P. C. DELATTRE[1], A. M. LIBERMAN[2], F. S. COOPER

FORMANT TRANSITIONS AND LOCI AS ACOUSTIC CORRELATES OF PLACE OF ARTICULATION IN AMERICAN FRICATIVES

Introduction

Earlier studies with synthetic speech have established two types of acoustic cues for the perception of consonantal place of production: one, which occurs in stops, fricatives, and affricates, is the position on the frequency scale of the noise or friction produced at the point of constriction; the other is the transition (relatively rapid change in frequency) of the second and third formants.[3] Noise in the relatively high frequency region is a cue for dentals. A relatively low frequency position for the noise indicates that the consonant is a velar or a labial. The former are located typically near the onset of the second-formant transition, wherever that might be; the latter are distributed over the low-frequency region, but primarily where the velar noises are not.[4]

Transitions of the second and third formants are cues for place of articulation according to the direction and extent of the frequency shift.[5] In the case of the second-formant transitions it has been possible to simplify the description of these cues by reference to the locus or the implicit point on the frequency scale at which the transition originates or to which it may be said to "point".[6] Thus, it has been found, for example, that for the second formant

[1] Also, University of Colorado.

[2] Also, University of Connecticut.

[3] *Cooper, F. S.; P. Delattre; A. M. Liberman; J. M. Borst, and L. Gerstman:* Some Experiments on the Perception of Synthetic Speech Sounds. Jour. Acoustical Soc. Amer., 24: 629—636 (1952).

[4] *Liberman, A. M.; P. Delattre, and F. S. Cooper:* The Role of Selected Stimulus-Variables in the Perception of the Unvoiced Stop Consonants. Amer. J. Psychol., 65: 497—517 (1952).

[5] *Liberman, A. M.; P. Delattre; F. S. Cooper, and L. Gerstman:* The Role of Consonant-Vowel Transitions in the Perception of the Stop and Nasal Consonants. Psychol. Monogr., 379; 1—14 (1954).

[6] *Delattre, P.; A. M. Liberman, and F. S. Cooper:* Acoustic Loci and Transitional Cues for Consonants. Jour. Acoustical Soc. Amer., 27: 769—774 (1955).

the labial locus is low (700 cps or lower), the dental locus somewhat higher (about 1800 cps), and the velar locus higher still (about 3000 cps).[7]

The role of third-formant transitions has also been investigated,[8] and it has been found that this transition is especially important in distinguishing /l/ from /r/ and in setting apart the dental or alveolar stops from the other two (labial and velar). Because the second formant exerts in general a strong influence in perception and must always be included in synthetic patterns, it has been difficult to obtain clear results concerning the precise frequency positions of the third-formant loci. It is quite clear, however, that these loci exist, and that for dental stops, the locus is higher than for either the velar or the labial stops, the latter being perhaps the lowest of all.

In the case of the fricatives several investigations have revealed the nature of the friction cues,[9] and a study by Harris[10] has eva-

Stevens, K. and *A. House:* Studies of Formant Transitions Using a Vocal-Tract Analog. Jour. Acoustical Soc. Amer., 28: 578—585 (1956).

[7] For velar stops, the locus is clearly high before spread vowels. This agrees with what can be seen on spectrograms as well as with what was found by moving a synthetic *straight* formant up and down the frequency scale. When the velar stops occur before a rounded vowel, however, the second-formant transition does not effectively point to that high locus, either in natural or in synthetic speech, and apparently does not contribute to the perception of velar place of articulation.

[8] *Harris, K. S.; H. S. Hoffman; A. M. Liberman; P. C. Delattre,* and *F. S. Cooper:* Effect of Third-Formant Transitions on the perception of the Voiced Stop Consonants. Jour. Acoustical Soc. Amer., 30: 122—126 (Feb. 1958). *Hoffman, Howard S.:* Study of Some Cues in the Perception of Voiced Stop Consonants. Jour. Acoustical Soc. Amer. 30: 1035—1041 (Nov. 1958). *O'Conner, J. D.; L. Gerstman; A. M. Liberman; P. Delattre,* and *F. S. Cooper:* Acoustic Cues for the Perception of Initial /w j r l/ in English. Word, 13: 24—44 (1957).

[9] *Hughes, G.* and *M. Halle:* Spectral Properties of Fricative Consonants. Jour. Acoustical Soc. Amer., 28: 303—310 (1956). *Strevens, Peter:* Spectra of Fricative Noise in Human Speech. 3: 32—49 (Jan. 1960). *Heinz, J. M.,* and *K. N. Stevens:* On the Properties of Voiceless Fricative Consonants. Jour. Acoustical soc. Amer., 33: 589—596 (May 1961). *Jassem, Wiktor:* Noise Spectra of Swedish, English, and Polish Fricatives. Proceedings of Speech Communication Seminar (Stockholm, Royal Inst. Tech. 1962). *Martoni, J.:* Some Experiments on Perceptual Cues for Swedish Fricatives. Proceedings of Speech Communication Seminar (Stockholm, Royal Inst. Tech. 1962).

[10] *Harris, Katherine S.:* Cues for the Discrimination of American English

luated the relative contribution of friction and transition cues in this class of sounds. From these we know that the appropriate friction for /s/ lies above 3500 cps, while the /ʃ/ friction is above 2000 cps. The remaining fricatives /f/ and /θ/ are both cued by friction which spreads out through the whole spectrum above 1000 cps, and these sounds are perhaps not distinguished from each other primarily on the basis of noise. In evaluating the relative contributions of noise and transition, Harris [10] found, a) that the noise portion of the sound was the overriding cue in the case of /s/ and /ʃ/, b) that /f/ and /θ/ as a pair were distinguished from either /s/ or /ʃ/ on the basis of the noise portion, and c) that /f/ and /θ/ are distinguished from each other almost entirely on the basis of the transitions.

There exists, then, a significant gap in our knowledge of the acoustic cues for the *fricatives* in that there have been no experimental tests to determine the direction and extent of the transitions that best distinguish among these sounds. It is the primary purpose of this study to find these transitions for both the second and third formants, and to specify their loci.

General Methods

The method chosen for this investigation is in general similar to that we have used in earlier studies. It employs synthetic speech produced from schematized spectrograms which are painted by hand and converted to sound by the Pattern Playback.

In order to determine experimentally which transitions are most appropriate for the perception of place of production of the fricatives we must first overcome a rather considerable difficulty, one which did not exist in the earlier investigations of other consonant classes. The problem arises out of the fact that in order to synthesize a fricative we must have the fricative noise characteristic of the manner of production, and since, for some of the fricatives, the frequency position of this noise is itself a potent and overriding cue for place of production, we cannot expect to experiment effectively with the transitions unless we somehow minimize the effects of the friction. To accomplish this we adopted three expedients. First, we used frictions which were as

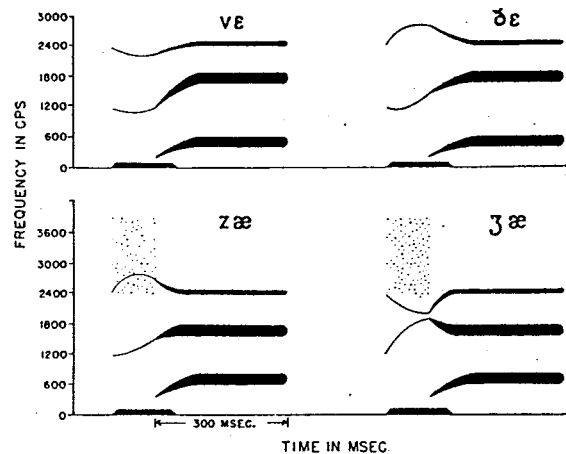Fricatives in Spoken Syllables. Language and Speech, 1: 1—7 (Jan.—March 1958).

Figure. 1. Typical hand-painted spectrograms for the synthesis of voiced fricatives. The thin lines on the left-hand portion of each of the four patterns are weak ›closure formants› that play an important role in voicing.

ambiguous as possible in regard to their cue value for place of production. Second, we elected to deal with the *voiced* fricatives. This gives us an advantage simply because the noise is here less intense relative to the transitions than is the case with the voiceless fricatives, yet any results we get are surely applicable also to the voiceless fricatives. Third, we gained a further advantage by exploiting one of the cues for voicing, *viz.*, the low-intensity formants that run through the friction; in articulatory terms, these occur during the closure phase of the consonant. It had previously been found that these ›closure› formants help to create an impression of voicing in the fricatives. Exploratory work done in connection with the present study showed that the closure formants, properly used, could also enhance the perceptual effect of the transitions for place of production. These closure formants are shown as part of sample hand-painted spectrograms in Figure 1. (Spectrograms like these were converted to sound by the Playback to produce the synthetic speech sounds used in this experiment.) Appearing as the relatively thin lines at the left of each pattern, these formants all begin near the frequencies of the schwa and move toward the consonant locus before joining the formant transitions.

To study the transitions as cues for the fricatives, we prepared

patterns like those of Figure 1 for consonant-vowel syllables in which transitions of the first and second formants were varied, and the resultant sounds (produced by the Playback) were presented to phonetically naive listeners for judgment. For various reasons, not the least of which is the problem of noise neutralization, we experimented with /v/, /ð/ as a pair and, separately with /z/, /ʒ/. /v/ was opposed to /ð/ without the use of any noise beyond that which is produced with normal operation of the Pattern Playback; but as shown in Figure 1, /z/ was opposed to /ʒ/ with a fixed "neutral" noise. The fixed neutral noise used in correlation with variations of the formant transitions opposing /z/ to /ʒ/ combined the lower frequencies of the /z/ noise with the upper frequencies of the /ʒ/ noise. It was determined by exploratory research and preliminary testing that this friction noise could be heard almost equally as /z/ or /ʒ/.

Under ideal conditions, no friction noise should have been used at all, not even in contrasting /z/ with /ʒ/. This would have made identification of the stimuli possible for trained ears only; trained linguists could generally tell from transitions alone whether a given pattern sounded more like /z/ or more like /ʒ/ without the presence of any friction noise. But naive listeners were not capable of such subtle discrimination. Neutral frictions were therefore used in all the /z/, /ʒ/ tests even though they admittedly introduced a slight element of error, a "neutral" friction being not one hundred per cent neutral even under the best conditions.

The noise for /v/ and /ð/ is much less intense, in normal speech, than for /z/ and /ʒ/. Perhaps for this reason our naive listeners accept the unavoidable broad band noise from the Pattern Playback as sufficient manner cue. Accordingly no friction noise had to be included on the patterns of Figure 1 for /v/ and /ð/.

The saw-tooth shape at the leading edge of the /z/, /ʒ/ friction patches serves to produce a *gradual* onset, typical of all fricatives, and to avoid confusion with affricates [11] such as /dz/, /dʒ/, which would have a sharp onset (and a shorter friction-time).

The presence of the fundamental tone (voice bar) contributes somewhat to voicing; so does the relative shortness of the noise (under 10 cs). But the strong voicing factor is in the low-intensity formants, referred to earlier, that cross the closure portion. They have been most efficient when they start, as they do on Figure 1, from a schwa position and move toward the locus before joining the onset of the regular formant transitions.

The first formants, as well as the noise, were held constant throughout the experiment. In the transition portions, the first formant, which is here a cue for *manner* of articulation," has a slower rate and a higher frequency onset for the class of voiced fricatives than it would for the class of voiced plosives.

A small problem of rate of transition (for all three formants) presented itself: exploratory work had indicated that /ð/ requires a slower tempo than /v/. A compromise tempo was used so that all conditions but that of one variable could be kept equal.

The experiment was carried out in two parts. In the first part we varied the extent and direction of the transitions before each of several vowels. In the second part we undertook to specify the loci by using an experimental technique similar to that used earlier in studying the plosives — that is, by ignoring the characteristic formant frequencies of the vowels and varying arbitrarily the frequency positions of *straight* second and third formants, we determined, by listening, which fricative was heard at which formant frequency.

First Experiment

Three sets of fricative + vowel stimuli were prepared, using steady-state formants for the three vowels /i, ɛ, u/ and second- and third-formant transitions as place cues for the fricatives.

Figure 2 shows the range of variations that was investigated for the second- and third-formant transitions. (Preliminary investiga-

---

[11] In this sketch of previous work on place of articulation cues, the class of affricates was not mentioned because it presents no new problem. The place of articulation cues of affricates are those of their homorganic fricative element.

[12] Recent research indicates that the first formant can also be a cue for place of articulation: when the consonant constriction is in the *back* half of the vocal tract as in /x/ or /R/ the first-formant locus is higher than the schwa first-formant (ca. 500 cps). However, this does not apply to American consonants since they all are articulated in the front half of the vocal tract. (See *P. Delattre:* Le jeu des transitions de formants et la perception des consonnes. Transactions of the Fourth Congress of Phonetic Sciences, pp. 401—403 (Helsinki 1962).
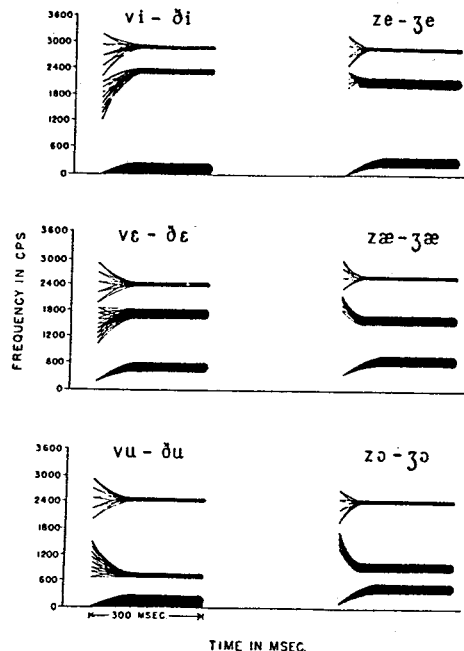
Figure 2. Range of variations that was used in investigating the second- and third-formant transitions of American fricatives. First formants are held constant for each vowel in a shape that is appropriate for voiced fricatives. The closure formants, added noise, and voice bar shown in Figure 1 have been omitted for clarity.

tion indicated that this is the range that can produce the greatest contrast by transitions alone.)

For the /v/, /ð/ contrast, the second-formant transition onsets vary, in eight steps of 120 cps, from 1320 cps to 2160 cps before /i/, from 1080 cps to 1920 cps before /ɛ/, and from 720 cps to 1560 cps before /u/. The third-formant transitions vary, in five steps of 240 cps, from 2400 cps to 3360 cps before /i/, and from 2040 cps to 3000 cps before /ɛ/ and /u/.

For the /z/, /ʒ/ contrast, the second-formant transition onsets vary in four steps of 120 cps from 1680 cps to 2040 cps before /e/, from 1560 cps to 1920 cps before /æ/, and from 1440 cps to 1800 cps before /ɔ/; the third-formant transition onsets vary, in four steps of 240 cps, from 2160 cps to 2880 cps before /e/, and from 2040 cps to 2760 cps before /æ/ and /ɔ/.

Results of judgments by twelve phonetically naive listeners are presented in graphic form in Figures 3 and 4. It should be remembered that the test stimuli for /v/, /ð/ were presented separately from those for /z/, /ʒ/ — that is, the listeners never had more than a binary (forced choice) decision to make. The graphs are drawn to show the third-formant transitions as the independent variable, the second-formant transitions as the parameter, and the percentage of judgments for one of the two possible choices as the dependent variable.

In Figure 3 are the data for the /v/, /ð/ contrast. By looking at the graph in the lower left-hand corner, one sees, for example, that with the second-formant onset held constant at 1320 cps, the judgments changed from 20 % for /ði/ and 80 % for /vi/ to 75 % for /ði/ and 25 % for /vi/ as the third-formant onset rose from 2400 cps to 3360 cps. Looking at the other graphs in the same left-hand column, one sees that the shaded areas have much the same size and shape, indicating that the various second-formant onsets have little effect. The situation is different in the middle and right-hand columns in that the graphs are very different for the various second-formant onsets. In both cases the proportion of /ð/ judgments increases as the second-formant onset is higher. Finally, one sees in the right-hand column that the shaded areas are very nearly flat, which means that with /u/ the third formant has relatively little effect.

In summary, the /v/, /ð/ distinction depends mainly on second-formant transitions before /u/, on third-formant transitions before /i/, and on both second- and third-formant transitions — about equally — before /ɛ/.

In Figure 4, the results are displayed in similar fashion for the /z/, /ʒ/ contrast. One sees that both the second- and third-formant transitions act as relatively strong cues before all vowels. As the frequencies of third-formant transition onsets rise and those of second-formant transition onsets fall, the /z/ judgments increase and the /ʒ/ judgments decrease.

We note from all curves that the naive listeners never agree completely. This does not necessarily mean that transition cues are weak; rather it must be attributed to the very special experimental conditions which required that fricatives be identified by transitions alone, in the presence of constant noise portions that may well have been confusing.
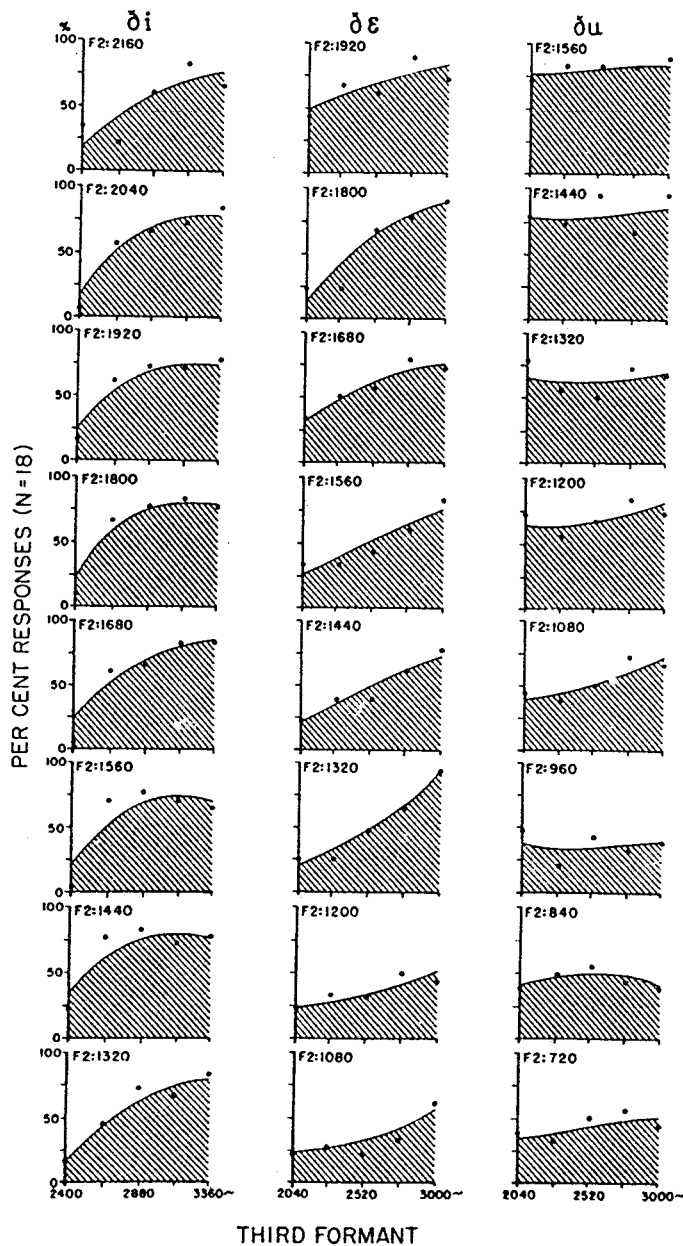
Figure 3. Results of forced-choice judgments for /v/ or /ð/ in Experiment One. The parameter is the second-formant transition (stated for each of the 24 graphs), the independent variable is the third-formant transition, and the percentage of judgments for one of the two possible choices is the dependent variable.
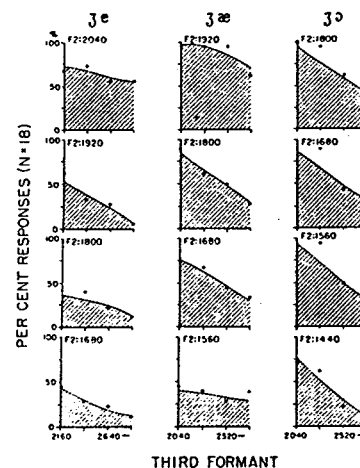

Figure 4. Results of forced-choice judgments for /z/ or /ʒ/ in Experiment One.

Discussion

We note that the curves do not show sharp peaks; therefore we cannot tell precisely which formant transitions produce the best /v/, /ð/, /z/, /ʒ/. Whe have to be content with a range of transitions for each fricative. However, the curves furnish important information about the strength of the third-formant cue relative to the second-formant cue. In the case of /v/ and /ð/, this relative strength depends upon whether the following vowel is front, mid, or back; in the case of /z/ and /ʒ/ it is less dependent on the following vowel.

In a more general way, this experiment with synthetic speech confirms that formant transitions have some cue value for the voiced fricatives — and presumably for the voiceless ones as well.

The cue of formant transitions, hovever, is not overwhelming here. Even in the case of the voiced fricatives which we have investigated in this experiment, the formant transitions, or at least those that we used, do not appear to provide the basis for unequivocal discrimination. For /z/, /ʒ/ this offers no great problem since we know that the noise carries a great deal of information. For the distinction between /v/ and /ð/, on the other hand, since the noise does not have much more than a negligible cue value, contrastive effectiveness must be low. This, however, fits with the well-known fact that /v/ and /ð/, like /f/ and /θ/, are, in normal speech, very hard to distinguish.
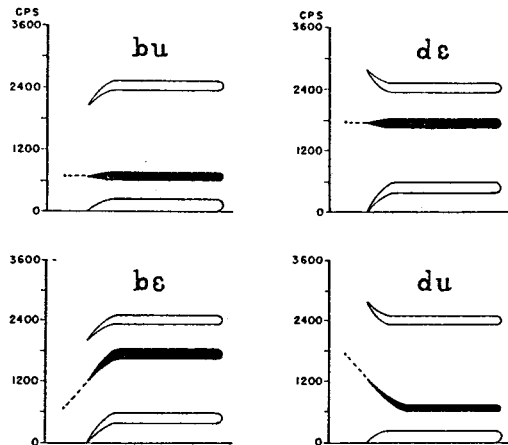
Figure 5. Example of the method of Experiment Two as applied to the stops /b/ and /d/. Because the loci for these consonants lie near the second-formant frequencies of /u/ and /ɛ/ respectively, the ›straight‹ second-formant transitions of /bu/ and /dɛ/ (top row) point more precisely toward the consonant loci than do the curved second-formant transitions of /bɛ/ and /du/ (bottom row).

Second Experiment

Having found now that transitions of the second and third formants do have some cue value, and having determined further the range of transition appropriate for each fricative, we undertook in the second experiment to find the *loci* for the fricative consonants of English. For this purpose we used the method that had yielded the loci for the stop consonants.[5] The method does not make use of curved transitions, but only of straight formants (called "zero transitions") because straight formants can be extrapolated more precisely to a locus than can the curves of non-zero transitions. As an example of the method, Figure 5 shows four patterns with optimal transitions for syllables with /b, d/ before /u, ɛ/. It happens that the second formants of /u/ and /ɛ/ occur, in normal speech, at about the same frequencies as the loci for /b/ and /d/, respectively. The straight second formants of the corresponding synthetic patterns for /bu, dɛ/ thus indicate quite directly the appropriate loci for the two consonants; the second-formant transitions that serve as place-of-closure cues for
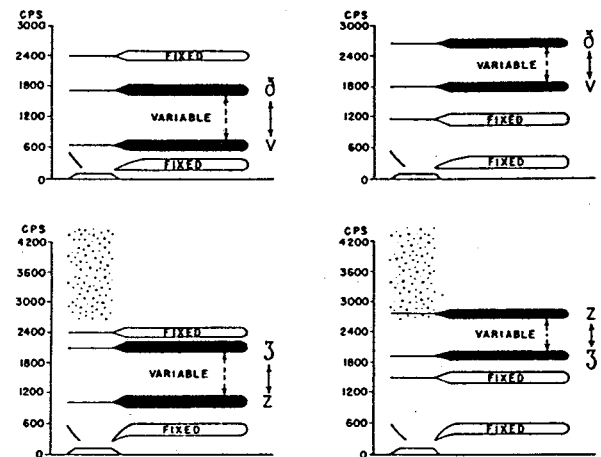
Figure 6. Range of frequency variations of the *straight* formants used in Experiment Two. On the left, second-formant frequencies are varied while first and third formants are held constant; on the right, third-formant frequencies are varied while first and second formants are fixed. In this diagram, the variable formant is shown twice (at the extremes of its range), and in black for emphasis.

/bɛ, du/ point to the same loci, but the extrapolation may be less sure.

In applying this method to the fricatives, we used patterns like those of Figure 6 with *straight* second and third formants that varied in the frequency placement of the one formant or the other. The ranges of variation were determined by preliminary investigation and include frequencies that can produce the greatest contrast by transitions alone. The sounds corresponding to the patterns are essentially CV syllables, though the vocalic portion is not, in general, heard as a familiar vowel and the fricatives are clear (as to place of production) only when the formant frequencies are close to the loci. As in the first experiment, when /v/ and /ð/ are contrasted, no friction noise is used beyond that which is produced in the normal operation of the Pattern Playback; when /z/ and /ʒ/ are contrasted, a neutral noise is used which combines the lower frequencies of the /z/ friction with the upper frequencies of the /ʒ/ friction. Vocalic formants during the closure are also used, but they are straight, not curved as they were in the first experiment. The first formant is always
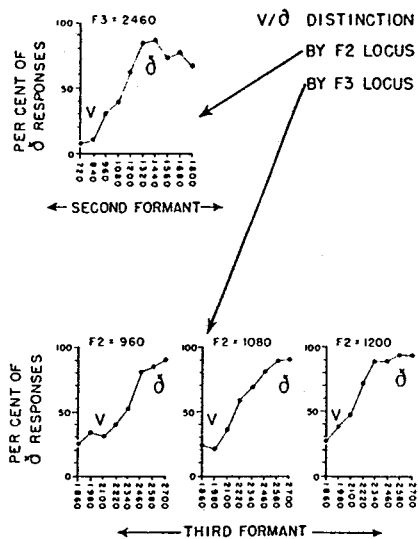
Figure 7. Results of forced-choice judgments for /v/ or /ð/ in Experiment Two. The upper graph shows how the proportion of judgments shifts from /v/ to /ð/ as the frequency of the straight second formant rises, while the third formant is held constant. The three lower graphs show how the proportion of judgments shifts as the frequency of the straight third formant rises, for each of three constant second formants.

fixed at an arbitrary frequency that does not interfere with the variations of the second formant, and has the appropriate transition for the class of fricatives.

First, the second formant was varied up an down the frequency scale (in steps of 120 cps) while the third formant was fixed at the most neutral frequency that could be found. Then, the third-formant frequency was varied while the second was fixed at a frequency judged to be neutral on the basis of the preceding test and of preliminary results of the third-formant tests. In this experiment we had to try successively three different fixed positions of the second formant for both the /v/, /ð/ and the /z/, /ʒ/ distinctions in order to obtain sufficiently balanced results.

Results

Judgments by 15 phonetically naive listeners are presented in graphic form on Figure 7 for the /v/, /ð/ contrast. On the upper
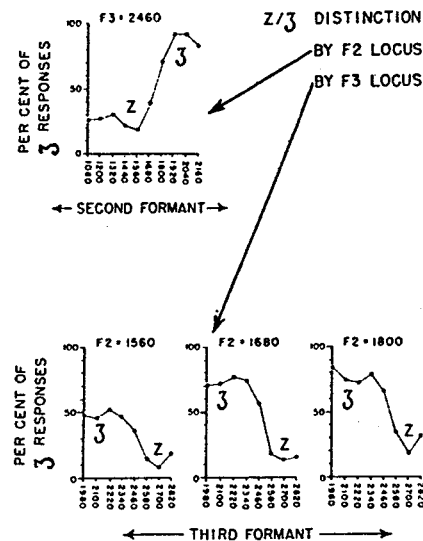
Figure 8. Results of forced-choice judgments for /z/ or /ʒ/ in Experiment Two.

graph, we see how the percent of the responses varied as a function of the frequency level of the straight second formant. In all of these cases the straight third formant was constant at 2460 cps — which proved to be a suitably neutral position. On the lower graphs, the third formants are the variables and the results are shown for each of three different straight second formants.

The fact that the proportion of /v/, /ð/ judgments changes systematically with (separate) variation of the frequency positions of straight second and third formants indicates the existence of loci and permits us to determine their approximate frequencies. Thus, from the upper curve, we find a second-formant locus for /ð/ close to 1400 cps, and for /v/ near or below 700 cps. The three lower curves indicate the existence of third-formant loci for /ð/ and /v/ near the high and low ends of the range of third-formant frequencies that were used in the investigation. Further work with a wider range of frequencies, and with the authors as judges, suggests that the third-formant locus for /v/ is in the vicinity of 1900 cps and for /ð/ in the vicinity of 2700 cps.

Judgments by 15 phonetically naive listeners are presented in graphic form on Figure 8 for the /z/, /ʒ/ contrast. Graphic presentation is the same as in Figure 7: On the upper graph the variable

is the second-formant frequency and on the three lower graphs it is the third-formant frequency for three different constant frequencies of the second formant.

These results suggest the existence of a second-formant locus near 1600 cps for /z/, and one near 2000 cps for /ʒ/. They also point to third-formant loci for /ʒ/ and /z/ near 2200 cps and 2700 cps respectively.

Assuming that our results are applicable to voiceless consonants as well as to voiced ones, the second- and third-formant loci of American fricatives, for an average male voice, have approximately the following frequencies.

	F_2 Locus	F_3 Locus
/f/ or /v/	700 cps	1900 cps
/Θ/ or /ð/	1400 cps	2700 cps
/s/ or /z/	1600 cps	2700 cps
/ʃ/ or /ʒ/	2000 cps	2200 cps

These results are not surprising. The locus being a function of place of articulation, it would have been logical to predict, for the second-formant transitions, that the /ð/ and /z/ loci should be between those of /b/ (700 cps) and /d/ (1800 cps), and the /ʒ/ locus between those of /d/ (1800 cps) and /g/ (3000 cps).[13] It is not surprising either to find, for the third-formant loci, some measure of agreement between /b/ and /v/, as well as between /d/ and /ð/-or-/z/.

Summary

Formant Transitions and Loci as Acoustic Correlates of Place of Articulation in American Fricatives

This study was made possible by the use of hand-painted patterns transformed into sound by means of a speech synthesizer called Pattern Playback.

---

[13] Caution must be called for, however, in comparing /g/, a velar, with /ʒ/, an alveolar. The /g/ situation in which second-formant transitions point toward the velar locus *only* before unrounded vowels has no parallel in /ʒ/ — in fact, it has no parallel in any other consonant. /g/ is the only consonant for which one finds two radically different kinds of transitions, one before rounded vowels, another before spread ones. In the case of all other consonants, the transitions before all vowels have in common that they point to the locus characteristic of that consonant.

In fricative consonants such as /f Θ s ʃ v ð z ʒ/ the identification of place of production depends on the acoustic cues of friction noise as well as those of formant transitions. In order to isolate the latter cues from the former, it became necessary to "neutralize" the friction cues. This was done, a) by manipulating *voiced* fricatives only, b) by enhancing the cue power of transitions through the use of the vocalic formants that appear during the consonant-closure portion on the spectrographic patterns, c) by painting no friction at all when contrasting /v/ with /ð/, and a neutral friction when contrasting /z/ with /ʒ/. Throughout this study, the four voiced fricatives were followed each by three different vowels, a front one, a center one, and a back one.

In a first experiment, the rate and direction of formant transitions were varied. This yielded a different, but relatively wide, frequency range of second- and third-formant transitions for each consonantal place of production — a clear indication that second- and third-formant transitions are indeed acoustic cues for the perception of place of production of the American fricatives. In a second experiment, the frequencies of *straight* formants (zero transitions) were varied. With that technique the frequency ranges for each place of production were narrowed and the actual loci appeared, suitably specified, for both the second and third formants. It is assumed that the loci for voiced fricatives are also valid for the corresponding voiceless ones.

Zusammenfassung

Formanttransitionen und Loci als akustische Korrelate der Artikulationsstellen für die Frikativae in Amerikanisch

Diese Arbeit wurde durch das Anwenden von Hand gefertigter spektrographischer Bilder möglich gemacht, die mittels eines "Pattern Playback", genannten Apparates (Lautsyntheseapparates) in Laute transformiert wurden.

Bei Reibelauten wie /f Θ s ʃ v ð z ʒ/ ist die Feststellung der Artikulationsstelle sowohl von den akustischen Merkmalen des Reibegeräusches als auch von jenen der Formanttransitionen abhängig. Um letztere von ersteren abzusondern, wurde es notwendig, die Merkmale des Reibegeräusches zu neutralisieren. Dies wurde erreicht: a) durch ausschliessliche Berücksichtigung der

stimmhaften Reibelaute, b) indem die Zeichenkraft der Transitionen durch Werwendung *der* Vokalformanten verstärkt wurde, die während der konsonantischen Verschlussbildung auf originalen Spektrogrammen zu erkennen sind, c) indem überhaupt kein Reibegeräusch bei der Kontrastierung /v/, /ð/ und ein neutrales Reibegeräusch bei der Kontrastierung /z/, /ʒ/ eingezeichnet wurde. Auf jeden der vier stimmhaften Reibelaute liessen wir jedesmal je drei verschiedene Vokale folgen: einen vorderen Vokal, einen mittleren Vokal und einen hinteren Vokal.

In einer ersten Versuchsreihe wurden Schnelligkeit und Richtung der Formanttransitionen variiert. Dies ergab einen verschiedenen, aber relativ breiten Frequenzumfang für die Transitionen der zweiten und dritten Formanten bei jeder einzelnen Artikulationsstelle der Konsonanten — ein klarer Hinweis, dass die Transitionen der zweiten und dritten Formanten in der Tat akustischen Merkmalen für die Perzeption der Artikulationsstelle der amerikanischen Frikativae sind. In einer zweiten Versuchsreihe wurden die Frequenzen von *geraden* Formanten (null Transitionen) verändert. Durch diese Methode wurden die Frequenzumfänge für jede Artikulationsstelle verengt und die tatsächlichen Loci für den zweiten sowohl wie für den dritten Formant sicher erkennbar. Es wird dabei angenommen, dass die Loci für die stimmhaften Reibelaute ebenso wie für die entsprechenden stimmlosen Reibelaute gelten.

Résumé

Transitions de formants et Locus comme corrélatifs acoustiques du lieu d'articulation des fricatives américaines

Cette étude a été rendue possible par l'emploi de formes spectrographiques peintes à la main et transformées en son par un synthétiseur de parole nommé Pattern Playback.

Dans les consonnes fricatives comme / ʃ Θ s ʃ v ð z ʒ /, l'identification du lieu d'articulation dépend des indices acoustiques qui se trouvent dans le bruit de friction aussi bien que de ceux qui se trouvent dans les transitions de deuxième et troisième formants. Pour isoler ces derniers indices des premiers, il a fallu »neutraliser» les indices de friction. Cela s'est fait, a) en ne manipulant expérimentalement que les fricatives *sonores*, b) en renforçant l'efficacité perceptive des transitions grâce à l'usage des légers formants vocaliques qui sont visibles pendant la phase de fermeture sur les formes spectrographiques, c) en ne peignant aucune friction quand il s'agit d'opposer /v/ à /ð/, et une friction neutre quand il s'agit d'opposer /z/ à /ʒ/. Dans toute cette étude, les quatre fricatives sonores étaient suivies chacune de trois voyelles différentes, une voyelle antérieure, une centrale et une postérieure.

Dans une première expérience, on a varié la vitesse et la direction des transitions de formant. Cette technique a produit, pour chaque lieu d'articulation consonantique, une étendue de fréquences différente, bien que relativement large — indication claire que les transitions des deuxième et troisième formants sont bien des indices acoustiques pour la perception du lieu d'articulation des fricatives américaines. Dans une seconde expérience, on a varié les fréquences de formants *droits* (transitions zéro). Par cette méthode, les étendues de fréquences de chaque lieu d'articulation se sont faites plus étroites, et les locus-mêmes ont apparu, convenablement spécifiés, pour les deuxièmes aussi bien que pour les troisièmes formants. On admet que les locus des fricatives sonores sont égalment valides pour les fricatives sourdes correspondantes.

Haskins Laboratories, New York.