Susceptibility to intraspeech spread of masking in listeners with sensorineural hearing loss

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Previous research with speechlike signals has suggested that upward spread of masking from the first formant (F1) may interfere with the identification of place of articulation information signaled by changes in the upper formants. This suggestion was tested by presenting two-formant stop consonant–vowel syllables varying along a /ba/-/da/-/ga/ continuum to hearing-impaired listeners grouped according to etiological basis of the disorder. The syllables were presented monaurally at 80 dB and 100 dB SPL when formant amplitudes were equal and when F1 amplitude was reduced by 6, 12, and 18 dB. Noise-on-tone masking patterns were also generated using narrow bands of noise at 80 and 100 dB SPL to assess the extent of upward spread of masking. Upward spread of masking could be demonstrated in both speech and nonspeech tasks, irrespective of the subject’s age, audiometric configuration, or etiology of hearing impairment. Attenuation of F1 had different effects on phonetic identification in different subject groups: While listeners with noise-induced hearing loss showed substantial improvement in identifying place of articulation, upward spread of masking did not consistently account for poor place identification in other types of sensorineural hearing impairment.

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INTRODUCTION

The aims of the research reported here were threefold. The first was to evaluate, among three groups of hearing-impaired listeners, individual susceptibility to upward spread of masking with speech and nonspeech stimuli. The second was to determine whether upward spread of masking from the first formant in speech (F1) can account for impaired identification of place of articulation in two-formant consonant–vowel syllables. The third was to investigate whether the severity of masking effects vary with the subject’s age, audiometric configuration, or presumed etiology of hearing impairment.

Abnormal frequency selectivity as a consequence of cochlear pathology has been demonstrated repeatedly by a variety of measures such as neural tuning curves (Ward and Fernandez, 1961; Evans, 1974; Evans and Klinke, 1974), psychophysical tuning curves (Zwicker and Schorn, 1978; Thornton and Abbas, 1980), critical bands (deBoer and Bouwmeester, 1974), and by masking patterns (Jerger et al., 1960; Rittmanic, 1962; Florentine et al., 1980). Because masking patterns as a measure of frequency selectivity were used in the research reported here, we briefly review masking experiments in the following paragraphs.

Masking experiments can be divided into two general classes: detection masking and recognition masking. In traditional pure tone and noise masking experiments, the objective is the detection of one signal (the probe) when a competing signal (the masker) is introduced. A great deal of attention has been directed to the question of whether these masking effects differ among normal and hearing-impaired listeners. The answer to this question depends, of course, on the measure used to gauge masking. If the measure is the elevation in threshold for a probe in noise relative to the threshold for a probe in quiet, then hearing-impaired listeners evidence less masking than normal. This is a consequence of (1) a relatively large elevation in quiet threshold for the hearing-impaired listener; and (2) a nearly identical masked threshold for normal and hearing-impaired listeners when the masker is centered on the probe tone (Rittmanic, 1962). Given this circumstance the shift in threshold from the quiet to the noise masking condition is less for the hearing-impaired than for the normal hearing listeners.

This measure, which stresses the elevation in masked threshold relative to the threshold in quiet, does not speak as directly to the issue of masking spread as another measure. That is the difference in the level of the masked threshold when the masker is centered at the probe frequency and when the masker is made remote from the probe. The change in masked threshold as the masker frequency diverges from that of the probe is an indication of the spread of masking—that is, the ability of the cochlea to respond selectively to maskers centered at different frequencies. From this point of view, hearing-impaired listeners show greater spread of masking than normal. For hearing-impaired listeners there is a smaller than normal change in threshold as the masker is made remote from the probe, or alternatively, the slope of the masking function is more shallow for the hearing-impaired than for the normal hearing listeners (Jerger et al., 1960; Rittmanic, 1962; Florentine et al., 1980. See also Martin and Pickett, 1970 for a review of measures of masking). In these studies and others, a consistent finding has been that low frequencies mask high frequencies more than vice versa. That is, the “upward spread” of masking is larger than the “downward spread.”

In a second type of masking experiment, one part of a complex signal may influence the recognition of another part of the same signal (see Massaro, 1972, for a review of recognition masking with pure tone stimuli). Examples of this type
of experiment with speechlike stimuli may be found in the work of Pickett and his colleagues. They demonstrated that masking generated by a (low-frequency) F1 can interfere with the ability of severely hearing-impaired listeners to discriminate formant transitions occurring in a higher frequency range (Martin et al., 1972; Pickett and Danaher, 1975; Danaher et al., 1973). The discriminability of the higher formant transitions was improved by reducing F1 amplitude (Danaher et al., 1973), by presenting F1 to the opposite ear, and by delaying the onset of F1 (Pickett and Danaher, 1975). These results suggest that intraspeech masking, and upward spread of masking in particular, may account for the difficulty in speech intelligibility often manifested with sensorineural hearing loss. Direct evidence in support of this hypothesis from natural speech, however, is equivocal.

Studies in which low-frequency components of the speech signal were attenuated relative to the higher-frequency components have reported increases in intelligibility for only some phones and for only some speech materials (Pascoe, 1975; Dubno, 1978; Kamm, 1980; Skinner, 1980). Studies in which low- and high-frequency components were presented dichotically have also found variable benefits in phonetic intelligibility (Franklin, 1975; Turek et al., 1980; Kaplan and Pickett, 1981). Indeed, a common outcome of these experiments is great variability in the amount of improvement afforded the hearing-impaired subjects by such maneuvers. Several sources of variability may affect the outcome of recognition masking experiments.

First, past studies may not have achieved complete group homogeneity by grouping subjects on the basis of audiogram configuration or severity of impairment. Second, when subjects are tested at a fixed sensation level (SL) or diogram configuration or severity of impairment. Second, group homogeneity by grouping subjects on the basis of acoustic hearing-loss may be introduced—variations among the subjects in response to the stimuli. Third, these experiments are great variability in the amount of improvement afforded the hearing-impaired subjects by such maneuvers. Several sources of variability may affect the outcome of recognition masking experiments.

In the present investigation, one question of interest was the relationship between upward spread of masking and phonetic identification among listeners with sensorineural hearing impairment. Two experiments, one a detection masking task and another a recognition masking task, were designed to measure susceptibility to upward spread of masking. In experiment 1, masking effects of noise on a tone stimulus were studied. The frequency of the probe tone was chosen to correspond roughly to the midpoint of the frequency region used to identify place of articulation in the two-formant consonant–vowel syllables of experiment II. In that experiment, masking effects on phonetic identification were studied by varying the amplitude of F1 relative to F2. A secondary aim of this investigation was to control some of the factors which, as discussed above, may affect the results of the experiment. Accordingly, the hearing-impaired listeners were grouped according to the etiology of the disorder, matched for age, and selected so that their sensitivity for the probe tone frequency (and thus the midpoint of the F2 frequency range) was no poorer than 50 dB HL.

I. EXPERIMENT I: NOISE MASKING PATTERNS

A. Subjects

Both normal hearing and hearing-impaired subjects were employed. All subjects were male, had English as a primary language, an educational level of at least eighth grade, and no history of familial or genetic hearing impairment, chronic or recurrent middle ear disease, diabetes mellitus, ototoxic drug therapy, or neurological disorder.

A complete audiometric evaluation was completed within six weeks of the experimental tests. The evaluation included immittance, pure tone, and speech audiometric measures. In the impaired group, the results of all tests indicated sensorineural hearing loss of presumably cochlear origin. Subjects with evidence of conductive or retrocochlear disorder were not included in the study.

The subjects with sensorineural hearing impairment were divided into three groups, based on the apparent etiology of the disorder. Specific criteria for inclusion in each group were as follows:

1. Noise-induced hearing loss (NIHL)

Subjects were young males with a history ofoccupational or recreational noise exposure directly related to the onset of hearing impairment. According to their history, no other factors contributed to the hearing impairment. Nine subjects met these criteria; their average age was 33.7 years, with a range of 29 to 40 years.

2. Meniere's disease

Subjects were young males with confirmed otologic diagnosis of Meniere's disease, including the symptom triad of episodic vertigo, fluctuating sensorineural hearing loss, and tinnitus. They had no history of traumatic noise exposure or of other factors capable of contributing to the hearing impairment. Eight subjects were included in this group. Their mean age was 35.8 years, with a range of 30 to 40 years.

3. Presbycusis

The ten subjects of this group ranged in age from 65 to 76 years, with a mean age of 71.9 years. The onset of their hearing loss had been after age 50 and was not related to traumatic noise exposure or to other common etiological factors.

Ten normal subjects were studied, who ranged in age from 24 to 39 years, with the mean age of 30.9 years. Their sensitivity for pure tones measured at octave intervals from 250–8000 Hz was 15 dB HL (re: ANSI, 1969) or lower. They had no history of repeated traumatic noise exposure.
The mean audiograms of the four groups of listeners are presented in Fig. 1.

B. Stimuli

The probe stimulus was a 1500-Hz tone pulsed twice per second on a 50% duty cycle, having a total on-time of 250 ms, including 25-ms rise-decay times. The maskers were narrow bands of noise having center frequencies of 0.25, 0.5, 0.75, 1, 2, and 3 kHz. The noise had a uniform bandwidth of 300 Hz measured at the half-power point, and was attenuated at a rate of 48 dB per octave on each side of the center frequency. Noise spectrum level, therefore, was 55.2 and 75.2 dB No when presented at 80 and 100 dB SPL, respectively.

C. Apparatus

Noisebands were produced by a sine random generator (Bruel and Kjaer, 1024) and routed through a separate attenuator (Hewlett-Packard 350-D) before being delivered to a speech audiometer (Grason-Stadler 162) for mixing and attenuation. The pulse probe tone was generated by a modified Bekesy audiometer (American Electromedics BA-75) and then delivered to the speech audiometer to be attenuated and mixed with the noisebands. The mixed signals were routed to the subject through a single earphone (TDH-49, mounted in a CZW-6 circumaural cushion). Broadband noise was generated by the Bekesy audiometer and delivered to the opposite earphone for masking of the nontest ear if there was an interaural difference greater than 40 dB between the probe intensity and the threshold of the nontest ear. All testing was carried out with the subject seated in a double-walled sound treated enclosure (IAC, series 1200).

D. Procedure

Audiometer output was measured and calibrated to criterion levels of 80 and 100 dB SPL prior to each test session.

E. Results and discussion

Two questions were asked in this experiment. First, did listeners with sensorineural hearing impairment experience greater than normal upward spread of masking? Second, did masking spread vary among listeners as a function of degree of hearing impairment, audiogram configuration, age, or etiological basis of the hearing disorder?

1. Comparison of masking patterns

The results of the 80- and the 100-dB masker conditions are shown in Figs. 2 and 3, respectively. Threshold for the 1500-Hz probe is plotted as a function of masker center frequency. As shown in these figures, both normal and hearing-impaired listeners evidenced asymmetrical masking functions, i.e., "upward spread" was greater than "downward spread" of masking. With the 1500-Hz masker, the mean thresholds of the normal and impaired listeners differed by less than 8 dB. As the masker was moved to frequencies lower than that of the probe, the difference in thresholds between normal and impaired listeners increased. This results in a relatively steep masking function for the normal group and in a relatively shallow function for the hearing-impaired group.

A statistical evaluation of the group differences in masking as a function of masker frequency and intensity was conducted by analysis of variance of the data from the 750-, 1000-, and 1500-Hz maskers in the 80- and 100-dB masker conditions. The data for the 250-, 500-, 2000-, and 3000-Hz maskers were excluded from this analysis for two interlocking reasons. First, consider that the mean threshold in quiet of the group with the greatest hearing impairment was 43 dB. No matter how remote the masker was made from the probe, the masked threshold could be no less than 43 dB.
Second, consider that (in the 80-dB condition) the masked threshold for the normal hearing listeners for the 250-, 500-, 2000-, and 3000-Hz maskers was 20, 35, 39, and 17 dB, respectively. A comparison of masked thresholds for these maskers between normal and hearing-impaired listeners would be inappropriate due to the limit imposed on the hearing-impaired subjects’ masked thresholds by their thresholds in quiet. Appropriate comparisons among groups could be made only when the masked thresholds of the normal hearing group were higher or equal to the unmasked thresholds of the hearing-impaired groups. These conditions were met for the 750-, 1000-, and 1500-Hz maskers.

The analysis of variance for the data from the 80- and 100-dB conditions revealed significant main effects for groups ($F_{3,33} = 17.92$, $p < 0.001$), masker intensity ($F_{1,33} = 449.73$, $p < 0.001$), and masker frequency ($F_{2,66} = 315.65$, $p < 0.001$). The latter effect consisted of both linear ($F_{1,33} = 429.48$, $p < 0.001$) and quadratic ($F_{1,33} = 16.08$, $p < 0.001$) components. In addition to these main effects, the first-order interaction of groups and masker frequency was significant ($F_{2,66} = 315.65$, $p < 0.001$). This effect was due to differences in the linear component of the masker frequency effect ($F_{3,33} = 5.25$, $p < 0.005$), supporting the observation that the slopes of the masking functions varied among the groups. A subsequent analysis of variance showed that the masking functions of the three hearing-impaired groups did not differ in absolute masked thresholds or in slope. Rather, the slope of the normal groups was significantly steeper than that of the hearing-impaired groups ($F_{1,35} = 13.03$, $p < 0.001$). Finally, neither the two-way interaction of masker frequency and masker intensity nor the three-way interaction of masker frequency, masker intensity, and groups reached significance. Thus the effect of masker intensity was simply to elevate the level of the functions and affected the normal and hearing-impaired listeners comparably.

2. Correlation between quiet and masked thresholds

In the analyses presented above we were careful to exclude data from conditions in which the quiet thresholds of the hearing-impaired listeners imposed a “floor effect” on the level of the masked threshold. Nonetheless, we were interested in the correlation of quiet and masked thresholds among the hearing-impaired listeners. To assess this, we computed the Pearson product-moment correlation...
between quiet and masked thresholds in the 80- and 100-dB
conditions (see Table I). For the 80-dB condition the correla-
tions were positive and significant. In contrast, for the 100-
dB conditions the correlations were essentially zero. Thus
the differences in level of the masked thresholds at the two
masker levels was not related to the quiet thresholds in a
simple linear fashion.

3. Susceptibility to masking among hearing-impaired groups

The analyses presented above confirm the impression
(from visual inspection of Figs. 2 and 3) that the hearing-
impaired groups produced virtually the same masking pat-
terns. In spite of considerable group differences in audi-
ogram configuration, absolute sensitivity in low- and
high-frequency regions (see Fig. 1), age, and duration and
etiology of the hearing disorder, the three groups produced
masking patterns which did not differ significantly. Factors
such as age and audiogram contour are known to affect the
outcome of other physiological and behavioral tests of audi-
tory function such as the auditory brain stem response (Seitz
et al., 1980; Jerger and Hall, 1980; Coats and Martin, 1977;
Stockard et al., 1979), acoustic stapedial reflexes (Jerger et
al., 1978; Gelfand and Piper, 1981; Hall, 1982a,b), and per-
formance on the Synthetic Sentence Identification (SSI) test
(Jerger and Hayes, 1977; Hayes, 1981). Why, then, should
these factors play so minor a role in the outcome of the present
experiment?

One explanation may lie in the nature of the task—the
simple detection of a tone in noise. Such a task demands
neither perception of frequency change over time, nor the
short-term storage, retrieval, and comparison of a complex
signal such as speech. In a simplistic sense, the only process
involved was that of a mechanical deformation of the coch-
lear partition by noise and its interference with the percep-
tion era tone presented at a fixed frequency. In fact, the noise
masking pattern appears to reflect a very low level cochlear
process which, although certainly not normal in the hearing-
impaired groups, was not affected differentially by the hair
cell disruption associated with acoustic trauma, the fluid en-
gorgement of the cochlear duct typical of Meniere’s disease,
or the degeneration of both sensory and neural elements at-
tributed to the aging process.

4. Summary of experiment I

The results of the narrow-band masking experiment
supported the premise that, within the constraints of this
design: (1) Persons with sensorineural hearing impairment
experience greater upward spread of masking than persons
with normal hearing when tested at equivalent sound pres-
sure levels; and (2) the amount of upward spread of masking
in hearing-impaired individuals does not appear to be
strongly related to the severity, configuration, or etiology of
peripheral auditory sensitivity impairment.

II. EXPERIMENT II: PHONETIC IDENTIFICATION

A. Subjects

The same subjects employed in experiment I served as
subjects in this experiment.

B. Stimuli

Synthetic speech produced on the Haskins Laborato-
ries parallel resonance synthesizer was used in this experi-
ment. The stimuli consisted of two-formant stop consonant-
vowel syllables lying along a 10-step continuum from /ba/ to
/da/ to /ga/. Figure 4 illustrates the signal parameters. In
all ten stimuli, $F_1$ rose from 100 to 765 Hz; $F_2$ rose or fell to a
steady-state vowel formant of 1230 Hz from onset frequen-
cies ranging from 619 to 1993 Hz in ten equal steps of 153
Hz. Transitions were linear and stepwise. The bandwidth of
$F_1$ was 60 Hz; $F_2$ bandwidth was 90 Hz. The total duration
of each syllable was 200 ms, including transition durations of
40 ms for both $F_1$ and $F_2$. The fundamental frequency fell
linearly from 114 to 86 Hz throughout the utterance.

Ten tokens of each stimulus were generated for each list
of 100 syllables. Five randomized lists were recorded on
audio tape with a 3-s interstimulus interval. Separate chan-
nels were used for each of the two formants to allow indepen-
dent attenuation.

C. Apparatus

The synthetic speech tape was played from a stereo tape
recorder (Sony, TC 788-4) through a two-channel speech au-

<table>
<thead>
<tr>
<th>Masker intensity</th>
<th>Masker center frequency</th>
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<tbody>
<tr>
<td></td>
<td>750</td>
</tr>
<tr>
<td>80 dB</td>
<td>0.456*</td>
</tr>
<tr>
<td>100 dB</td>
<td>-0.086</td>
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*Significance <.05.
diometer (Grason-Stadler 162) for independent attenuation of each channel and subsequent mixing. The speech materials were delivered to a single earphone (TDH-49, mounted in a CZW-6 circumaural cushion). When the signal intensity was more than 40 dB above the pure tone average of the non-test ear, broadband masking noise from the Bekesy audiometer used in experiment I was routed into a second earphone and delivered to the non-test ear to preclude its participation in the listening task.

D. Procedure

Audiometer output was measured and calibrated to peak vowel amplitude prior to each test session. The test ear was determined by the criteria used for experiment I.

Each subject listened first to a training tape. This tape presented ten tokens of each of the stimuli judged by three independent listeners to represent the best exemplars of /ba/, /da/, and /ga/. When it had been established that the subject could identify at least two of the three syllables presented at his individual comfortable listening level, testing commenced. Subjects were required to make a response by marking an answer sheet, choosing from the three alternatives, /ba/, /da/, and /ga/.

Two intensity conditions (80 and 100 dB SPL) and four attenuation conditions were used in this experiment. In the attenuation conditions, the intensity of $F_1$ relative to $F_2$ was equal (0-dB attenuation), then reduced by 6, 12, and 18 dB while $F_2$ intensity remained constant. Thus the amplitude relationship of the two formants was not identical to that usually found in natural utterances in this vowel environment, where $F_2$ may be on the order of 3 dB lower than the amplitude of $F_1$. Subjects responded to one list of 100 stimuli presented monaurally at each of the eight conditions. Earphones were removed and a brief rest was given after each 200 stimuli to minimize fatigue. Attenuation and intensity conditions were randomized within all groups so that there was no consistent progression from one listening condition to another for any given subject or group.

E. Results and discussion

1. Normal listeners

In order to assess the intelligibility of our stimuli, especially in conditions where the reduction in $F_1$ amplitude caused extremely abnormal amplitude relations between the two formants—and thus abnormal onset spectra of the Stevens and Blumstein (1978) type—the stimuli were first presented to normal listeners. The identification performance of the listeners in the 80-dB condition is shown in Fig. 5(a)-(d) (80/0, 80/-6, 80/-12, and 80/-18). In general, stimuli 1, 2, and 3 were identified as /b/ with high accuracy, stimuli 5, 6, and 7 as /d/, and stimuli 9 and 10 as /g/. The largest effect of $F_1$ attenuation occurred in the 80/-18 condition in which the overall level of performance dropped slightly for /b/ and /g/ and in which the identification of /d/ fell to the 50% level.

We can draw several conclusions from the data of this condition. First, in the baseline 80/0 condition, signal intelligibility was very high. Thus the stimuli could be used with hearing-impaired listeners with some confidence. Second, overall identification accuracy was relatively unaffected by $F_1$ attenuations of 6 and 12 dB. We note that in both of these conditions, the onset spectra for /bdg/ were all "peaked" (in the Stevens and Blumstein sense) due to the reduction of $F_1$ amplitude. In these syllables, then, the shape of the onset spectrum had little to do with phonetic identification. A similar outcome for three-formant stimuli has been reported by Walley and Carrell (1983). For a discussion of the relative

![Image](https://example.com/figure5.png)

**FIG. 5.** Mean phonetic boundary functions of the normal group for two-formant /bdg/ presented at 80 dB SPL, with [a] equal amplitudes of $F_1$ and $F_2$ (80/0) and with $F_1$ attenuated 6 dB (b), 12 dB (c), and 18 dB (d) relative to $F_2$. Parameter is starting frequency of $F_2$. 

M. Hannley and M. F. Dorman: Intraspeech spread of masking 45
use of onset spectra and formant transitions in phonetic identification, see Walley et al. (1981) and Blumstein et al. (1982).

The results for the 100-dB condition are shown in Fig. 6(a)–(d) (100/0 through 100/-18). Two large effects of the increase in presentation level are apparent. First, at 100/0, the /g/ category was functionally eliminated, with /d/ and /g/ responses occurring with nearly equal probability for the stimuli with falling transitions. However, attenuation of F1 brought performance to the same level as in the 80-dB condition. Second, the /d/ category was weakened with increasing attenuation in a manner similar to that of the 80-dB condition.

From the outcome of increased /g/ accuracy with attenuation of the low-frequency F1, we infer that upward spread of masking can affect phonetic identification in normal listeners, and that identification accuracy can be enhanced by reducing F1 amplitude. This outcome is consistent with the observations of Danaher et al. (1973), derived from experiments with speechlike stimuli, that normal listeners may be subject to intraspeech masking when tested at a high sound pressure level. The outcome is also consistent with those of previous experiments in which the perception of falling frequency glides were adversely affected by low-frequency spread of masking (Martin et al., 1972; Nabelek, 1976).

The difference in phonetic identification functions between the 80/0 and the 100/0 conditions confirms the observations of Dorman and Dougherty (1981) that high sound pressure levels can adversely affect the identification of place of articulation for stimuli synthesized without release bursts. In the Dorman and Dougherty study, the /d/ category was weakened at the expense of a very broad /g/ category at 90- vs 70-dB SPL presentation level. In the present study, by contrast, the /g/ category weakened with increasing SPL. Details of synthesis including, of course, the difference in F1–F2 amplitude ratios, apparently account for the difference in outcomes between the two studies.

2. Hearing-impaired listeners

The identification accuracy functions comparing normal and hearing-impaired listeners are shown in Figs. 7 and 10. Post-hoc inspection of the data indicated a four-way interaction of presentation level × group × phonetic category × attenuation condition. That is, the effect of F1 attenuation differed among groups, affected the identification of the three phonemes in different ways, and varied with signal presentation level. However, statistical evaluation of this interaction was made difficult by the large differences in variance among the conditions. Indeed, for several conditions, the variance was essentially zero in one or more groups. Given these circumstances, evaluation of the data by parametric statistics was inappropriate. In the section that follows we simply describe the largest effects and, when necessary, use nonparametric statistics to make critical comparisons.

In order to simplify the comparison of the results for the normal listeners and the three groups of hearing-impaired listeners we pooled the responses to stimuli 1, 2, and 3 to form a /b/ category, the responses to stimuli 5, 6, and 7 to form a /d/ category, and the responses to stimuli 9 and 10 to form a /g/ category. The identification accuracy for the normal listeners and for the hearing-impaired listeners in the 80-dB condition appears in Fig. 7.

Identification accuracy for /b/ was high relative to identification accuracy for /d/ and /g/ among all groups. Here, the listeners with hearing impairment due to presby-
cussis tended to perform the poorest.

Identification accuracy for /d/ described an inverted U-shaped function for all hearing-impaired groups. In the 0-dB attenuation condition these groups performed at a lower level of accuracy than the normal listeners. Of the hearing-impaired groups, those with presbycusis losses performed significantly worse than the others. At 80/-6, both the Meniere’s disease group and the NIHL group reached a normal level of performance. In contrast, the group with presbycusis reached only 50% identification accuracy for /d/. At 80/-12 the normal listeners began a trend toward poor identification of /d/, which indicates that the stimuli were beginning to fall outside the acceptable range for /d/. In this light, the decrease in /d/ identification shown by the Meniere’s and the NIHL subjects can be seen as a slight exaggeration of the normal trend. An interpretation of the identification function for the group with presbycusis is made difficult by the fact that at 80/-12 they labeled virtually every stimulus from along the continuum as /d/ with some consistency. Thus, the increase in /d/ accuracy does not, in this case, indicate a finely tuned phonetic percept in this group of aging listeners.

The largest effects of F1 attenuation can be seen in /g/ identification accuracy (Fig. 7). At 0- and 6-dB attenuations, all hearing-impaired groups evidenced very poor phoneme identification accuracy. With further attenuation of F1, both the noise-induced group and the group with Meniere’s disease reached normal levels of performance.

To illustrate the beneficial effects attainable with F1 attenuation, the data of one subject in the NIHL group are presented in Figs. 8 and 9(a)–(d). This subject, a 34-year-old male with a nearly lifelong history of occupational and recreational noise exposure, produced markedly widened masking functions at both masking intensities; 80 dB is shown in Fig. 8. Figure 9 presents this subject’s phonetic identification results at 80 dB under all four attenuation conditions. In the 80/0 condition [Fig. 9(a)], all ten stimuli were identified as /b/ or, to a lesser extent, as /d/. When F1 was attenuated by 6 dB [Fig. 9(b)], he developed two clear categories, /b/ and /d/, with a few /g/ responses appearing. Successive amounts of F1 attenuation [Fig. 9(c) and (d)] resulted in phonetic categories which were indistinguishable from those produced by normal listeners in an unattenuated condition. As the order of presentation for this subject was 80/-12; 80/-6; 80/0; 80/-18, it appears that the attenuation was responsible for the changes in phonetic identification, rather than practice or fatigue effects.

When F1 and F2 are presented at equal amplitudes (as in the 80/0 condition) and a /g/ category does not appear for the stimuli with rapidly falling F2 transitions, we cannot be certain whether the failure in perception is related peripherally to upward spread of masking, poor temporal resolution of very brief formant transitions, or to a combination of the...
two. If, however, reduction of $F_1$ amplitude (without an increase in the transition duration) results in the emergence of an appropriate /g/ category, as in the above case, then we may surmise that masking has been a primary factor in interfering with the perception of that acoustic pattern. Such reasoning leads us to infer, for the NIHL and Meniere's disease groups, that upward spread of masking impairs the identification of /g/, and that the effects of masking can be ameliorated by $F_1$ attenuation. In this context, it is important to note that the group with presbycusis remained at poor levels of identification, in spite of $F_1$ attenuation. Although we cannot be sure that further attenuation of $F_1$ would not increase identification accuracy in this group, we suspect it would not. If our suspicion is correct, then it appears that the mechanism underlying the failure to identify /g/ differs among the hearing-impaired groups.

The identification accuracy functions for the normal and hearing-impaired groups in the 100-dB condition are shown in Fig. 10. The effect which dominates the data at this presentation level is the "normal" increase in masking by $F_1$. As we noted earlier, normal listeners evidenced poor identification of /g/ at 100/0 and 100/-6, but then showed a "release from masking" with increased $F_1$ attenuation. The normal identification function for /d/ at this intensity is similar to that of the hearing-impaired listeners' /d/ function at 80 dB. We suppose that the performance at the two tails of the function reflects different underlying processes. At 0-dB attenuation, masking interfered slightly with signal intelligibility, whereas in the 100/-12 and 100/-18 conditions the stimulus did not fit the range of normal "templates" for /d/.

In summary, we find evidence of greater spread of masking at 100 than at 80 dB in the normal group. In this case, reducing $F_1$ amplitude ameliorates the effect of masking. The data for the hearing-impaired groups are similar, with the exception of the group with presbycusis. Further attenuation of $F_1$ may be necessary for them to achieve improved identification performance.
context, the performance of the hearing-impaired listeners was lawful. Identification accuracy for /b/ was depressed slightly for all impaired groups. Identification accuracy for /d/ was poorer than normal, with the peak in the function delayed relative to that in the 80-dB condition for the NIHL subjects, and absent altogether for the other groups. The identification functions for /g/ show a similar trend; that is, if the hearing-impaired subjects showed an improvement in identification accuracy with attenuation, a greater amount was needed to achieve that result. In this case, the group with noise-induced losses benefited the most from attenuation but did not reach the level of performance seen in the 80-dB condition.

The interlocking goals of experiment II were to determine: (1) whether upward spread of masking detrimentally affects phonetic identification; (2) whether masking can be reduced by attenuation of F 1; and (3) whether the effects of F 1 attenuation differ among the hearing-impaired groups. The answer to all three questions was affirmative. The implications of these outcomes, and the outcome of experiment I, for the understanding of mechanisms underlying poor speech intelligibility, are discussed in the following section.

III. GENERAL DISCUSSION
A. Inter- and Intra-group variability

The hearing-impaired groups in this investigation could not be differentiated by their performances in experiment I, noise masking patterns. Virtually the same masked thresholds were produced by the three impaired groups, irrespective of age, audiometric configuration, absolute sensitivity for the probe tone, or presumed etiological basis of the hearing impairment. By contrast, experiment II, phonetic identification with and without F 1 attenuation, produced very different results. Here, two clear effects appeared which distinguished among the groups: (1) The phonetic identification of the presbycusis group was poor and was little improved by F 1 attenuation at either intensity; (2) the ability to label /d/ and /g/ improved significantly with F 1 attenuation in the NIHL group and, to some extent, in the Meniere's group.

Some of the variability which has characterized previous studies of the speech perception of the hearing impaired continued to be observed within the present groups. However, the main effects observed in experiment II would not have appeared and the variability represented by the range of performances would have been considerably greater under different subject grouping methods. For example, were we simply to compare all hearing-impaired subjects to the normal group we would conclude that F 1 attenuation has only a minor effect on /g/ identification in hearing-impaired listeners—the NIHL results (showing the greatest effect) would be attenuated by those of the presbycusis group (showing the least). Another commonly used method of grouping hearing-impaired subjects is by audiogram contour. In this case again, the NIHL and presbycusis listeners would be pooled as having sloping high-frequency losses (see Fig. 1), and again the main effects of experiment II would have been less apparent. A grouping based on pure tone aver-

age would have been no more effective than the previous two methods, for the groups were matched only in the 1500-Hz region, and low- and high-frequency sensitivity varied both within and among the groups. Indeed, a Spearman rank-order correlation between pure tone average and /g/ identification was nonsignificant at \(-0.13\) (80/18) and \(-0.20\) (100/18). Therefore, although the groups clearly differed with respect to audiogram configuration and overall sensitivity in the 250–8000-Hz range, neither of these factors seem to be responsible for the differences observed on the speech materials.

B. Effect of age

The three groups, representing distinct etiologies, differed also in age. Spearman rank-order correlations between age and /g/ identification in the extreme attenuation condition were significant at 80 dB (\(\rho = 0.58\)) but not at 100 dB (\(\rho = 0.21\)). There are several possible explanations, apart from peripheral masking spread, which may account for the inability of the elderly listeners to identify place of articulation in this experiment.

First, a central auditory component would be manifest-
ed more readily with speech materials than with pure tones and noise bands. The synthetic syllables used in this study were highly schematic, having incomplete acoustic cues to the place feature. The performances of the presbycusis listeners might therefore be likened to deficits reported using filtered speech tests with individuals suffering from central auditory dysfunction (Palva and Jokinen, 1970; Lynn and Gilroy, 1977).

In the present experiment, four of the presbycusis listeners showed evidence of a central auditory component in a PB word/Synthetic Sentence Identification discrepancy on a performance-by-intensity function (see Jerger and Hayes, 1977). When we compared their phonetic identification results to those of their “noncentral” peers, however, the two subgroups did not differ. Therefore, it does not appear that a central auditory disorder of the type to which the PB-SSI discrepancy is sensitive, can account for the poor performances of the entire presbycusis group.

The poor identification of partial-cue stimuli may be related more directly to the ability to perceive a given phone with acoustically incomplete information. We note that two-formant CV syllables, as used in this experiment, do not generate the auditory representation of naturally produced stop consonants. This circumstance seems to be of only minor importance with young listeners who can recognize stops under a variety of abnormal formant configurations (see, for example, Kuhn, 1975). However, it may well be the case that elderly listeners are less “plastic” in their recognition schemes for stops than are younger normal hearing or hearing-impaired listeners. Preliminary research (Hannley and Dobbins, 1981) suggests that old and young hearing-impaired listeners may differ in their ability to utilize partial-cue stimuli.

The important conclusion to be drawn from analysis of the present data is that elderly hearing-impaired subjects should be regarded as a separate category in future studies of
speech perception of the hearing impaired. These data support previous reports that the effects of aging on the processing of complex acoustic signals, although imperfectly understood, are not limited to peripheral distortions. Equally clear is the conclusion that other psychoacoustic phenomena must play some interactive or additive role in impaired speech perception. For example, in the present study we showed a major effect in /g/ identification with F1 attenuation. Here, the onset of both formants was simultaneous, a circumstance in which masking may occur quite readily. In natural speech or in more complete synthetic stimuli, however, the release burst is a perceptually salient cue to place of articulation and it may occur 5–30 ms prior to the onset of F1. In this instance, factors other than upward spread of masking, such as poor spectral or temporal resolution, must be considered when correct identification fails.

In addition to suggesting further avenues of research, the results of the present study indicate that future investigations involving hearing-impaired subjects should exercise caution in the selection of groups for study. It appears that, in studying speech perception, the hearing impaired cannot be treated as a homogeneous group simply on the basis of audiometric contour or sensitivity loss for pure tones. At the very least, subject age should be controlled.

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