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Use of second formant transition and relative amplitude cues in labeling nasal place of articulation

Susan Lynn Frisbee

To the Graduate Council:

I am submitting herewith a thesis written by Susan Lynn Frisbee entitled "Use of second formant transition and relative amplitude cues in labeling nasal place of articulation." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Audiology.

Mark Hedrick, Major Professor

We have read this thesis and recommend its acceptance:

Samuel Burchfield, James Thelin

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

April 6, 1999

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Committee Member

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Committee Member

Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

Use of Second Formant Transition and Relative Amplitude Cues in Labeling Nasal Place of Articulation

A Thesis Presented for a

Master of Arts Degree

The University of Tennessee, Knoxville

Susan Lynn Frisbee

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constant support and encouragement and made this process as least stressful as possible.

ABSTRACT

Previous studies have shown that manipulation of the amplitude of a particular frequency region of the consonantal portion of a syllable relative to the amplitude of the same frequency region in an adjacent vowel influences the perception of place of articulation. This manipulation has been called the relative amplitude cue. The earlier studies examined the effect of the relative amplitude manipulation upon labeling place of articulation for fricatives and stop consonants. This current study looked at the influences of this manipulation upon labeling place of articulation for the /m/ - /n/ nasal distinction. Twenty-five listeners with normal hearing labeled nasal place of articulation for the synthetic syllables. Results show an influence of both relative amplitude and formant transition manipulation upon labeling behavior. These results add further evidence to the importance of acoustic boundaries in processing consonant place of articulation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE PAGE

CHAPTER I

INTRODUCTION

Background and Rationale

Nasal consonants are produced as a result of bifurcation at the velopharyngeal port, allowing sound energy to pass from the larynx through the nasal tract while the oral cavity is closed. Thus, the nasal radiation of the sound energy produces an acoustic effect called a nasal murmur. Nasal murmurs have spectral properties similar to the formant, or resonance patterns, of sustained vowels. Murmurs and vowels share the same spectral properties, such as formants and antiformants. Antiformants are the result of bifurcation or constriction of the vocal tract, effectively blocking energy from transmission through the system. This blockage creates zeros, or regions where energy is severely attenuated (Kent and Read, 1992). Fujimura (1962) stated that there are three common properties of nasal murmurs: (1) all have a first formant of approximately 300 Hz that is well separated from higher formants, (2) the formants have large bandwidths, and (3) there is a high density of formants with the presence of antiformants (Kent and

Read, 1992).

Like other consonants, nasals also produce formant transitions when articulated consecutively with other sounds. Nasals mimic stops in that their place of articulation and formant transitions are similar such that the F2 transition correlates to the place of articulation, and F1 transition correlates to obstruction of the oral cavity (Kent and Read, 1992). It is the nasal murmur and formant transitions that are important for providing accurate information about place of articulation (Kurowski and Blumstein, 1984; Repp, 1986; Repp, 1987; Ohde, 1994; Ohde and Ochs, 1996; Ohde and Perry, 1994).

The Quantal Theory

Kenneth N. Stevens and colleagues have conducted studies to determine the effects of articulatory parameters on acoustic parameters. They also studied the relationship between these acoustic parameters and perception of sounds described by these acoustic parameters. Stevens' Quantal Theory predicts that there are small regions of articulator movement that can result in large acoustical changes. Similarly, there may be areas of small acoustic changes, which result in large perceptual changes. This region where large perceptual changes occur could be considered a threshold region such that, as the acoustical parameter changes through this region the perceptual categorization shifts from one type of pattern to another. The Quantal Theory also states that relative acoustic amplitude changes between adjacent consonantal and vocalic portions of a syllable may result in perceptual shifts for labeling consonant place of articulation (Stevens, 1989).

Ohde and Stevens (1983) provided supporting evidence to the quantal theory by showing that relative amplitude between a stop consonant and vowel in a particular frequency region affects listeners' perception of stop consonant place of articulation. Ohde and Stevens proposed identification of alveolar or labial place of articulation involved two acoustic properties. One acoustic property is relative amplitude which has been defined as "the amplitude of a major peak in the spectrum of the consonantal portion of a consonant vowel syllable relative to a spectral peak in the same frequency region in the onset of the adjacent vocalic portion" (Hedrick, Schulte, and Jesteadt, 1995). In Ohde and Stevens' study relative amplitude was compared between the consonant and the adjacent vowel spectrum (Ohde and Stevens, 1983). For example, equivalent or higher burst amplitude in the high frequency region compared tot he vowel designates an alveolar stop and equivalent or lower burst amplitude in the high frequency region compared to the vowel designates a labial stop. The second acoustic property was the proximity of F2 and F3 in relation to F1 in the formant transition. For a labial stop, a close proximity between F2 and F1 is required, whereas a critical distance is needed between F2 and F1 for correct identification of an alveolar stop (Ohde & Stevens, 1983).

Acoustic Analysis of Nasals

Research has shown that small, but systematic changes in nasal murmur and formant transition can be correlated with place of articulation. More specifically, the starting frequency of the second formant transition has been designated as the distinguishing cue between the labial nasal consonant, /m/, and alveolar nasal consonant, /n/. Kurowski and

Blumstein (1987) further suggest that it is the relationship between the spectral properties of the murmur and the formant transitions that form a single integrated perceptual cue for place of articulation. In their study they found a spectral peak in the 11-15 Bark region (1170 Hz to 2500 Hz) at the onset of the formant transition for the alveolar /n/. The spectral peak for the labial /m/ at the onset of the formant transition was discovered in the 5-7 Bark region (450 Hz to 700 Hz). There has been no systematic variation of the amplitude of these spectral peaks to determine if they are perceptually important. Nasals are analogous to stop consonants, and relative amplitude changes between the consonant and adjacent vowel affect perception of stop consonant place of articulation. It would follow, then, that perception of nasal consonant place of articulation should be affected by similar relative amplitude changes. Therefore, the following questions will be the focus of this research:

1) Do changes in relative amplitude at the consonant-vowel boundary affect nasal place of articulation perception?

2) Do systematic and simultaneous variations in the second formant transition and relative amplitude cues determine if relative amplitude cues provide a significant contribution to perception of place of articulation beyond the formant transition?

CHAPTER II

REVIEW OF LITERATURE

Previous studies have shown that formant transitions, particularly F2, play a dominant role in the perception of place of articulation of nasals (Liberman, Delattre, Cooper, & Gerstman, 1954; Malecot, 1956; Recasens, 1983). Later studies have suggested that the murmur also provides important information for perception of place of articulation (Nakata, 1959; Carlson, Granstrom, and Pauli, 1972). Most studies suggest that both murmur and formant transition information is needed for accurate identification of nasal place of articulation (Kurowski and Blumstein, 1984; Repp, 1986; Repp, 1987; Ohde, 1994; Ohde and Ochs, 1996; Ohde and Perry, 1994).

Work by Stevens and colleagues has suggested that variations in consonant amplitude relative to vowel amplitude in a particular frequency region may be an acoustic correlate for perception of place of articulation for stop consonants (Ohde and Stevens, 1983; Hawkins and Stevens, 1987; Hedrick, Schulte, and Jesteadt, 1995) and fricative consonants (Stevens, 1985; Hedrick and Ohde, 1993). According to the quantal theory, variations in the relative amplitude in discrete frequency regions between consonant and vowel may be a basis for discerning place of articulation of the consonant (Stevens, 1989). Stevens further assumed that these changes in relative amplitude would be most apparent near the consonant-vowel boundary. Ohde and Stevens (1983) found that manipulation of relative amplitude had a significant effect on perception of place of articulation for both voiced and voiceless stop consonants, although the effect size was larger for voiceless than for voiced stops. There are two potential explanations for this difference in effect size: greater salience of spectral peaks in the region of formant transitions for the voiced stops, or the use of steady-state vowel amplitude as the amplitude reference point rather than using vowel onset amplitude. If vowel onset would have been used as the amplitude reference point, the difference in effect size could have been reduced between voiced and voiceless stops. Because nasal consonants can be considered nasalized voiced stops, a relative amplitude manipulation near the murmur-vowel boundary should affect perception of nasal place of articulation similar to that of voiced stops in the Ohde and Stevens (1983) study.

Kurowski and Blumstein (1987) found a spectral peak in the 11-15 Bark region (1170 to 2500 Hz) at the initiation of formant transitions for the alveolar /n/. The spectral peak for the /m/ at formant transition onset was at a lower frequency (5-7 Bark, or 450 to 700 Hz). Thus, there appears to be an acoustic basis in naturally produced speech for changes in resonance and potential changes in relative amplitude between /m/ and /n/. The perceptual importance of this relative amplitude change between nasals and adjacent vowels has not been investigated.

Most perceptual studies investigating nasal place of articulation used naturally produced speech and therefore did not attempt to systematically vary the spectral relations or relative amplitude between the murmur and the vowel. The studies that did use synthetic syllables (Larkey, Wald, and Strange, 1978; Nakata, 1959; Recasens, 1983) did not employ a relative amplitude manipulation. The acoustic analysis study by Kurowski and Blumstein (1987), and the previous work by Ohde and Stevens (1983), however, does provide a framework for synthesizing nasal consonant-vowel (CV) syllables that include variations in the relative amplitude between the murmur and the vowel. Thus, the first aim of the present study is to determine if variations in relative amplitude between the murmur and the vowel of CV syllables influenced listeners' perception of the /m/-/n/ contrast. The second aim is to systematically and simultaneously vary second formant transition and relative amplitude cues to ascertain if relative amplitude cues provide a significant contribution to perception of place of articulation beyond the formant transition.

CHAPTER III

METHODS

Subjects

Twenty-five subjects ranging in age from 22-35 years participated in this experiment. Inclusion criteria were: (i) hearing sensitivity less than or equal to 15 dB HL (ANSI S3.6-1989) for 250-8000 Hz in the right ear and (ii) no evidence of abnormality of the pinna or ear canal. There was one experimental session for each listener and all listeners were unpaid volunteers. All subjects were given a criterion test using continua endpoints. Subjects had to classify the most /m/ - like and the most /n/ - like stimuli with at least 80% accuracy before inclusion in the study. The criterion test was presented at a comfortable listening level.

Stimuli

The stimuli for this investigation were synthetic consonant-vowel (CV) syllables generated by a PC software version of Klatt's cascade/parallel formant synthesizer (Klatt, 1980) using a sampling rate of 10 kHz. All syllables contained the /ɑ/ vowel. Two different acoustic cues were manipulated in the synthetic stimuli: F2 transition onset frequencies and relative amplitude. To test the specific aims of this project, three stimulus conditions were constructed.[1] Following is a brief summary of stimulus synthesis for each condition.

Condition One

This condition tested the first aim of this project; namely, whether variations in relative amplitude between the murmur and the vowel of CV syllables influenced listeners' perception of the /m/ - /n/ contrast. To test this aim, two stimulus continua were synthesized. The stimuli in the first continuum had a second formant (F2) transition onset frequency appropriate for /m/ (F2=900 Hz). In the second continuum, all stimuli had an F2 transition onset frequency appropriate for /n/ (F2=1500 Hz). These formant transition onset values were modified from the Klatt (1980) synthesis protocols. Within a continuum, the amplitude levels of the formants at vowel onset were changed. This was done using the parallel option on the synthesizer. For an /m/ - like percept, the A1 synthesis parameter (controlling the

[1]Parameters of the end point stimuli are in Appendix B.

amplitude level of the first formant) was set at a high dB level at vowel onset, with low initial amplitude levels for A2 and A3 (amplitude levels of second and third formants). For an /n/ - like percept, amplitude levels of A2 and A3 at vowel onset were set at a high dB level. These changes were made to simulate findings from acoustic analyses of bilabial and alveolar nasals, which show more high-frequency energy at vowel onset for the alveolar than the bilabial (Kurowski and Blumstein, 1987).

The following is a generic description of synthetic parameter settings and changes over time. Initially, the frequency of the lower nasal pole (FNP) was set at 250 Hz and the frequency of the nasal zero (FNZ) was set at 550 Hz. To create the pole-zero-pole complex for nasal synthesis described in Klatt (1980), F1 also was set at 600 Hz to simulate the second pole in the murmur. The total duration of the murmur was 100 ms. Near the murmur/vowel boundary, the value of FNZ was moved to 250 Hz to coincide with FNP. At the beginning of the vowel, A1 through A3 were initiated at a starting level in the parallel synthesis mode. Formant transitions began at this time and were completed in 40 ms. The amplitudes of the lower three formants rose within 40 ms to these steady-state values: A1=60, A2=55, A3=50. The formant amplitudes remained at these levels for 160 ms. The entire vocalic portion was 200 ms, and total stimulus duration was 300 ms (100 ms murmur plus 200 ms vowel). Fundamental frequency was initiated at 100 Hz at murmur onset, rose to 130 Hz at vowel onset, and declined to 100 Hz throughout the vowel. Steady-state vowel formant frequency values were F1=700 Hz, F2=1220 Hz, F3=2440 Hz, F4=3600 Hz, and F5=4500 Hz.

Figure 1 depicts the waveform and spectrogram for the stimulus in continuum number one having an F2 transition onset frequency appropriate for /m/ and a relative amplitude value appropriate for /m/. Figure 2 shows the waveform and spectrogram for the stimulus in continuum number one having an F2 transition onset appropriate frequency for /m/, but a more /n/ -like relative amplitude value. Figure 3 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how relative amplitude or spectral shape was varied along the continuum. These and succeeding frequency spectra were obtained using

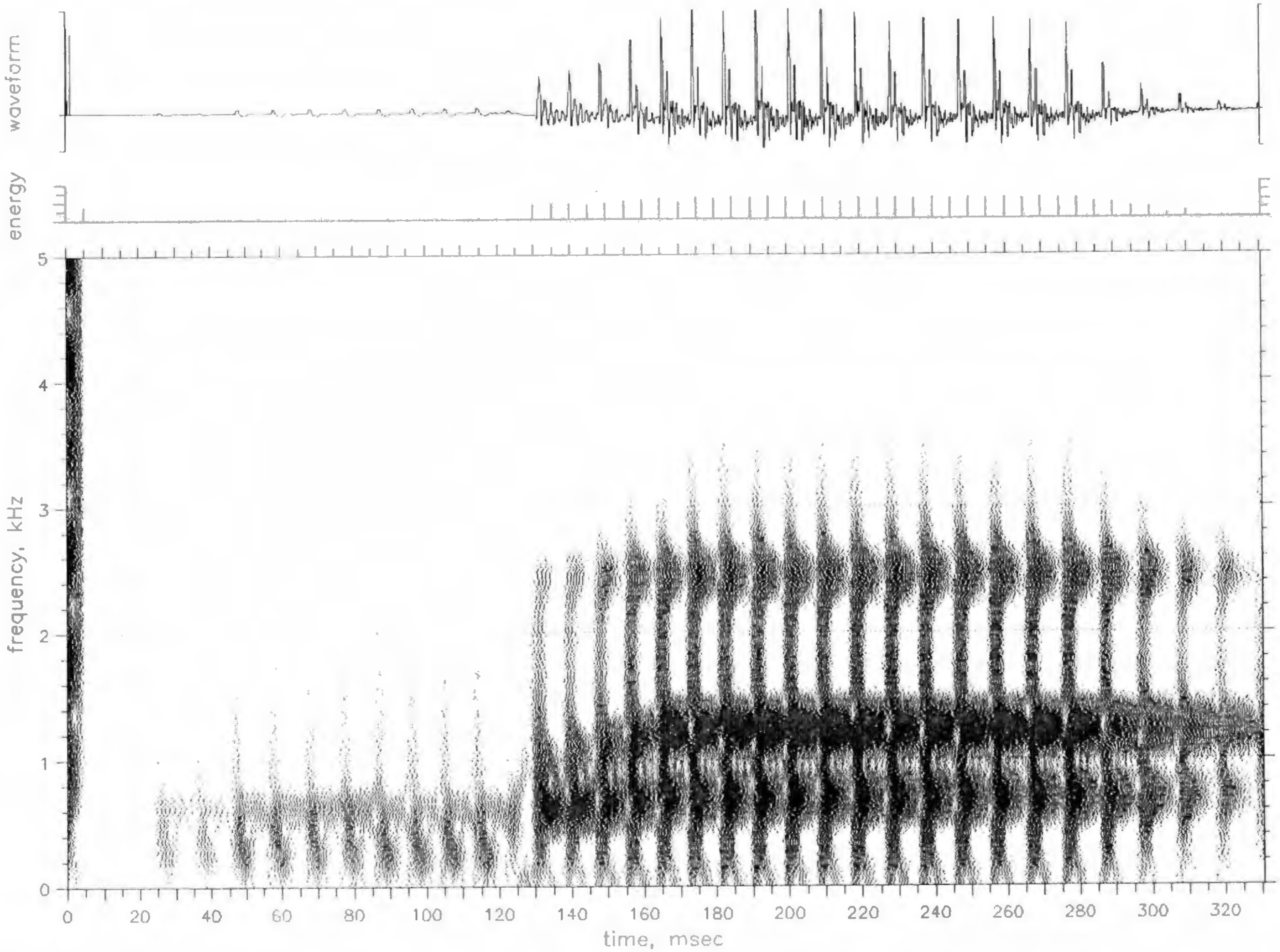
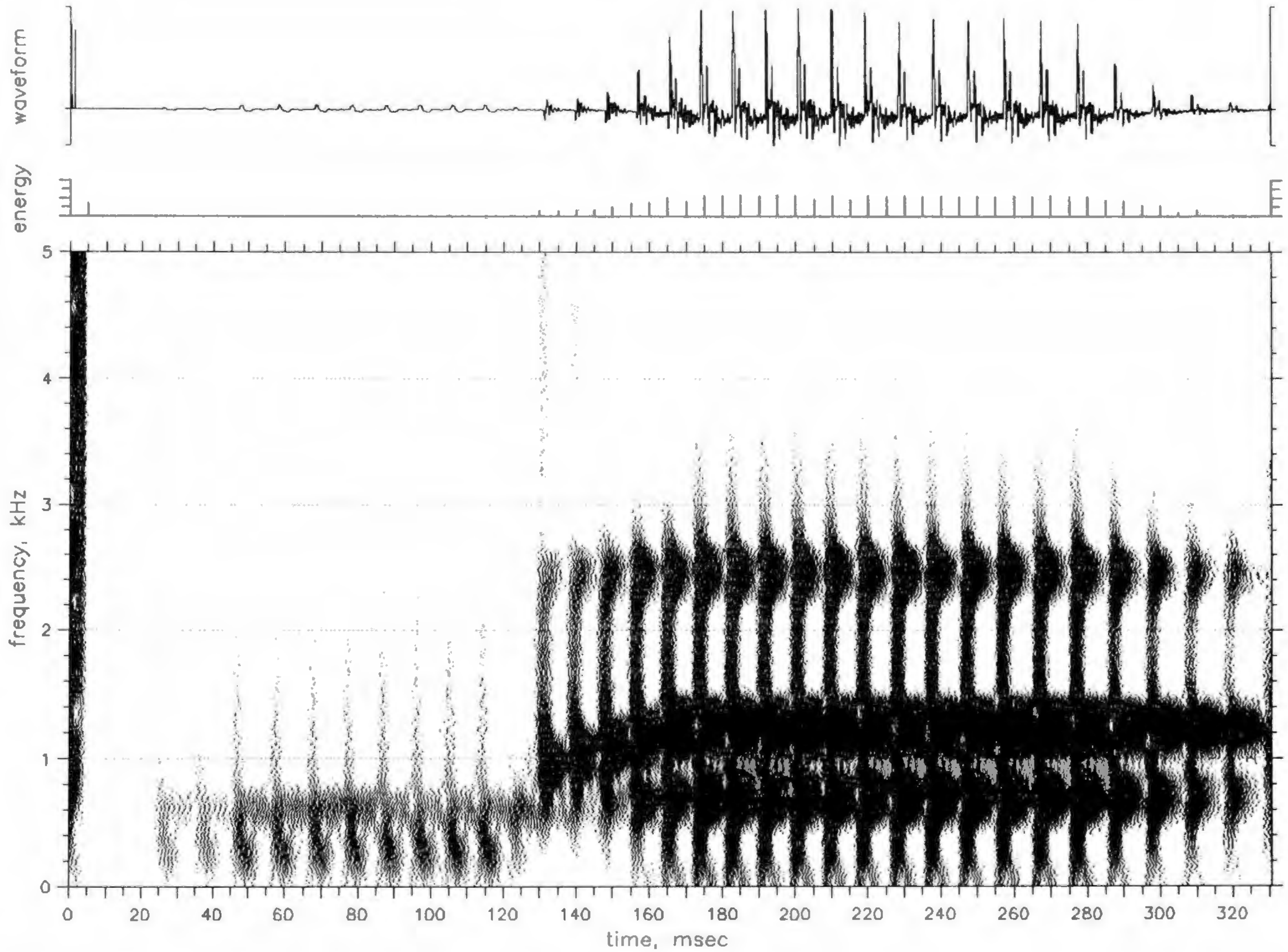


Figure 1. Waveform and spectrogram of the end point stimulus in condition one, continuum number one, having an F2 transition appropriate for /m/ and an /m/ -like relative amplitude value.



<u>Figure 2.</u> Waveform and spectrogram of the end point stimulus in condition one, continuum number on, having an F2 transition appropriate for /m/ and an /n/ -like relative amplitude value.

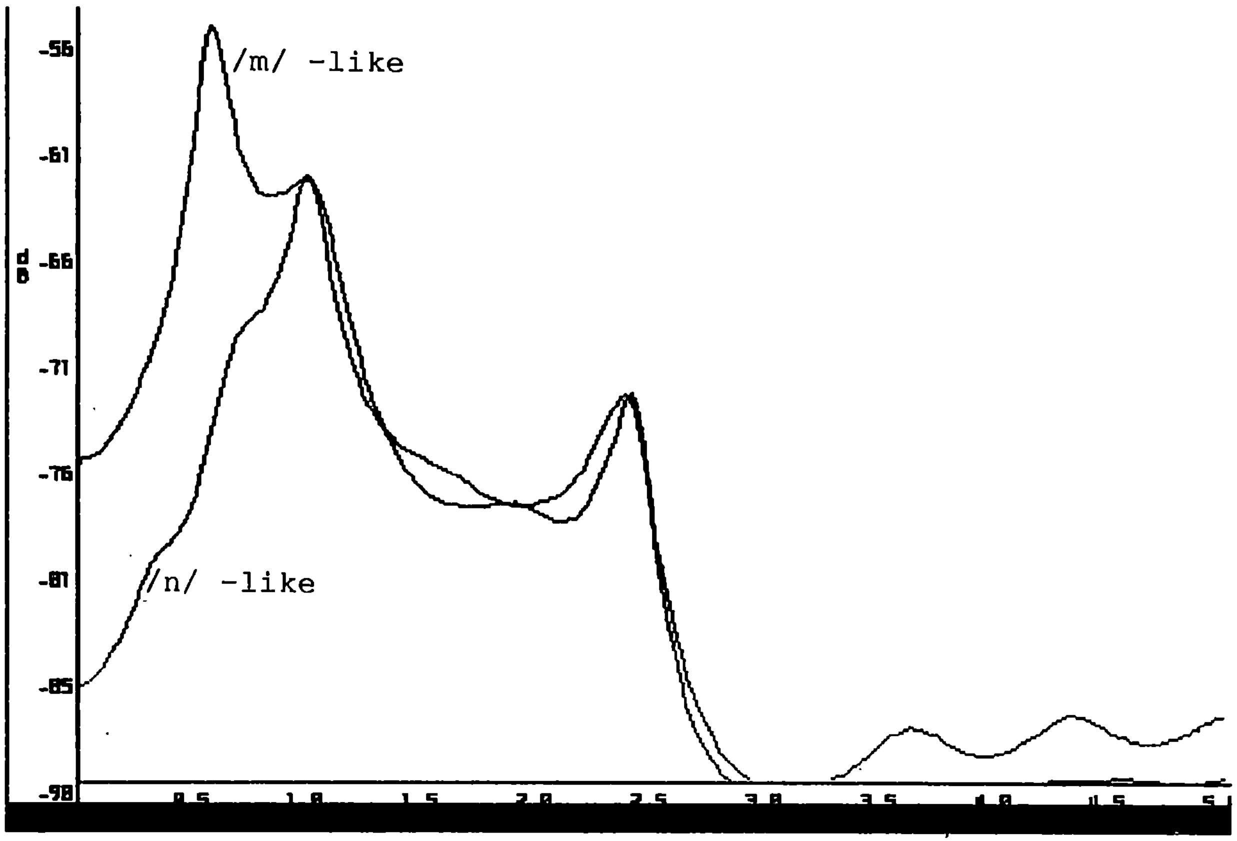


Figure 3. Vowel onset frequency spectra from the end point stimuli in condition one, continuum number one, illustrating the change in relative amplitude across the continuum.

linear predictive coding (LPC) and a 25.6 ms Hanning window which began at the vowel onset.

Similarly, Figure 4 shows the waveform and spectrogram of the end point stimulus in continuum number two having an F2 transition onset appropriate for /n/ and a relative amplitude value appropriate for /n/. Figure 5 shows the waveform and spectrogram for the stimulus in continuum number two having an F2 transition onset appropriate for /n/ but a more /m/ - like relative amplitude value. Figure 6 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how relative amplitude or spectral shape was varied along continuum number two.

Condition Two

This condition also tested the first aim of the study; that is, could the overall amplitude at vowel onset, irrespective of the spectral shape of the vowel onset, influence listeners' perception of nasal place of articulation? To test this assumption, two additional continua were synthesized. Stimuli in one continuum had an F2 transition onset frequency value appropriate for /m/ (F2=900 Hz), and stimuli in the other continuum had an F2 transition onset frequency

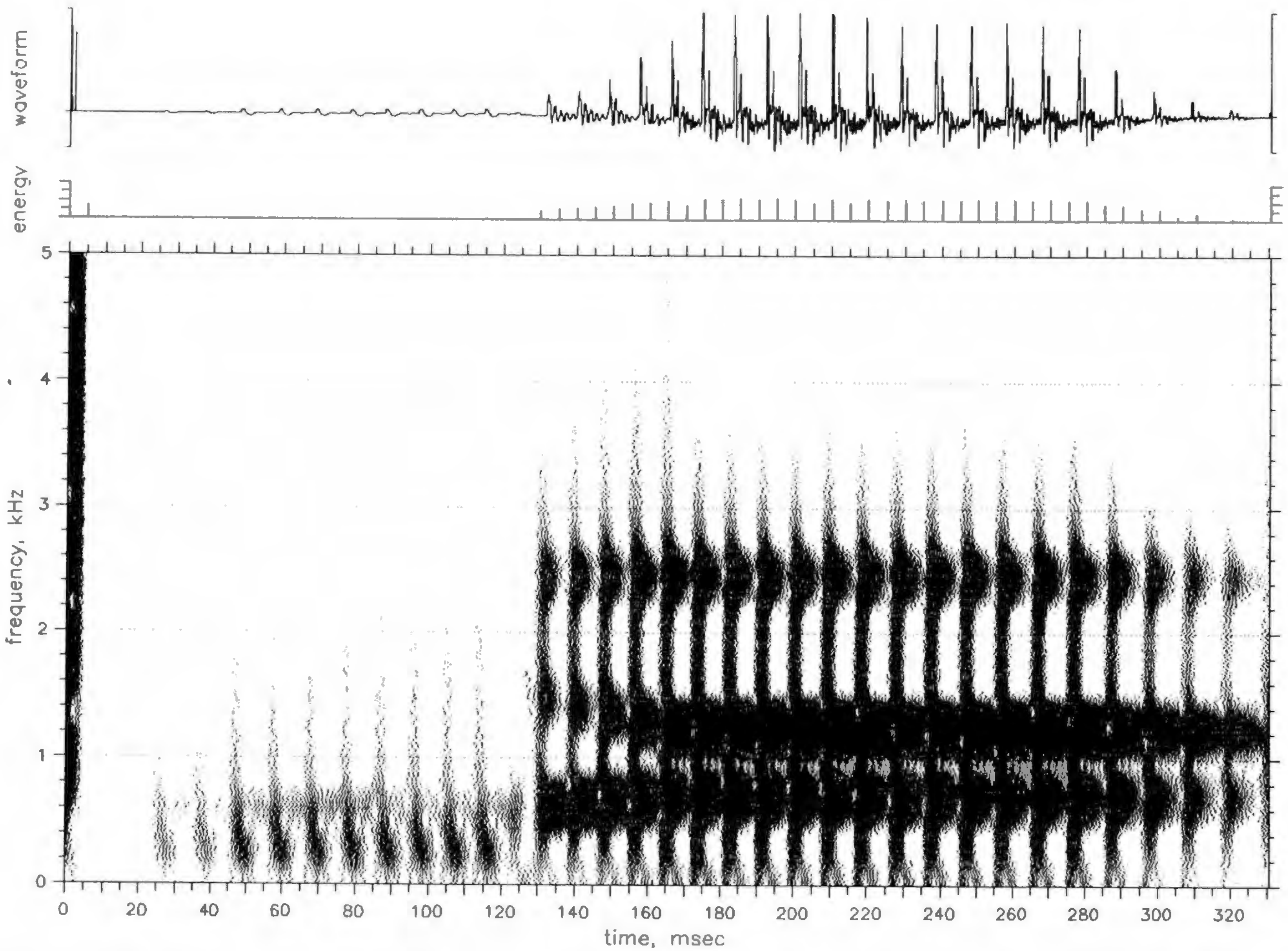
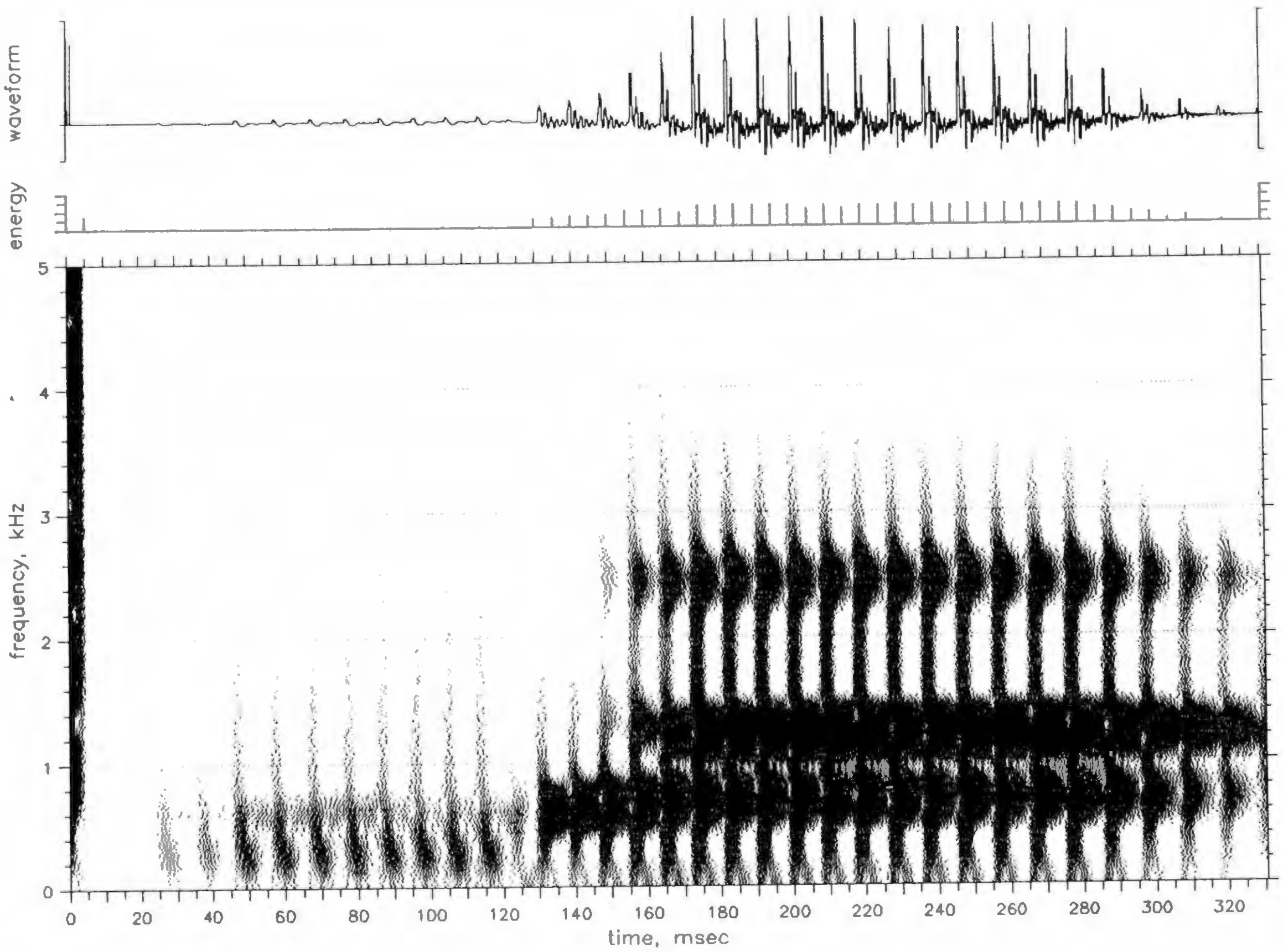


Figure 4. Waveform and spectrogram of the end point stimulus in condition one, continuum number two, having an F2 transition appropriate for /n/ and an /n/ -like relative amplitude value.



<u>Figure 5.</u> Waveform and spectrogram of the end point stimulus in condition one, continuum number two, having an F2 transition appropriate for /n/ and an /m/ -like relative amplitude value.

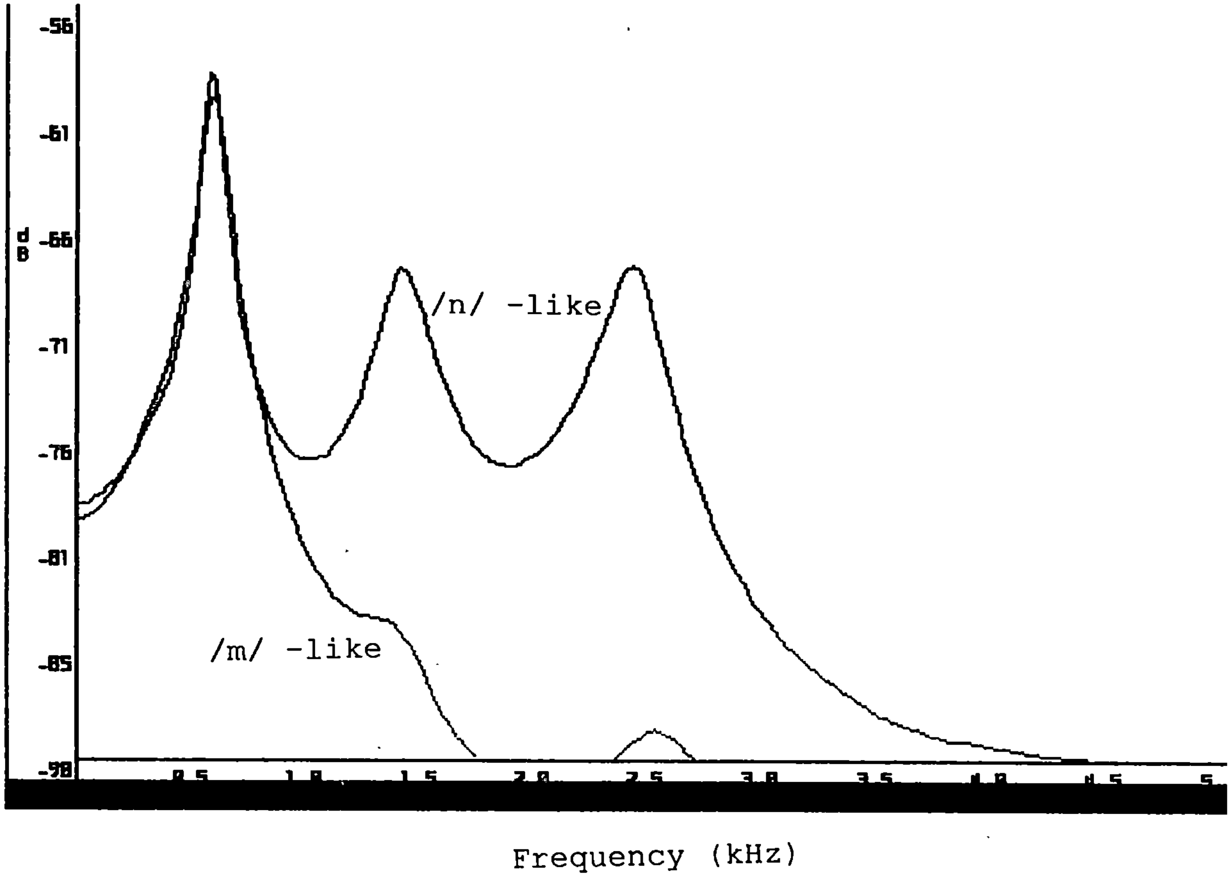


Figure 6. Vowel onset frequency spectra from the end point stimuli in condition number one, continuum number two, illustrating the change in relative amplitude across the continuum.

value appropriate for /n/ (F2=1500 Hz). Within each of the two continua, the overall amplitude levels of the first three formants were decreased uniformly at vowel onset. That is, for one endpoint stimulus of a continuum, the amplitude levels at vowel onset were as follows: A1=55 dB, A2=50 dB, and A3=50 dB. For the other endpoint stimulus, the amplitude levels at vowel onset were as follows: A1=30 dB, A2=25 dB, and A3=25 dB. All other synthesis parameters were as in condition one.

Figure 7 depicts the waveform and spectrogram for the stimulus in continuum number one having an F2 transition onset frequency appropriate for /m/ and A1, A2, and A3 onset amplitudes of 55, 50, and 50 dB, respectively. Figure 8 shows the waveform and spectrogram for the stimulus in continuum number one having an F2 transition onset frequency appropriate for /m/ and A1, A2, and A3 onset amplitudes of 30, 25, and 25 dB, respectively. Figure 9 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how the overall amplitudes of the formants were changed across the continuum.

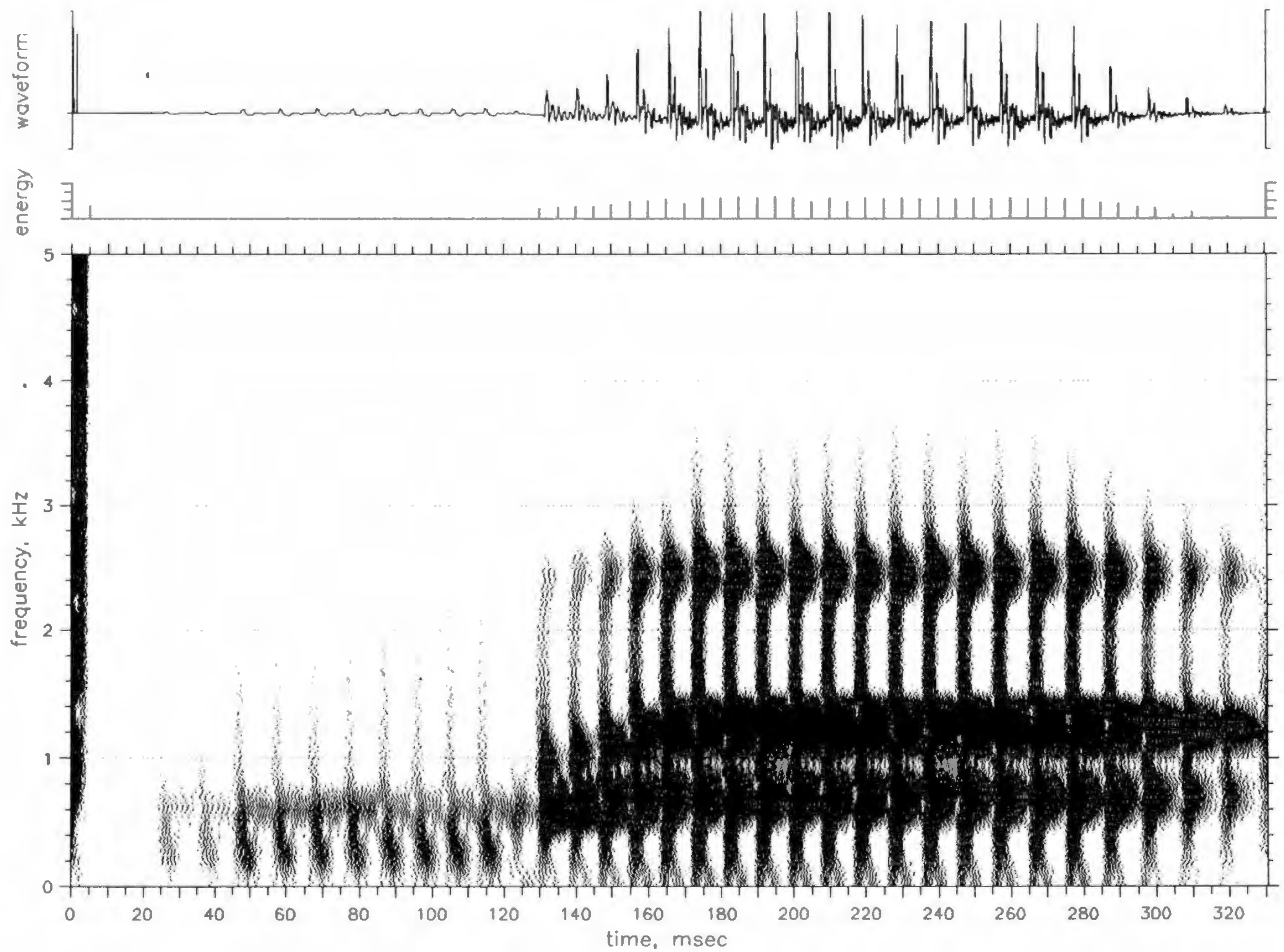


Figure 7. Waveform and spectrogram of the end point stimulus in condition two, continuum number one, having an F2 transition onset frequency appropriate for /m/ and A1, A2, and A3 onset amplitudes of 55, 50, and 50, respectively.

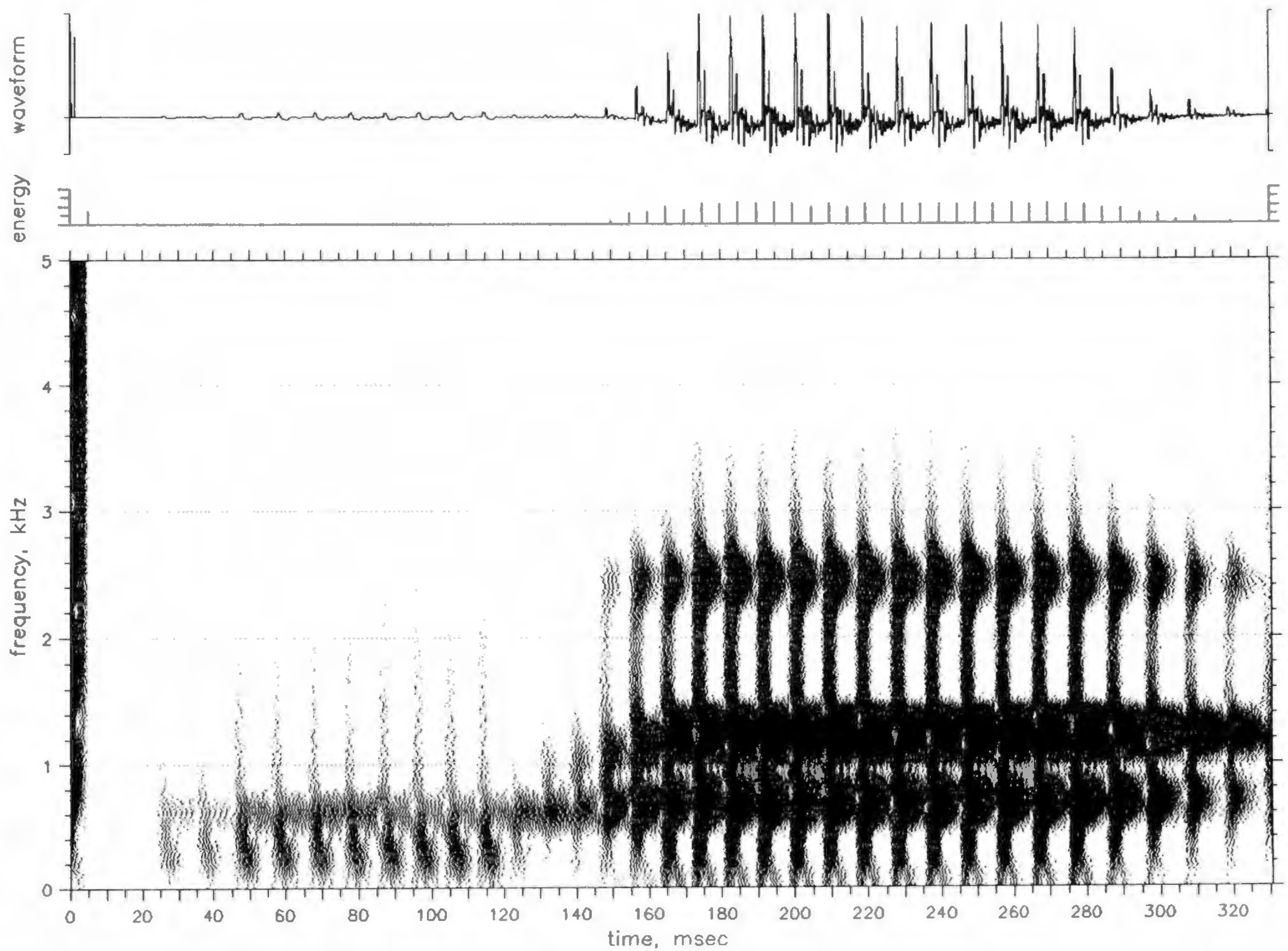


Figure 8. Waveform and spectrogram of the end point stimulus in condition two, continuum number one, having an F2 transition onset frequency appropriate for /m/ and A1, A2, and A3 onset amplitudes of 30, 25, and 25, respectively.

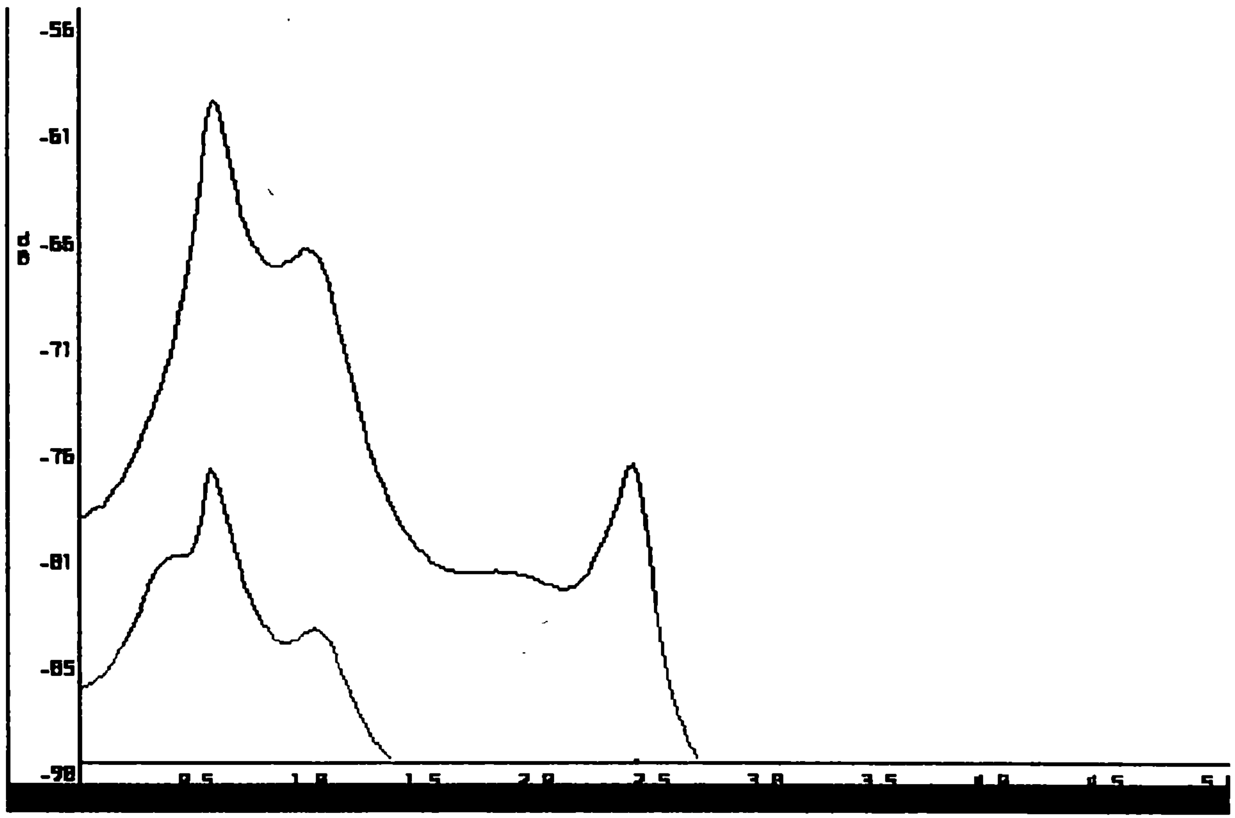
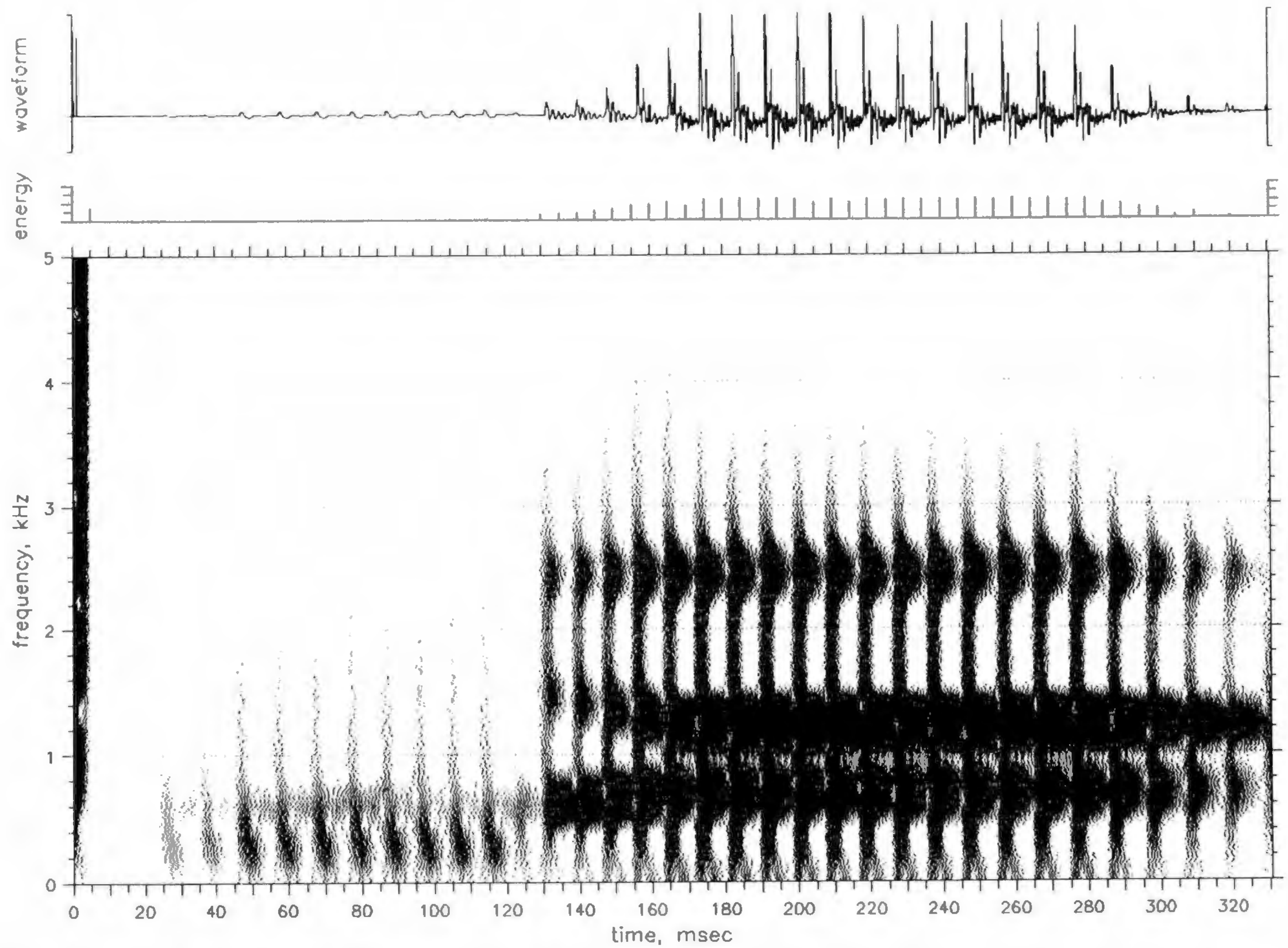


Figure 9. Vowel onset frequency spectra from the end point stimuli in condition two, continuum number one, illustrating the change in overall formant amplitude across the continuum.

Similarly, Figure 10 shows the waveform and spectrogram for the stimulus in continuum number two having an F2 transition onset frequency appropriate for /n/ and A1, A2, and A3 onset amplitudes of 55, 50 and 50 dB, respectively. Figure 11 shows the waveform and spectrogram for the stimulus in continuum number two having an F2 transition onset frequency appropriate for /n/ and A1, A2, and A3 onset amplitudes of 30, 25, and 25 dB, respectively. Figure 12 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how the overall amplitudes of the formants were changed across the continuum.

Condition Three

This condition tested the second aim of the project; that is, to determine the result of systematically and simultaneously varying second formant transition and relative amplitude cues to determine if relative amplitude or spectral shape influences listeners' perception of nasal place of articulation beyond simple F2 transition frequency values. To test this assumption, three stimulus continua were constructed. In the first continuum,



<u>Figure 10.</u> Waveform and spectrogram of the end point stimulus in condition two, continuum number two, having an F2 transition onset frequency appropriate for /n/ and A1, A2, and A3 onset amplitudes of 55, 50, and 50 dB, respectively.

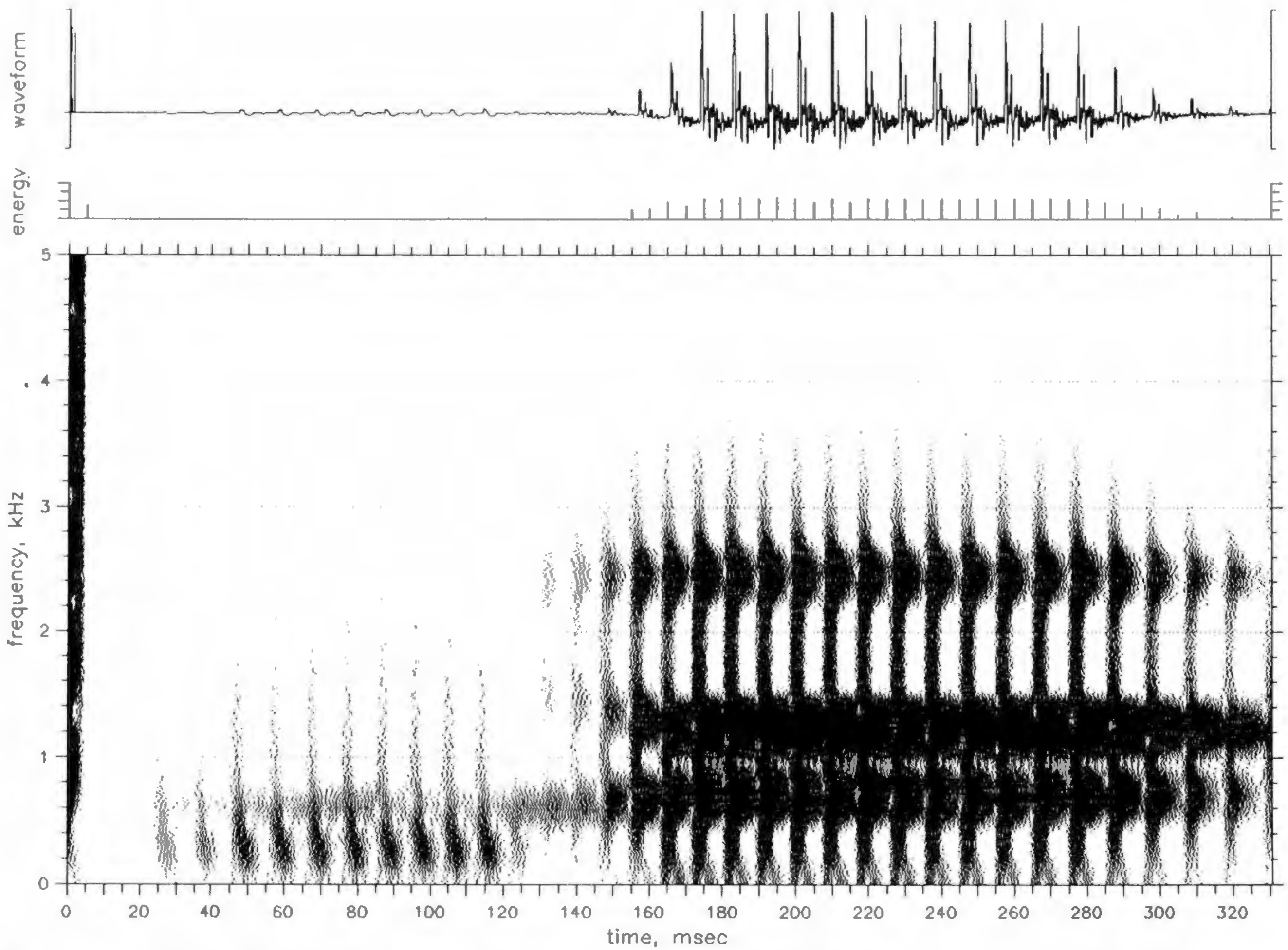


Figure 11. Waveform and spectrogram of the end point stimulus in condition two, continuum number two, having an F2 transition onset frequency appropriate for /n/ and A1, A2, and A3 onset amplitudes of 30, 25, and 25, respectively.

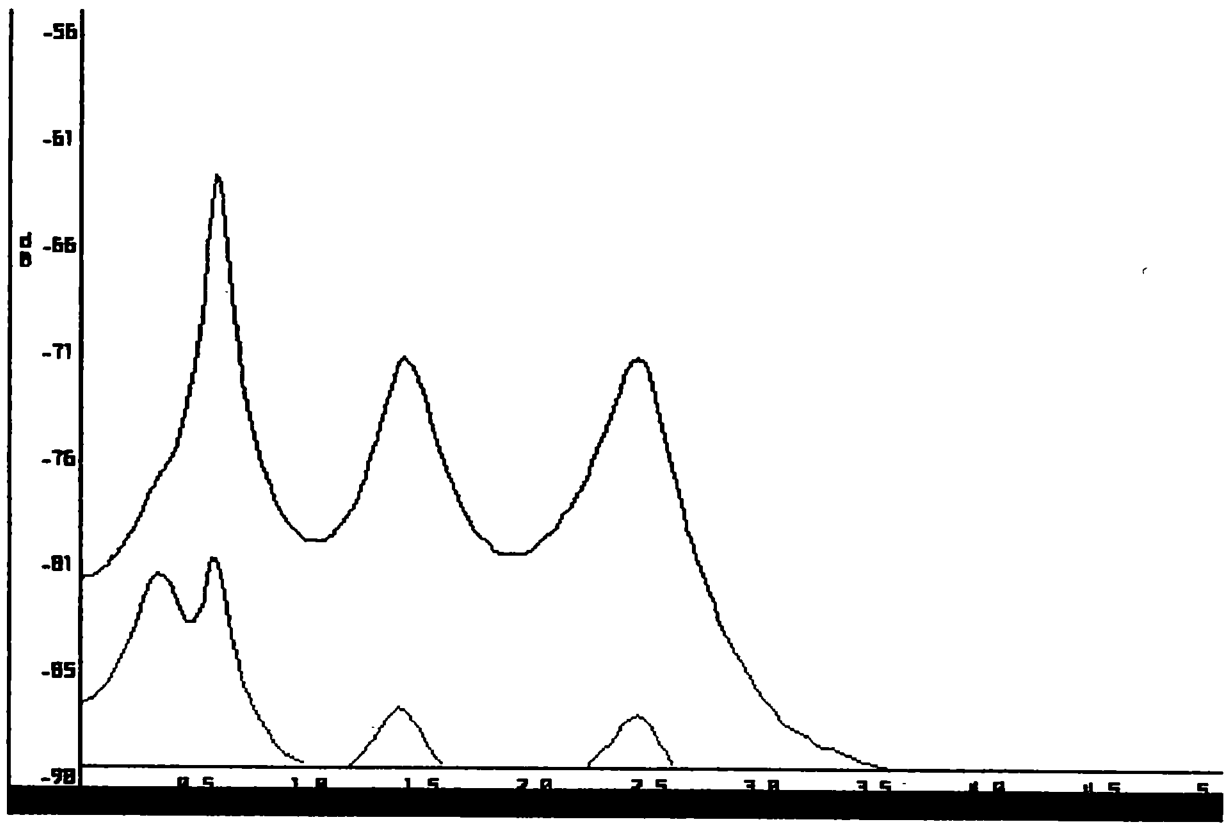


Figure 12. Vowel onset frequency spectra from the end point stimuli in condition two, continuum number two, illustrating the change in overall formant amplitudes across the continuum.

all stimuli had a vowel onset spectral shape like that of /n/. Within the continuum, F2 transition onset frequency values vary from /m/ - like (900 Hz) to /n/ - like (1500 Hz) in 100 Hz steps. In the second continuum, all stimuli had a vowel onset spectral shape like that of /m/, and again F2 transition onset frequency values were varied from 900 to 1500 Hz. In the third continuum, all stimuli had a vowel onset spectral shape that was arithmetically neutral, and F2 transition onset frequency values were again varied from 900 to 1500 Hz. All other synthesis parameter values were as in conditions one and two.

Figure 13 depicts the waveform and spectrogram for the stimulus in continuum number one having /m/ - like relative amplitude values and an F2 transition onset frequency appropriate for /m/. Figure 14 shows the waveform and spectrogram for the stimulus in continuum number one having /m/ -like relative amplitude values and an F2 transition onset frequency appropriate for /n/. Figure 15 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how the F2 transition onset frequencies were changed across the continuum.

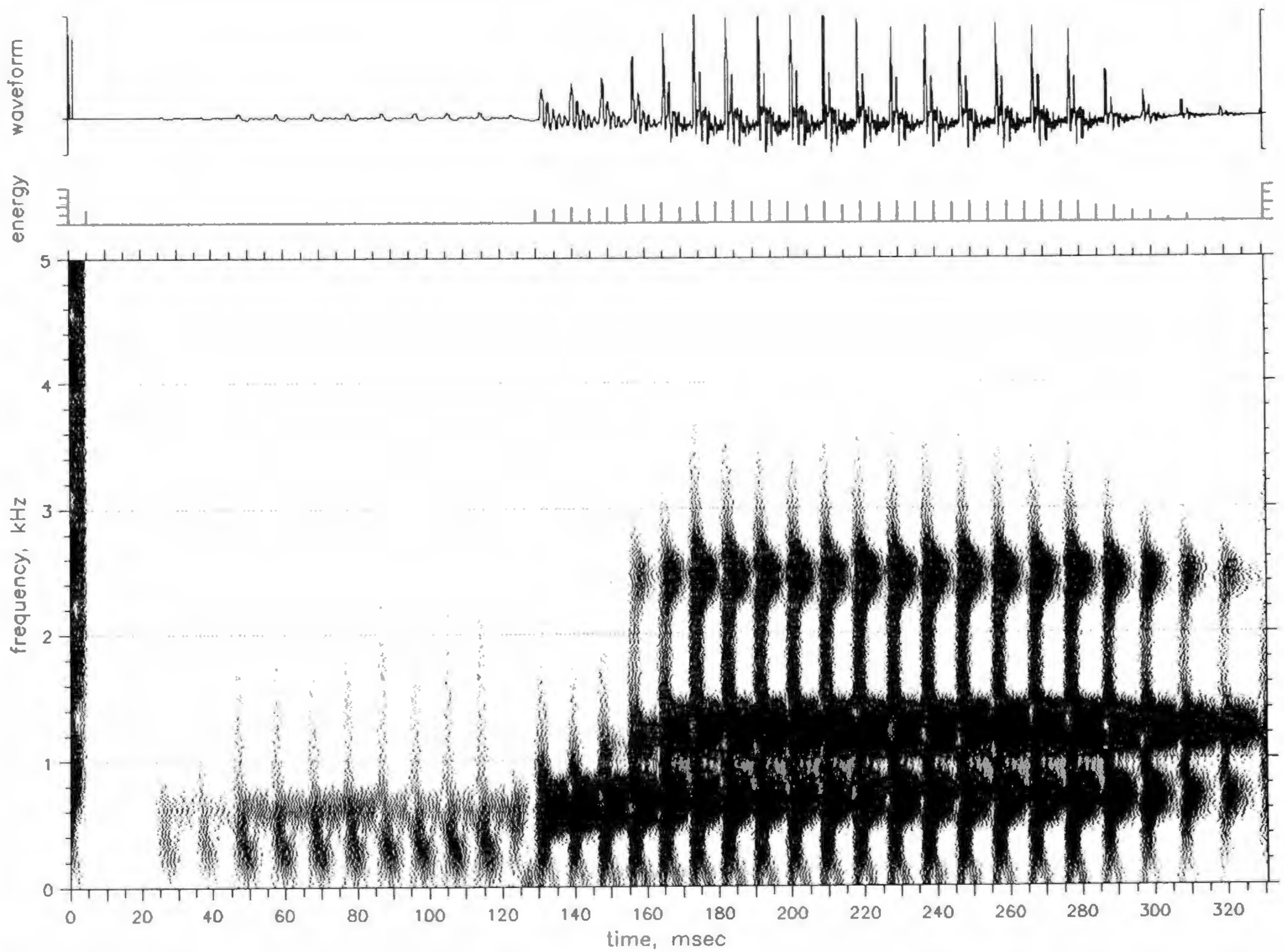


Figure 13. Waveform and spectrogram of the end point stimulus in condition three, continuum number one, having /m/ -like relative amplitude values and an F2 transitions onset frequency appropriate for /m/.

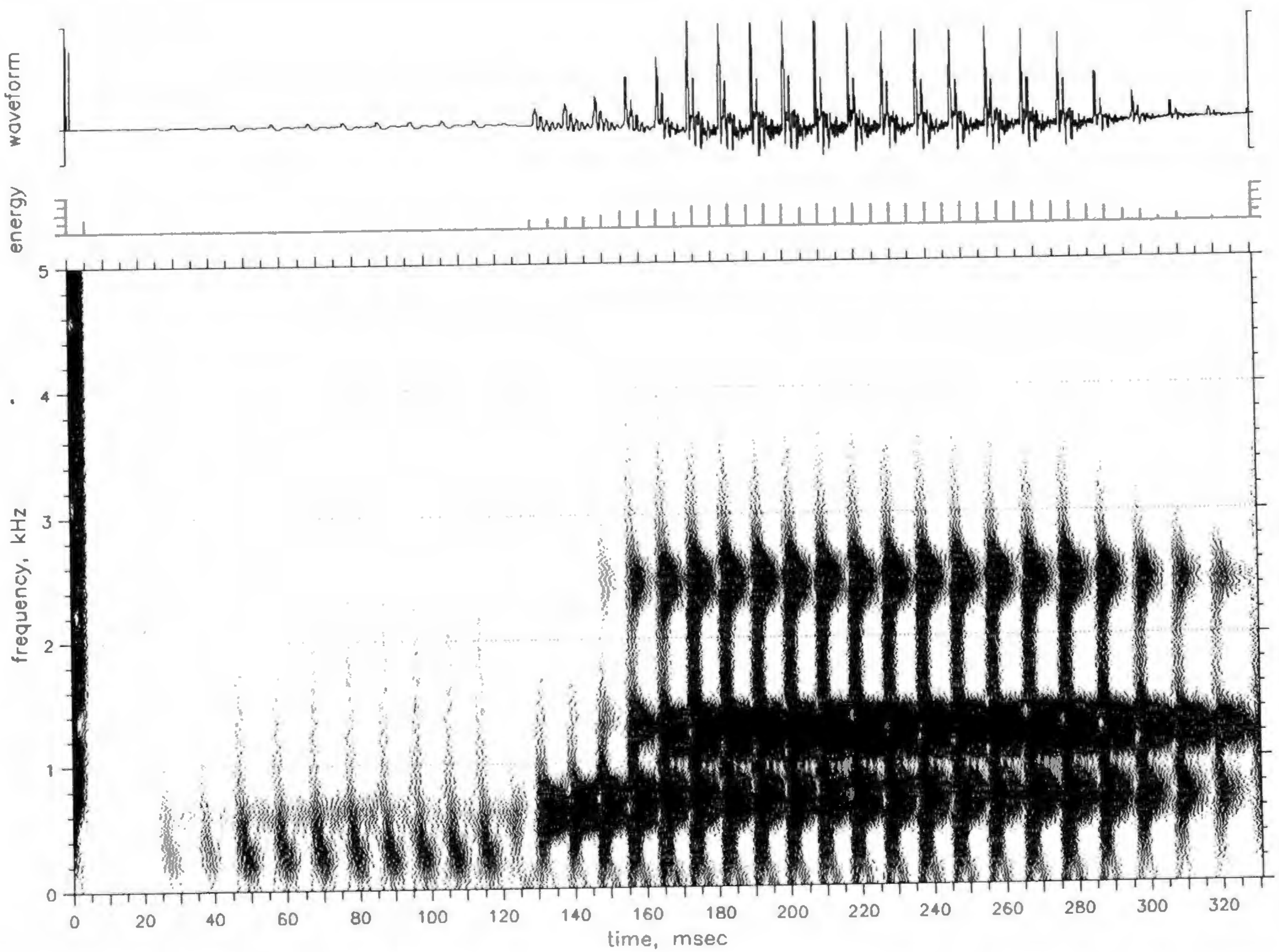
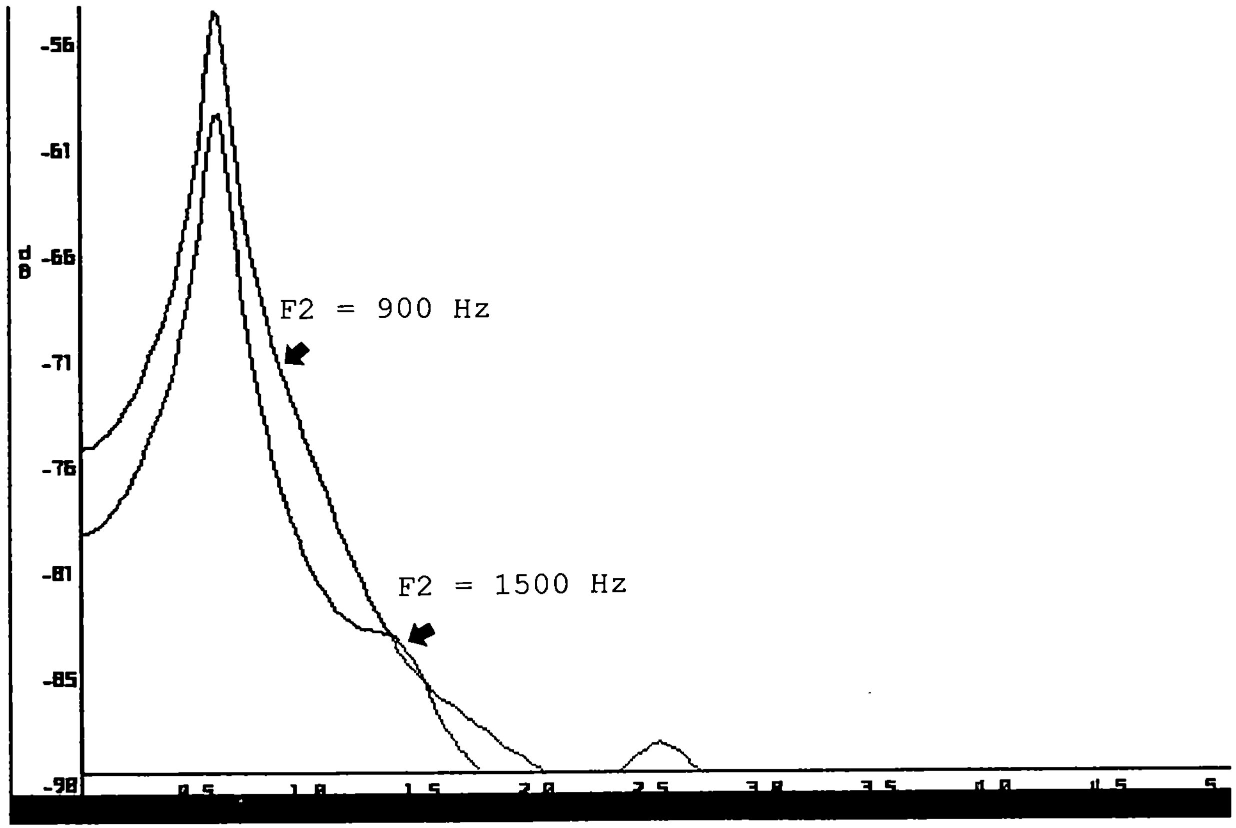


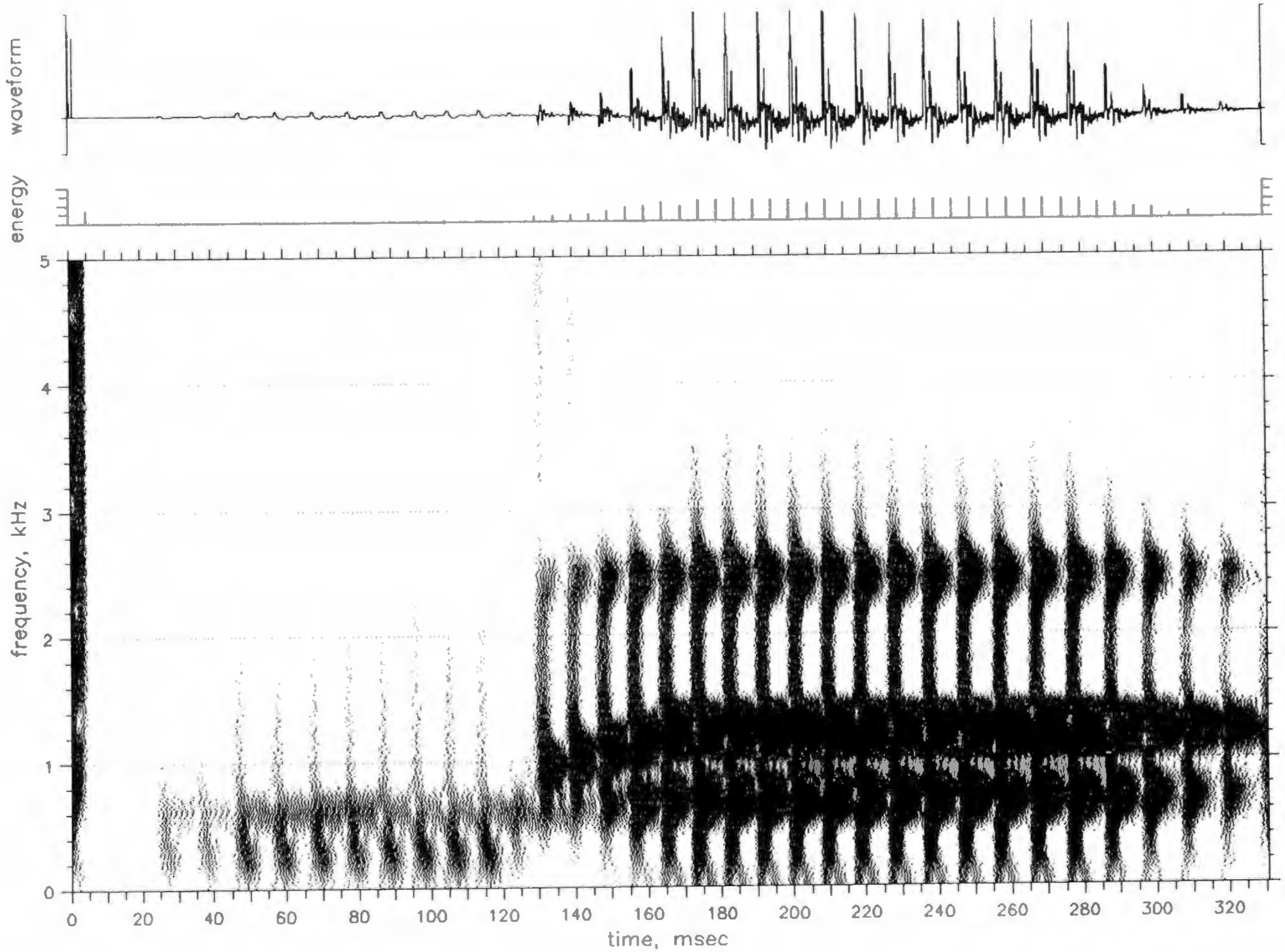
Figure 14. Waveform and spectrogram of the end point stimulus in condition three, continuum number one, having /m/ -like relative amplitude values and an F2 transition onset frequency appropriate for /n/.



<u>Figure 15.</u> Vowel onset frequency spectra from the end point stimuli in condition three, continuum number one, illustrating a change in the F2 transition onset frequency from /m/ -like to /n/ -like.

Similarly, Figure 16 depicts the waveform and spectrogram for the stimulus in continuum number two having /n/ -like relative amplitude values and an F2 transition onset frequency appropriate for /m/. Figure 17 shows the waveform and spectrogram for the stimulus in continuum number two having /n/ -like relative amplitude values and an F2 transition onset frequency appropriate for /n/. Figure 18 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how the F2 transition onset frequencies were changed across the continuum.

Likewise, Figure 19 depicts the waveform and spectrogram for the stimuli in continuum number three having arithmetically neutral relative amplitude values and an F2 transition onset frequency appropriate for /m/. Figure 20 shows the waveform and the spectrogram for the stimulus in continuum number three having neutral relative amplitude values and an F2 transition onset frequency appropriate for /n/. Figure 21 shows overlapping vowel onset frequency spectra from these two stimuli, and illustrates how the F2 transition onset frequencies were changed across the continuum.



<u>Figure 16.</u> Waveform and spectrogram of the end point stimulus in condition three, continuum number two, having /n/ -like relative amplitude values and a F2 transition onset frequency appropriate for /m/.

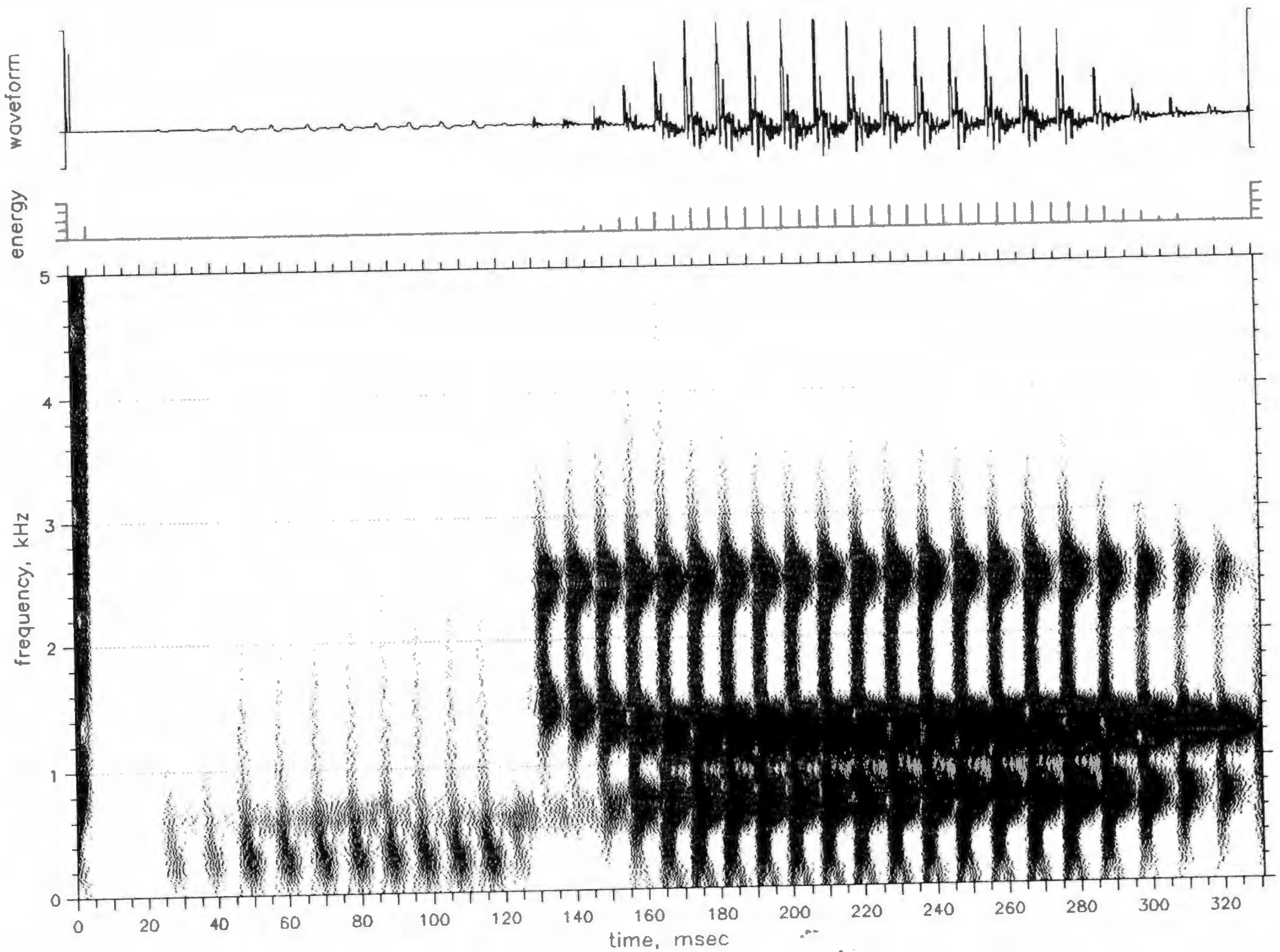


Figure 17. Waveform and spectrogram of the end point stimulus in condition three, continuum number two, having /n/ -like relative amplitude values and an F2 transition onset frequency appropriate for /n/.

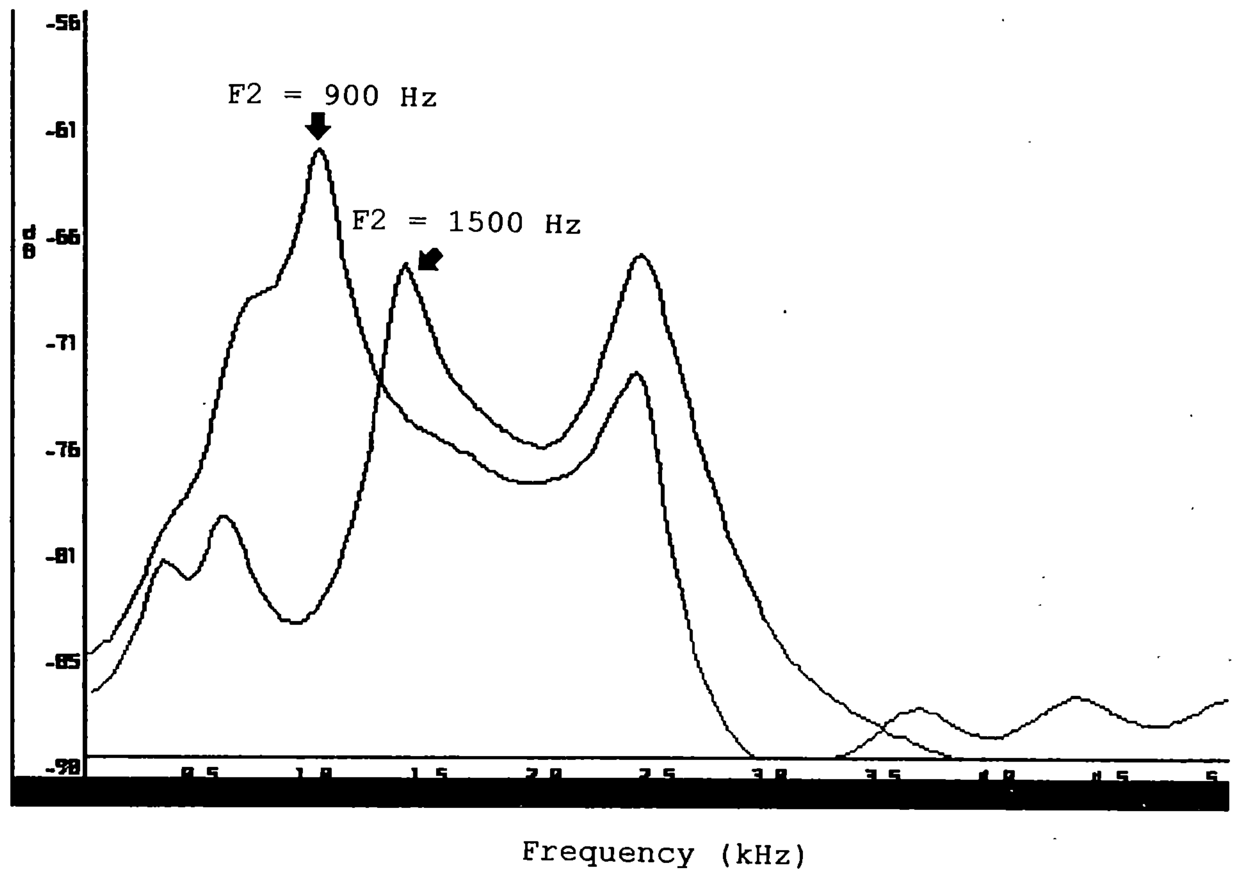
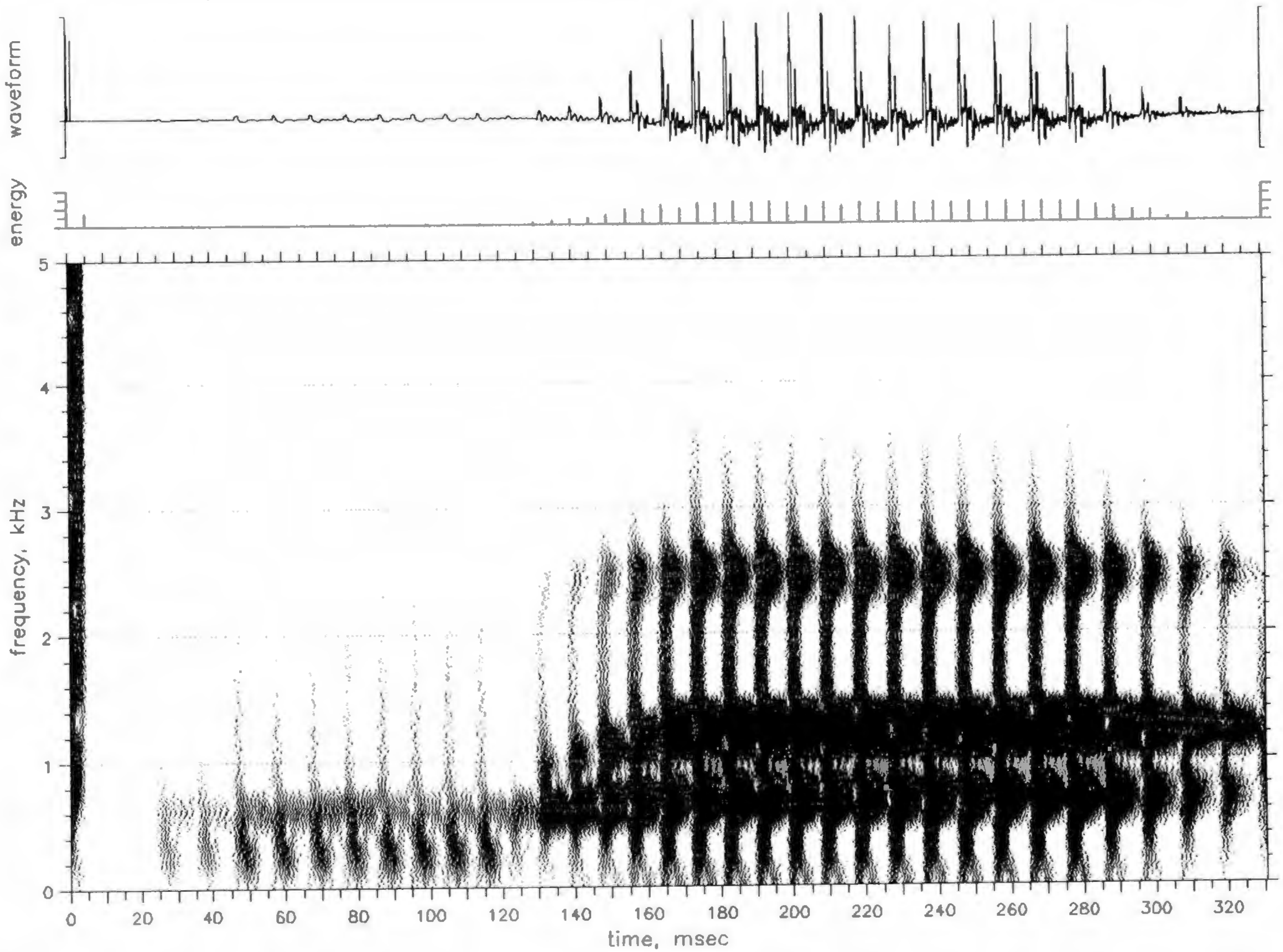
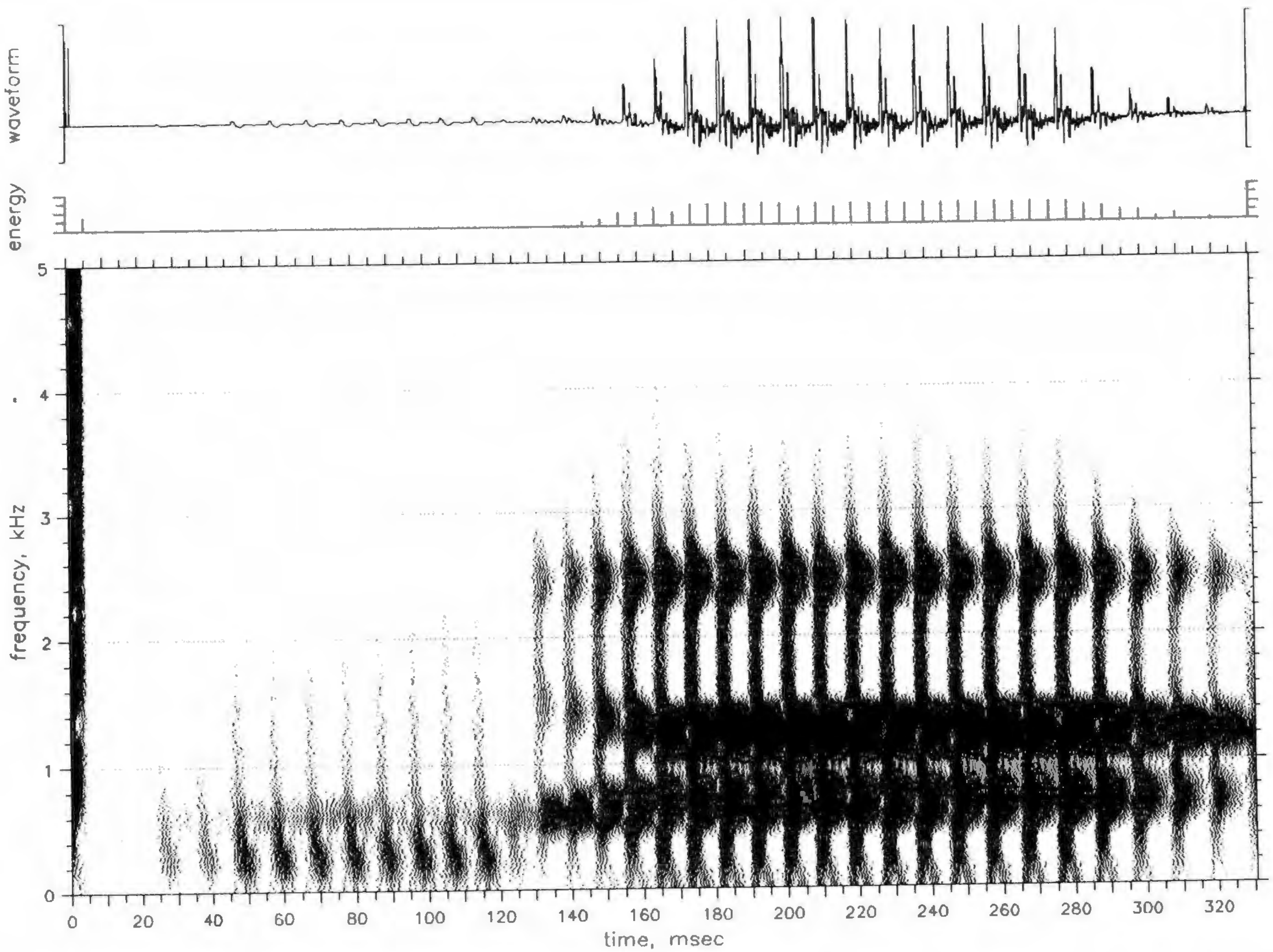


Figure 18. Vowel onset frequency spectra from the end point stimuli in condition three, continuum number two, illustrating a change in the F2 transition onset frequency from /m/ -like to /n/ -like.



<u>Figure 19.</u> Waveform and spectrogram of the end point stimulus in condition three, continuum number three, having arithmetically neutral relative amplitude values and an F2 transition onset frequency appropriate for /m/.



<u>Figure 20.</u> Waveform and spectrogram of the end point stimulus in condition three, continuum number three, having arithmetically neutral relative amplitude values and an F2 transition onset frequency appropriate for /n/.

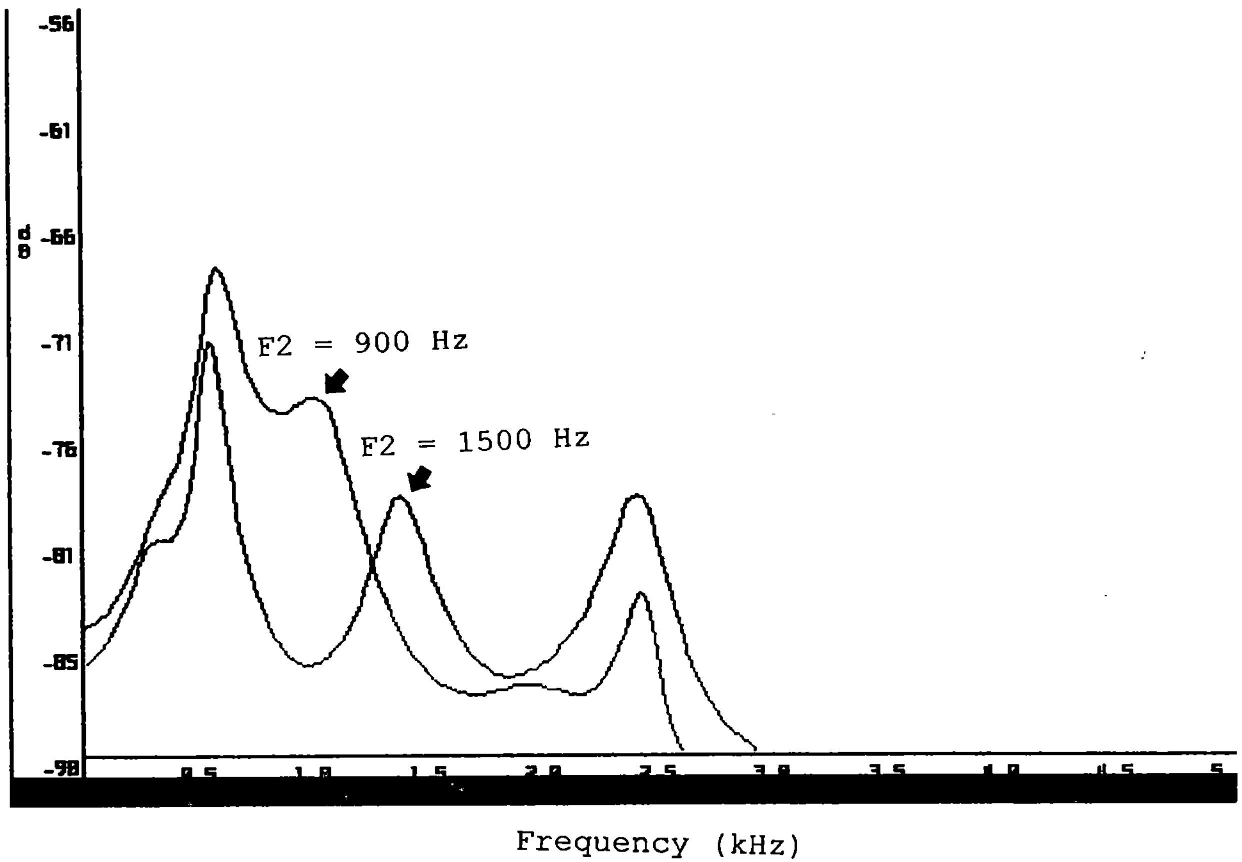


Figure 21. Vowel onset frequency spectra from the end point stimuli in condition three, continuum number three, illustrating a change in the F2 transition onset frequency from /m/ -like to /n/ -like.

Procedure

The stimuli were synthesized and the research protocol was implemented using interactive signal generation and control software (CSRE version 4.5, with a Compaq 2000 586 microcomputer). The stimuli were synthesized at a 10 kHz sampling rate, output by a Tucker-Davis DD1 D/A converter, low-pass filtered at 4.9 kHz (Tucker-Davis PF1), sent to a final attenuator (Tucker-Davis PA4), routed to a headphone buffer (Tucker-Davis HB), and sent to Sennheiser HD 265 headphones inside an IAC sound booth.

Generation of random orderings and online data collection were performed using the interactive software. Subjects were instructed to identify the consonant perceived by selecting the appropriate symbol ("M" or "N") displayed on a computer monitor via a mouse. In condition one, all 14 stimuli were presented together to each listener in 10 random orders. In condition two, all 12 stimuli were presented together to each listener in 10 random orders. Finally, in condition three, all 21 stimuli were presented together to each listener in 10 random orders. Stimuli were presented at a peak level of 80 dB SPL as measured using a Larson-Davis 800B sound level meter with a 6cc coupler.

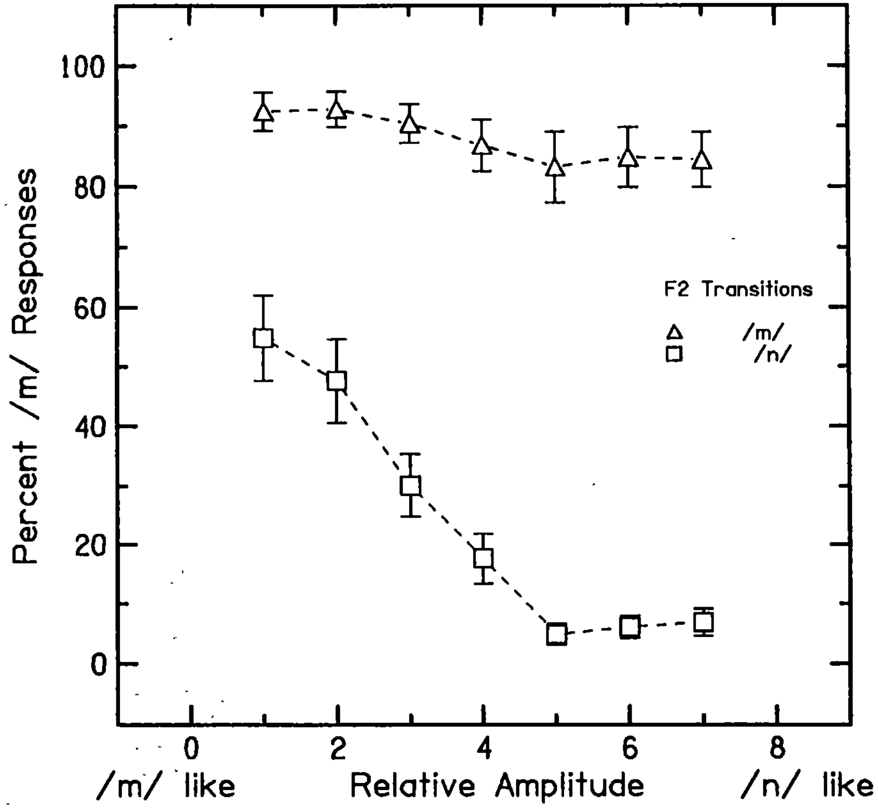
CHAPTER IV

RESULTS

Condition One

Figure 22 illustrates the mean percent /m/ responses plotted as a function of the above relative amplitude variations, with F2 transition onset held constant. The triangles represent results from the stimuli of continuum number one, in which the F2 transition onset was appropriate for /m/ and the relative amplitude or spectral shape was varied from /m/ -like to /n/ -like by decreasing the amplitude level of A1. The squares represent results from the stimuli of continuum number two, in which the F2 transition onset was appropriate for /n/ and the relative amplitude or spectral shape was varied from /m/ -like to /n/ -like by increasing the amplitude levels of A2 and A3.

Figure 22 shows that for stimuli with /m/ F2 transitions, relative amplitude did not influence labeling of nasal place of articulation. In referring back to Figure 3, note that the F1 and F2 formant peaks appear as a complex peak and this proximity evidently results in a labial percept.



<u>Figure 22.</u> Percent /m/ responses plotted as a function of relative amplitude. As stimulus number progresses from left to right along the x-axis, relative amplitude changes from /m/ -like to /n/ -like. The parameter is F2 transition onset frequency, with triangles representing transitions appropriate for /m/, and squares representing transitions appropriate for /n/. Error bars represent standard error of the mean.

Condition Two

Figure 23 illustrates mean percent /m/ responses plotted as a function of overall amplitude variations, with overall formant amplitudes increasing in dB moving from left to right along the x-axis. F2 transition onset is held constant. The triangles represent results from the stimuli of continuum number one, in which the F2 transition onset was appropriate for /m/. The squares represent results from the stimuli of continuum number two, in which the F2 transition onset was appropriate for /n/.

Condition two was designed to determine if overall amplitude at vowel onset, instead of relative amplitude or spectral shape changes, is responsible for the perceptual effects illustrated in Figure 22. Figure 23 shows that overall amplitude without corresponding relative amplitude or spectral shape had little influence in the subjects' perceptual judgment of the stimuli.

Condition Three

Figure 24 illustrates the percent /m/ responses plotted as a function of F2 transition onset frequency, with F2 transition onset frequency

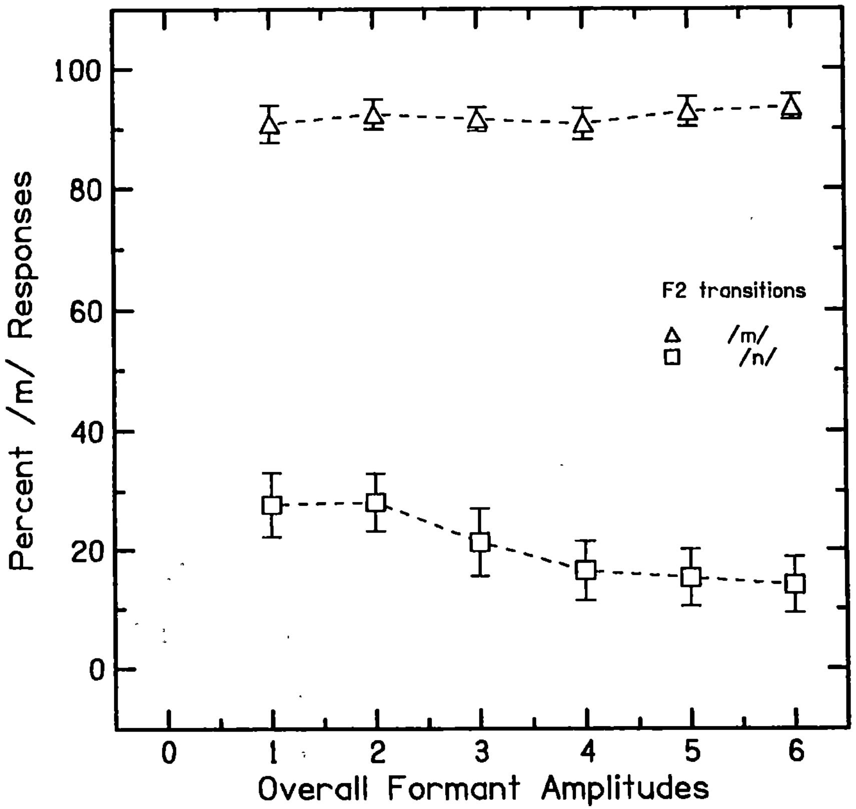


Figure 23. Percent /m/ responses plotted as a function of overall formant amplitude. As stimulus number progresses from left to right along the x-axis, overall formant amplitude is increased. The parameter is F2 transition onset frequency, with triangles represent transitions appropriate for /m/, and squares representing transitions appropriate for /n/. Error bars represent standard error of the mean.

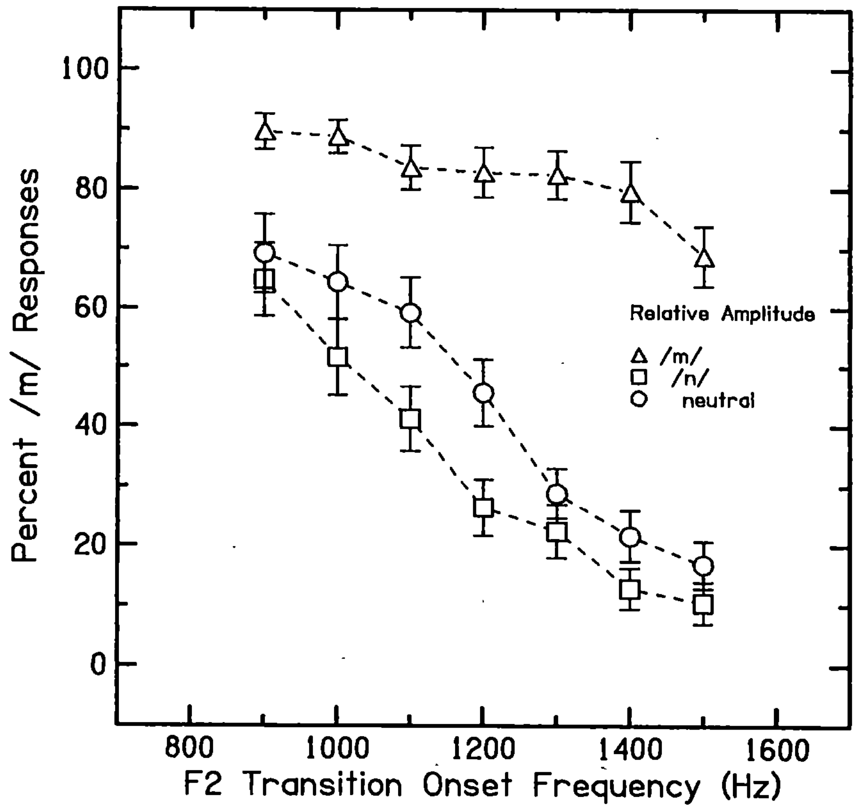


Figure 24. Percent /m/ responses plotted as a function of F2 transition onset frequency, with F2 transition onset frequency increasing in Hertz (Hz) moving from left to right along the x-axis. The parameter is relative amplitude, with triangles representing relative amplitude appropriate for /m/, and squares representing relative amplitude appropriate for /n/, and circles representing relative amplitude that is neutral. Error bars represent standard error of the mean.

increasing in Hertz (Hz) moving from left to right along the x-axis. Relative amplitude values were held constant. The triangles represent results from the stimuli in continuum number one, in which relative amplitude values were appropriate for /m/. The squares represent results from the stimuli in continuum number two, in which relative amplitude values were appropriate for /n/. The circles represent results from the stimuli in continuum number three, in which relative amplitude values were arithmetically neutral.

Figure 24 illustrates that formant transition and relative amplitude influence place of articulation judgments particularly for the neutral and the /n/ relative amplitudes in the region of F2 onset formant transition at 1100 Hz and 1200 Hz. With /m/ relative amplitude, no critical threshold of loudness for F2 was reached in order to make a perceptual difference in normal hearing listeners.

Because not all subjects showed a clear phonemic boundary for all psychometric functions, the area under each function was estimated by adding the number of /m/ responses for a continuum and then dividing by the total possible number of responses from the continuum. This 'average percent /m/' was then used as the dependent variable in a repeated measures one-way ANOVA, with relative amplitude (/m/ - like, /n/ - like, and neutral) as the factor. Results showed a significant effect of relative amplitude [$F(1,24) = 76.4$; $p<0.001$].

Figure 24 clearly shows a difference between the /m/ - like relative amplitude versus the /n/ - like and neutral relative amplitude. Contrast tests showed all three relative amplitude conditions to be significantly different one from another ($p<0.001$).

CHAPTER V

SUMMARY

Discussion

The first aim of this study was to determine if variations in relative amplitude between the murmur and the vowel of CV syllables influenced listeners' perception of the /m/-/n/ contrast. The results of condition one show that for stimuli with F2 transition appropriate for /m/, listeners judged the stimuli without using the relative amplitude information. Part of the reason /m/ was not affected may be related to the setting of the second pole in the synthetic pole-zero-pole complex. In previous research, when the frequency of the second pole approached the zero at 450 Hz, listeners labeled more stimuli as /n/ (Hedrick & Carney, 1994). Another factor could possibly be due to the close proximity of the F1 and F2 peaks, as shown in Figure 3.

Relative amplitude does appear to influence listener place of articulation judgments with stimuli having F2 transition appropriate for /n/. Figure 22 also shows that, for stimuli with /n/ F2 transitions, relative amplitude did influence labeling of nasal place of articulation. This may be related to a greater amplitude emphasis in A2 and a clearer separation of F1 and F2 spectral peaks as depicted in Figure 6.

In condition two, the overall amplitudes of the first three formants were changed in conjunction, to determine if overall amplitude alone, as opposed to onset relative amplitude, was responsible for perceptual shifts. This study shows cues other than overall amplitude were used in labeling nasal place of articulation.

The second aim was to systematically and simultaneously vary second formant transition and relative amplitude cues to ascertain if relative amplitude cues provided a significant contribution to perception of place of articulation beyond the formant transition. Manipulations of second formant transition cues provided little change in place of articulation judgments for stimuli having relative amplitude values appropriate for /m/. Significant differences were noted, however, in place of articulation judgments for changes in F2 transition onset for stimuli with neutral and /n/ appropriate relative amplitude values. In terms of relative amplitude, there were statistically significant differences between /m/, neutral, and /n/ appropriate relative amplitude stimuli. The biggest difference between neutral and /n/ relative amplitude functions was at 1100 Hz and 1200 Hz F2 values. These F2 values are neutral for the /m/ - /n/ contrast. Thus, a stronger influence of relative amplitude would be expected.

There are two limitations of the current study that should be mentioned. One is that only one vowel context, /ɑ/, was investigated. Repp (1987), has found vowel context-specific effects on the relative perceptual weight given cues; for example, he found that formant transitions were weak cues for perception of nasal place of articulation in the /i/ vowel context. The second limitation is that used of a forced-choice test with synthetic speech in only one vowel context may yield trading relation between cues that may not be generalizable to naturally produced stimuli.

Theoretical Implications

Results from the current study are partially in agreement with earlier research using fricatives and stop consonants which found that manipulations near the consonant-vowel boundary affected perception of consonant place of articulation (Ohde and Stevens, 1983; Stevens, 1985; Hawkins and Stevens, 1987; Hedrick and Ohde, 1993; Hedrick et al., 1995). The current study does, however, add to the findings of earlier work showing the importance of relational information at phoneme boundaries (Stevens, 1985; Furui, 1986; Hedrick and Ohde, 1993; Ohde and Perry, 1994).

Practical Implications

Knowing that relative amplitude could be a cue for nasal consonants and that hearing impaired listeners use relative amplitude to make stop consonant place of articulation judgments (Hedrick et al., 1995), the relative amplitude cue should be taken into account for future processing strategies of prosthetic devices such as hearing aids and cochlear implants.

The current information may also add to the understanding of clear speech. Based on the work of Nabelek, Ovchinnikov, Czyzewski, and Crowley (1996), the most intelligible speakers tend to have higher F2 transition amplitudes. Results from the current study suggest that higher F2 amplitudes for stimuli that had /n/ transitions were more often labeled as /n/ than stimuli with lower amplitude F2. This information could lead to future improvements in prosthetic devices. Furthermore, additional work could focus on comparison of speaker intelligibility and the proximity of F1-F2 for labial-alveolar contrasts.

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APPENDICES

APPENDIX A:

SUBJECT CONSENT FORM

Consent From to Participate in the Following Project:
"Use of Second Formant Transition and Relative Amplitude Cues in Labeling Nasal Place of Articulation"

You are being asked to participate in a study of speech perception. The goal of this study is to learn what acoustic information persons use to perceive speech sounds.

Procedures

If you take part in this study, you will have your hearing tested, unless there is a record of an audiogram within the past year. Following the hearing test, you will be given a criterion test. In the criterion test, you will be asked to listen to and label approximately 20 speech sounds presented by earphones while seated in a sound booth. The speech will be presented at a comfortable loudness level. Completion of this experiment will take one, 1 to 1 ½ hour, session and you will be given breaks of two to five minutes for every ten to fifteen minutes of listening.

Potential risk or discomfort

There are no significant risks associated with participation in this study.

Benefits

The purpose of this research is to gain a better understanding of speech perception, and how speech perception by listeners with a hearing loss may differ from listeners with normal hearing. There are no immediate, direct benefits to you from this study.

Assurance of confidentiality

Information learned about you will be kept confidential. When referring to data collected from you in presentations or publications, we will use a code number and will not use your name.

Alternatives

You do not have to take part in this study if you do not want to. Your participation or non-participation in this project will in no way affect any future treatment or services you seek in any department at any time.

Right to withdraw

You can stop taking part in the study at any time, even after you sign this agreement. If you want to stop taking part in the study, simply tell us. There is no penalty for quitting.

Right to inquire

If you have any questions about this study, you can write or call the researchers listed at the bottom of this form.

Authorization

I have read this form in its entirety and feel I understand the possible risks, discomforts, and benefits of this study. I agree to participate in this study. I acknowledge that I have received a copy of this consent from.

______________________________ ____________________

Participant's signature Date

Investigator's assurance

The person whose name appears below is responsible for carrying out this research program. She will assure that all questions about this research program are answered to the best of her ability. She will assure that you are informed of any changes in the procedures or the risks and benefits if any should occur during or after the course of this study. She will assure that all information remains confidential.

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APPENDIX B:

PARAMETERS OF THE END POINT STIMULI

The following tables illustrate the parameters used in the synthesis of the stimuli. Each table represents an endpoint of each continuum of stimuli for each condition. The following is a legend of the control parameters used in the synthesis of stimuli:

AV = Amplitude of voicing (dB),

F0 = Fundamental frequency of voicing (Hz),

F1 = First formant frequency (Hz),

F2 = Second formant frequency (Hz),

F3 = Third formant frequency (Hz),

F4 = Fourth formant frequency (Hz),

FNZ = Nasal zero frequency (Hz),

AN = Nasal formant amplitude (dB),

A1 = First formant amplitude (dB),

A2 = Second formant amplitude (dB),

A3 = Third formant amplitude (dB),

B1 = First formant bandwidth (Hz),

B2 = Second formant bandwidth (Hz),

B3 = Third formant bandwidth (Hz),

B4 = Fourth formant bandwidth (Hz),

F5 = Fifth formant frequency,

B5 = Fifth formant bandwidth,

FNP = Nasal pole frequency (Hz),

BNP = Nasal pole bandwidth (Hz).

Table 1

<u>Parameters of the end point stimulus in condition one, continuum number one, having an F2 transition appropriate for /m/ and an /m/ -like relative amplitude value.</u>

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					30	55	55	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 2

Parameters of the end point stimulus in condition one, continuum number one, having an F2 transition appropriate for /m/ and an /n/ -like relative amplitude value.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					60	55	55	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 3

Parameters of the end point stimuli in condition one, continuum number two, having an F2 transition appropriate for /n/ and an /m/ -like relative amplitude value.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					60	25	25	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 4

Parameters of the end point stimulus in condition one, continuum number two, having an F2 transition appropriate for /n/ and an /m/ -like relative amplitude value.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					60	55	55	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 5

<u>Parameters of the end point stimulus in condition two, continuum number one, having an F2 transition onset frequency appropriate for /m/ and low-level initial formant values.</u>

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					30	25	25	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 6

Parameters of the end point stimulus for condition two, continuum number one, having an F2 transition onset frequency appropriate for /m/ and high-level initial formant values.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					55	50	50	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 7

Parameters of the end point stimulus in condition two, continuum number two, having an F2 transition onset frequency appropriate for /n/ and low-level initial formant values.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					30	25	25	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	300	1220			250		60	55	55		70	160				250	200

Table 8

Parameters of the end point stimulus in condition two, continuum number two, having the F2 transition onset frequency appropriate for /n/ and high-level initial formant values.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					55	50	50	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 9

Parameters of the end point stimulus in condition three, continuum number one, having /m/ -like relative amplitude values and an F2 transition onset frequency appropriate for /m/.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					60	25	25	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 10

<u>Parameters of the end point stimulus in condition three, continuum number one, having /m/ -like relative amplitude values and an F2 transition onset frequency appropriate for /n/.</u>

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					60	25	25	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 11

<u>Parameters of the end point stimulus in condition three, continuum number two, having /n/ -like relative amplitude values and an F2 transition onset frequency appropriate for /m/.</u>

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					35	55	55	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 12

Parameters of the end point stimulus in condition three, continuum number two, having /n/ -like relative amplitude values and an F2 transition onset frequency appropriate for /n/.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					35	55	55	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 13

Parameters of the end point stimulus in condition three, continuum number three, having arithmetically neutral relative amplitude values and an F2 transition onset frequency appropriate for /m/.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	900	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	900					45	40	40	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

Table 14

Parameters of the end point stimulus in condition three, continuum number three, having arithmetically neutral relative amplitude values and an F2 transition onset frequency appropriate for /n/.

	AV	F0	F1	F2	F3	F4	FNZ	AN	A1	A2	A3	B1	B2	B3	B4	F5	B5	FNP	BNP
0	35	90	600	1500	2440	3600	550	75	35	0	0	40	200	200	250	4500	250	250	200
10	35								35										
20	45																		
85							550												
95								75	35	0	0								
100	45	120	600	1500					45	40	40	40	200	200					
120								0											
140	60		700	1220			250		60	55	55	130	70	160					
200	60				2440	3600						130			250	4500	250		
300	35	90	700	1220			250		60	55	55		70	160				250	200

VITA

Susan Lynn Frisbee was born in Asheville, North Carolina on December 3, 1973. She graduated from McDowell High School in Marion, North Carolina in 1992. She received her Bachelor of Science degree in Communication Disorders from Appalachian State University in Boone, North Carolina in 1997. She immediately began a graduate program in Audiology at the University of Tennessee, Knoxville. While at the university, she was employed as a graduate assistant in the Department of Audiology and Speech Pathology. In May 1995, she received a Master of Arts degree in Audiology from the University of Tennessee in Knoxville. Future plans include completing a Clinical Fellowship Year in Audiology.