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ASSESSMENT OF FREQUENCY SELECTIVITY WITH PSYCHOACOUSTIC MASKING CURVES

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Psychophysical tuning curves (PTCs) and narrow-band masking curves (NMCs) were obtained for three frequencies: 500, 1600, and 2500 Hz, using the Bekesy tracking method. Comparisons of the data obtained for seven normal and one slightly impaired ears indicate that PTCs measured at 20 dB SL and NMCs measured at 40 dB SL seem to be equally effective in describing frequency selectivity using $Q(10)$ criterion. Therefore, the choice of either methodology for assessment of frequency resolution may be dictated by its convenience and avilable instrumentation. Due to dependence of PTCs and NMCs on signal presentation level, the conclusions of this study are limited to normally hearing listeners. It is yet to be shown whether and within what range of hearing loss both measures can be treated as equivalent at higher presentation level.

1. Introduction

Psychophysical tuning curves (PTCs) and narrow-band masking curves (NMC) are two measures of frequency selectivity (frequency resolution) of the hearing system. Although there are many conflicting reports in the literature, the reduced frequency resolution is commonly regarded as one of the main factors responsible for poor speech discrimination [1, 20, 23, 24, 30]. Decrease in frequency resolution appears as „an increase in the bandwidth of a hypothesized auditory filter and a decrease in the slopes of this filter, particularly on the low-frequency side" [6, p. 667]. West and Evans [27] observed that frequency resolution tests allow the detection of early asymptomatic hearing loss unrevealed by pure tone audiometry.

The most common measure of the auditory filter selectivity is the „coefficient of sharpness" $Q(10)$ defined as a center frequency of the filter divided by the filter bandwidth measured 10 dB below its maximum response [6, 21, 22, 25]. Other measures of the auditory filter selectivity recommended by various authors include:

1) the difference (in dB) between the level at the tuning curve tip and the level at which the masking or the tuning curve is an octave wide, 2) high frequency slope, and 3) tip-to-tail difference, defined as the difference (in dB) between the L_{max} at tip and the level at the intersection of two main segments of the low frequency slope [1, 4, 22]. Special advantages of the $Q(10)$ measure are its convenience and relative invariance with signal level in comparison to other measures listed above [21].

The use of frequency selectivity measures in the audiology clinic has been limited due to the correlation between the degree of hearing loss and the sharpness of tuning curves [6, 13]. The sharpness of both PTCs and NMCs changes with level and measures obtained from normally hearing listeners cannot be used as standards for comparison with data obtained from hearing impaired listeners at higher levels [15, 17]. Measures of frequency resolution may, however, by helpful in explaining differences in perceived hearing handicap for individuals with comparable pure tone thresholds [5, 26]. It is generally believed that abnormally poor frequency resolution is related to the difficulties in speech recognition in persons with similar audiometric configurations. This belief is supported by reports demonstrating wide variations in effects of masking, such as signal detection and speech recognition, among persons with similar hearing threshold configurations [2, 14, 19]. Similarly, there are reports indicating that impaired frequency resolution is not always attributable to elevated threshold of hearing [10, 12, 18] and is highly dependent on the type of hearing loss.

Clinical measures of frequency resolution are generally obtained from PTCs measured with precise but arduous laboratory methods. Davidson and Melnick [4] indicated that one of the reasons that PTC measurements are rarely used in audiology clinics is the cost and time-consuming character of these measurements. In comparison to PTCs, the NMCs are much easier and faster to obtain. For example, application of the frequency-roving tracking procedure does not require specialized equipment such as a sweeping narrow-band noise signal source needed for PTC measurements. If dicrete frequencies are used then the audiologist can just measure several thresholds of hearing in a fixed narrow-band noise using a conventional audiometer. More importantly, the task of listening to a signal that actually changes is simpler for the listener than listening to a fixed signal while ignoring the changes in the other signal. Finally, the meaning of NMCs is generally easier to explain to a client than that of PTCs.

Despite the fact that the body available literature on PTCs and NMCs is quite impressive, there are only a few studies that compared both of these measures of frequency selectivity. Florentine *et al.* [6] compared four different tests of frequency selectivity: 1) psychophysical tuning curves, 2) narrow-band masking, 3) two-tone masking, and 4) loudness summation. The reference frequency was kept constant at 500 Hz or 4000 Hz. The authors concluded that the two most sensitive measures of reduced frequency sensitivity were the $Q(n)$ values of the tuning curves and the narrow-band masking.The authors used interrmittent pure tones and a 40 dB SL narrow-band masker for measuring NMCs and a 10 dB SL test tone and a continuous pure tone masker in measuring PTCs. Their $Q(n)$ values for NMCs for normal-hearing listeners were slightly lower (mean = 5.73) than those obtained for PTCs (mean = 6.92). For hearing impaired listeners, the $Q(n)$ values were always lower than those obtained for normal hearing listeners and NMCs were frequently sharper than PTCs. The comparison of $Q(n)$ measures obtained from NMCs and PTCs is, however, possible only in relative terms since the authors used different types of maskers and different definitions of $Q(n)$ for both methods. Humes [8] compared PTCs and NMCs using a pure tone masker and a pure tone test signal. The masker was presented at 60 or 85 dB SPL (NMC method) and the test tone at 35 dB SPL (PTC method). Inspection of his data for several heating-impaired listeners indicates much larger deviations of NMCs than PTCs from those obtained with normal-hearing listeners. He did not make, however, a direct comparsion between these two methods and only concluded that both methods showed similar results.

Despite methodological advantages, the NMC measurement have not gained the clinical popularity of the PTC measurements. The primary reason for this fact is that at high intensity levels the shapes of PTCs and NMCs are not the same. Tuning curves demonstrate effects of various narrow-band changing in frequency on a preselected narrow region of the basilar membrane. Masking curves demonstrate effects of a fixed narrow-band masker on various along the basilar membrane. The former have steeper high-frequency slopes and the latteer have steeper low-frequency slopes. However, the masking curves and the psychophysical tuning curves obtained for the „represent identical data that can be transformed from one to the other by simply interchanging ordinates and parameters" [28, p. 71]. A low stimulation levels, the shapes of PTCs and NMCs become fairly symmetrical and $Q(10)$ s of selected pairs of PTCs and NMCs may become similar measures of frequency resolution.

The purpose of the present study was to determine whether PTCs and NMCs can be equivalent measures of frequency selectivity in listeners who are audiometrically normal or exhibit a slight (<20 dB HL) hearing loss. The authors hypothesized that if the NMCs provide the same amount of clinically relevent information as the PTCs, the NMCs could be an attractive clinical alternative for frequency resolution testing of audiometrically normal patients who experienced disproportional difficulties with speech recognition. This, in turn, may lead to greater clinical popularity of frequency selectivity measures.

2. Methods

2. 1. *Subjects*

Four listeners participated in the study. Their air-conduction audiometric thresholds are listed in Table 1. The listeners were 30 to 42 years old. All Tests were performed monaurally for the left and right ear of each listener.

TABLE 1. Pure tone air conduction hearing thresholds (in dB HL) of the four listeners (A-D) participating in this study.

		Frequency (Hz):					
Listener	Ear	250	500	10000	2000	4000	8000
A	LEFT EAR	0	0	0	−10	−10	0
	RIGHT EAR	0	0	0	−5	−5	−5
B	LEFT EAR	10	5	10	10	5	0
	RIGHT EAR	15	10	15	10	5	−5
C	LEFT EAR	15	15	0	0	10	10
	RIGHT EAR	20	15	5	5	10	10
D	LEFT EAR	30	25	15	10	20	30
	RIGHT EAR	15	15	10	0	10	25

2.2. *Stimili and equipment*

The same three frequencies: 500, 1600 and 2500 Hz, subsequently referred to as main frequencies, were used to determine the frequency resolution of the listeners on the basis of their PTCs and NMCs. The selected frequencies correspond to the typical values of $F1$, $F2$, and $F3$ formant frequencies of several English vowels. Both tuning and masking curves were measured at seven test frequencies: 4/3, 1 –, 2/3, and 1/3-octave below the main frequency, at the main frequency, and 1/3 – and 2/3-octave above the main frequency. The larger number of data points below than above the main frequency was based on previous studies indicating that the steepness of the low-frequency side of PTCs varies more among subjects than the steepness of the high-frequency side. Such arrangement of test frequencies allowed us to capture all main elements of both tuning and masking curves at low intensity levels. Pilot experiments indicated that two test frequencies set at 1/3 – and 2/3-octave intervals above the main frequency would be sufficient to obtain $Q(10)$ measures from both tuning and masking curves.

Experimental instrumentation included a Bekesy audiometer (Grason-Stadler, Model E800) supplemented by a tone generator (Wavetek, Model 159), a noise generator (Grason-Stadler, Model 455C), an electronic switch (Grason-Stadler, Model 829E), and a band-pass filter (B and K, Model 2113). The probe signal was a pulsed pure tone fixed at one of the main/test frequencies. The pulsation frequency was 2.5 pulses/sec with a 50% duty cycle. The masker was a 1/3-octave wide band of random noise centered at one of the main/test frequencies. Both signals were added together in a mixer (Numark, Model DM – 1550) and the resulting composite signal was delivered to a single TDH – 50 earphone the second earphone was inactive and covered the opposite ear of the subject through a power amplifer (SAE, Model 2200).

2.3. *Procedures*

In the PTC measurement task, the probe tone was presented at 20 dB SL for each subject at each main frequency and the subject controlled the level of the masker presented at various test frequencies. In the NMC measurement task, the masking noise was presented at 40 dB SL for each subject at each main frequency and the subject controlled the level of the test tone presented at each of test frequencies. The masker level of 40 dB SL have been determined on the basis of several pilot runs with masker level 30, 40, 50, and 60 dB SL. Data reported by several authors indicate that for tone signals below 60 dB SPL the frequency resolution curves are fairly symmetrical and $Q(10)$ measures relatively invariant with level [8, 16, 21].

In both measurements performed in this study, the masked thresold estimates were obtained using a Bekesy tracking technique [4]. The listener was asked to alternately depress and release the control button of the Bekesy audiometer in order to lose and recover the signal alternatively. In the PTC task the listener controlled the level of the masker whereas in the NMC task the listener controlled them level of the tone. The listener's task was to maintain the tone at a level which was just barely audible. The listener's threshold for each main frequency was defined as the midpoint of the up-down excursions of the Bekesy tracings during the test period. The duration of each test period was set to one minute.

3. Results and discussion

Results of the measurements are shown in Figs. 1, 2, and 3 for the main frequencies 500, 1600, and 2500 Hz. Each Figure includes results of the NMC task (upper panel) and the PTC task (lower panel). The shape of data points in Figures 1 – 3 identifies the listener. To compare the slopes of individual curves obtained for the same test condition, the masked threshold values measured at the main frequency were normalized for all tested ears and expressed in the form of Relative Masking Level dB.

The psychophysical tuning curves obtained in this study (Figs. 1 – 3, lower panels) have typical „V" shapes reported in the literature. The high-frequency skirts of the curves were very similar for all listeners at all main frequencies. The NMCs (upper panels) mirrored the shapes of respective PTCs in their central and high-frequency parts. Their low-frequency slopes appeared to be less steep than high frequency slopes, contrary to findings reported by Florentine *et al.*[6] for the same signal level. A possible explanation of this finding may be the inverse frequency dependence of masking patterns at low intensity levels [3, 7, 9, 11, 29].

The „coefficients of sharpness" $Q(10)$ calculated for both types of curves are listed in Table 2. The values in Table 2 are lower than those reported by other authors for listeners with normal hearing [4, 14]. They may be explained however by a relatively wide masker signal and the age of the listeners [12, 13, 17, 18].

An analysis of variance of $Q(10)$ with repeated measures on two factors (method, main frequency) showed that differences between $Q(10)$ coefficients obtained for PTC and NMC methods were not statistically significant at any main frequency. This indicates that the $Q(10)$ values derived from PTCs measured at 20 dB SL and NMCs measured at 40 dB SL can be assumed to be equivalent measures of frequency selectivity.

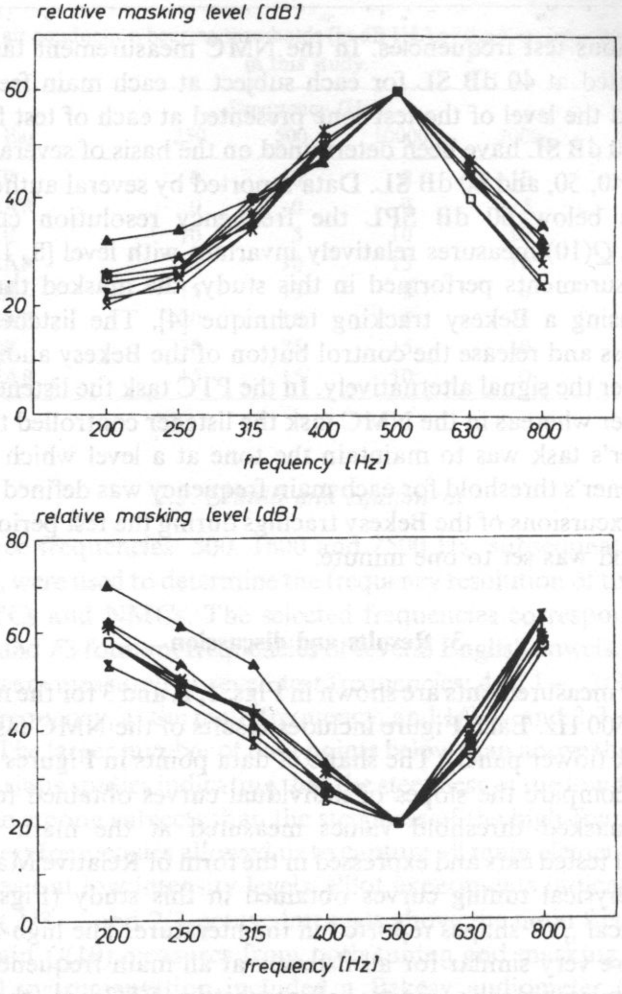

Fig. 1. Narrow-band masking curves (upper panel) and psychophysical tuning curves (bottom panel) for 500 Hz.

TABLE 2. Coefficients $Q(10)$ obtained from PTCs and for four listeners (A—D) participating in this study.

	Measure →	Coefficient $Q(10)$					
	Frequency →	500 Hz		1600 Hz		2500 Hz	
	Curve →	PTC	NMC	PTC	NMC	PTC	NMC
A	LEFT EAR	3.1	2.8	3.9	4.2	4.0	4.2
	RIGHT EAR	3.0	2.8	3.9	3.8	4.3	4.2
B	LEFT EAR	2.3	2.2	3.8	3.6	3.6	3.4
	RIGHT EAR	2.4	2.4	3.2	3.2	3.1	3.0
C	LEFT EAR	2.6	2.8	3.4	3.1	3.2	3.3
	RIGHT EAR	2.4	2.6	2.7	2.9	3.8	3.6
D	LEFT EAR	3.7	3.6	4.0	4.3	3.7	3.6
	RIGHT EAR	3.4	3.3	4.9	4.6	3.4	3.4

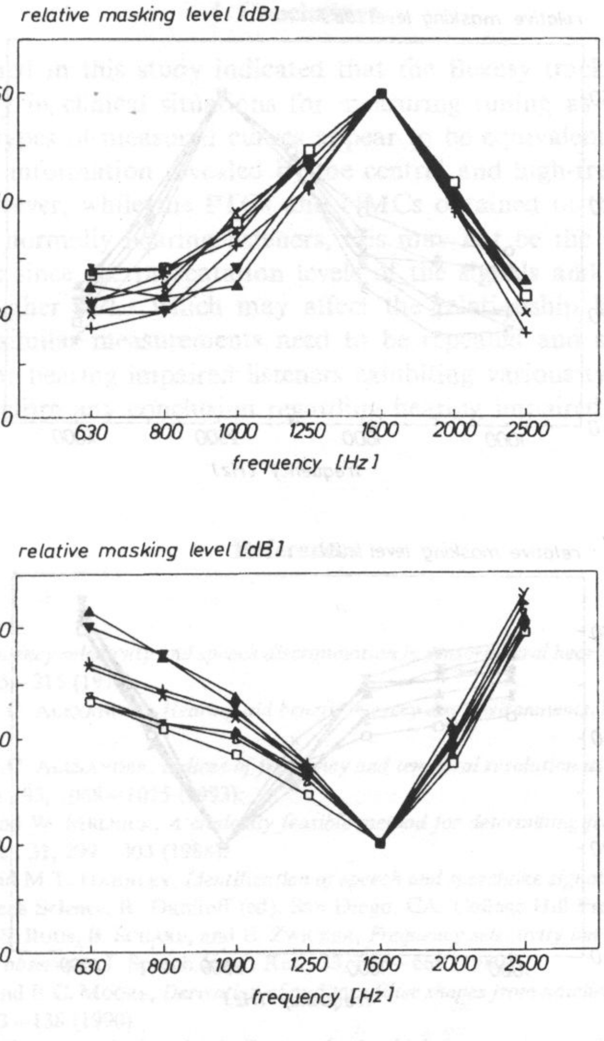

Fig. 2. Narrow-band masking curves (upper panel) and psychophysical tuning curves (bottom panel) for 1600 Hz.

The $Q(10)$ coefficients obtained from PTCs and NMCs at 500 Hz were significantly lower than those obtained at 1600 and 2500 Hz at the 0.01 level. Florentine *et al.* [6] reported that $Q(10)$ calculated at 500 Hz did not differ significantly among groups of listeners with various etiologies of hearing loss whereas $Q(10)$ differed when calculated at 4000 Hz. They also reported that $Q(10)$ values were significantly smaller in all listeners with elevated bone-conduction thresholds. In our study listener D had a mild air conduction hearing loss and normal bone conduction threshold in his left ear. His $Q(10)$ values for PTC and NMC are quite similar.

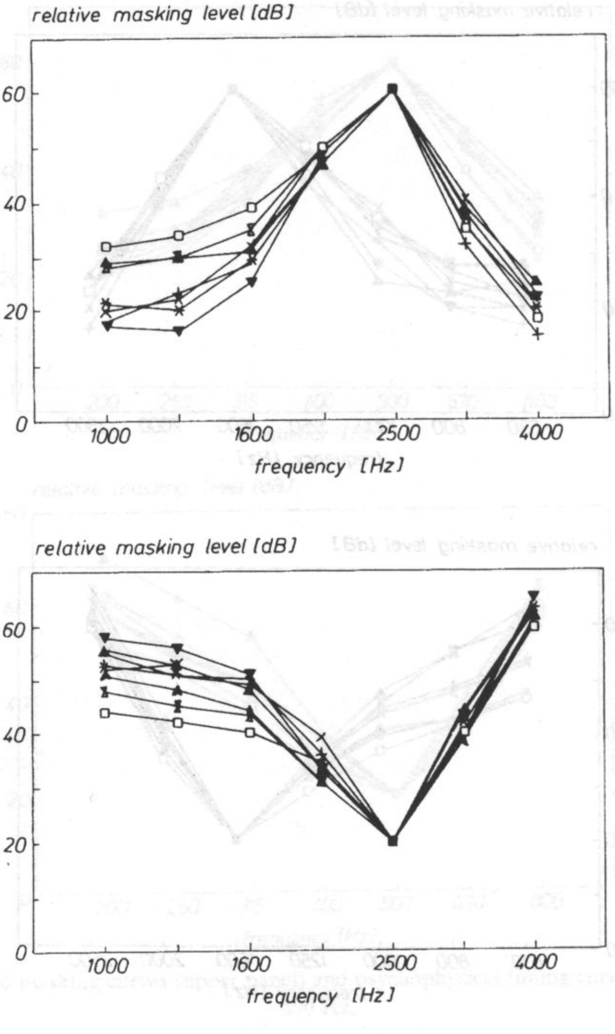

Fig. 3. Narrow-band masking curves (upper panel) and psychophysical tuning curves (bottom panel) for 2500 Hz.

However, his PTC and NMC for the left ear show steeper slopes than those observed for normal ears. This artifact was due to the presence of a conductivity hearing loss which differentially affected the signal and masker levels reaching the cochlea resulting in the shape of the curves. The subjects actual frequency sensitivity could have been the same or even worse than the frequency selectivity of the other subjects but his masking curves did not reflect this. This is an example how measurements of frequency selectivity can be confounded by the presence of conductive hearing loss.

4. Conclusions

Results obtained in this study indicated that the Bekesy tracking method can be used effectively in clinical situations for measuring tuning as well as masking curves. The two types of measured curves appear to be equivalent in terms of the type and amount information revealed by the central and high-frequency parts of their shapes. However, while the PTCs and NMCs obtained in this study appear to be similar for normally hearing listeners, this may not be the case for hearing impaired listeners since the presentation levels of the signals and maskers will be at significantly higher SPLs which may affect the relationship between the two measures. Thus, similar measurements need to be repeated and similar relationships confirmed for hearing impaired listeners exhibiting various types and degrees of hearing loos before any conclusion regarding hearing impaired listeners can be made.

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