psychophysical tuning curves from subjects with spontaneous otoacoustic emissions. Unpublished doctoral dissertation. University of Arizona, Tucson.

Bright, K.E. & Glattke, T.J. (1984). Spontaneous otoacoustic emission in normal listeners. American Speech and Hearing Association, 26, 147.

Citron, L. (1969). Observations on a case of objective tinnitus. Amsterdam, Excerpta Medica International Congress Series, 189, 91.

Clark, W.W., Kim, D.O., Zurek, P.M. & Bohne, B.A. (1984). Spontaneous otoacoustic emission in chinchilla ear canals: Correlation with histopathology and suppression by external tones. Hearing Research, 16, 299-314.

Coles, R.R.A., Snashell, S.E. & Stephens, S.D.G. (1975). Some varieties of objective tinnitus. British Journal of Audiology, 9, 1-6.

Glanville, J.D., Coles, R.R.A. & Sullivan, B.M. (1971). A family with high-tonal objective tinnitus. Journal of Laryngology and Otology, 85, 1-10.

Gold, T. (1948). Hearing. II. The physical basis of the action of the cochlea. Proceedings of the Royal Society of London, 135, 492-498.

Huizing, E.H. & Spoor, A. (1973). An unusual type of tinnitus. Archives of Otolaryngology, 98, 134-136.

Kemp, D.T. (1980). Towards a model for the origin of cochlear echoes. Hearing Research, 2, 533-548.

Kiang, N.Y.S. (1965). Stimulus coding in the auditory nerve and cochlear nucleus. ACTA Oto-Laryngologica, 59, 186-200.

Kiang, N.Y.S., Watanabe, T., Thomas, E.C., & Clark, L.F. (1965). Tuning curves. In Discharge Patterns of Single Fibers in the Cat's Auditory Nerve, Res. Monograph No. 35 (pp. 84-92). Cambridge, MA: M.I.T. Press

Loebell, E. (1962). Demonstration of a patient. Hals-Nasen-Ohrenheilkunde, 10, 22.

Rabinowitz, W.M. & Widin, G.P. (1984). Interaction of spontaneous oto-acoustic emissions and external sounds. Journal of the Acoustical Society of America, 76, 1713-1720.

Ruggero, M.A., Rich, N.C. & Freyman, R. (1983). Spontaneous and impulsively evoked otoacoustic emissions: indicators of cochlear pathology? Hearing Research, 10, 283-300.

Sachs, M.B. & Kiang, N.Y.S. (1968). Two-tone inhibition in auditory-nerve fibers. Journal of the Acoustical Society of America, 43, 1120-1128.

Schloth, E. & Zwicker, E. (1983). Mechanical and acoustical influences on spontaneous oto-acoustic emissions. Hearing Research, 11, 285-293.

Stelmachowicz, P.G. & Jesteadt, W. (1984). Psychophysical tuning curves in normal-hearing listeners: test reliability and probe level effects. Journal of Speech and Hearing Research, 27, 396-402.

Strickland, E.A., Burns, E.M. & Tubis, A. (1985). Incidence of spontaneous otoacoustic emissions in children and infants. Journal of the Acoustical Society of America, 78, 931-935.

Wier, C.C., Norton, S.J. & Kincaid, G.E. (1984) Spontaneous narrow-band oto-acoustic signals emitted by human ears: A replication. Journal of the Acoustical Society of America, 76, 1248-1250.

Wilson, J.P. & Sutton, G.D. (1981). Acoustical correlates of tonal tinnitus. In Tinnitus, CIBA Foundation Symposium, 85, 82-107.

Zurek, P.M. (1981). Spontaneous narrowband acoustic signals emitted by human ears. Journal of the Acoustical Society of America, 69, 514-523.

Zwicker, E. & Manley, G. (1981). Acoustical responses and suppression-period patterns in guinea pigs. Hearing Research, 4, 43-52.