



# Psychophysical Tuning Curves Measured with Hearing Aids: an Alternative Method

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## ABSTRACT

Psychophysical Tuning Curves (PTCs) have been used to determine the frequency selectivity/resolution of the auditory system. The methodology for measuring PTCs is time consuming and difficult for the average researcher, let alone sites with limited equipment. A new method involving the measurement of adaptive thresholds in the presence of narrow-band maskers has been developed to allow the measurement of PTCs with hearing aids. The goal is to evaluate the impact of amplification on frequency resolution in normal-hearing and hearing-impaired listeners. This presentation will focus on describing the procedures used to measure PTCs in hearing impaired subjects as well as in normal listeners. Eight subjects were tested unaided, with linear amplification, and with output limiting compression to evaluate their effect on the slopes of the PTCs. It is proposed that multi-channel compression may be effective at reducing the upward spread of masking, thus improving the Signal-to-Noise Ratio (SNR) when listening to speech in noise. Given this, we should expect an increase in the Low Frequency slope of the PTC relative to the linear amplification and unaided conditions. Preliminary results will be presented and discussed.

## INTRODUCTION

Recent studies have demonstrated improved speech intelligibility in noise when hearing-impaired subjects were aided with omnidirectional hearing instruments<sup>1 2 3</sup>. Although this apparent improvement in the Signal-to-Noise Ratio (SNR) is only now becoming documented, it gives rise to the question of how this SNR benefit is conveyed through the auditory system. One hypothesis proposes that the hearing-impaired listener may be experiencing a reduction in the upward of masking as a consequence of multi-channel compression and/or other advanced signal processing strategies. Using PTCs to evaluate this proposed reduction in the upward spread of masking is a logical way to approach this question, as it lends itself very well to matters relating to masking. Empirical support to justify this approach comes from the report that multi-channel compression changes the shape of the PTC function to help minimize the upward spread of masking<sup>4</sup>.

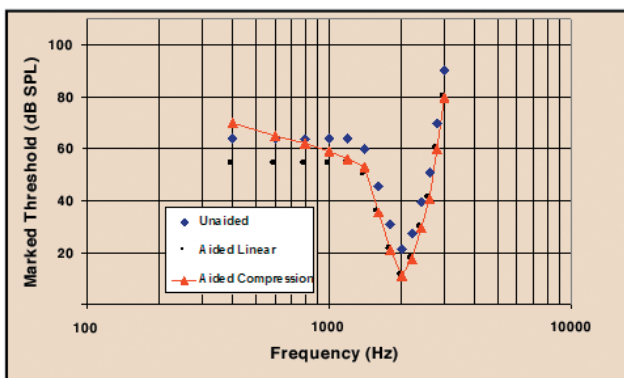


Figure 1: Predicted Outcomes

To evaluate this proposed reduction in the upward spread of masking, a clinically friendly procedure for measuring aided PTCs was developed which was intended to be clinically friendly. We anticipate that linear amplification will improve hearing sensitivity as indicated by a lowering of the overall PTC curve while preserving a similar PTC shape (see Figure 1). If output limiting compression serves to minimize the upward spread of masking, then an increase in the low frequency segment of the PTC should also be observed.

This study will focus on describing a newly developed adaptive procedure to measure aided PTCs and examine the test-retest performance on a group of normal and hearing-impaired listeners. The effects of amplification and output limiting compression will also be presented.

## METHODS

### Subjects:

Eight subjects were selected for this study, half of which had normal hearing sensitivity between 250 and 3000 Hz.

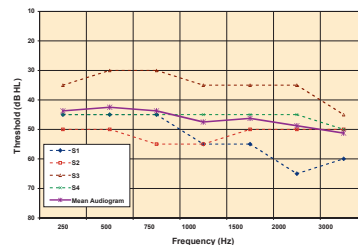


Figure 2: Mean Audiogram

The remaining subjects included hearing-impaired listeners with relatively flat, sensorineural losses as shown in Figure 2. Owing to output limitations of the audiometric equipment, the Pure Tone Average (PTA) of

the hearing-impaired subjects was restricted to losses of 65 dB HL or better.

### Hearing Aids:

All subjects were tested with a NATURA 2 SE CIC or ITC device. This instrument utilizes nine narrow-band compression channels with very fast, symmetric time constants. Larger devices were excluded because of the greater probability of feedback under headphones.

### Stimuli and Apparatus:

The probe tone and masker stimuli were generated using PC-based sound editing software. These sounds were rendered as 44.1Khz, 16 bit mono wav files and uploaded to the test equipment. 2000 Hz pure-tone pulses were presented every 500 msec via the headphones. Each pulse was 150 msec in length with a rise and fall time of 50 msec. This short tone duration was intended as a precaution to minimize the possibility of beating, particularly when using masker frequencies near 2000 Hz. This potential problem could cause erroneous responses as the subjects may respond to off-frequency cues rather than the probe tone itself. The 300 Hz narrow-band masker was designed to be slightly wider than the calculated critical band (235 Hz) for a 2 KHz probe signal to ensure maximum masker efficiency. The masker frequencies were presented in 200 Hz intervals, with the lowest masker being 400 Hz, and the highest 3000 Hz. This masker interval produced well-defined PTCs with observable Low Frequency (LF) slopes, High Frequency (HF) slopes, and LF tails during the initial pilot tests. The stimulus material was uploaded to the digital audio workstation and patched through the clinical audiometer. The probe tone and maskers were presented monaurally through headphones. The masker and probe tone stimuli were calibrated to agree with the level indicator on the audiometer. The masker frequencies were selected by accessing the appropriate track in the audio workstation, while the masker level was adjusted via the audiometer.

### Procedure:

Subjects were tested unaided, aided with 10 dB linear amplification, and aided with 3:1 output limiting compression. Subjects underwent testing twice to evaluate test-retest reliability. The second testing session occurred 4-6 weeks following the initial test run. Thresholds for the probe tone (without masker) was initially measured using the same adaptive procedure adopted when testing masked thresholds. For each presentation run, the probe tone was set a +5 dB above the recorded threshold. Subjects were instructed to raise the finger whenever the probe tone was audible and lower-it when it became inaudible. On each presentation, the probe tone was initially presented alone to ensure that the subject acquired the target signal. At this point, the masker was enabled. The tester would locate the general upper and lower limits necessary to mask/unmask the probe signal. Once the tester was reasonably assured of being in the correct zone, the formal data collection run would begin. The masked threshold is calculated as the average of three consecutive ascending and descending masker reversals. In effect, this average consists of 6 data points with three upper and three lower limit scores. The rate of masker level change was adjusted in a variable manner to minimize any anticipatory responses. Each PTC required approximately 20-30 minutes to complete.

error at 2800 and 3000 Hz. Most of these subjects reported that as the masker approached very high levels (around 85 dB SPL), they would also hear the tone become increasingly louder. Although it is not clear what is contributing to this phenomenon, some equipment-related artifact is suspected. Paradoxically, the hearing-impaired subjects did not make this observation, despite the fact that masker levels of 85 dB and greater were a common occurrence in these subjects.

## TEST-RETEST RESULTS

Figure 3 shows the relationship between the test-retest difference and the average tuning curves for both subject groups. Overall, the test-retest difference across all frequencies was 2.88 dB, an acceptable level of consistency. However, this single value betrays the fact that this difference appears to vary as a function of PTC slope. Support for this observation is depicted in figure 4, which separates the performance data for the normal and hearing-impaired listeners. As the normal listeners exhibit inherently steeper PTC slopes, an overall increase in the test-retest difference is observed. This relationship is supported by a moderate correlation of .59 in the normal hearing subjects while a much smaller relationship exists in the hearing-impaired group ( $r=.22$ ). Due to the small sample size, statistical significance could not be established for these correlations. The normal hearing subjects also exhibited a large amount of test-retest

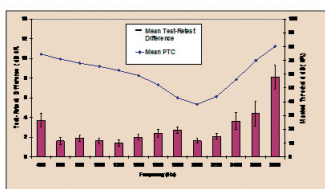


Figure 3: Test-Retest Results

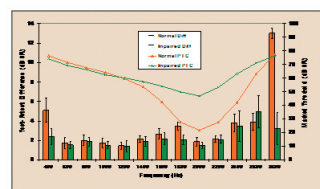


Figure 4: PTC Slopes and Test-Retest Results

## TEST-RETEST DISCUSSION

Given the small sample size, the procedure nevertheless yields consistent repeatability. An average test-retest variability of less than 3 dB is acceptable and justifies the use of this instrument when exploring the effects of hearing aid signal processing on frequency resolution. One weakness with this procedure is the loss of precision whenever steeper slope segments are encountered in the PTC. This problem may stem directly from the rate of masker level change rather than from some psychophysical property of the auditory system. One way to improve consistency would be to slow down the rate of masker change in order to minimize the possibility to over/under-estimate the masked threshold. This solution would be particularly relevant in the steeper segments of the PTC (low and high frequency slopes). Another strategy would be to retain the same variable masker presentation rate, but increase the number of reversals when calculating the threshold. Although these alternate strategies may help improve accuracy, they would also increase the amount of time necessary to perform the test, hence reduce its clinical desirability. Interestingly, the hearing-impaired subjects showed more consistent results due to the relatively flat tuning characteristics of their PTCs. Since this protocol was primarily designed for use on elderly hearing-aid users, this flatter tuning characteristic works in our favor when ensuring test-retest repeatability. More importantly, the level of PTC accuracy necessary to evaluate the effects of various signal processing strategies in hearing aids may not require excessively stringent levels of precision, as we are seeking the presence of major and obvious effects, not functionally irrelevant benefits. It is nevertheless desirable to achieve homogenous test-retest variability across all the tested frequencies. As hinted earlier, slowing the rate of masker change, particularly in the steeper segments of the PTC, may help achieve this consistency.

## EFFECTS OF AMPLIFICATION AND COMPRESSION ON THE PTC

Both groups of subjects underwent PTC testing unaided, aided with 10 dB SPL linear gain, and aided with 3:1 output limiting compression. The test-results for all subjects were averaged for each treatment condition and summarized in figures

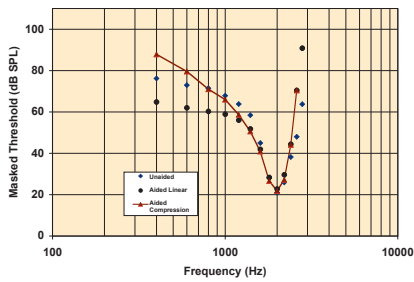


Figure 5: Aided PTC for Normals

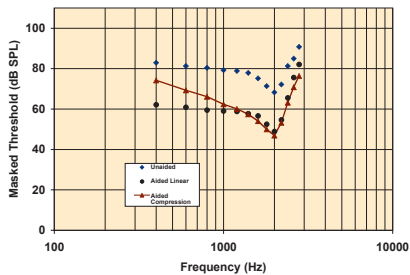


Figure 6: Aided PTCs for Impaired Listeners

5-6. Since the output limit of the audiometer was reached at some of the extreme frequencies (lower limit equals upper limit threshold), these scores were removed from the data set, as they did not reflect masked thresholds. The normal hearing subjects clearly demonstrate sharper PTCs compared to the hearing impaired subjects. This effect is consistent with the improved frequency resolution expected from normal hearing listeners. The overall PTC elevation for the hearing impaired

group is greater relative to the normal listeners owing to the poorer thresholds in these listeners. Both sets of PTCs demonstrate the improved audibility afforded by linear amplification as shown by the black symbols in figures 5-6. You will note that the application of gain does not produce homogenous masked threshold shifts across frequencies, particularly in the normal hearing listeners. The tip of the aided tuning curve does not demonstrate the predicted improvement in threshold as seen with the hearing impaired listeners.

When output limiting compression is applied, we can see that the energy required to mask the probe-tone increases as the masker shifts away from the probe tone frequency, particularly in the low frequency portions of the PTC. This demonstrates that output-limiting compression is effective at reducing the upward spread of masking. This release from masking begins around 1200 Hz, or slightly less than 1 octave below the probe tone frequency. This benefit is afforded for moderate to high intensity noises.

provides the necessary tool to investigate this intriguing possibility.

## REFERENCES

1. Bray, V. & Valente, M. (2001): Can Omni Directional Hearing Aids Improve Speech Understanding in Noise?. *Audiology Online*. Sept 24, 2001
2. Bray, V. & Nilsson, M (2000): Objective Test Results Support Benefits of a DSP Noise Reduction System. *Hearing Review* 7(11):60-65.
3. Bray, V. & Nilsson, M. (2001): Additive SNR Benefit of Signal Processing Features in a Directional DSP Aid. *Hearing Review*; 8(12):48-51.
4. Sasaki, N., Kawase, T., Hidaka, H, Ogura, M, Takasaka, T., Ozawa, K., Susuki, Y. (2000): Apparent Change of Masking Functions with Compression-Type Digital Hearing Aid. *Scand. Audiology* 29(3):159-169.

## DISCUSSION

Results from this pilot study demonstrate that some aspects of signal processing, namely output limiting compression, can reduce the upward spread of masking. Although a reduction has been demonstrated, it does not imply the capability of inducing frequency "sharpening". Improvements in frequency resolution would require a reduction in the masking closer to the probe-tone frequency, between 1600-2400 Hz. Nevertheless, the possibility of doing this is implied in multi-channel digital hearing instruments that incorporate such features as noise reduction, spectral sharpening algorithms, and other signal processing strategies to improve speech intelligibility in noise. The test procedure used in this study

