Speech competition effects on synthetic stop-vowel perception by normal and hearing-impaired listeners

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A triadic comparisons task and an identification task were used to evaluate normally hearing listeners' and hearing-impaired listeners' perceptions of synthetic CV stimuli in the presence of competition. The competing signals included multitalker babble, continuous speech spectrum noise, a CV masker, and a brief noise masker shaped to resemble the onset spectrum of the CV masker. All signals and maskers were presented monotically. Interference by competition was assessed by comparing Multidimensional Scaling solutions derived from each masking condition to that derived from the baseline (quiet) condition. Analysis of the effects of continuous maskers revealed that multitalker babble and continuous noise caused the same amount of change in performance, as compared to the baseline condition, for all listeners. CV masking changed performance significantly more than did brief noise masking, and the hearing-impaired listeners experienced more degradation in performance than normals. Finally, the velar CV maskers (gɛ and kɛ) caused significantly greater masking effects than the bilabial CV maskers (bɛ and pɛ), and were most resistant to masking by other competing stimuli. The results suggest that speech intelligibility difficulties in the presence of competing segments of speech are primarily attributable to phonetic interference rather than to spectral masking. Individual differences in hearing-impaired listeners' performances are also discussed.

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INTRODUCTION

Noisy environments lead to speech understanding difficulties for both normal hearing and hearing-impaired listeners. The type of noise, in addition to its level, is important. Results of several studies suggest that with normal hearing listeners, a single competing talker causes less interference with perception of target speech stimuli than does steady-state noise (Speaks and Karmen, 1967; Carhart *et al.*, 1969), while a multitalker speech competition causes more interference than a steady-state noise (Carhart *et al.*, 1969). In addition, comparisons of normal with hearing-impaired listeners consistently show significant differences in performance between the two groups, both in noisy backgrounds and in competing speech backgrounds (Groen, 1969; Cooper and Cutts, 1971; Keith and Talis, 1972; Carhart and Tillman, 1970). Cross-study comparisons of the relative masking effects of speech and noise competition on hearing-impaired listeners' performances led Carhart and Tillman (1970) to suggest that hearing-impaired listeners experience a greater masking effect with competing speech than with competing steady-state noise. This effect has never been directly assessed.

To further understand the interaction of hearing impairment and speech competition, it would be helpful to know which properties of a competing speech stimulus are responsible for its masking efficiency. Several properties that might be considered include the spectral, phonetic and semantic components of the competition. In other words, the masking effects of competing speech may be attributable to one, or a combination, of three factors: spectral masking, in which the spectral match of the competition with the target signal accounts for the masking effects; phonetic interaction, in which the phonetic structure of the speech target and speech competition interact to yield an altered phonetic percept; and semantic distraction, in which the meaning of the competing speech distracts the listener from accurately perceiving the target speech message. To date, only the relative roles of spectral masking and semantic distraction have been investigated in normal hearing listeners, and the results have been inconclusive. Some investigators report that the spectral properties of competing speech are primarily responsible for its masking effects (Dirks and Bower, 1969); others suggest that the semantic properties play an important role (Trammell and Speaks, 1970). Unfortunately, the signals and maskers employed in these earlier studies consisted of naturally produced words and sentences, and thus the spectral levels and linguistic properties were not well controlled. Using currently available synthesis techniques, these problems can be avoided.

The suggestion that hearing-impaired listeners experience excessive interference from competing speech as compared to competing noise has not been adequately assessed. That was the purpose of the research reported here. The study consisted of four parts. In the first, we attempted to determine whether speech perception of both normal and hearing-impaired listeners is affected more by competing speech maskers than by competing noise maskers. The second part of the study evaluated whether or not hearing-im-

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paired listeners are more affected than the normal hearing controls by the same competing signals. In the third part, we hoped to determine how the masking effects of competing speech might be attributed to its spectral content in comparison to its phonetic content. Finally, we wanted to identify some of the factors that may contribute to the poor speech perception performance of hearing-impaired and normal listeners in the presence of competing noise and speech. Particularly for hearing-impaired listeners, such factors as upward spread of masking (Danaher and Pickett, 1975); poor perception of phonemic place of articulation (Owens *et al.*, 1972); and poor perception of voicing (Bennett and Ling, 1973) may be implicated as contributory. By presenting synthetic stimuli in well controlled paradigms and analyzing the data with multidimensional scaling techniques, we believe that many of these elements can be separately resolved. In our experiments, two perceptual tasks were used: (1) identification of the synthetic stimuli from a closed set of choices, and (2) selection of the two most similar stimuli from among three presented (i.e., a triadic comparisons task).

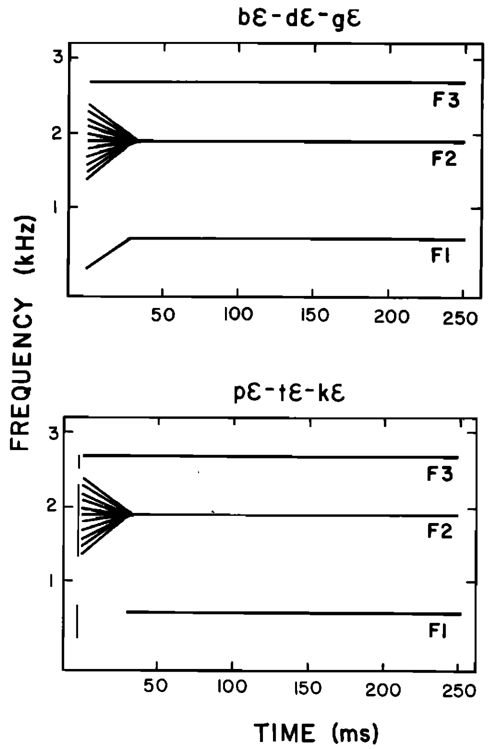

FIG. 1. Schematic spectrograms of the two CV continua. The top spectrogram represents the voiced /bɛ — dɛ — gɛ/ continuum; the bottom spectrogram represents the voiceless /pɛ — tɛ — kɛ/ continuum.

I. METHODOLOGY

A. Subjects

Two groups of listeners participated in the experiments. Group I was composed of six listeners with normal hearing, defined by pure tone sensitivity less than or equal to 10 dB HL (ANSI, 1969), from 250 through 4000 Hz. Group II consisted of six hearing-impaired listeners, who exhibited mild-to-moderate, flat or gradually sloping sensorineural hearing losses. Each hearing-impaired listener had excellent speech discrimination ability (greater than 90% performance on Northwestern University Auditory Test #6) and a probable cochlear lesion. All subjects were young adults, with a mean age of 24.33 years in group I, and a mean age of 28.5 years in group II.

B. Target stimuli

Two sets of CV stimuli were synthesized digitally on a DEC PDP 11/40 computer, using a modified version of the Klatt speech synthesizer (Klatt, 1980). The first set of CVs consisted of a continuum of 11 three-formant burstless, voiced stop consonants, paired with the vowel /ɛ/ (i.e., a bɛ — dɛ — gɛ continuum). Each CV stimulus was 250 ms in duration, with a 30-ms initial transition. The CVs within the series varied only in the starting frequency of the second formant transition. The second continuum of CV stimuli was comprised of voiceless stop consonants paired with the vowel /ɛ/ (a pɛ — tɛ — kɛ series). The voiceless series differed from the voiced series in that the onset of $F0$ was delayed 45 ms and replaced with an aspiration source; the onset of $F1$ was delayed 30 ms, and a 10-ms burst was appended to the beginning of the waveform. The frequency content of the burst was varied across stimuli. Figure 1 shows schematic spectrograms of the two CV continua.

C. Maskers

Eight maskers were also created with the synthesizer. Four of these were CV maskers, which were actually the first and last stimuli of the two speech continua. Four additional maskers were 250-ms broadband noises which were spectrally shaped to resemble the onset spectrum of each CV masker. Each of these noise maskers was synthesized by replacing the periodic voicing source of each CV masker with white noise; then replacing the formant frequency transitions with the steady-state values present at stimulus onset; and finally by low-pass filtering the white noise to produce a noise with an overall -6 dB/oct slope, corresponding to the average slope of the combined voice source spectrum, vocal tract transfer function, and the mouth–head radiation.

Two continuous maskers were also used during these experiments. The continuous speech masker was the 12-talker babble used in the SPIN test (Kalikow *et al.*, 1977). The continuous noise masker was white noise, the spectrum of which had been shaped by a General Radio Multifilter to resemble the smoothed long-term spectrum of continuous speech (-10 dB/oct above 1000 Hz and -50 dB/oct below 100 Hz, as suggested by French and Steinberg, 1947).

D. Apparatus and procedures

In each condition, the stimuli were stored on disk and presented via a PDP 11/10 computer. Digitized stimuli and maskers were converted to analog signals (10-kHz rate), and then low-pass filtered at 4000 Hz (48 dB/oct). The signals and maskers were separately attenuated, mixed, amplified, and presented monaurally to the listener's test ear via a TDH-49 earphone. All normal hearing subjects were tested in the right ear. The hearing-impaired listeners were tested in the better ear, as determined by pure tone thresholds. All testing was conducted in an IAC double-walled sound insulated chamber.

The levels of all stimuli, targets and maskers, were adjusted to be equal in rms voltage to a 1000 Hz tone of 80 dB SPL. For the normal hearing listeners, stimuli were presented at this 80 dB SPL level, because it was considered a comfortable listening level. For the hearing-impaired subjects, the actual signal presentation level was established at each listener's most comfortable listening level as determined by a bracketing procedure, and ranged from 80 to 90 dB SPL.

Two listening tasks were used in each condition. The first task was a standard identification paradigm in which the 11 CV stimuli of a continuum were randomized, and presented individually 10 times, with a 250-ms interstimulus interval. The listener's task was to select one of three categories corresponding to the initial consonant perceived: either b, d, or g for the voiced series; or p, t, or k for the voiceless series. The second task was a triadic comparisons task, in which three CV stimuli were presented on each trial (interstimulus interval = 60 ms, intertrial interval = 250 ms). The listener was instructed to select the two stimuli of the triad that were perceived as most similar. All possible triads of the 11 CV stimuli of each continuum were presented once (number of triads = 165). The order of stimulus presentation within a triad, and the order of triad presentation, were randomized among subjects.

II. CONDITION I: BASELINE MEASURES

A. Methods

In the baseline condition, stimuli from each continuum were presented in quiet (e.g., without competition) for both the identification and triadic comparisons tasks. Prior to administration of the baseline condition, an identical session was administered to each subject as a practice session.

B. Results

The data were analyzed in two ways. First, the identification data were evaluated to determine how the stimuli were categorized according to the usual phonetic labels. Because of the small variability between subjects, the data were averaged across subjects to produce two composite identification functions (one for each condition), as shown in Fig. 2. The crossover points on the identification function suggest in general that stimuli with rising $F2$ transitions were labeled as bilabial, stimuli with relatively flat transitions were labeled as alveolar, and stimuli with falling transitions were labeled as velar. Stimuli within each phonetic category appear to have been consistently identified by the listeners, as reflected by the fact that at least one stimulus in each category was consistently identified 85% of the time (with the exception of the /dɛ/ category).

The second method of data analysis involved a multidimensional scaling (MDS) analysis of the triadic comparisons data. Each subject's triadic comparisons data were arranged in a frequency matrix, representing the number of times two stimuli were chosen as most similar. The matrix, then, reflects the perceived similarity among pairs of stimuli. In the MDS model, it is assumed that frequencies in this matrix are linearly (inversely) related to Euclidean perceptual distances between stimuli in an individual's perceptual space. The ALSCAL-4 program (Young and Lewyckyj, 1979) was used to derive this stimulus space from the given similarity matrix. The program uses an iterative, alternating least-squares procedure that produces a solution which accounts for the maximum variance in the data. The percentage of variance accounted for (RSQ) by the MDS solutions is presented in Table I. It was important to insure that the subjects were perceiving the stimuli in an orderly manner in the baseline

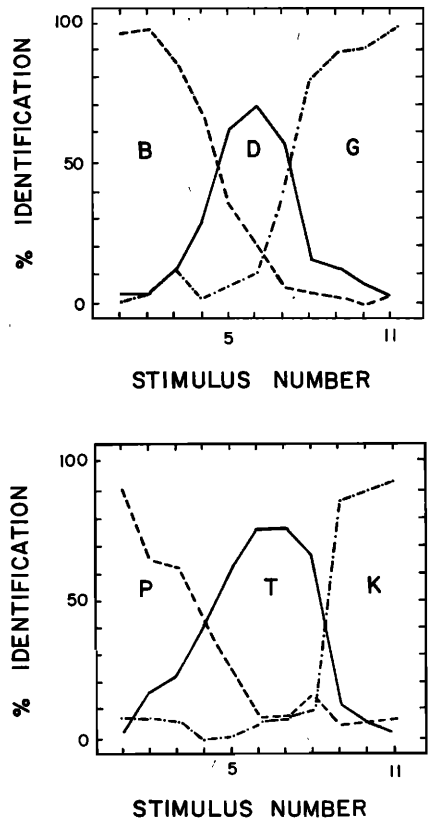

FIG. 2. Composite baseline identification functions of all 12 subjects: /bɛ — dɛ — gɛ/ series (top); /pɛ — tɛ — kɛ/ series (bottom).

TABLE I. Percentage of variance accounted for (RSQ) by individual MDS solutions, baseline condition.

Subject	Voiced series	Voiceless series
1	0.996	0.968
2	0.968	0.999
3	0.988	0.992
4	0.958	0.877
5	0.963	0.926
6	0.845	0.916
7	0.953	0.999
8	0.900	0.929
9	0.900	0.832
10	0.928	0.954
11	0.911	0.801
12	0.902	0.796

conditions before proceeding to the conditions involving competition. The results indicate high RSQ values for all baseline solutions (> 80%) suggesting that each subject was fairly consistent in perceiving the stimuli in the perceptual space that was recovered by the MDS analysis.

III. CONDITION II: CONTINUOUS MASKERS

A. Methods

In this condition, we wished to determine whether competing speech and competing noise produce the same degree of interference with perception of target CV stimuli, and whether hearing-impaired and normal hearing listeners are affected similarly by competition. To do this, we assessed both groups of listeners' perceptions of the target stimuli when the stimuli were presented in competition with two different continuous maskers, a speech masker (12-talker babble) and a continuous noise masker.

During stimulus presentation, each continuous masker was mixed with the test stimuli and presented monotically at a 0-dB signal-to-competition ratio (s/c). The normal hearing listeners were tested at two additional s/c ratios in order to describe psychometric functions relating masker level and performance, and were + 5 and + 10 dB, in the continuous masker condition. As in the baseline condition, both the identification task and the triadic comparisons task were performed by the subjects, using stimuli from both continua presented in competition with both maskers.

B. Results

Individual MDS solutions were computed from each subject's triadic comparisons data, as described above. To quantify the amount of interference caused by the two maskers, we computed a correlation (or goodness fit) between each MDS solution from a masking condition, and the comparable solution from the baseline condition, by the process described by Lingoes and Schönemann (1974). The computed "Schönemann r" values were transformed (inverse hyperbolic tangent transform) to normalize the distribution of the data. Finally, the transformed correlations were subjected to an analysis of variance in a split-plot factorial design (Lindquist type VI), with one completely randomized factor (group) and two repeated measures factors (masker type and CV continuum). The results revealed no significant effects for any of the factors assessed. That is, there were no significant differences between the amount of interference caused by the speech masker and the noise masker, between the amount of masking experienced by the hearing-impaired listeners and the normal hearing listeners, nor between the amount of interference encountered during perception of the voiced CV series and the voiceless CV series.

To assess the magnitude of differences between the two groups' performances, we plotted psychometric functions for the normal hearing subjects (in each condition) and compared the hearing-impaired listeners' average performance to this function. The MDS solutions derived from each normal hearing listeners' triadic comparisons data were obtained in the two masking conditions at each of three s/c levels. The transformed Schönemann r values, averaged across the six subjects (comparing the "competing" solutions to the "baseline" solutions) were plotted as a function of s/c level. Each function for the normal listeners was fit by a straight line as a first approximation to the shape of the function. This procedure appears appropriate in view of the reasonably good fits between the data points and the straight lines. Comparisons of the hearing-impaired subjects' performances to the normal hearing listeners' performances, are shown in Fig. 3. There is little difference between the performances of the two groups of listeners (the data points from the hearing-impaired listeners fall less than 5 dB from the normal listeners' psychometric functions).

IV. CONDITION III: BRIEF DURATION MASKERS

A. Methods

The purpose of this condition was twofold. First, we wanted to determine the relative amounts of interference in the perception of speech attributable to phonetic versus spectral interaction. Second, we wished to determine whether the interference effects are the same for normally hearing and hearing-impaired listeners. To achieve both objectives, we measured the masking effects of two additional types of synthetic maskers: the CV maskers, and the brief broadband noise maskers.

The voiced CV maskers and noises shaped to resemble the voiced CV maskers were presented in monotic competition with stimuli from the voiced CV series. Likewise, the voiceless CV maskers and corresponding noises were presented in competition with stimuli from the voiceless CV series. To describe psychometric functions for the normal listeners, the CV maskers were presented at 0, + 5, and + 10 dB s/c levels; the brief noises were presented at − 5, 0, and + 5 dB s/c levels to the normal hearing listeners. In all masking conditions, stimuli were presented in both the identification paradigm and the triadic comparisons paradigm.

B. Results

In general, the results showed that the CV maskers caused more masking than the noise maskers, and that the hearing-impaired listeners demonstrated more masking effects than the normal hearing controls. To quantify these effects, an ANOVA was performed on the transformed correlation data (comparing MDS solutions from these brief masking conditions to the baseline condition). The split-plot factorial design consisted of three repeated measures factors (masker type, CV continuum, and place of masker), and one completely randomized factor (group). The ANOVA for main effects revealed a significant effect of group ($F = 6.689, p < 0.05$); a significant effect of masker ($F = 6.549, p < 0.05$); and a significant interaction between CV continuum and place of articulation of the masker ($F = 11.767, p < 0.01$). A further examination of the data indicated that the normal hearing listeners were not as affected by competition with short duration maskers as were the hearing-impaired listeners. Also, the CV masker caused greater decrements in performance than the short duration

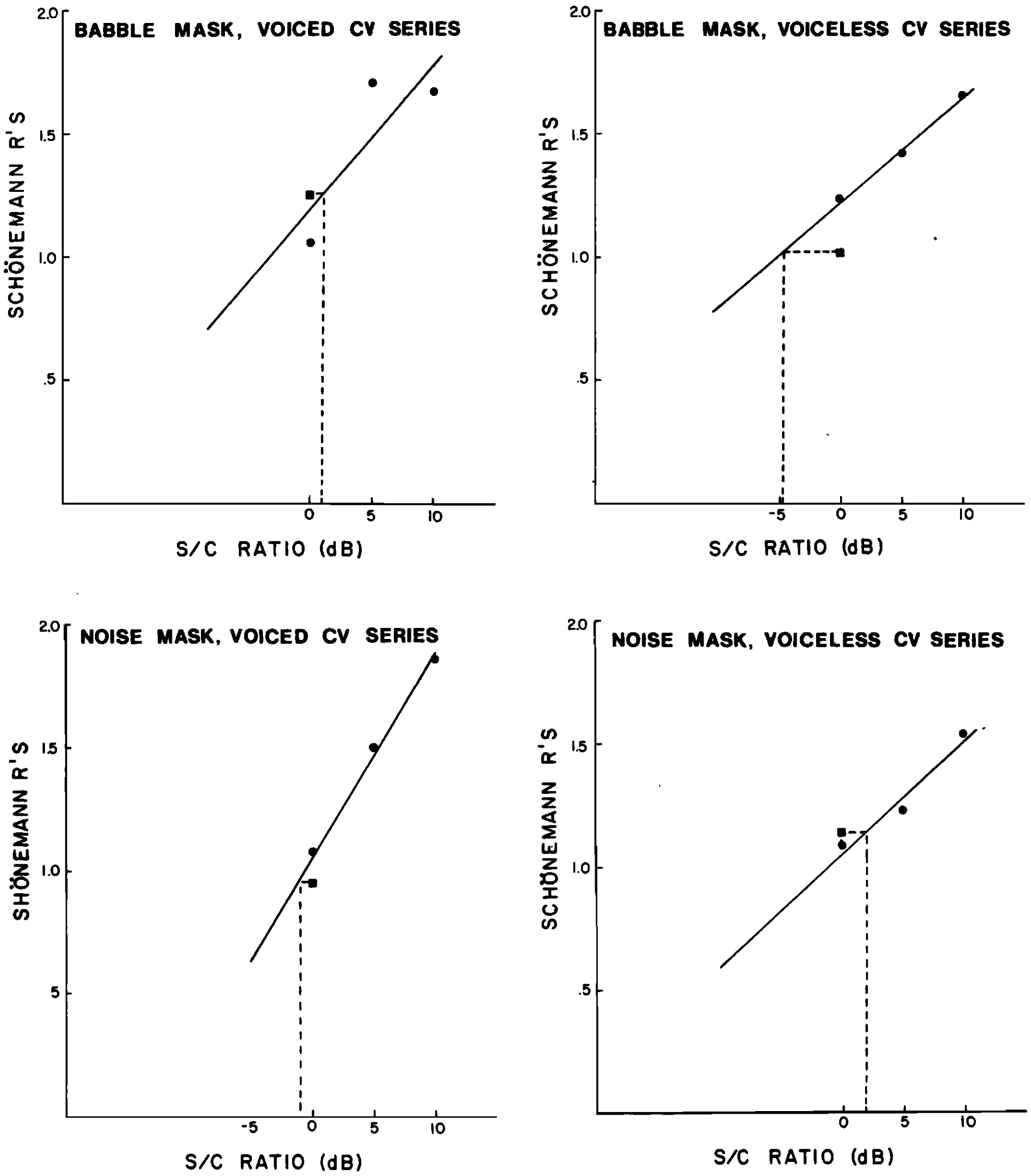

FIG. 3. Psychometric functions for the continuous maskers. Top left: babble masker, voiced series; top right: babble masker, voiceless series; bottom left: noise masker, voiced series; bottom right: noise masker, voiceless series. Circles represent the average data of the six normal hearing subjects at each s/c. Squares represent the average data of the six hearing-impaired subjects at 0 dB s/c. Results show that neither type of continuous masker produced large differences in performance between the two groups of listeners at 0 dB s/c.

noise maskers. Further, it appeared that the velar place maskers had a highly significant effect on performance for both CV continua, but that performance was degraded more for the voiceless CV continuum than for the voiced CV continuum.

Figures 4 and 5 show the normal hearing listeners' psychometric functions from the eight short duration mask conditions. The average performance of the hearing-impaired subjects is indicated by a point on each function. The displacement (in dB) of the performance of the hearing-impaired listeners from the normal function (i.e., the normal-hearing-impaired difference) varies considerably from one condition to another (between 1 and 25 dB), although the hearing-impaired subjects consistently performed more poorly than the normals. Generally, the shaped noise maskers caused greater "decrements' than the CV maskers. However, this interaction was not significant.

V. ADDITIONAL ANALYSES

A. Group dimensional patterns versus individual patterns

Speech perception by hearing-impaired listeners is frequently found to be highly variable across subjects having similar hearing losses. To evaluate the homogeneity of our subjects' perceptions of the stimuli in the various experimental conditions, the data were analyzed via Individual Differences Scaling (using ALSCAL). (The reader is referred to Young and Lewykyj, 1979, for a description of the INDSCAL procedure.) Spaces with dimensionality higher than two did not increase the interpretability of the solution, and are not reported. Table II presents the percentage of variance accounted for (RSQ) for each ALSCAL solution for each condition.

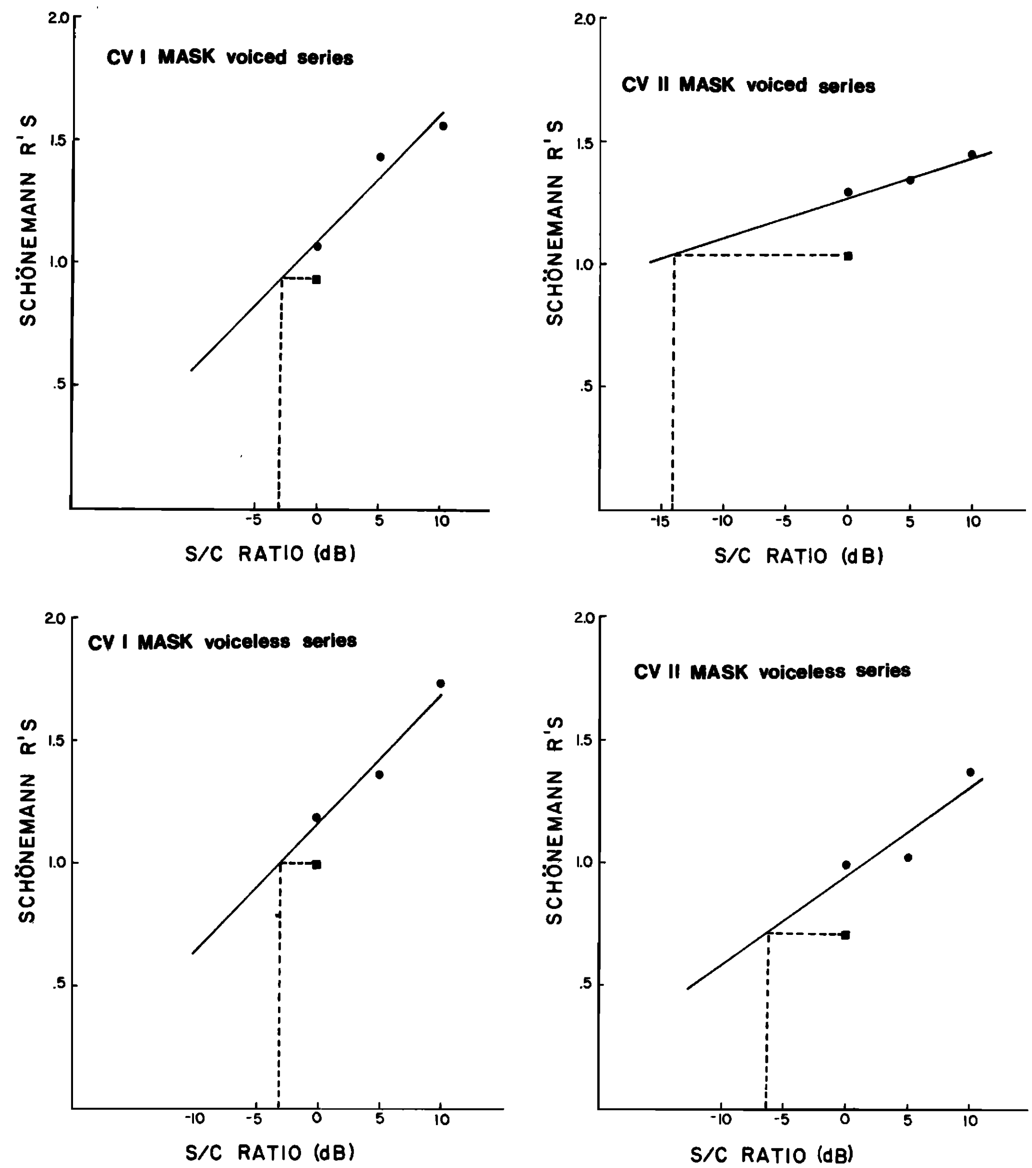

FIG. 4. Psychometric functions for the CV maskers. Top left: CV1 masker, voiced series; top right: CV11 masker, voiced series; bottom left: CV1 masker, voiceless series; bottom right: CV11 masker, voiceless series. Circles represent the average data of the six normal hearing subjects at each s/c. Squares represent the average data of the six hearing-impaired subjects at 0 dB s/c. CV masking by the velar masker (#11) produced large performance differences between the two groups at 0 dB s/c, for both CV series. CV masking by the labial masker (#1) did not have a differential effect on the two groups.

The group stimulus spaces obtained from the baseline conditions (Fig. 6) revealed three clusters, corresponding roughly to the three stop-place categories observed in the identification experiment. In the continuous noise and babble masking conditions, the group stimulus spaces were strikingly similar to those obtained from the baseline condition. However, with CV masking and short duration noise masking, sizeable changes in the group stimulus spaces were observed. Specifically, the cluster of CVs that included the CV masker (or comparable brief noise masker) was enlarged to include stimuli from the alveolar cluster.

The subject spaces, reflecting the statistical "importance" of each dimension for each subject, were derived from all conditions and formed three distinct patterns (depicted in Fig. 7). Pattern 1 is characterized by homogeneous performance by all subjects; and was obtained from the baseline (bɛ–dɛ–gɛ continuum), babble masking (pɛ–tɛ–kɛ continuum) and continuous noise masking (pɛ–tɛ–kɛ continuum) conditions. The pattern 2 subject space reveals that three of the hearing-impaired subjects (10, 11, and 12) performed quite differently from the other subjects. This configuration was obtained from the baseline (pɛ–tɛ–kɛ continuum), continuous noise mask (pɛ–tɛ–kɛ continuum) and babble mask (bɛ–dɛ–gɛ continuum) conditions. Pattern 3, obtained from all brief masking conditions (CV and brief noises), indicates that most of the hearing-impaired listeners perceived the stimuli differently than did the normal hearing listeners.

B. Comparisons of identification and triadic comparisons data

The extensive analyses of the triadic comparisons data, rather than the identification data, were based on our expectation that these data may reflect perception rather than simple categorization behavior. To determine the similarity between the two types of results, we subjected the identifica-

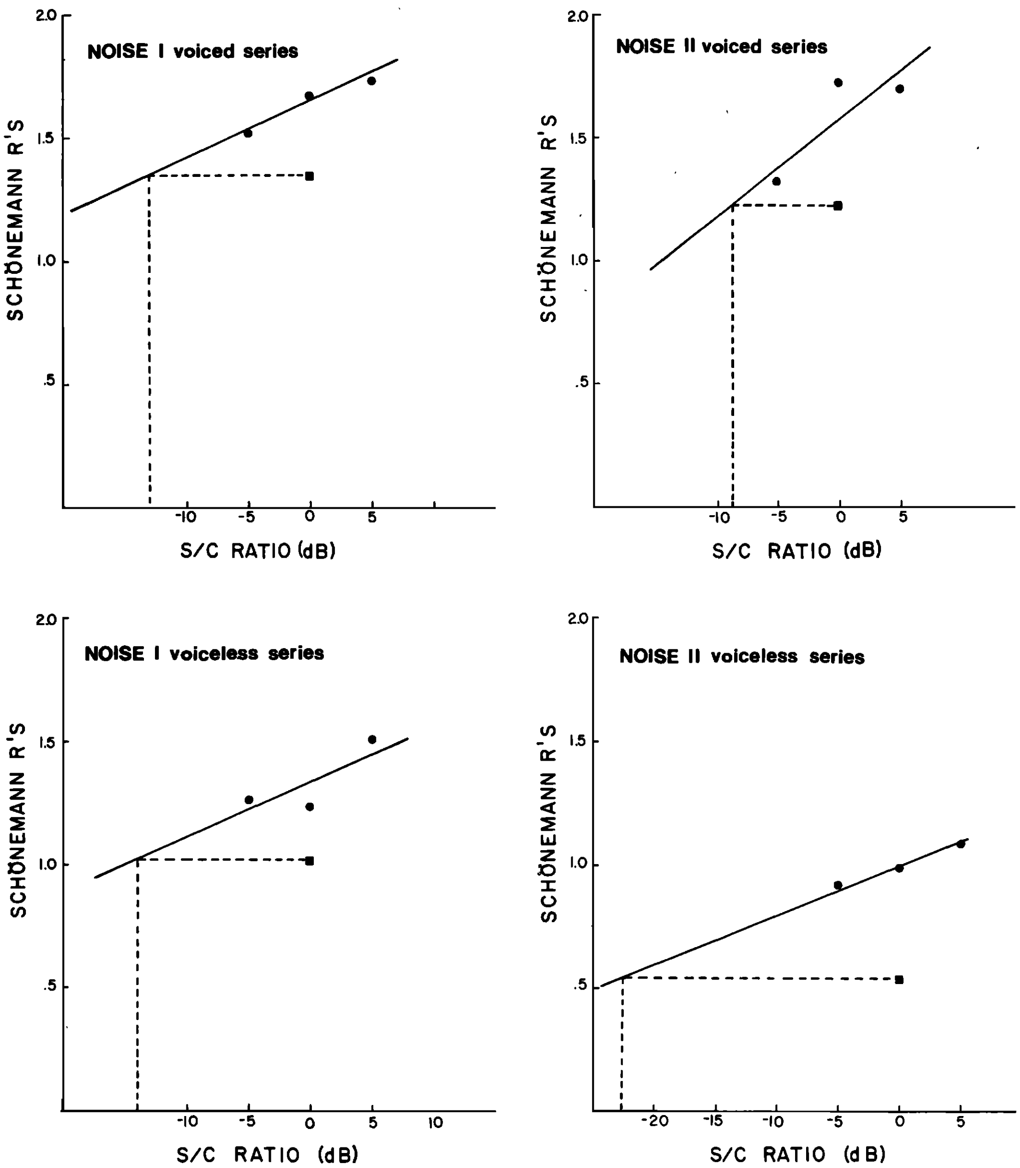

FIG. 5. Psychometric functions for the broadband noise maskers. Top left: noise masker shaped to resemble CV1, voiced series; top right: noise masker shaped to resemble CV11, voiced series; bottom left: noise masker shaped to resemble CV1, voiceless series; bottom right: noise masker shaped to resemble CV11, voiceless series. Circles represent the average data of the six normal hearing subjects at each s/c. Squares represent the average data of the six hearing-impaired subjects at 0 dB s/c. Brief noise masking by all four maskers caused large performance differences between normal and hearing-impaired listeners.

tion data to a multidimensional scaling analysis. Then, utilizing the Schönemann correlation measure (described above) we compared the group stimulus space obtained from the triadic comparisons data with the comparable group stimulus space obtained from the identification data. The results (presented in Table III) show high positive correlations between the two sets of data in all conditions, with a mean of 0.9286. We conclude that trends observed in the triadic comparisons data are present in the identification data. This high correlation also suggests that the triadic comparisons task involved the same perceptual ability as the identification task.

VI. DISCUSSION

A. Degree of interference by continuous maskers

To determine whether competing speech and competing noise exert the same degree of interference on the perception of target CV stimuli, we compared the masking effects of the continuous speech masker and the continuous noise masker. The results revealed no significant differences between the effects of these two maskers, indicating that the two types of maskers effected the same degree of change in the listeners' perceptions of the target CVs. This result conflicts with those reported by Carhart *et al.* (1969), and Speaks and Karmen (1967). The apparent contradiction is most likely a result of differences in stimuli, maskers, and the listener's task, between this study and previous investigations. In particular, the stimuli of previous studies were natural words and sentences, while those in the present study were synthetic nonsense syllables.

B. Hearing-impaired versus normal hearing listeners' performances

The second issue addressed was whether speech perception of hearing-impaired listeners and normal hearing listen-

TABLE II. Percentage of variance accounted for (RSQ) by two-dimensional ALSCAL solutions, group stimulus space.

CV continuum	Condition	RSQ
bε − dε − gε	Baseline	0.803
pε − tε − kε	Baseline	0.769
bε − dε − gε	Babble competing	0.602
pε − tε − kε	Babble competing	0.712
bε − dε − gε	Continuous noise	0.683
pε − tε − kε	Continuous noise	0.693
bε − dε − gε	CV 1 Mask	0.475
pε − tε − kε	CV 1 Mask	0.751
bε − dε − gε	CV 11 Mask	0.735
pε − tε − kε	CV 11 Mask	0.436
bε − dε − gε	Noise 1 mask	0.786
pε − tε − kε	Noise 1 mask	0.752
bε − dε − gε	Noise 11 mask	0.681
pε − tε − kε	Noise 11 mask	0.461

ers would be affected similarly by the presence of competing speech and noise. The continuous masker results obtained from the hearing-impaired listeners were not significantly

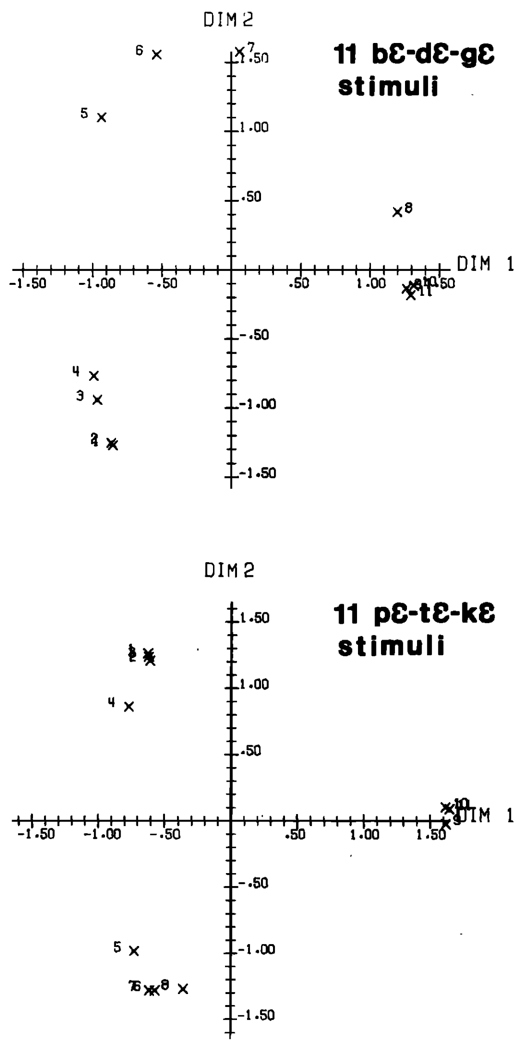

FIG. 6. ALSCAL group stimulus spaces: /bε − dε − gε/ stimuli, baseline condition (top); /pε − tε − kε/ stimuli, baseline condition (bottom). Both spaces reflect that listeners perceived the 11 stimuli on each continuum in three clusters, corresponding to the three stop-place labels.

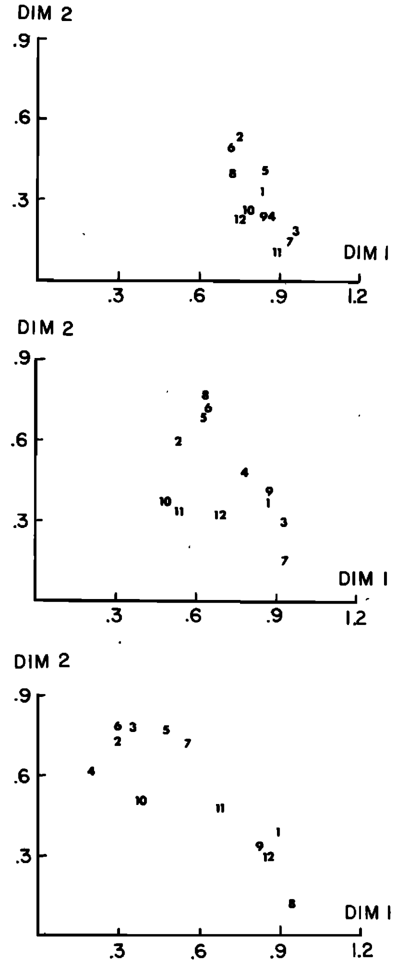

FIG. 7. Group subject space patterns. Subjects 1 through 6 are normally hearing; subjects 7 through 12 are hearing-impaired. The top panel is pattern 1, middle panel is pattern 2, bottom panel is pattern 3.

different from those of normal hearing listeners. This finding also appears to contradict previous reports (Carhart and Tillman, 1970; Keith and Talis, 1972; Garstecki and Mulac, 1974; and Groen, 1969). Two possible reasons for this dis-

TABLE III. Schönemann r values, indicating correlations between identification ASLCAL data and triadic comparisons ALSCAL data.

Condition	Correlation
BDG baseline	0.9814
PTK baseline	0.9730
BDG with babble	0.9382
PTK with babble	0.8781
BDG with noise	0.9602
PTK with noise	0.9533
BDG with CV 1	0.8763
PTK with CV 1	0.9631
BDG with CV 11	0.9167
PTK with CV 11	0.8793
BDG with noise of CV 1	0.9810
PTK with noise of CV 1	0.9548
BDG with noise of CV 11	0.9613
PTK with noise of CV 11	0.7835
Mean of BDG conditions:	0.9450
Mean of PTK conditions:	0.9122
Grand mean of all conditions:	0.9286

crepancy are the subject selection criteria of excellent word identification ability and the young age of the subjects. Both requirements may have minimized differences between the subject groups. Some of the earlier studies (Garstecki and Mulac, 1974; Groen, 1969) employed presbycusic hearing-impaired subjects, but young normal hearing listeners. Response bias differences between young and old subjects in listening tasks have been reported (Rees and Botwinick, 1971; Potash and Jones, 1977). Thus differences between the performances of the two groups reported in other studies may be more related to age-dependent differences in response strategies rather than to the effects of hearing loss.

A surprising finding of this study, given the results discussed above, was that the hearing-impaired listeners experienced significantly greater interference than the normals in the brief-duration masking conditions. The psychometric functions (Figs. 4 and 5) revealed that the brief noise masking conditions clearly separated the performance of the two groups, suggesting that the hearing-impaired subjects simply could not distinguish the target information from the brief mask information as well as could the normals. We can offer no simple explanation for this result.

C. Spectral and phonetic masking effects

We hypothesized that if the masking effects of speech were completely attributable to spectral interaction, there would be no significant differences between the masking effects caused by CVs and those caused by spectrally shaped noises. Our results indicated that the CV maskers caused significantly greater disruption in perception of the target CVs than the brief noise maskers, consistent with the view that the masking effect of competing CVs is not completely attributable to spectral masking. Rather, there is something "special" about competing speech that enhances its masking effectiveness. One explanation for this phenomenon is that the target and mask cues combine to produce a percept that may or may not be related to the target's identity. During CV masking, this combination of cues apparently resulted in a shift in the phonetic percept. However, with brief noise masking the alteration in target identity was minimized, perhaps because the broadband composition of these maskers did not combine in a phonetically "relevant" way with the formant structure of the target CVs.

D. Phonetic interactions

Two factors that may contribute to poor speech perception performance in noisy conditions are the phonetic content of the masker, and the phonetic content of the stimuli. Consider the masking effects obtained with the two endpoint CVs. The results suggest that the bilabial (CV 1) and velar (CV 11) consonants had significantly different masking effects on stimuli from both CV continua. The velar CVs were apparently much more effective maskers than the bilabial CVs. This effect may be attributed to the relative spectral energy of the formants comprising the mask CVs as compared to the other CVs along the continuum.

An alternate way of evaluating the effects of masking is to compare the perception of CVs that vary in one acoustic dimension, in degraded listening conditions. One trend in our data is that the listeners' perceptions of the voiced CVs were not affected differently from their perceptions of the voiceless CVs. Since these two continua differed primarily in the presence of low frequency ($F1$) energy, upward spread of masking was not a significant factor in our results. A second trend, observed in the group stimulus spaces, is that the velar place stimuli of both continua were more resistant to change in the presence of six different types of competing signals than either the bilabial or alveolar CVs. Other investigators have reported that velar CVs are highly resistant to the effects of competition in both dichotic and monotic tasks (Berlin *et al.*, 1973). This may be another manifestation of the importance of the relative formant energy of the target CVs. The unique, compact spectrum of the velar CVs may thus contribute to its resistance to masking.

In summary, the current investigation shows that the effects of speech maskers on the perception of CVs by normal and hearing-impaired listeners cannot totally be accounted for by the masker's spectrum. However, the results are highly dependent upon the specific type of masker. Further study is clearly warranted to further delineate the complex interaction between speech perception, hearing loss, and masking by speech competition.

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