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TONE BURST SENSITIVITY IN NORMAL AND SENSORINEURAL HEARING IMPAIRED LISTENERS

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Independent Study
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Click evoked auditory brainstem response (ABR) testing has emerged as a clinically useful tool for the assessment of the auditory sensitivity of the pediatric population, particularly the very young and difficult to test. However, the result of this testing is generally a prediction of the degree of hearing impairment in the 2000-4000 Hz region. Results are restricted to this region because the click stimulus is broad band with a main concentration of acoustic energy at 2000-4000 HZ. Although click evoked ABR findings are often invaluable for identification, the findings have limited habilitative implications, particularly with respect to selection of an appropriate hearing aid.

The research I will discuss is part of an ongoing project at Central Institute for the Deaf. The objective is to predict the pure tone audiogram from the results of Electric Response Audiometry (ERA) utilizing frequency-selective tone burst stimuli. It is expected that the predicted pure tone audiogram will provide more useful information to the audiologist faced with habilitative decisions than the results of click evoked auditory brainstem response testing.

It is believed that an audiogram can be predicted from tone burst evoked ERA data provided:

1) the relationship between the behavioral threshold for tone bursts and pure tones has been established in listeners with normal and impaired hearing

2) the electrophysiological response evoked by the stimulus is well defined in both normal and hearing impaired listeners

3) normative data and correction factors for predicting the behavioral pure tone threshold from the electrophysiological threshold are determined.

This research investigated the first requirement while the other requirements remain under investigation at Central Institute for the Deaf.

This portion of the project revealed that the tone burst threshold is a good predictor of the pure tone threshold im impaired listeners at a particular frequency provided that the per octave slope of the audiometric configuration is not greater than 30 dB. The predictive accuracy is limited. These findings appear to be related to the acoustic spectra of the tone bursts and reduced temporal integration in the impaired listener.

Two types of tone burst stimuli were used. They were produced by amplitude modulation of a sinusoid of either 500, 1000, 2000, or 4000 Hz with a linear rise and fall of two periods of the tone and a plateau of one or ten periods. These stimuli are designated 2-1-2 or 2-10-2 tone bursts.

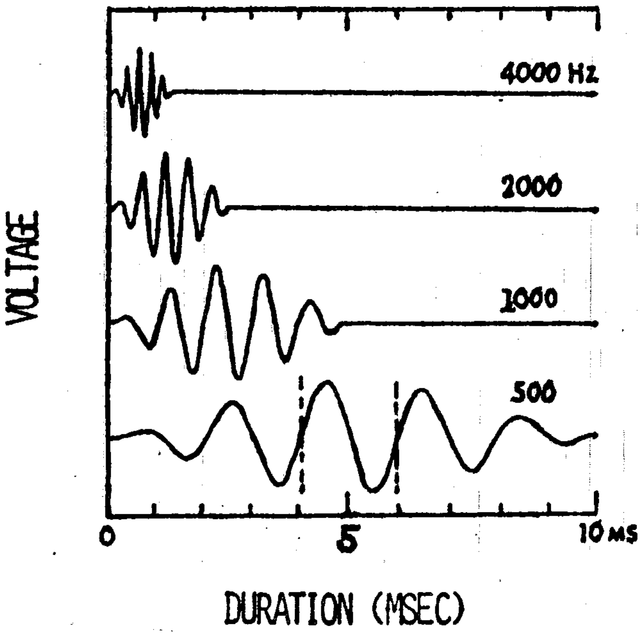


Figure 1: Electrical waveform of tone pip stimuli

The names are based on the characteristics of the electrical waveform of the stimuli. The waveform of 2-1-2 tone bursts, as shown in Figure 1, have a linear rise and fall of two periods of the modulated tone and a plateau of one period. 2-10-2 tone bursts have a linear rise and fall of two periods of the modulated tone and a plateau of of ten periods. The inverse relationship between frequency and duration is also depicted.

As a tone is shortened the frequency specificity is decreased and sidebands of energy are generated at frequency regions lower and higher than the tone. Since the duration of the rise/fall and plateau of these tone bursts is a constant number of periods, the number of milliseconds in the rise/fall and plateau time of each burst in a category varies by the inverse relationship between time and frequency. By defining the duration of the stimuli as a constant number of periods rather than a constant number of milliseconds, the acoustic spectra of each burst in a category are logarithmically constant with frequency. The 2-1-2 tone bursts, as shown in Figure 2, are slightly more frequency specific than octave bands of noise. The main lobe of each spectrum is centered at the frequency of the modulated tone and rises about 27-30 dB above the sidebands of energy that spread to the lower and higher frequencies. The spectra overlap with each other 27-30 dB below each main lobe.

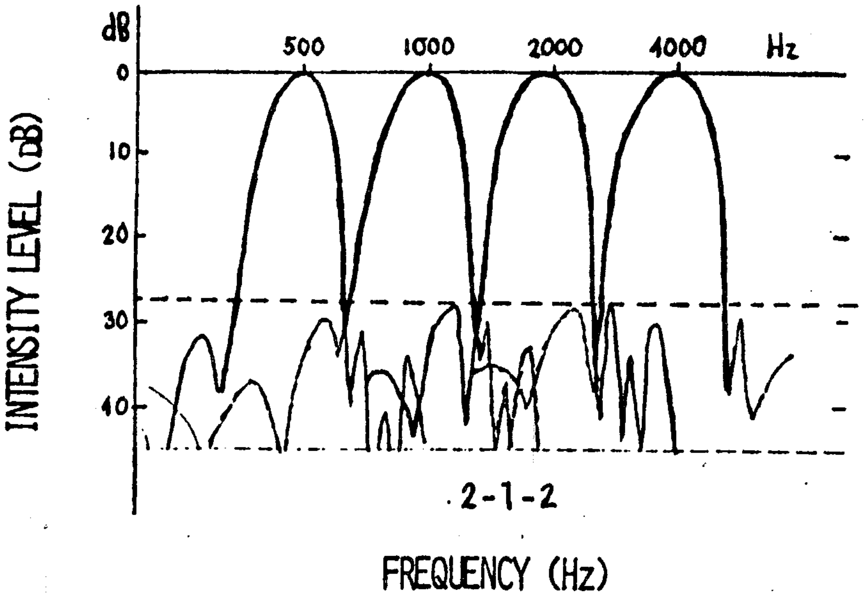
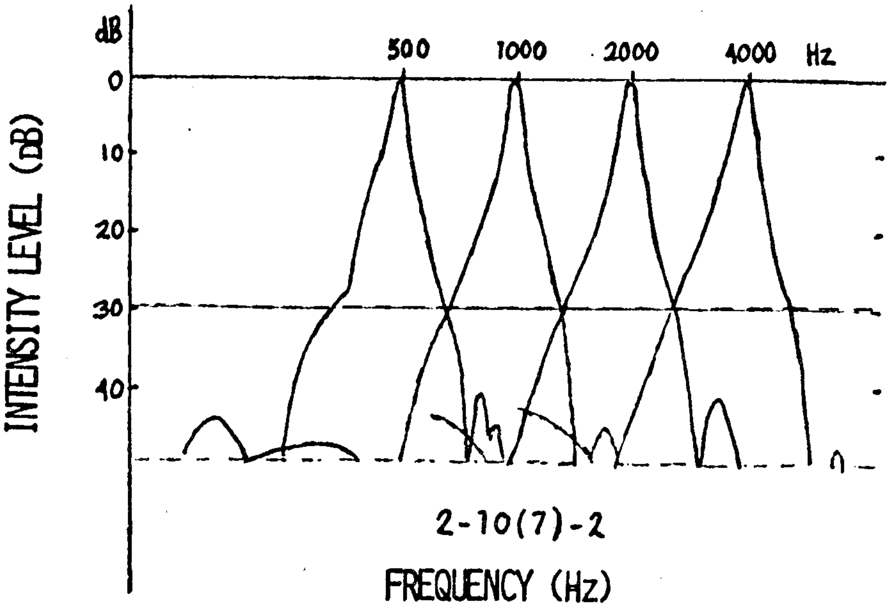


Figure 2: ACOUSTIC POWER SPECTRA OF 2-1-2 TONE BURSTS

The spectrum of each 2-10-2 tone burst is also centered at the frequency of the modulated tone but the main lobe rises 40 dB above the sidebands of energy that spread to the lower and higher frequencies as shown in Figure 3.



Here, the spectra overlap 10 dB above the sidebands and 30 dB below the main lobe. By increasing the plateau ten times, the lobes become sharper and the sidebands are reduced by ten dB.

Figure 3: **ACOUSTIC POWER SPECTRA OF 2-10(7)-2 TONE BURSTS**

The subjects consisted of sixteen normal hearing individuals, ages 22-36 years, and 22 sensorineural hearing impaired individuals, ages 6-85 years. The average age of the normal listeners is 26 years and the average age of the hearing impaired listeners is 36 years.

The degree of hearing impairment and type of audiometric configuration among the hearing impaired subjects is shown in Table 1. The degree of impairment ranged from borderline to profound. The distribution of hearing impairment is skewed toward greater hearing loss. The audiometric configuration of the hearing impaired subjects ranged from rising to abruptly falling. The distribution of audiometric configuration is relatively even. The configuration sloped downward with frequency in 68% of the subjects.

Pure tone stimuli at octave intervals from 500-4000 Hz were generated by an oscillator and shaped into 2-1-2 or 2-10-2 tone bursts by a digital electronic switch. Presentation of the bursts was controlled by a second electronic switch set at 10 msec rise/fall

TABLE I

AUDIOMETRIC CONFIGURATION* AND DEGREE OF HEARING LOSS IN IMPAIRED SUBJECTS

	Flat	Gradually Falling	Sharply Falling	Abruptly Falling	Rising	Trough	TOTAL
Borderline	1						1
Mild				1			1
Mild-Moderate		1					1
Moderate	2						2
Normal-Severe				2			2
Moderate-Severe		2	2	1		1	6
Severe	1	1					2
Severe-Profound		2	3	1	1		7
Profound				1	2		3
TOTAL	4	6	5	6	3	1	25

If there was a slope between one or more octaves the audiometric configuration was characterized upon the basis of the slope

* Lloyd and Kaplan, Audiometric Interpretation, University Park Press, 1978

time. The tone bursts were then amplified, attenuated by the experimenter and presented through a TDH-49 earphone.

Behavioral thresholds for both type tone bursts and pure tones were obtained utilizing the method of limits. The threshold was bracketed in 2 dB steps and chosen as the level where three or more responses were obtained in five presentations. The repetition rate was approximately 40 per second.

Comparison of averaged pure tone and tone burst thresholds in the normal listeners, as shown in Figure 4, reveals the 2-1-2 threshold is greater than the pure tone threshold, while the 2-10-2 threshold is between the two. Averaged across frequencies, the 2-1-2 threshold

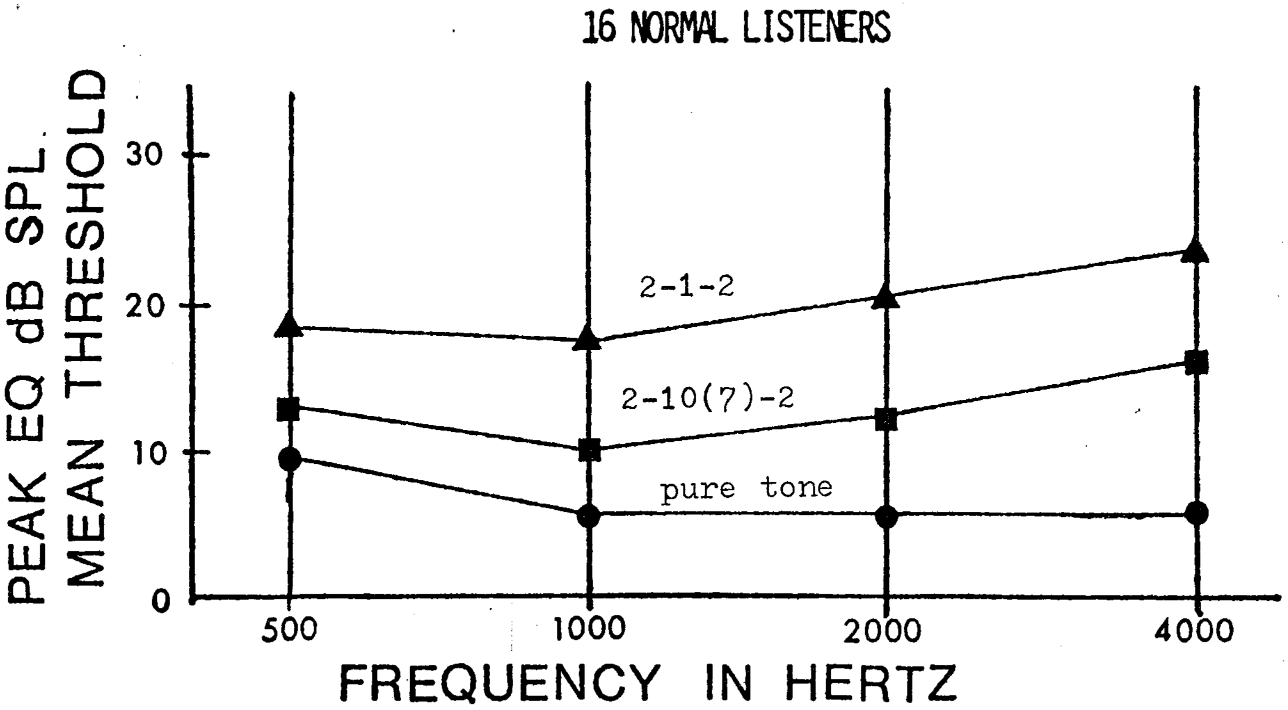


Figure 4: **AVERAGE NORMAL THRESHOLD WITH STIMULUS TYPE AS THE PARAMETER**

is 13 dB greater than the pure tone threshold. The 2-10-2 threshold is 6 dB greater than the pure tone threshold and 7 dB less than the 2-1-2 threshold. These averaged thresholds for each type tone burst were used as the 0 dB reference level for the hearing impaired listeners yielding dB nHL as the intensity calibration of the tone bursts. The values of 0 dB nHL are shown in Table II. Comparison of the mean pure tone threshold for the normal listeners with ANSI, 1969, as shown in Table II reveals the normal listeners 4 dB more

TABLE II

REFERENCE LEVEL FOR 0 dB n HL

	500 Hz	1000 Hz	2000 Hz	4000 Hz
Pure Tone dB SPL	9.9	5.4	5.9	6.4
2-10-2 Tone Burst dB peEQ SPL	12.8	10.1	12.3	16.6
2-1-2 Tone Burst dB peEQ SPL	18.4	17.6	20.1	23.3
ANSI, 1969 dB SPL	13.5	7.5	11.0	10.5

sensitive, averaged across frequencies, than ANSI standards for normal hearing.

For flat sensorineural losses, the difference between thresholds appeared minimal, but increased with hearing level. As shown in Figure 5, there is a wider spread between the tone burst thresholds and the pure tone thresholds at the frequencies 500 through 2000 Hz in the severe- profoundly impaired subject as compared to the moderately impaired subject.

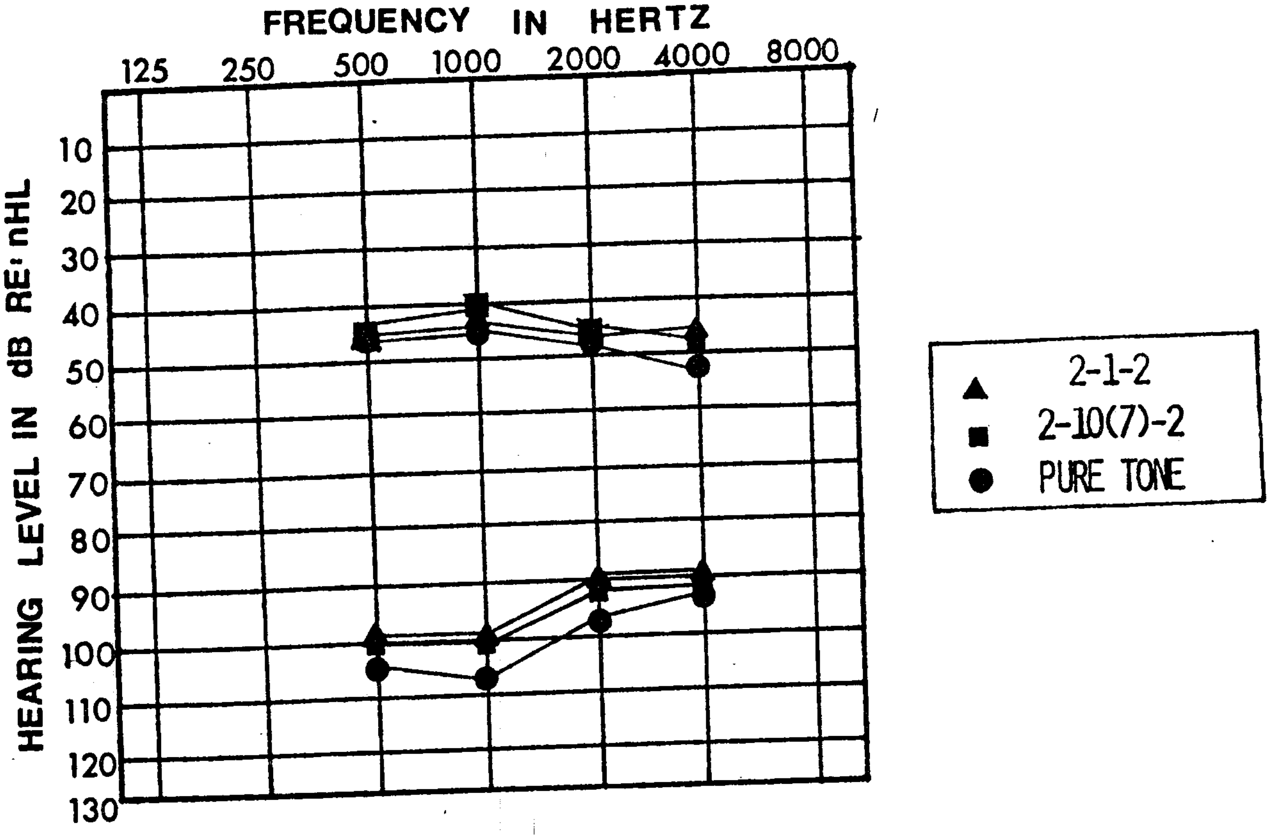


Figure 5: Effect of degree of hearing loss

The tone burst thresholds paralled the audiometric configuration when the slope at any one octave was 25-33 dB as shown in Figure 6. Here, the upper left figure shows a 29 dB octave slope between 500 and 1000 Hz. The upper right figure shows a 25 dB per octave slope between 2000 and 4000 Hz while the lower figure shows a 33 dB octave slope between 1000 and 2000 Hz. In all three cases the tone burst thresholds parallel the audiometric configuration, but the spread between the thresholds vary. This spread may be due to differences in the degree of hearing loss or a possible interaction between audiometric configuration and degree of hearing loss.

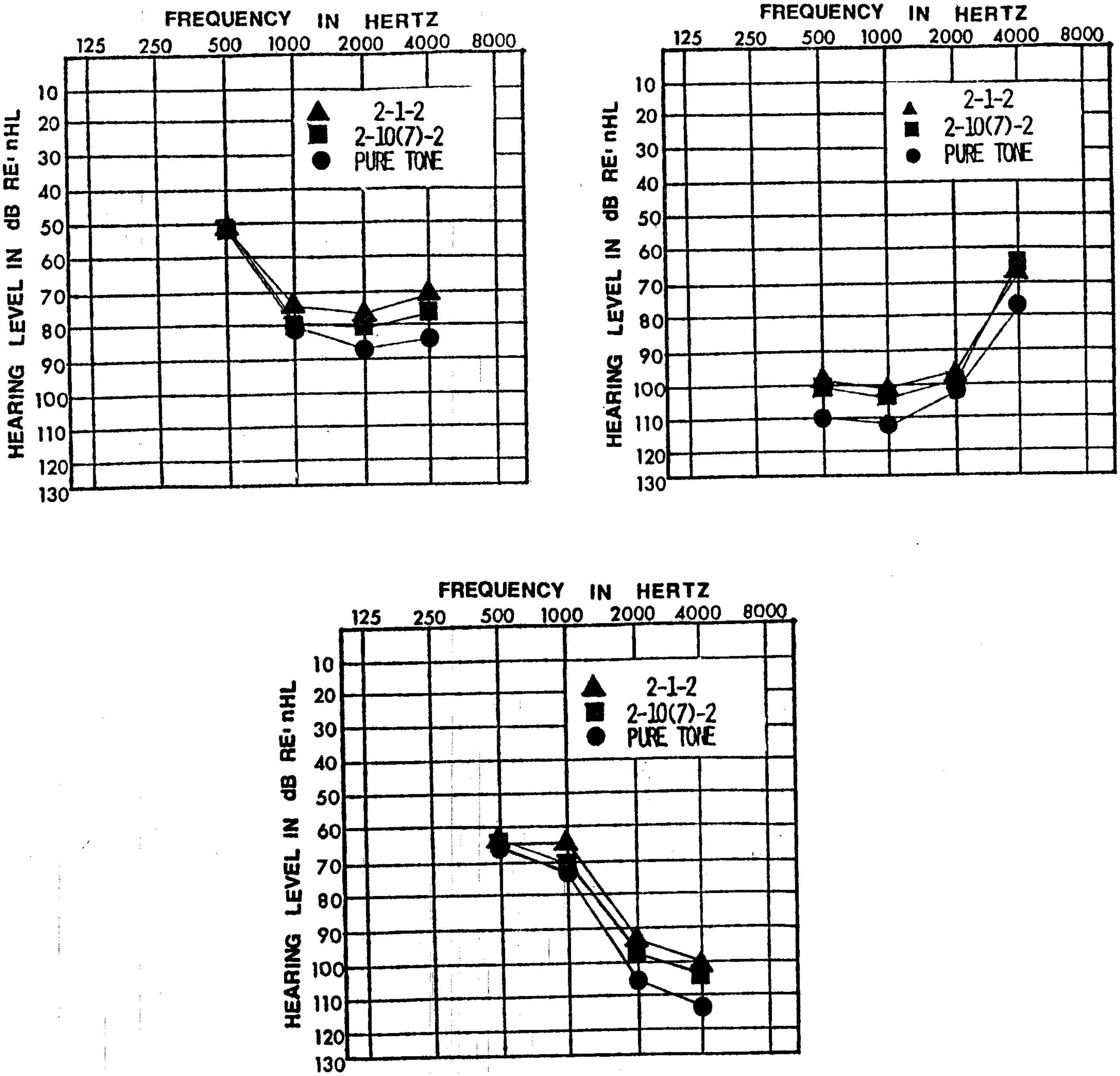


Figure 6: For a 30 dB per octave slope, configuration of hearing loss is similar for all stimuli.

As shown in Figure 7, the tone burst threshold also paralled the audiometric configuration when the slope for adjacent octaves was 20 dB. The pure tone configuration is reflected in the tone burst configuration. Note that the difference between thresholds is greater at 4000 Hz where the hearing loss is greatest.

The tone burst threshold significantly differed from the pure tone threshold when the octave slope was greater than 30 dB as shown in Figure 8. Here the 1000 to 2000 Hz slope is 28 dB and the 2000 to 4000 Hz slope is 50 dB. Although the tone burst thresholds parallel the configuration through 2000 Hz, there is a significant departure at 4000 Hz.

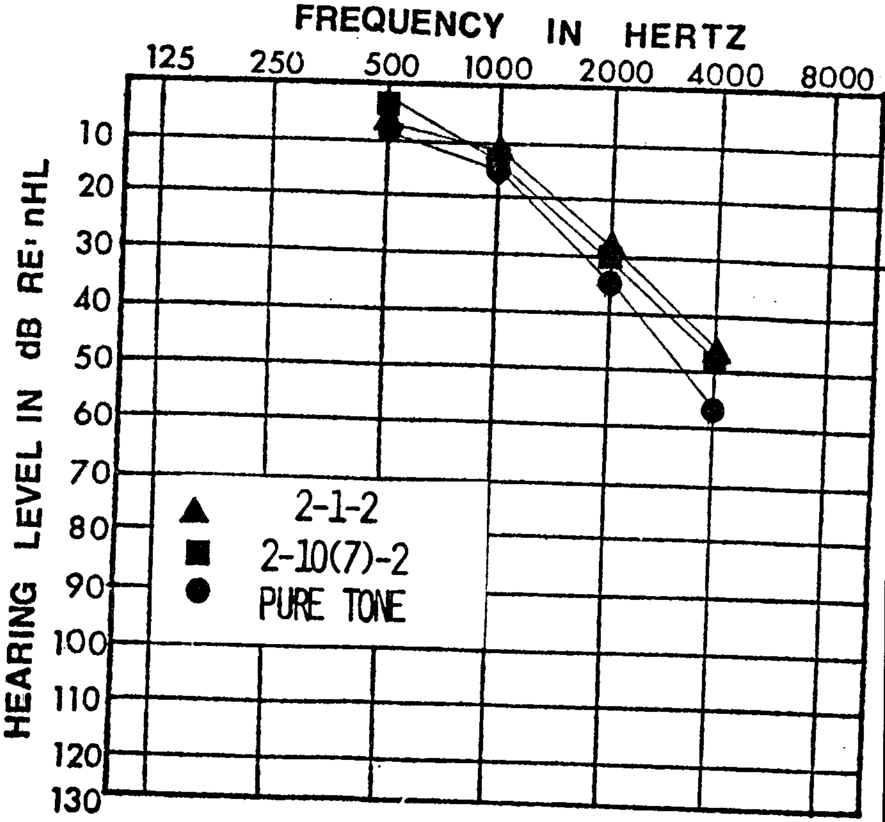


Figure 7: The audiometric configuration is similar for all stimuli when the slope between octaves is 20 dB.

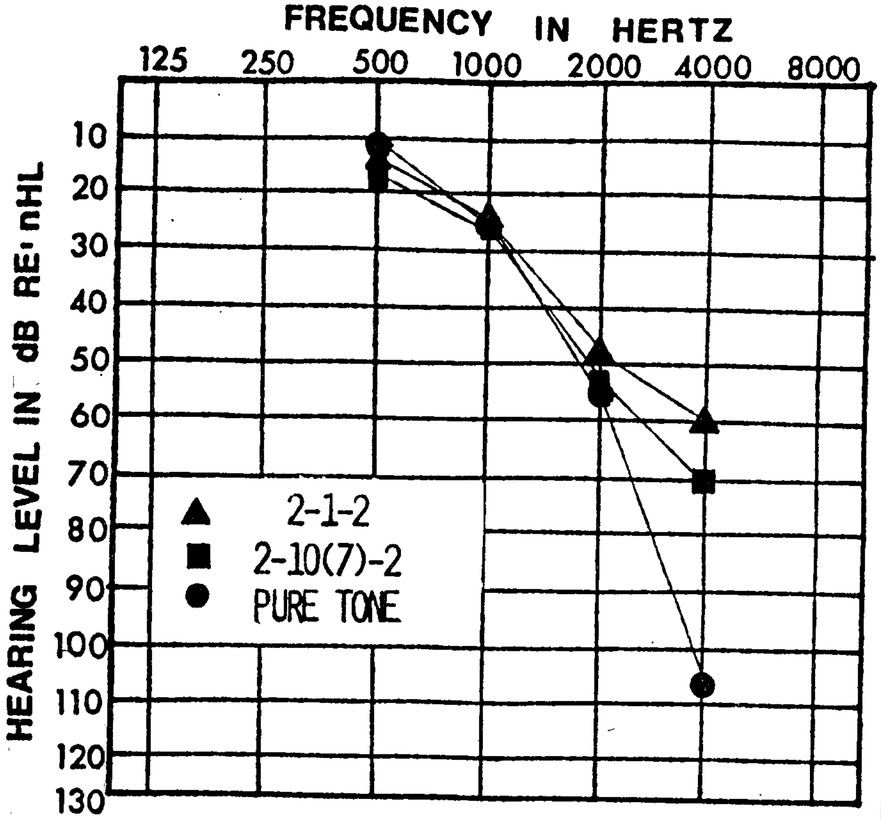


Figure 8: The tone burst stimuli do not reflect the 50 dB per octave slope

In a similar fashion, there is even a greater difference between the pure tone and tone burst thresholds when a 30 dB per octave slope continues to slope at the adjacent octave as shown in Figure 9. Here the 500-1000 Hz slope is 30 dB and the adjacent 1000-2000 Hz slope is 20 dB resulting in a significant difference between the pure tone and tone burst thresholds at all of the frequencies above the 30 dB slope.

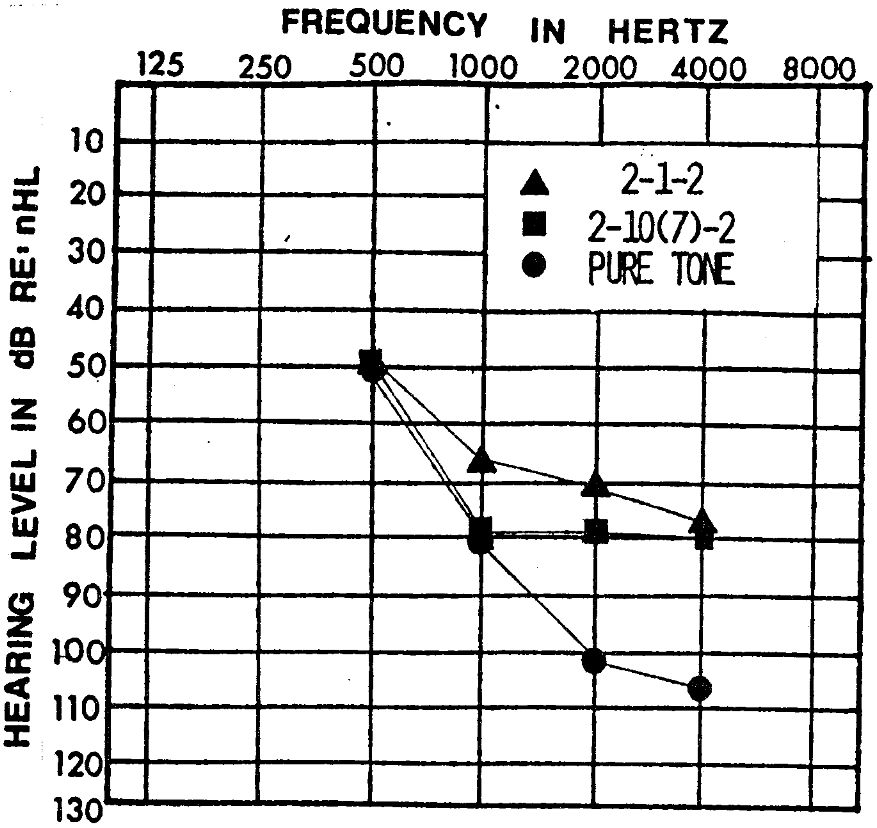


Figure 9: For a 30 dB per octave slope, the configuration of the hearing loss is not reflected by the tone burst stimuli.

Results of regression analysis with the pure tone as the dependent variable and the 2-1-2 tone burst thresholds as independent variable are shown in Tables III and IV. The results reveal that the tone burst threshold at 500, 1000 and 2000 Hz are/a good predictor of the pure tone threshold at the respective frequency. The tone threshold can be predicted by the product of a slope coefficient and burst threshold plus a constant. However, the range of the 95% confidence interval for a predicted value is rather wide, ranging from 16-27 dB across frequencies.

TABLE III

BIVARIATE REGRESSION ANALYSIS 500, 1000, 2000 Hz

Prediction of Pure Tone Threshold from Tone Burst Threshold

	Correlation Coefficient	Proportion of Variance	Standard Error	F	Significance Level
500 Hz	0.984	0.969	5.90	733	.01
1000 Hz	0.994	0.988	3.79	1971	.01
2000 Hz	0.982	0.963	6.03	612	.01

Prediction Equations	Standard Error
500 Hz $\text{Tone}_{500} = 1.05(\text{Burst}_{500}) + 0.92$	0.039
1000 Hz $\text{Tone}_{1000} = 1.11(\text{Burst}_{1000}) + 1.16$	0.025
2000 Hz $\text{Tone}_{2000} = 1.12(\text{Burst}_{2000}) + 1.35$	0.045

95% Confidence Intervals for Predicted Pure Tone Thresholds

Burst Threshold	500 Hz	1000 Hz	2000 Hz
0	-11-----16	-7.4-----9.7	-12.7-----15.4
60	51-----76	59-----75	54.5-----79
120	114-----140	126-----143	122-----149
Range	25-27	16-17	24-25

The results for 4000 Hz, as shown in Table IV, are different. Here, the slope of the audiometric configuration is a factor as multivariate regression analysis reveals that the pure tone threshold is predicted by the tone burst threshold at both 4000 Hz and at 2000 Hz. In addition, the subjects appear to be divided into two groups by the degree of hearing loss at 4000 Hz. The tone burst threshold at 2000 Hz is a stronger predictor in the group with the greater hearing loss.

TABLE IV

MULTIVARIATE REGRESSION ANALYSIS--4000 Hz

Prediction of Pure Tone Threshold from Tone Burst Threshold at 4000 and 2000 Hz

	Complete Sample N=25	Split Sample Pure Tone Threshold≤78 N=12	Split Sample Pure Tone Threshold>78 N=12
Multiple Correlation Coefficient(r)	0.696	0.722	0.865
Proportion of Variance(r^2)			
Overall	0.48	0.52	0.75
4000 Hz Burst	0.34	0.34	0.35
2000 Hz Burst	0.14	0.14	0.39
Standard Error	17.07	12.7	7.28
Significance Level			
Overall	.01	.05	.01
4000 Hz Burst	insignificant	.05	.01
2000 Hz Burst	.025	insignificant	.01

Prediction Equations--4000 Hz

Overall

$$\text{Tone}_{4000} = \underset{\text{SE}=0.53}{0.26(\text{Burst}_{4000})} + \underset{\text{SE}=0.32}{0.4(\text{Burst}_{2000})} + 39.3$$

Pure Tone Threshold 78

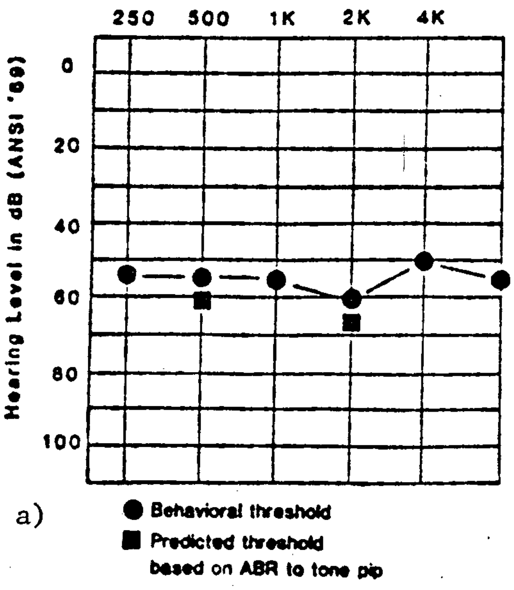
$$\text{Tone}_{4000} = \underset{\text{SE}=0.53}{1.35(\text{Burst}_{4000})} - \underset{\text{SE}=0.32}{0.47(\text{Burst}_{2000})} + 19.3$$

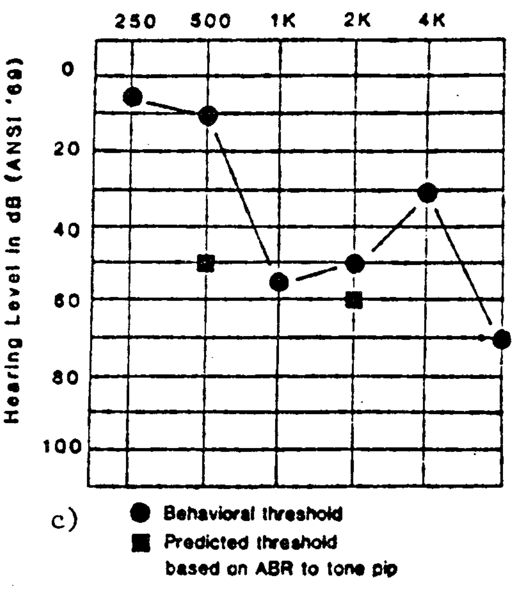
Pure Tone Threshold 78

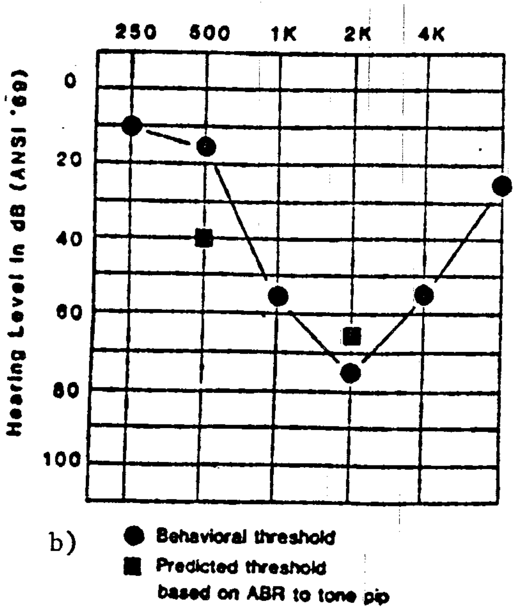
$$\text{Tone}_{4000} = \underset{\text{SE}=0.24}{1.27(\text{Burst}_{4000})} - \underset{\text{SE}=0.27}{1.03(\text{Burst}_{2000})} + 78.6$$

Although the confidence intervals for a predicted value are not available, they would be larger than those at 500 through 2000 Hz because here the standard error of estimate is larger and the degree of association poorer.

It is important to keep in mind that this study deals exclusively with behavioral results and is difficult to apply to potential electrophysiological findings. However, these findings can be compared to those of studies dealing with prediction of the tonal threshold from electrophysiological results. While my results at 4000 Hz are problematic, in 1982 Hays and Jerger reported problems with the prediction of the tonal threshold from SN_{10} threshold with a 500 Hz tone pip as shown in Figure 10. They found that the 500 Hz tone pip underestimates the hearing loss at that frequency by 40 dB and that the predictive error varies with audiometric configuration. They suggested that the lower limit for ABR audiometry utilizing tone pips lies above 500 Hz.







D. HAYES AND J. JERGER, 1982

Figure 10: a) Audiometric configuration is relatively flat and threshold predictions based on ABR to tone-pips are within 5 dB of actual behavioral result b) Steeply sloping configuration, ABR to tone-pips overestimates hearing loss at 500 Hz by 25 dB and underestimates hearing loss at 2000 Hz by 10 dB. c) ABR to tone-pips overestimates degree of loss by 40 dB at 500 Hz

However, the attempt to predict an audiogram from frequency-specific ERA data sould not be abandoned until:

a) the electrophysiological response is well defined

b) and correction factors are determined for predicting the tonal threshold from ERA data in view of the behavioral findings discussed here.

It is possible that the slope of the latency-intensity function will be a factor improving estimation. The final judgement of the appropriateness of ERA utilizing tone pips needs to be made considering the present state of the art in selecting a hearing aid without complete audiometric results and the flexibility in electroacoustical characteristics of hearing aids.

Acknowledgements:

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References:

Hays, D. and Jerger, J 1982 "Auditory brainstem Response (ABR) to Tone-Pips: Results in Normal and Hearing-Impaired Subjects", Scandanavian Audiology, 11:133-142