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# FREQUENCY DISCRIMINATION OF SHORT- VERSUS LONG-DURATION TONES BY NORMAL AND HEARING-IMPAIRED LISTENERS

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This investigation explored the effects of stimulus level on the frequency discrimination of long- and short-duration pure tones by 5 subjects with normal hearing and 7 with sensorineural hearing impairment. Frequency difference limens (DLs) were obtained as a function of signal intensity for 5-ms and 300-ms tones at 500, 1000, and 2000 Hz. The performance of most of the hearing-impaired subjects was poorer than normal for 300-ms tones, but not for 5-ms tones. This result was relatively independent of the stimulus sensation levels at which the data were compared. However, the current results also show an unexpected dependence of the frequency DL on the sensation level of short-duration tones. In several normal-hearing subjects, frequency discrimination performance for these short tones is poorer at moderately high levels than at low levels.

It is well established that the frequency discrimination ability of listeners with moderate or greater degrees of sensorineural hearing loss is generally poorer than that of listeners with normal hearing. Whether the task involves the detection of frequency modulation (Zurek & Formby, 1981), or the frequency discrimination of pulsed pure tones (e.g., Butler & Albrite, 1956; Gengel, 1973; Turner & Nelson, 1982; Wightman, 1982), the data show that most hearing-impaired listeners have larger frequency difference limens (DLFs) than do normal-hearing subjects. Despite the fact that the frequency discrimination abilities of hearing-impaired listeners have been widely studied, the mechanisms underlying deficits in pure-tone frequency discrimination are still poorly understood, and very little is known about how these deficits may be related to difficulties they may experience with the discrimination and recognition of more complex signals. Before these issues can be resolved, the variables affecting the frequency discrimination performance of hearing-impaired listeners must be thoroughly described.

Except for a very few studies, the effects of signal duration on the relationship between the DLFs of normal-hearing and hearing-impaired listeners have not been thoroughly investigated. Most of the data from impaired listeners have been collected using relatively long-duration pure tones of 200 ms or more. The tones are long in the sense that the auditory system's temporal integration processes appear to be nearly complete by 200 ms. Additionally, these tones are long enough so that their spectra are narrow band and, for practical purposes, closely resemble the line spectra associated with pure tones of infinite duration. Finally, although the frequency discrimination ability of normal listeners improves as stimulus duration increases, only very small improvements are typically observed as duration approaches 200 to 300 ms (Henning, 1970; Liang & Chistovich, 1961; Moore, 1973; Turnbull, 1944).

The few studies that have examined the discrimination abilities of hearing-impaired listeners for signal durations shorter than 200 ms show that their relative performance is closer to normal than it is for longer-duration tones. Gengel (1973) compared the DLFs of 3 normal-hearing and 5 hearing-impaired listeners for 50-ms and 500-ms pure tones. Mean DLFs of the hearing-impaired listeners for 500-ms tones were from 4 to 9 times as large as the normal mean, depending on the frequency of the standard. For 50-ms tones, the average DLFs were only between 2 and 4 times the normal mean. As Gengel pointed out, the absolute differences in Hz between the DLFs for 50-ms and 500-ms tones were approximately the same in the two groups of subjects. However, the relative change was smaller in the hearing-impaired subjects. Hall and Wood (1984) obtained DLFs for 90 dB SPL tones at 5 durations between 5 and 200 ms for 500-Hz and 2000-Hz standards. The DLFs obtained from hearing-impaired subjects for 200-ms tones were poorer than those obtained from normal-hearing subjects. However, several of the hearing-impaired subjects demonstrated a less rapid deterioration in the DLF as signal duration was decreased in the shortest duration region (i.e., from 10 to 5 ms). For 5-ms tones, only minimal differences existed between the average DLFs obtained from normal and impaired listeners.

Because these studies of frequency discrimination for short-duration tones in hearing-impaired listeners have used only one presentation level for each subject, it is not yet known how the intensity of the stimulus affects the relationships between the DLFs of normal and hearing-impaired listeners for short-duration tones. It is well known that for long tones, frequency discrimination performance deteriorates at low sensation levels (SLs) (e.g., Harris, 1952; Nelson, Stanton, & Freyman, 1983; Wier, Jesteadt, & Green, 1977). As a result, most investigators interested in using a single presentation level to estimate the optimum frequency discrimination performance of

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normal-hearing and hearing-impaired listeners have selected levels of at least 25 dB SL. For example, the majority of Zurek and Formby's (1981) subjects were tested at 25 dB SL. Others (e.g., Butler & Albrite, 1956) have used high stimulus SPLs for both normal-hearing and hearing-impaired listeners. Gengel's (1973) normal-hearing subjects were tested at 95 dB SPL. The hearing-impaired listeners were tested at a comfortable loudness level, which also averaged approximately 95 dB SPL. For most subjects in these studies, the sensation levels were high enough so that it may be assumed that optimum or nearly optimum discrimination performance was measured for long-duration tones. However, this same assumption may not be made for high-level short-duration tones, because very little is known about the effects of signal level on the DLF for these tones. The goals of the current investigation were to compare the frequency discrimination performance of normal and hearing-impaired subjects for both long and short tones, and to study the effects of stimulus level on these relationships, particularly for short-duration tones.

## METHOD

### *Subjects*

Five normal-hearing subjects and 7 subjects with sensorineural hearing impairment participated in this experiment. All subjects except one hearing-impaired subject, EJ, were college students. The normal-hearing subjects ranged in age from 21 to 28 years (median = 23) and had hearing thresholds better than 10 dB HL from 125 to 4000 Hz. The hearing-impaired subjects ranged in age from 20 to 46 years with a median age of 23. Most subjects had moderate hearing losses with flat or gradually sloping audiometric configurations, although one subject (RX) had a hearing loss classified as severe. It was desirable to study subjects with moderate or greater degrees of hearing loss to increase the likelihood that their DLFs for long-duration tones would be abnormal, thus allowing the effects of signal duration on this deficit to be investigated. Specific etiologies of most of the hearing losses were unknown, although audiological test results were in every case indicative of cochlear pathology. Two of the hearing-impaired listeners (GR & JC) had extensive previous experience as subjects in psychoacoustic experiments. Among the normal-hearing listeners, only the first author (RF) had extensive previous experience. Only one ear of each subject was tested.

### *Stimulus Generation*

The standard test signals were pure tones with frequencies of 500, 1000, or 2000 Hz with durations of 5 or 300 ms. Each tone consisted of a 2-ms linear rise time (0–100% of full amplitude) followed by a 5- or 300-ms steady-state portion, and then a 2-ms linear fall time. The standard pure tones were created digitally on a PDP-8 computer, and were presented via digital-to-analog (D/A) conversion at 20,000 points/s. The variable tones were always lower in frequency than the standards and were generated through D/A conversion of these same waveforms at rates below 20 kHz. A Rockland Frequency Synthesizer with .001 Hz resolution served as the clock that controlled the D/A conversion rate. Therefore, the frequency of the stimulus was easily controlled by changing the frequency of the synthesizer. At slower D/A conversion rates, the number of waveform points in the steady-state and rise-fall portions of the waveform was adjusted to preserve essentially constant (to within .05 ms) overall durations and rise-fall times. The onset phase of the stimuli was varied randomly from presentation to presentation.

The output of the D/A converter was low-pass filtered at 5600 Hz with an attenuation characteristic of 24 dB/octave. The output of the low-pass filter was attenuated via two programmable attenuators, the first active and the second passive. It was then passed through a passive mixer, a transformer, and finally, to a TDH-49 earphone mounted in an MX-41/AR cushion. The low-pass filter, in combination with the high frequency attenuation provided by the TDH-49 earphone, was sufficient to ensure that the level of distortion components arising from aliasing was so low that they could not have provided cues for discrimination. For the rarely occurring worst-case condition, the lowest frequency distortion product due to aliasing was calculated to be at approximately 17000 Hz and at least 67 dB down from the peak level at the nominal frequency of the test tone. Acoustically measured harmonic distortion components were more than 60 dB down from the level of the fundamental.

### *Psychophysical Procedures*

A four-alternative forced-choice (4AFC) adaptive procedure similar to that described in Nelson et al. (1983) was employed. Standard-frequency tones were presented in three of the intervals, while the fourth, randomly chosen, interval contained the variable-frequency tone, which was always lower than the standard. Each 4AFC trial consisted of a warning light, followed by the four signal intervals that were also marked by lights, and then an answer interval. The time between the onset of one stimulus and the onset of the following stimulus was a constant 550 ms. During the answer interval, the subject pressed one of four response buttons corresponding to the interval that was believed to be different. Feedback was provided by illuminating the button corresponding to the interval in which the lower frequency tone was presented.

A two-hits-down one-miss-up adaptive procedure was used to estimate the 70.7% point on the psychometric function (Levitt, 1971), down indicating a smaller frequency difference and up a larger difference. The starting frequency difference was 10% of the standard frequency. The initial adaptive step increased or decreased the frequency difference by a factor of 2.0 following one miss or two consecutive hits, respectively. After four reversals, the step size was reduced to a factor of 1.19 ($2^{1/4}$). Threshold was taken as the geometric mean of the frequency differences existing on the last 8 out of 12 total reversals.

DLF estimates were obtained at as many as 10 SPLs that were above each listener's threshold for the standard tone. For normal-hearing listeners, the test levels were whole-number multiples of 10 dB SPL, ranging from near threshold levels to 80 dB SPL for 300-ms tones and 100 dB SPL for 5-ms tones. Because of the reduced dynamic ranges of the hearing-impaired listeners, or the smaller range of levels between their thresholds and the maximum output of the equipment, we were able to use a smaller interval size of 5 dB in most cases. Ten-dB steps were employed for some hearing-impaired subjects in conditions in which the dynamic range was large and the use of 5-dB steps would have resulted in excessively long experimental sessions. The order of the test levels for a given experimental run was random. Typically, two 5-ms and two 300-ms DLF intensity functions were obtained in a 2-hour session. For the subjects who were tested at more than one frequency, the order of data collection always began with the 1000-Hz standard, usually followed first by 500 Hz and then by 2000 Hz.

Immediately before each intensity-function run, subjects obtained a detection threshold in quiet for the standard tone, so that thresholds for both 5-ms and 300-ms tones at the standard frequencies would be available for SL computations. A 4AFC adaptive procedure similar to that used in the frequency discrimination experiment was employed. The signal was presented in one of four lighted intervals, and the subject responded by pressing one of the four buttons corresponding to those intervals. Feedback was again provided after each response by lighting the button associated with the interval that contained the signal. The initial adaptive step increased or decreased the signal level by 8 dB for one miss or two consecutive hits respectively. After four reversals, the step size was reduced to 2 dB. Threshold was taken as the mean SPL existing on the last 6 of 10 total reversals. This identical procedure was used to obtain absolute thresholds for 200-ms tones across the frequency range of 125 to 8000 Hz. These forced-choice audiograms for the test ear in each hearing-impaired subject are displayed in Figure 1.

All subjects received at least 6 hours of practice before their data were used for DLF estimates. Final DLF estimates were based on the geometric means of at least four retests, and final absolute threshold estimates were also based on the mean of at least four retests.

## RESULTS

### *Normal-Hearing Listeners*

Complete long- and short-duration DLF intensity functions were obtained at 1000 Hz from all 5 normal-hearing subjects. One of the 5 (CE) was also tested at 500 Hz, a second subject (RF) was also tested at 2000 Hz, and a third (DH) was tested at all three frequencies. The 1000-Hz DLF intensity functions are displayed in Figure 2, where the DLFs are plotted on a log scale as a function of stimulus sensation level. (Data for the other frequencies are displayed in composite form in Figure 4.)

There are obvious differences across subjects in the form of the 300-ms functions. The function obtained from Subject RF shows a rapid improvement in the DLF at low sensation levels, then levels off beyond approximately 30 dB SL. However, the DLFs obtained from Subject DH, and to a lesser extent, Subject AN, continue to decrease gradually to at least 65 dB SL. Subjects JH and CE show gradual but steady increases in the DLF with increasing level beyond approximately 20 dB SL. Similar subject differences in the form of the functions were observed at 500 and 2000 Hz. Subject DH showed continued improvement at higher sensation levels at all 3 frequencies, while Subject CE, who demonstrated poorer performance at high sensation levels at 1000 Hz, also showed this trend at 500 Hz. In general, the level effects at high SLs appear to be small and the functions do not differ markedly from the published normal data which show slow monotonic decreases in the DLF above 30 dB SL.

In contrast, the short-duration results clearly do not show monotonic decreases in the DLF with increasing stimulus intensity. At 1000 Hz, an increase in the DLF over a range of sound pressures between 30 and 70 dB SL, followed by a decrease at higher levels, is observed in the data of 4 of the 5 subjects (CE is the lone exception). The data obtained at 500 and 2000 Hz (shown only in Figure 4) indicate that the nonmonotonicity may be frequency dependent. The 500-Hz data are similar to those obtained at 1000 Hz. The function obtained from Subject DH again displayed nonmonotonic behavior while that obtained from Subject CE again did not. However, at 2000 Hz, no evidence of a "hump" was found in Subject DH's data, and the nonmonotonicity was clearly less evident in Subject RF's 2000-Hz function than in his 1000-Hz function.

### *Hearing-Impaired Subjects*

Both short- and long-duration DLF intensity functions were obtained from all 7 hearing-impaired subjects at 1000 Hz. Two subjects (RX & EJ) were also tested at 500 Hz. Four subjects (GR, JC, KE, & BA) were tested at 500, 1000, and 2000 Hz. The 1000-Hz results for the 7 hearing-impaired subjects are plotted in Figure 3. The details of the 300-ms functions differ substantially from subject to subject. However, the general form of the functions is essentially the same: A rapid decrease in the DLF over the first 15 to 25 dB SL is followed by a flat or slowly changing function with further increases in level. The data that are the most difficult to evaluate are those of Subject RX, who had the highest absolute thresholds. Because only three levels were tested, it is difficult to determine whether her DLFs were approaching an asymp-

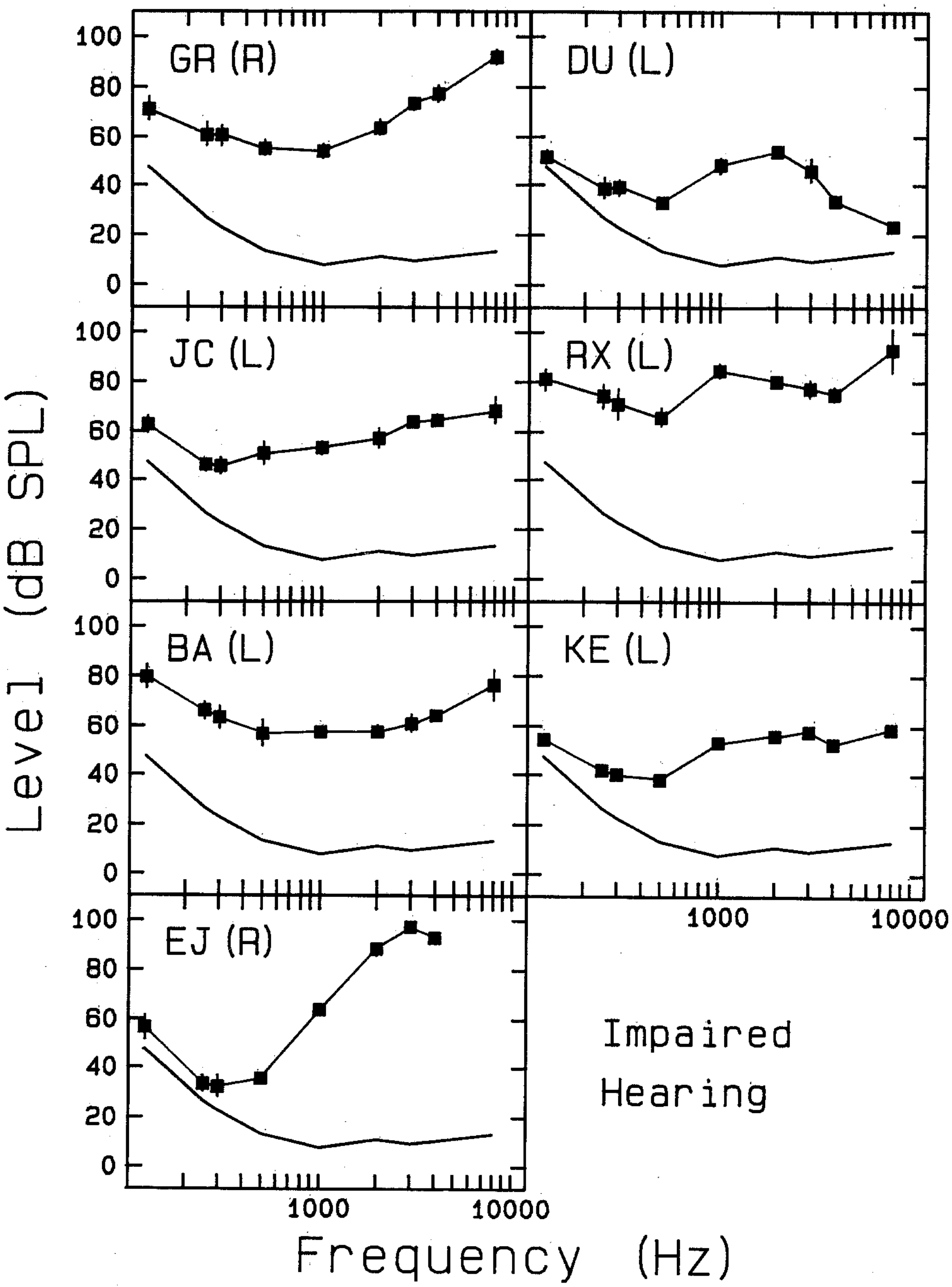


FIGURE 1. Sensitivity curves, using 200-ms tones, for the 7 hearing-impaired subjects. The test ear (R) or (L) is indicated with the initials of each subject. The solid lines without symbols are the mean thresholds of normal-hearing subjects tested in our lab with the 4AFC procedure.

tote or whether they would have improved further had it been possible to present higher signal levels.

The vast majority of the data points obtained from the impaired listeners are above the dashed lines (fitted normal means established with this 4AFC procedure by Nelson et al., 1983), indicating that their DLFs at 1000 Hz for 300-ms tones were poorer than normal. Similar results were observed at the other test frequencies.

The short-duration data also show rapid decreases in the DLF at low sensation levels, and relatively flat functions at higher levels. However, there are a few exceptions. The functions obtained from Subject EJ and especially from Subject DU show a worsening trend at the highest levels. This trend was also observed in several of the functions obtained at 500 Hz but was not apparent in any of the 2000-Hz data.

The long- and short-duration DLFs obtained from most of the hearing-impaired subjects clearly converged at low sensation levels, in some cases (e.g., Subject JC) because the long-duration DLF intensity function was steeper than the short-duration function, and in others (e.g., Subject KE) because the steep portion of the 300-ms function extended to higher SLs. The convergence is in contrast with the normal data, which show large differ-

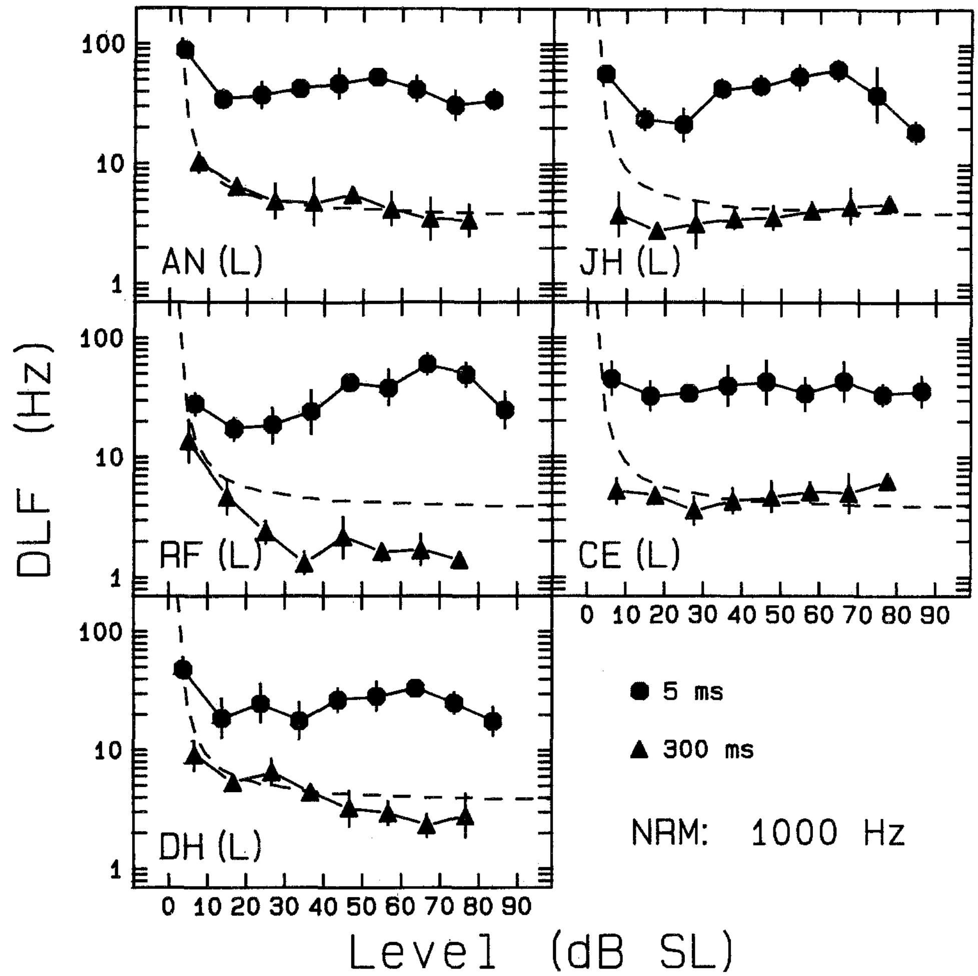


FIGURE 2. DLF intensity functions at 1000 Hz for normal-hearing subjects. Solid vertical lines represent one standard deviation above and below each mean. Dashed lines are the DLFs predicted by a fitting equation for normal frequency discrimination (Nelson et al., 1983) using a revised set of parameters based on the 3 subjects from that study and 4 additional subjects tested since 1983.

ences between short- and long-duration DLFs even at low sensation levels.

## DISCUSSION

### *Comparisons Between Normal and Hearing-Impaired Subjects*

It may be observed in Figures 2 and 3 that the differences between long- and short-duration DLFs are generally smaller for the hearing-impaired than for the normal-hearing subjects. This implies that the 5-ms DLFs measured in hearing-impaired subjects are closer to normal than are their 300-ms DLFs. The combined data demonstrate this result more clearly. Figure 4 displays the 300-ms and 5-ms DLF functions, as plots of log DLF versus stimulus sensation level, for all of the subjects at the three test frequencies. Filled squares represent data from normal-hearing subjects and open squares represent results from hearing-impaired subjects. Figure 4 demonstrates that, although there is some overlap, the hearing-impaired listeners generally had larger DLFs for 300-ms tones than did the normal-hearing subjects at all three frequencies.

In contrast to the 300-ms data, the 5-ms plots in Figure 4 demonstrate that at equivalent sensation levels, the data from normal-hearing and hearing-impaired subjects almost completely overlap. The results are, therefore, in agreement with those of Hall and Wood (1984). The DLFs of their hearing-impaired subjects were also quite similar to those of normal-hearing subjects for very short-duration tones. Our data displayed in Figure 4 also show that this general result—that DLFs obtained from hearing-impaired listeners for long-duration tones are poorer than normal, but their DLFs for very short-duration tones are not—is relatively independent of the sensation level at which the stimuli are presented.

A common problem that arises when normal and hearing-impaired subjects are to be compared on any psychoacoustic task is the selection of stimulus levels that

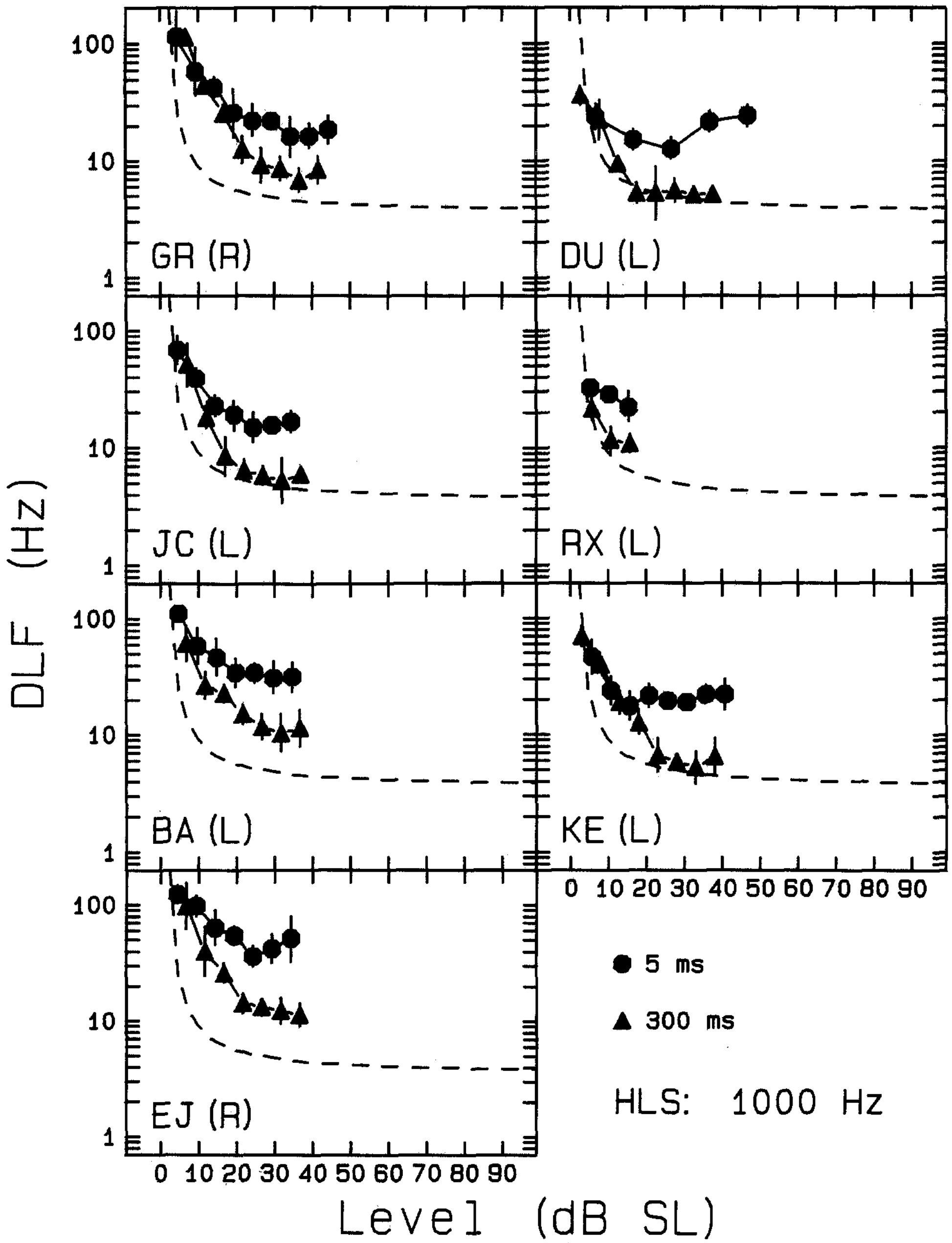


FIGURE 3. DLF intensity functions at 1000 Hz for hearing-impaired subjects. Legend as in Figure 2.

permit a valid comparison of the performance of the two groups of subjects. Frequently the conclusions of the experiment are crucially dependent on which levels are chosen. Clearly, it is not possible to compare performance on precisely equal terms because, for example, if the stimuli are equated for SL, then the SPLs are much higher for hearing-impaired subjects. If the stimuli are equated for SPL, then the SLs are much higher in normal-hearing subjects. For frequency discrimination of long-duration tones, the differences between an equal SL and an equal SPL comparison appear to be only quantitative and are reasonably predictable, as long as the sensation level for the hearing-impaired subjects is at least 25 dB. Mean normal DLFs do not asymptote completely at 25–30 dB SL but improve slowly as the sensation level is increased further (e.g., Nelson et al., 1983; Wier et al., 1977). Therefore, an equal SPL comparison, in which the SLs are much higher in the normal subjects, would generally produce slightly greater differences between normal and hearing-impaired subjects than would a comparison at equal SLs.

Table 1 displays two different comparisons of the mean DLFs. In the left column for each frequency, the mean DLFs obtained at the nearest sensation level to 25 dB are displayed and compared.[1] Twenty-five dB was selected

[1]As described in the Method section, the data were collected at

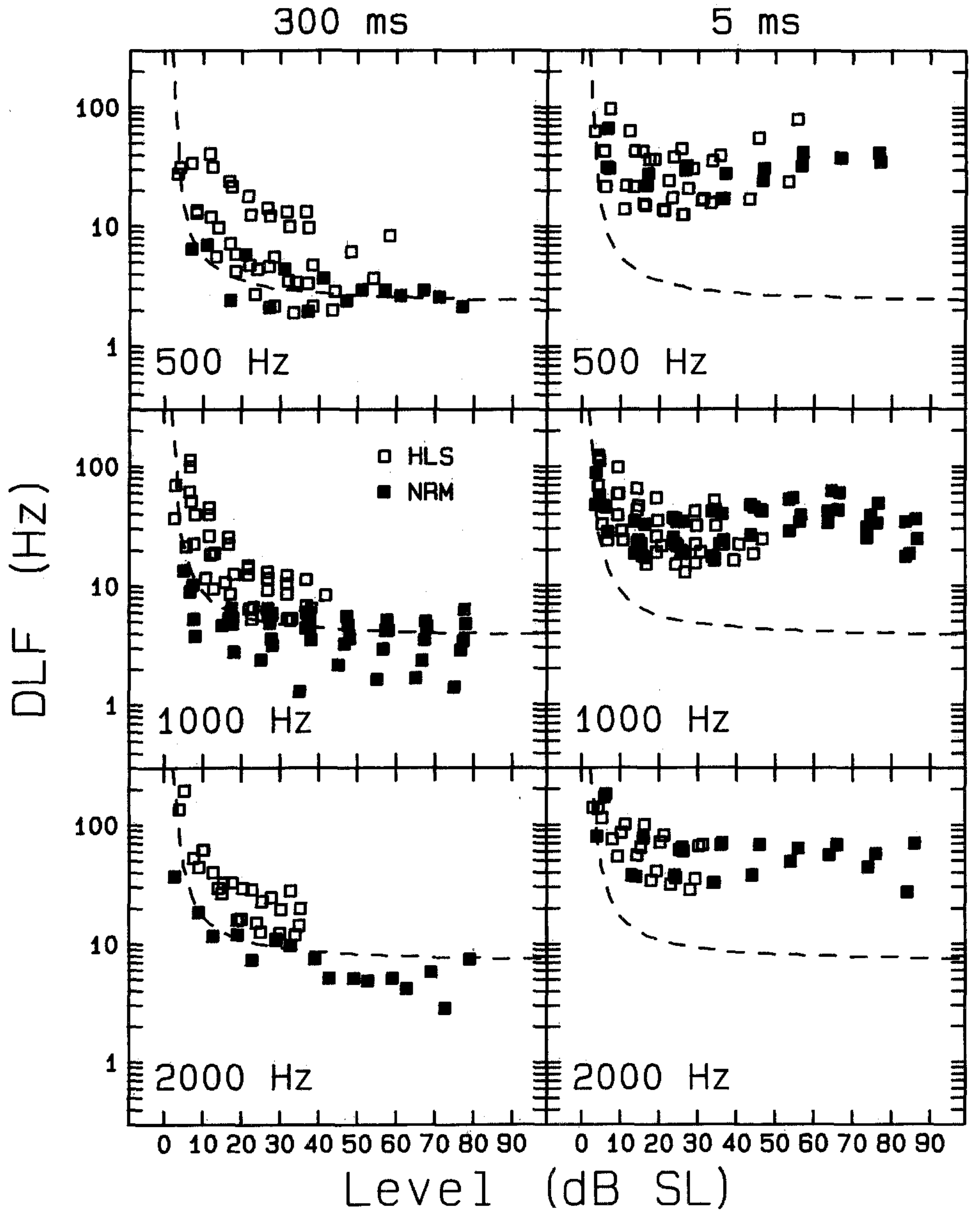


FIGURE 4. DLFs as a function of sensation level for normal-hearing listeners (filled symbols) and hearing-impaired listeners (open symbols) at different frequencies and at two durations. Dashed lines are as explained for Figure 2.

because, across conditions, the DLFs obtained from hearing-impaired listeners consistently showed little or no improvement above that sensation level. At 1000 Hz, for example, mean DLFs improved by only approximately 0.5 Hz as the sensation level of 300-ms tones was increased from 25 to 35 dB. For 5-ms tones, mean DLFs at 35 dB SL were very slightly poorer than they were at 25 dB SL. These data are consistent with Zurek and Formby's (1981) conclusion, after measuring DLFs at several SLs in some of their subjects, that 25 dB SL was an appropriate level for estimating the frequency discrimination performance of their hearing-impaired listeners.

In the table, the right column for each frequency displays the mean DLFs for normal-hearing subjects at the average SPL at which the 25 dB SL signals were presented to the hearing-impaired subjects. This level ranged from 70 to 90 dB SPL, depending on the signal frequency and duration. Thus, the table presents comparisons in which the normal data are averaged at low but similar SLs to the hearing-impaired subjects, and also at

fixed SPLs (largely for the purposes of another experiment conducted with the same listeners). Therefore, the SLs for a constant SPL signal varied according to subjects' thresholds for that signal. To combine the data within a condition at "25 dB SL," it was necessary to average them across a small range of SLs. The vast majority of these were between 23 and 27 dB SL. The smallest was 21 dB SL and the largest was 29 dB SL. Also, because Subject RX could not be tested at SLs as high as 25 dB at 1000 Hz, her data were not included in the calculation of the means at that frequency.

TABLE 1. Geometric mean DLFs in Hz for normal (NRM) and hearing-impaired (HI) subjects at 25 dB SL and, for the normals, at the average SPLs at which the 25-dB SL signals were presented to the hearing-impaired subjects. The ratio of the hearing-impaired to normal mean is also presented for each condition.

| *Subjects* | *500 Hz* | | *1000 Hz* | | *2000 Hz* | |
|---|---|---|---|---|---|---|
| 300 ms | *25 SL* | *70 SPL* | *25 SL* | *80 SPL* | *25 SL* | *80 SPL* |
| NRM | 3.48 | 2.75 | 3.84 | 3.29 | 8.90 | 4.66 |
| HI | 6.62 | 6.62 | 8.11 | 8.11 | 18.45 | 18.45 |
| HI/NRM | 1.90 | 2.41 | 2.11 | 2.47 | 2.07 | 3.96 |
| 5 ms | *25 SL* | *80 SPL* | *25 SL* | *80 SPL* | *25 SL* | *90 SPL* |
| NRM | 31.26 | 36.44 | 26.20 | 46.59 | 49.42 | 49.88 |
| HI | 21.52 | 21.52 | 21.57 | 21.57 | 45.10 | 45.10 |
| HI/NRM | 0.69 | 0.59 | 0.82 | 0.46 | 0.91 | 0.90 |

high SLs but similar SPLs to the levels at which the hearing-impaired data were analyzed.

The data displayed in the table show that for long-duration tones of 25 dB SL, mean DLFs of hearing-impaired subjects are approximately twice those of normal-hearing subjects. At equal (high) stimulus SPLs the general result is the same, but because the normal DLFs continue to improve as the level is increased to more than 25 dB SL, the ratios of hearing-impaired to normal DLFs are greater than they are for the equal SL comparison. For 5-ms tones at 25 dB SL, the means of the two groups are much more similar; in fact they are slightly better in the hearing-impaired subjects. At higher SPLs (right column) the mean normal DLFs become poorer at 500 Hz and especially at 1000 Hz, so that at 1000 Hz the average normal DLF is more than twice that of the hearing-impaired subjects at similar SPLs. We do not wish to conclude from this small group of subjects that, in general, moderately hearing-impaired listeners will have smaller DLFs than normal-hearing listeners for short-duration tones. However, it is clear, at least for the kinds of short-duration signals used here, that stimulus level may affect the relationships between the short-tone DLFs of normal and hearing-impaired subjects at some frequencies. The design of the current experiment does not permit us to draw any strong conclusions about the effects of frequency on the form of the DLF intensity function for short tones. It would be interesting to explore this issue over a wide range of frequencies in a future experiment.

Our data, and those of Hall and Wood (1984), suggest that one must be cautious in generalizing the results of frequency discrimination experiments using long-duration pure tones to the frequency discrimination of other kinds of signals. In this experiment we find that it is not valid to generalize from long-duration to short-duration versions of the same signals. Given this result, the generalization of long-duration pure-tone frequency discrimination results to the discrimination of more complex signals, such as speech formant transitions, should be regarded with even more caution, especially because the mechanisms underlying either kind of discrimination are not completely understood at the moment.

## *Theoretical Interpretations*

The fact that subjects with moderate degrees of sensorineural hearing loss appear to be able to discriminate frequency changes in short-duration tones as well as normal-hearing subjects is at least qualitatively consistent with a model in which frequency differences are detected on the basis of changes in the location of the excitation patterns evoked by the tones. The excitation-pattern model, which was described by Zwicker (1970), assumes that the discrimination of frequency differences depends on the detection of intensity differences along the steep edge of the auditory excitation patterns evoked by the standard and variable tones. Thus, the DLF is predicted to be directly proportional to the steepness of the excitation-pattern slopes. Under the assumptions of this type of model, the poorer than normal frequency discrimination performance by hearing-impaired subjects for long-duration tones may be due to more gradually sloped excitation patterns evoked by those signals. If this hypothesis were correct, then a signal that produced the same excitation-pattern slopes in hearing-impaired and normal-hearing subjects should be discriminated equally well by both groups of subjects.

It is suggested that short-duration tones may evoke excitation patterns that have similar slopes in all listeners. Following the reasoning used by Moore (1973) it may be assumed that, as a result of the broad spectral characteristics of short-duration tones, the slopes of the excitation patterns they evoke are largely determined by the slopes of the signal spectra themselves, rather than by the frequency analyzing abilities of the auditory system. Therefore, the slopes of the excitation patterns evoked by these short-duration signals should be similar for all listeners, including those who have sensorineural hearing losses. This type of excitation-pattern model then predicts that short-duration DLFs obtained from hearing-impaired subjects should not be systematically larger than those obtained from normal-hearing listeners, a prediction that is consistent with data presented in this paper and by Hall and Wood (1984). The quantitative predictions of this type of model are considered in some detail in another paper (Freyman & Nelson, 1986). Although we have not considered them here, it is possible, of course, that other types of models (e.g., temporally-based models) may also predict that hearing-impaired listeners would be able to discriminate frequency changes in short-duration tones as well as normal-hearing subjects.

The unexpected finding of larger DLFs at moderately high levels than at low levels for some subjects and conditions is not easily explained. One theory that we are testing is that the phenomenon is related to the shape of the spectrum of short-duration tones. For low-level short-duration tones, the spectrum may be effectively narrower than it is for high-level signals, because much of the spectral splatter is likely to be below threshold. The narrower effective spectrum might lead to better discrimination performance for low-level signals.

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