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Robyn M. Cox, and Genevieve C. Alexander

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Robyn M. Cox
Memphis State University, and Department of Veterans Affairs Medical Center, Memphis, Tennessee 38105

Genevieve C. Alexander
Department of Veterans Affairs Medical Center, Memphis, Tennessee 38105

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Several investigators have suggested that between-subject variations in hearing aid benefit may be related to between-subject variations in auditory resolution. Evaluation of this relationship is complicated by the need to assess resolution at several frequencies and levels in hearing-impaired listeners who may not tolerate lengthy test procedures. This paper reports data from normal-hearing listeners for abbreviated indices of frequency and temporal resolution. For a particular frequency-stimulus level combination, both indices may be derived from three pure-tone thresholds obtained with different masking stimuli. Norms are reported as a function of masker level for each index at four test frequencies. Changes in the indices as a function of masker level were consistent with expectations based on related studies by other investigators. Norms were obtained using a supra-aural earphone. Comparison of results from supra-aural and insert earphones suggested that low-frequency sound leakage substantially affected the norms for 500 Hz. Reliability of individual indices was good to excellent.

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INTRODUCTION

When we measure the extent to which amplification improves the ability of hearing-impaired persons to understand speech, it is common to observe substantial between-subject differences, even for individuals with similar pure-tone thresholds, especially if speech intelligibility is measured in the presence of a competing noise (Cox and Alexander, 1991). Some investigators have hypothesized that these between-subject differences in benefit may be related to differences in the frequency and/or temporal analysis abilities of the individuals' auditory systems (e.g., Glasberg and Moore, 1989).

Many studies suggest that frequency resolution is poorer than normal, but widely variable, in individuals with sensorineural hearing impairment (see Tyler, 1986, for a review). Some studies of the relationship between frequency resolution and speech intelligibility have found evidence of a significant link between these two variables (e.g., Glasberg and Moore, 1989; ter Keurs *et al.*, 1992; Thibodeau and Van Tasell, 1987) although others have failed to find a link (e.g., Dubno and Schaefer, 1992; Lutman and Clark, 1986).

Although temporal resolution *per se* may not be affected by cochlear hearing loss (e.g., Moore and Glasberg, 1988), many studies present evidence that performance on certain temporal resolution tasks is, on average, poorer than normal in listeners with sensorineural hearing impairment, and that there are wide individual differences (e.g., Zwicker and Schorn, 1982; Nelson and Freyman, 1987; Glasberg *et al.*, 1987). Of the studies exploring the relationship between temporal resolution and speech intelligibility, some have found evidence of a significant link between the two (e.g., Tyler *et al.*, 1982; Dreschler, 1989), but some have not (e.g., Festen and Plomp, 1983).

In view of the wide variability in frequency and temporal resolution observed in individuals with the same hearing loss, and the probable relationship between auditory resolution and speech intelligibility, it is reasonable to hypothesize that between-subject differences in hearing aid benefit (defined as improved speech understanding ability) can be partially explained by between-subject differences in auditory resolution variables. One factor that complicates the evaluation of any relationship between hearing aid benefit and resolution abilities is the effect of stimulus level. Both frequency and temporal resolution are known to vary with stimulus level in normal-hearing listeners but data describing variations with level in hearing-impaired listeners are more scarce. If auditory resolution varies with stimulus levels, the relationship between resolution and hearing aid benefit would be influenced by the listening levels for amplified and unamplified speech. The potential importance of this factor is supported by studies showing that speech recognition is strongly related to presentation level in hearing-impaired listeners and that there is often an optimal presentation level for which the highest scores are obtained (e.g., Gutnick, 1982; Yantis *et al.*, 1966).

Before the relationship between auditory resolution and hearing aid benefit can be explored, it is necessary to formulate procedures for measurement of frequency and temporal resolution in hearing aid wearers. Most laboratory methods are arduous and may be too demanding for the typical elderly hearing aid wearer, especially if we wish to generate resolution data at several frequencies and stimulus levels. This paper describes results for two indices, one for frequency resolution and one for temporal resolution, that were developed for use with hearing aid wearers. The present data encompass results obtained for normal-hearing subjects as a function of presentation level. The goals of this work were to

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determine whether these temporal and frequency resolution indices would produce patterns for normal hearers that were consistent with published data based on related but more traditional measurement procedures; to generate norms for each index at several test frequencies; and, to evaluate the reliability of the indices.

I. EQUIPMENT I: DERIVATION OF NORMS

A. Method

1. Resolution indices

The frequency resolution index (FRI) measurement procedure was based on a method suggested by Patterson *et al.* (1982). The approach is an abbreviation of the notched-noise masking method used by these and many other investigators to determine auditory filter bandwidth. The FRI was taken as the difference between two pure-tone thresholds. The first threshold was obtained in the presence of a bandpass white noise masker centered on the test frequency and having a bandwidth of $0.8 f_0$ Hz ($f_0 =$ test frequency). The second threshold was obtained in the presence of a notched-noise masker in which a notch, $\pm 0.3 f_0$ Hz wide, centered on the test frequency, was defined by two bands of white noise each $0.4 f_0$ Hz in width. Notch slopes were about 200 dB/octave and minimum notch depth was 35 dB. This minimum depth was chosen based on a pilot study which determined that the FRI was essentially unchanged for notch depths ranging from 50 to 30 dB when masker spectrum level was held constant at 40 dB. In practice, notch depths as small as 35 dB were used only for low-level maskers. Typical notch depths were 40–50 dB.

The temporal resolution index (TRI) measurement procedure was an adaptation of the test for temporal resolution factor described by Zwicker (1980). Like the FRI, the TRI was taken as the difference between two pure tone thresholds. The first threshold was obtained using the same $0.8 f_0$-Hz bandwidth white noise masker as used for the FRI. The second threshold was obtained with the same masking noise ($0.8 f_0$-Hz bandwidth) 100% amplitude modulated by a 14-Hz square wave.

Thus, for one test frequency, at one masking level, both the FRI and the TRI were derived from pure-tone thresholds obtained with three different bandlimited white noise maskers. They will be referred to as bandpass (unmodulated-unnotched), notched (unmodulated-notched), and modulated (modulated-unnotched). Wide-band modulated and unmodulated noises were produced by a function synthesizer (Hewlett Packard model 8904A). These noises were notched and/or bandlimited using two cascaded two-channel brickwall filters (Wavetek model 852), and a bandpass filter (Frequency devices model 9002), respectively. Signals were presented via a Telephonics TDH49 earphone encased in a Telephonics MX41-AR supra-aural cushion and spring headband. Levels were calibrated in a standard 6-cm^3 coupler. The nominal level of all maskers was the corresponding one-octave band level of the bandpass masker. At each nominal masker level, the three masking noises were presented at the same spectrum level.

2. Procedure

The indices were measured using a Bekesy tracking test method. Threshold for the pulsed test tone was tracked in the presence of each of the three continuous masking noises. The one-octave band level of the bandpass and modulated maskers was varied from 40 to 90 dB SPL at all test frequencies. For the notched masker, the lowest sound-pressure level used was the lowest level at which it was possible to maintain a 35-dB notch depth (44 dB SPL at the three lower test frequencies and 52 dB SPL at 3000 Hz), 90 dB SPL was the upper limit.

A test run began with the masker at the lowest level. During a run, the level of the masker was incremented in 1-dB steps at the rate of 10 dB/min. The test tone was pulsed at a rate of 2.5 pulses/s (rise/fall time = 15 ms) with a 50% duty cycle. The subject was instructed to respond by depressing a button when the tone was audible and releasing the button when the tone was not audible. The level of the tone was varied at a rate of 3 dB/s. If the button was depressed, the tone level was decremented. If the button was released, the tone level was incremented. A reversal occurred when the test tone level changed from increasing to decreasing or vice versa. The levels of test tone and masker were recorded at each reversal.

For all test frequencies, a white noise with low-pass cutoff below the frequency limits of the primary maskers was added at a spectrum level 25 dB below that of the primary maskers to ensure that switching transients or other distortion products would be inaudible. In addition, to prevent participation by the untested ear, white noise at an effective masking level of 40–45 dB SPL was presented to the contralateral earphone.

Data were collected at four test frequencies: 500, 1250, 2000, and 3000 Hz. For each test frequency, two runs were executed for each of the three maskers. This test procedure required about 40 min of testing time per frequency.

3. Subjects

Ten subjects provided data for each index at each test frequency. Except for one subject at 3000 Hz, the same individuals served at all frequencies. Subjects' pure-tone thresholds for the test frequencies were less than 25 dB SPL. Ages ranged from 22 to 34 years, with a mean of 26.

B. Results and discussion

For each subject and test frequency, masking functions were generated for each of the three maskers. For a given masker, the function was computed using the midpoints of tracking excursions for both test runs combined. The analysis procedures provided for discarding any data where masked thresholds were within 5 dB of threshold in quiet (however, it was not necessary to discard any data on this basis). The number of excursion midpoints used to produce each function varied across subjects because tracking excursion widths differed. The range was 84 to 238, with a mean of 147 data points per function. To generate a masking function, these midpoint data were subjected to regression analysis to establish a least-squares best-fit line.

A preliminary analysis was performed to determine whether data for each masker were more accurately described by a first- or second-order polynomial. Both first and second-order functions were generated for each subject-frequency-masker condition and the standard error of estimate (S_{ee}) was determined for each function. The S_{ee} data were subjected to a three-way analysis of variance with test frequency, masker, and regression order as variables. This analysis produced a significant interaction between masker and regression order ($F[2,18] = 111.1$, $p < 0.001$). Post hoc analysis revealed that, for the notched masker, the S_{ee} was significantly smaller ($p < 0.001$) when a second-order regression was used whereas regression order did not significantly impact the S_{ee} for the two other maskers. Based on this outcome, a first-order polynomial was used to produce masking functions for both the bandpass and modulated maskers. A second-order polynomial was used to generate functions for the notched masker. Using these procedures, the mean S_{ee} was in the range 2.0 to 2.2 dB, and standard deviations of $S_{ee}s$ were < 0.5 dB, for all maskers.

The resulting masking functions are illustrated in Fig. 1. This figure depicts masking functions determined for each subject for the 3000-Hz test frequency. The left panel depicts the two functions that would be used to derive the FRI and the right panel shows corresponding data for the TRI. Results for the other test frequencies were qualitatively similar to these for 3000 Hz. Functions for the bandpass noise showed a relatively small range of variation across subjects. For the modulated noise masker, between-subject variability was considerably larger. The notched noise also produced a fairly wide range of results across subjects and the functions generally were substantially curved with a slope that increased with masker level. Weber (1977) reported similarly curved growth of masking functions for notched-noise maskers with notch widths greater than ± 0.075.

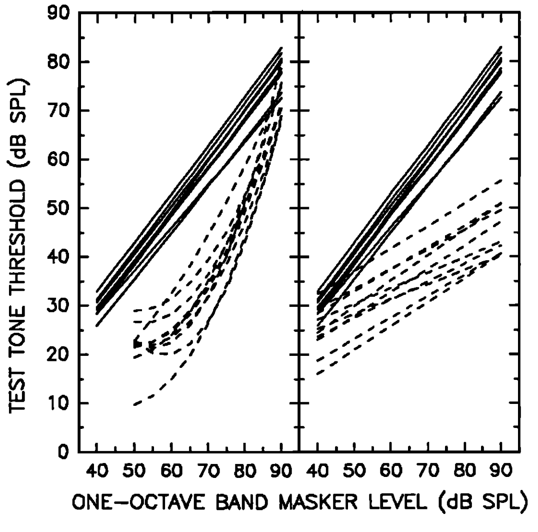

FIG. 1. Masking functions for a 3000-Hz tone as a function of the one-octave band sound-pressure level of the bandpass masker. The right panel depicts functions for the bandpass (solid lines) and notched (dashed lines) maskers. The left panel shows functions for the bandpass (solid lines) and modulated (dashed lines) maskers. Functions are given for all ten subjects.

For each test frequency, these data were used to generate norms for each index. The procedure was as follows: (1) the masking functions for the bandpass noise were normalized at a one-octave band masker level of 70 dB; (2) for each subject, the two other masking functions were adjusted in level by the same amount as the bandpass function; (3) means and unbiased standard deviations for the normalized data were computed for each function across the 10 subjects at 5-dB masker increments encompassing the tested range; (4) for each masker increment, the range of levels estimated to encompass 95% of the population data were determined.

The results are shown in Figs. 2–5. The solid lines depict the 95% range of the masking function for the bandpass masker after normalization at a one-octave band level of 70 dB SPL. The dash-dot lines describe the 95% range of the masking function for the corresponding notched masker (left panel) and the corresponding modulated masker (right panel). It is anticipated that only 5% of normal hearing listeners would produce data outside these bounds. Normalization of the masking functions for the bandpass masker minimized the effects of between-subject differences in detector efficiency. Nevertheless, even after normalization, between-subject differences were substantial for the other two maskers. This is revealed by the relatively wide separation between the upper and lower bounds of the norms for these maskers in Figs. 2–5 (the dash-dot lines). To allow accurate reproduction of these norms by other investigators, the four curves comprising each panel were empirically fitted with second-order polynomials. All of the derived curves produced a correlation in excess of 0.999 with the original curve. Coefficients for the resulting equations are given in Table I.

The slope of the mean functon for the bandpass masker was close to 1.0 for all test frequencies (range 0.98–1.01), as

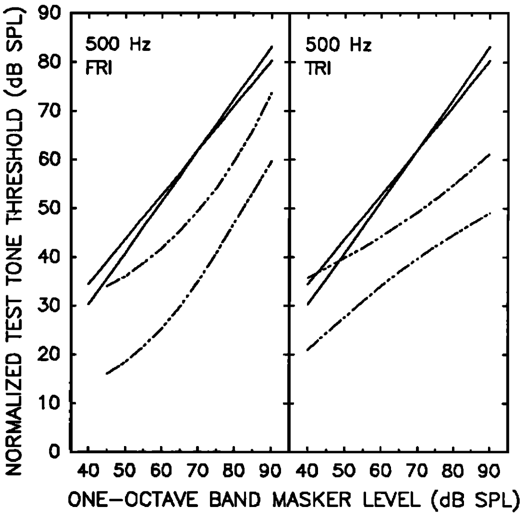

FIG. 2. Norms for masking functions comprising the frequency resolution index (FRI, right panel) and the temporal resolution index (TRI, left panel) at 500 Hz. The pair of solid lines illustrates the estimated range of the masking function for the bandpass masker for 95% of normal hearing listeners, after normalization at a masker level of 70 dB SPL. The pair of dash-dot lines illustrates the corresponding range of masking functions for the notched masker (right) and modulated masker (left).

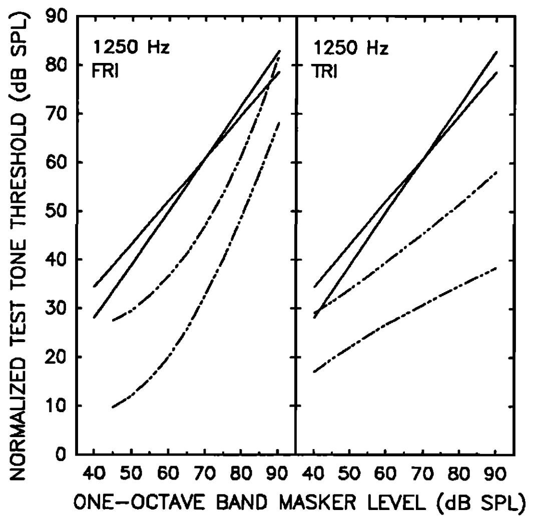

FIG. 3. Same as Fig. 2, for 1250 Hz.

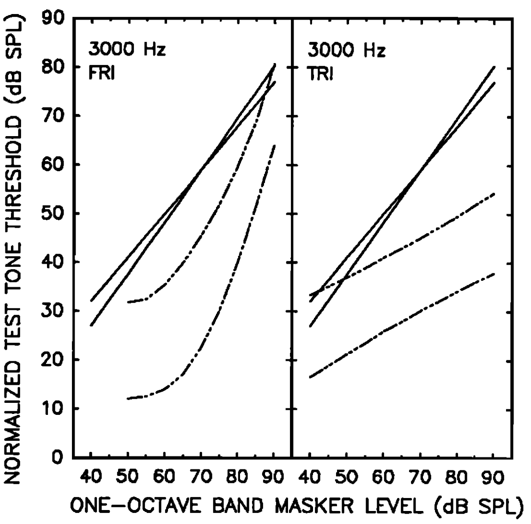

FIG. 5. Same as Fig. 2, for 3000 Hz.

would be expected for simultaneous masking with coincident test and masker frequency (e.g., Stelmachowicz *et al.*, 1987).

On the basis of the reports by Zwicker and Schorn (1982, 1990), we would predict that the slopes of the mean masking functions for the modulated noise would approximate 0.5. The obtained mean functions were close to this prediction, ranging from 0.53 to 0.42 (these functions would bisect the TRI dash-dot lines in Figs. 2–5). However, there was a systematic decrease in slope with increase in test frequency. The four mean slopes were 0.53, 0.50, 0.43, and 0.42 at test frequencies 500, 1250, 2000, and 3000 Hz, respectively. Studies of gap detection in bandlimited noises similar to those used in this study have shown that normal-hearing listeners can detect shorter gaps at higher test frequencies (e.g., Shailer and Moore, 1985). Based on this outcome, it was not surprising to observe apparently better performance

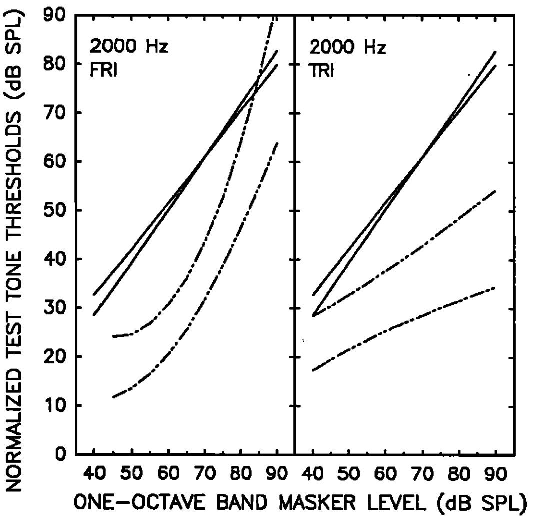

FIG. 4. Same as Fig. 2, for 2000 Hz.

TABLE I. Coefficients of second-order polynomials describing the upper and lower bounds of norms shown in Figs. 2–5. For each polynomial, $y = \beta_0 + \beta_1 x + \beta_2 x^2$, where y = test tone threshold, after normalization (dB), and x = one-octave band masker level (dB SPL). BP = bandpass masker, NCH = notched masker, MOD = modulated masker.

Hz	Masker	Bound	β_0	β_1	β_2
500	BP	Upper	3.8995	0.6788	0.0022
		Lower	−18.228	1.2973	−0.0022
500	NCH	Upper	46.872	−0.8527	0.0127
		Lower	16.159	−0.5066	0.0111
500	MOD	Upper	26.472	0.1149	0.003
		Lower	−12.423	0.9542	−0.003
1250	BP	Upper	8.9214	0.5092	0.0035
		Lower	−25.442	1.4697	−0.0035
1250	NCH	Upper	58.624	−1.6244	0.0209
		Lower	27.911	−1.2783	0.0192
1250	MOD	Upper	11.57	0.3667	0.0017
		Lower	−5.8259	0.6408	−0.0017
2000	BP	Upper	1.4003	0.6972	0.0023
		Lower	−21.179	1.3283	−0.0023
2000	NCH	Upper	105.89	−3.4657	0.0368
		Lower	31.339	−1.2504	0.0179
2000	MOD	Upper	14.466	0.2691	0.0019
		Lower	−3.2339	0.5923	−0.0019
3000	BP	Upper	3.873	0.6026	0.0027
		Lower	−23.209	1.3595	−0.0027
3000	NCH	Upper	90.425	−2.5124	0.0267
		Lower	119.88	−4.0686	0.0383
3000	MOD	Upper	21.391	0.2453	0.0013
		Lower	−5.4767	0.6021	−0.0013

at higher frequencies in the present study, since the temporal resolution task required detection of a tone during brief gaps (36 ms) in the masking noises.

Figure 6 depicts the mean TRI function determined for each test frequency. These functions were obtained by subtracting the mean normalized masking function for the modulated masker from that for the bandpass masker. They describe the extent to which the typical listener was able to exploit the brief intervals in the masking noise to improve detection of the test tone. Each TRI function rose monotonically with masker level, indicating that this measure of temporal resolution produced improved performance as masker level increased. A similar outcome can be seen in the data generated by Zwicker (1980) and Zwicker and Schorn (1982, 1990), using similar procedures. Studies of temporal gap detection thresholds have also typically produced improved performance with increasing level (e.g., Fitzgibbons, 1983; Shailer and Moore, 1983), although other approaches to the quantification of temporal resolution have not always shown this trend (e.g., Nelson and Freyman, 1987).

The curved masking functions for the notched noise were indicative of a region of masker levels where frequency resolution abilities were at a maximum: both higher and lower masker levels produced smaller indices. These results can be seen in Figs. 2–5 but are especially clear in Fig. 7 which depicts the mean FRI function for each test frequency. To produce these functions, the mean normalized masking function for the notched masker was subtracted from that for the bandpass masker at each test frequency. These mean functions describe the extent to which the typical listener was able to benefit from the spectral notch in the masking noise to improve detection of the test tone. As Fig. 7 shows, the influence of masker level on FRI was quite marked for all four frequencies. The masker level producing the maximum FRI was somewhat different across test frequencies, with octave band levels ranging from 60 to 70 dB SPL. The magnitude of the maximum FRI increased slightly with test frequency, ranging from 20 dB at 500 Hz to 26 dB at 3000 Hz.

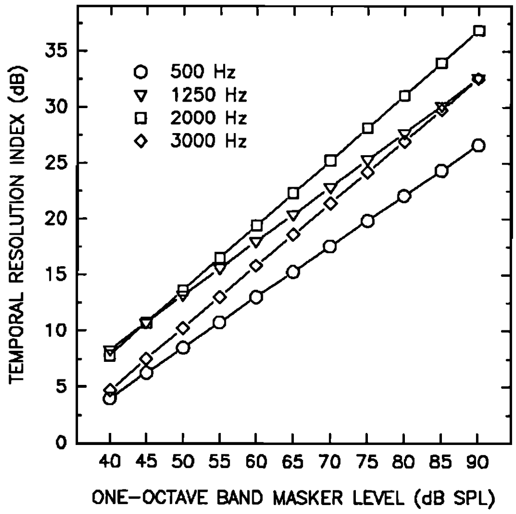

FIG. 6. Mean TRI function for each test frequency. Each function was derived by subtracting the mean normalized masking function for the modulated masker from that for the bandpass masker.

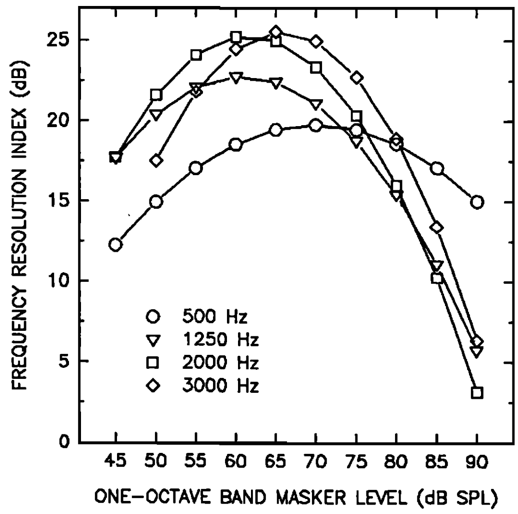

FIG. 7. Mean FRI function for each test frequency. Each function was derived by subtracting the mean normalized masking function for the notched masker from that for the bandpass masker.

Spread of masking studies reported by Zwicker and Jaroszewski (1982) and Lutfi and Patterson (1984) indicate that low level maskers produce downward spread of masking effects, whereas high level maskers produce upward spread of masking effects. This result is consistent with the changing shape of auditory filters as a function of level (see Moore and Glasberg, 1987; Glasberg and Moore, 1990, for reviews). These observations provide a basis for interpreting the FRI data in the present study. It seems likely that the effects of the notched-noise masker were dominated by downward spread of masking from the high-frequency masking band at low masker levels and by upward spread of masking from the low-frequency masking band at high masker levels. At each test frequency, there was a narrow region of masker levels for which neither upward nor downward spread of masking was substantial and these masker levels produced the maximum FRI values.

Lutfi and Patterson (1984) reported that the masker spectrum level producing a symmetric masking pattern (not dominated by upward or downward spread of masking) was about 35 dB at 1000 Hz whereas Zwicker and Jaroszewski (1982) estimated a level of 40 dB SPL to produce symmetric effects at this frequency. Glasberg and Moore (1990) note that the masker level for which the auditory filter is roughly symmetric corresponds to approximately 51 dB SPL/ERB. At the test frequencies used in this study, the corresponding spectrum levels would be approximately 32, 29, 27, and 26 dB for 500, 1250, 2000, and 3000 Hz, respectively.

In the present study, the masker spectrum levels yielding maximum FRI data were hypothesised to correspond to regions of symmetric masking effects. Using the data of Fig. 7, the spectrum levels were found to be 44.5, 30.5, 28.5, and 31.7 dB at 500, 1250, 2000, and 3000 Hz, respectively. Except for the somewhat high value at 500 Hz (see experiment II), these results correspond well to the levels cited by other investigators as producing symmetric masking, lending support to our interpretation of the FRI data in terms of a progression from downward spread of masking to symmetric masking and then to upward spread of masking effects as masker level is increased.

Figure 7 reveals that the mean FRI function obtained for 500 Hz was considerably less curved than those for the three other test frequencies, suggesting less upward spread of masking at high notched-masker levels. Furthermore, the octave band masker level producing the maximum FRI was higher (70 dB) at this frequency than at the other test frequencies. We postulated that this difference might be the result of low-frequency leakage under the TDH-49 earphones. Previous studies have shown that acoustic leakage under the Telephonics MX41-AR cushion/headband assembly may become substantial as frequencies decrease below about 400 Hz (Cox, 1986). This would have the effect of reducing the level in the low-frequency band of the notched masker at 500 Hz by 5–10 dB. This would, in turn, decrease upward spread of masking effects at high masker levels due to this band. Additional data were obtained to explore this hypothesis.

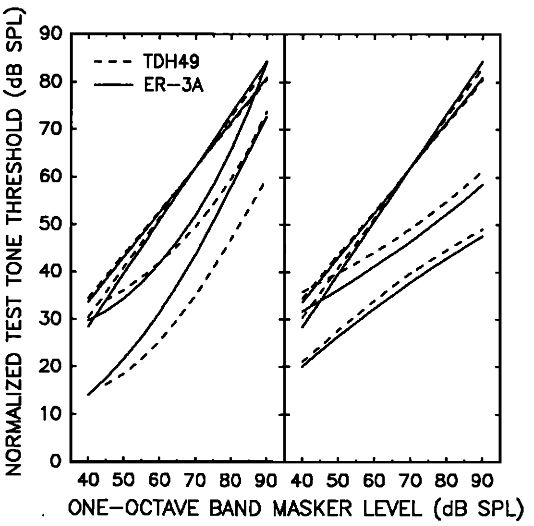

FIG. 8. Norms for masking functions comprising the frequency resolution index (FRI, right panel) and the temporal resolution index (TRI, left panel) at 500 Hz. Dashed lines depict results for TDH49 earphone and solid lines show corresponding data for ER-3A earphone. Each pair of lines illustrates the estimated range of the masking function for 95% of normal hearing listeners, after normalization at a one-octave masker level of 70 dB SPL.

II. EXPERIMENT II: NORMS FOR INSERT EARPHONE

To evaluate the likely effects of low-frequency leakage under the Telephonics earphone cushion, additional norms (both FRI and TRI) were generated for the 500-Hz test frequency using an insert earphone (Etymotic ER-3A) coupled to the earcanal with a compressible foam earplug. Because the foam earplug makes a tight seal with the earcanal, low-frequency acoustic leakage was essentially eliminated.

A. Method

1. Subjects

Ten normal-hearing subjects participated, eight of them also served in experiment I to generate norms at 500 Hz for the supra-aural earphone. The two new subjects were similar to those in the original group.

2. Procedure

Instrumentation, measurement procedures, and methods for generating masking functions and index functions were identical to those used in experiment I. Levels were calibrated in a standard HA-2 2-cm^3 coupler using the procedure recommended by the earphone manufacturer.

B. Results and discussion

Figure 8 depicts the FRI and TRI norms obtained using the insert earphone (solid lines) and compares them with the corresponding norms obtained with the supra-aural earphone reproduced from Fig. 2 (dashed lines). Examination of this figure reveals that the norms for the bandpass masker for both earphones (the two upper pairs of lines in both panels) were almost identical.

In contrast, the norms for the notched masker (lower pairs of lines, left panel) had a substantially different pattern for the insert earphone (solid lines) and the supra-aural earphone (dashed lines): The masking function slope was greater for the insert earphone and the width of the normal range of results was reduced at higher masker levels. This result is in agreement with our hypothesis that leakage under the supra-aural earphone cushion reduced the level of the low-frequency band of the notched masker, resulting in reduced upward spread of masking at higher masker levels. The outcome suggests that presentation of stimuli using an insert earphone reduced low-frequency sound leakage and also generated more consistent earcanal levels across subjects, thus decreasing variability.

The different outcome for the two earphones is seen very clearly in Fig. 9, which illustrates the mean FRI function for

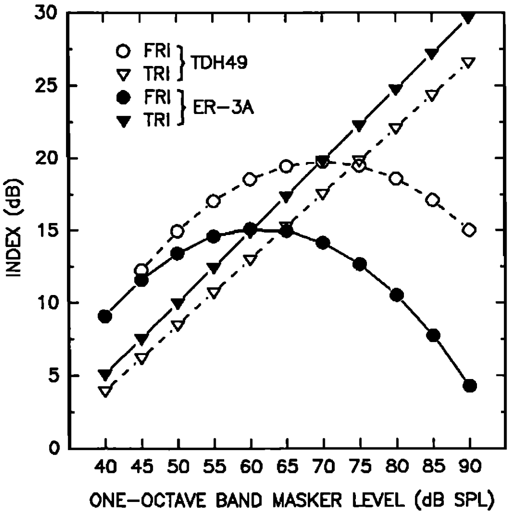

FIG. 9. Mean FRI and TRI functions at 500 Hz obtained using TDH49 and ER-3A earphones.

each earphone. The function for the insert (ER-3A) earphone is similar to that for the supra-aural (TDH49) earphone at low masker levels but diverges systematically as masker level increases. The octave band masker level that produced the maximum mean FRI was reduced from 70 dB for the supra-aural earphone to 60 dB for the insert earphone. This value is more consistent with the supra-aural earphone results for higher frequencies where acoustic leakage was not expected to occur (see Fig. 7). In addition, the corresponding spectrum level of 34.5 dB is in closer accord with levels determined by previous investigators to produce symmetrical masking and to correspond to a symmetrically shaped auditory filter.

The right panel of Fig. 8 compares the TRI norms obtained with the supra-aural and insert earphones. The results for the modulted noise are similar but at slightly different levels for the two earphones: For a given nominal masker level, tone thresholds in the modulated masker were a few decibels lower in the insert earphone condition. This outcome may be attributable to the slightly higher level produced in the earcanal by the insert earphone. The result was a slightly larger mean TRI for the insert earphone at all nominal masker levels, as illustrated in Fig. 9. Comparison of these data with those in Fig. 6 reveals that the insert earphone data at 500 Hz are in good agreement with the supra-aural earphone data at higher frequencies.

III. EXPERIMENT III: RELIABILITY OF INDIVIDUAL DATA

A. Method

1. Subjects

Nine normal hearing subjects served in this part of the study. Six of them also served in the group used in experiment I. The three new subjects were similar to those in the original group.

2. Procedure

Reliability of the indices was evaluated by comparing two independent measurements of both FRI and TRI functions. A total of 16 test-retest measurements of both indices were made. Five subjects provided data at two frequencies. One provided data at three frequencies. Test frequencies for the 16 measurements were distributed as follows: eight at 3000 Hz, six at 500 Hz, and two at 2000 Hz. Instrumentation, measurement procedures, and methods for generating masking functions and index functions were identical to those used in experiment I. TDH49 earphones were used. For 15 measurements, the two sets of data were obtained consecutively without removing the earphones. For one measurement, the two sets of data were collected several days apart.

B. Results and discussion

Two FRI functions were generated for each data set and differences between the two functions were determined by subtracting the second function from the first. The same procedures were followed for the TRI functions. Inspection of the data suggested that there were no systematic differences in test reliability at different test frequencies. Thus data were combined across frequencies for analysis. Means and unbiased standard deviations were computed for the difference data at 5-dB masker increments. The results are given in Fig. 10. For each index, the mean difference at each masker level was between 0.0 and 0.6 dB, suggesting that there was no trend for a systematic difference between the two tests. In addition, only one of the standard deviations (FRI: 90 dB) was larger than 2.5 dB and most were considerably smaller than this. This outcome indicates that both indices demonstrated good repeatability within the masker level range tested.

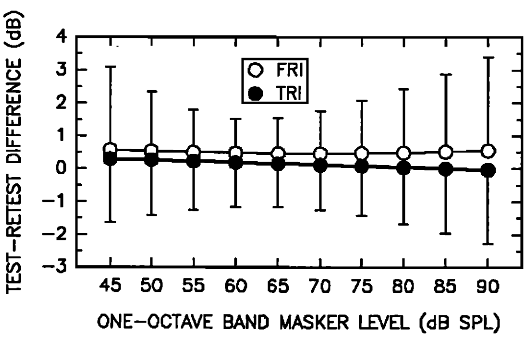

FIG. 10. Mean test–retest differences for frequency resolution indices (FRI) and temporal resolution indices (TRI) as a function of masker level. Error bars give one standard deviation.

IV. GENERAL DISCUSSION

Overall, these simplified measures of frequency and temporal resolution produced results for normal hearers that were consistent with data reported in several previous investigations that used similar or related procedures and stimuli. At each test frequency, the range of results for normal-hearing listeners was fairly wide, but the individual indices were quite reliable. Further research is needed to determine the extent to which performance of hearing-impaired listeners typically falls outside of these bounds.

It should be kept in mind that the norms presented in Table I apply to measurement of FRI and TRI obtained with Telephonics TDH49 earphones, MX41-AR supra-aural cushions, and spring headband. This transducer assembly was chosen because it is in widespread use in both research and clinical endeavors. However, the results of experiment II suggest that FRI and TRI data obtained at 500 Hz with this earphone are strongly influenced by leakage under the cushion-headband assembly. Although this does not invalidate the norms at 500 Hz, these data might be of limited usefulness. For measurements at 500 Hz, it would be reasonable to use the ER-3A earphone instead. However, the bandwidth and output limitations of this earphone make it unsuitable for tests at high frequencies or high levels.

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