INFLUENCE OF PRECEDING FRICATIVE ON STOP CONSONANT PERCEPTION: 
SOME AMENDMENTS

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Abstract. This paper presents two control experiments and one 
reanalysis of our earlier studies (Mann & Repp, 1979a) on the 
influence of [ʃ] vs. [s] on the perception of following [t] vs. [k]. 
While the basic finding of more [k] percepts following [s] was 
consistently replicated, the first control study failed to replicate 
the reduction in that effect when a syllable boundary intervened 
between fricative and stop (such an effect was reported in our 
earlier Experiment 1). The second control study showed that the 
relative amplitude of the fricative noise plays no important role in 
its effect on stop perception. However, this study and a reanalysis 
of our earlier Experiment 3 showed that—contrary to our earlier 
conclusion that the effect of the fricative on stop perception is 
primarily phonetic in nature—the spectral characteristics of the 
fricative noise do contribute significantly to the effect.

INTRODUCTION

In an earlier series of experiments (Mann & Repp, 1979a), we investigated 
the effect of a preceding fricative on the perceived place of stop consonant 
articulation. We preceded synthetic syllables from a [ta]-[ka] continuum with 
fricative noises appropriate to [ʃ] or [s] and showed that more velar stops 
are perceived in the context of [s]. Our earlier Experiment 1 demonstrated a 
decrease in the magnitude of this perceptual context effect with introduction 
of an additional vowel before the noise, which permitted a subjective syllable 
boundary after the fricative. Thus, instructions to place a syllable boundary 
between fricative and stop were confounded with the addition of a vowel 
preceding the fricative. Although it seemed unlikely that this initial vowel 
by itself should have been responsible for a reduction in the context effect, 
it was necessary to rule out that possibility by varying only instructions, 
holding the stimulus structure constant. This was the purpose of the 
following experiment.

EXPERIMENT 1

Method

Subjects. Ten subjects participated. They included eight paid vo-
unteers, a research assistant, and the first author.

Acknowledgment. This research was supported by NICHD Grant HD01994 and BRS 
Grant RR05596 to the Haskins Laboratories, and by NICHD Postdoctoral Fellow-
ship HD05677 to Virginia Mann.

Stimuli. A new, improved [ta]-[ka] continuum was created on the OVE IIIc synthesizer at Haskins Laboratories. This continuum consisted of seven stimuli differentiated only by the F3 transition. The F3 onsets ranged from 2700 Hz to 2100 Hz in 100-Hz steps (plus or minus up to 10 Hz). F1 and F2 started at 285 and 1770 Hz, respectively. The steady-state frequencies of the three lowest formants were 771, 1233, and 2520 Hz. All formant transitions were stepwise-linear and 50 msec in duration. The specified amplitude rise-time was likewise 50 msec. Stimulus duration was 250 msec, and fundamental frequency fell linearly from 110 to 80 Hz. Informal listening indicated these stimuli sounded more natural and were easier to identify than the CV stimuli used in our earlier experiments.

The two synthetic fricative noises, appropriate for [ʃ] and [s], had the same spectral specifications as those used in our earlier experiments, but their duration was 200 msec, they had a triangular amplitude contour that rose during the first 150 msec and fell during the last 50 msec, and they were of approximately equal amplitude. Their amplitude was approximately 12 dB below the steady-state [a].

VFCV stimuli were assembled by following an initial, steady-state [i] vowel of 120 msec duration with either of the two fricative noises, a 75-msec gap, and one of the seven stimuli from the [ta]-[ka] continuum. Thus, there were 14 stimuli which were repeated ten times in random order, with interstimulus intervals of 3 sec, and 6 sec after each block of 14. The stimuli were digitized at 10 kHz before recording.

Procedure. Each subject listened twice to the same stimulus tape, once with "V-FCV instructions" and once with "VF-CV instructions". Under V-FCV instructions, subjects attempted to place a syllable boundary before the fricative and labeled the stops as "t" and "k". Under VF-CV instructions, they attempted to place the syllable boundary after the fricative and labeled the stops as "d" and "g". In each case, identification of the fricatives as "sh" or "s" was also required. The order of instructions was counterbalanced across subjects.

That the subjects were at least moderately successful in carrying out these instructions was indicated by some listeners' expressions of surprise when, on completion of the experiment, they learned that the same stimuli had been presented twice. Two subjects—the first author and his research assistant—were informed of this fact in advance; nonetheless, they found it possible to maintain a V-FCV or VF-CV "mode" of listening without difficulty and without involuntarily switching back and forth between the two modes.

Results and Discussion

The pooled results of the ten subjects are shown in Figure 1. The basic context effect—fewer alveolar stop responses following [s]—was replicated, \( F(1,9) = \frac{42.8}{p} < .001 \). However, there was no indication of any effect of instructions, \( F(1,9) = 0.2 \). Even the two experienced listeners, who were convinced that they carried out the instructions successfully, both showed a slightly larger context effect in the VC-CV condition. Exclusion of trials on which the fricative was misidentified (3.0 percent) did not make any difference.
Figure 1. Effect of syllable boundary instructions (V-FCV vs. VF-CV) on the influence of fricatives on stop identification.
Thus, this well-controlled experiment failed to replicate the "syllable boundary effect" of our earlier Experiment 1. By default, that effect must be ascribed to the presence vs. absence of an initial vowel (VFCV vs. FCV). This interpretation is given some support by a comparison of the present results with those of Experiment 2, described below. In that experiment, the same subjects listened to stimulus sequences that included the present stimuli with the initial [i] portion removed. Indeed, the context effect was larger in FCV than in VFCV stimuli, although not significantly so. Thus, it seems that the context effect is sensitive to stimulus components preceding the fricative noise, but not to the cognitive variable of subjective syllable division.

EXPERIMENT 2

Experiment 2 had two purposes: (1) to investigate whether changes in fricative-noise spectrum within fricative categories would change the magnitude of the context effect, and (2) whether such within-category effects, if obtained, would diminish as the amplitude of the fricative noises is reduced. The presence of within-category effects would support the hypothesis that the context effect is due, in part, to auditory contrast and/or noise-offset cues to place of stop articulation (see Mann & Repp, 1979a), and sensitivity of these effects to noise amplitude would further point towards an auditory origin. Since fricative noise amplitudes had varied considerably among our earlier experiments, a controlled study of this factor was called for in any case.

Method

The subjects of Experiment 1 continued on to Experiment 2 in the same session. The stimuli were nearly the same, with three differences: (1) There were no initial vowels (i.e., the stimuli were of the FCV type); (2) instead of two fricative noises, there were four; (3) the noises existed in two versions, one "normal" (about 12 dB below the steady-state vocalic portion, as in Exp. 1), the other attenuated by 10 dB. The four noises were stimuli 1, 3, 7, and 9 from a nine-member [f]-[s] continuum (see Mann & Repp, 1979b). Stimuli 1 and 3 sounded [f]-like, stimuli 7 and 9 sounded [s]-like; thus, within-category effects could be assessed by comparing 1 with 3, and 7 with 9. Between-category effects, although confounded with a larger spectral difference, could be seen by comparing 1 and 3 with 7 and 9.

Two stimulus tapes were prepared, one with the normal noises and one with the attenuated noises. Each tape contained 10 random sequences of 28 stimuli, resulting from the combination of the four fricative noises with the seven CV stimuli, separated by 75 msec of silence. The order of the two tapes was counterbalanced across subjects.

Results

Figure 2 shows the stop identification results, with a summary of the data in the right-hand panel. As expected, there was a large effect of fricative category (fricative noises 1 and 3 vs. 7 and 9), F(1,9) = 50.5, p < .001. In addition, however, there was a significant within-category effect of fricative spectrum (fricative noises 1 and 7 vs. 3 and 9), F(1,9) = 11.5, p <
Figure 2. Effect of four different fricative noises on stop identification, for two different fricative noise amplitudes (panels a, b), summarized in panel c.
.01, but this effect was confined to the "sh" category (fricative noises 1 vs. 3), as indicated by a significant interaction, F(1,9) = 10.0, p < .02. Fricative noise amplitude had no effect at all; in fact, the effect of noise spectrum within the "sh" category was slightly larger for the attenuated noises.

The fricative noises were quite consistently identified as either "sh" (stimuli 1 and 3) or "s" (stimuli 7 and 9), regardless of amplitude, although "errors" were less frequent for the endpoint tokens. The error percentages for stimuli 1, 3, 7, 9 were 0, 4.1, 4.9, 1.5 at the normal amplitude and 1.9, 4.9, 2.4, 1.0 at the lower amplitude. Interestingly, [f]-like stimuli were more often mislabeled as "s" in conjunction with a "k" response (2.1 percent) than in conjunction with a "t" response (0.6 percent), while the reverse was true for mislabelings of [s]-like stimuli as "sh" (0.8 vs. 1.5 percent). Exclusion of these errors from the data did not change the pattern of results.

Discussion

The results of this experiment suggest that the effect of the fricative on stop perception is, at least in part, a continuous function of fricative noise spectrum. Why effects of fricative spectrum were confined to the "sh" category is not clear at this point. Extrapolating from the trend within the "sh" category (Fig. 2c), it seems possible that the fricative context effect is entirely continuous and independent of perceived fricative category. However, the present experiment did not include any ambiguous fricative noises, which are needed to examine that issue. Experiment 3 in Mann and Repp (1979a) did precisely that and indicated that there is a large categorical component to the effect: "t" responses are less frequent when a given ambiguous noise is labeled "s" than when it is labeled "sh". This categorical effect persisted in our reanalysis of those data (see below).

Our failure to find any effects of noise amplitude in the present study is reassuring as far as amplitude variability in earlier experiments is concerned. However, it does not have any theoretical implications, as a positive finding might have had. The error pattern suggested that the stop may have a reciprocal effect on fricative identification. This possibility is further pursued in Experiment 3.

Before proceeding to describe that experiment, we should mention that we have some relevant data from another study that conflict with the present results in that they showed a within-category effect for "s" but not for "sh". In that study, (conducted for a different purpose and described in detail as Experiment 2 in Mann & Repp, 1979b), noises drawn from a nine-member [f]-[s] continuum were followed by a variable silent interval and one of two fixed CV portions, called [ta] and [tu]. Since the formant transitions in the CV portions had not been chosen to be optimal for alveolar stops, and since the nine subjects were given the option to identify the stops as either "t" or "k", a large number of "k" responses was obtained, especially to stimuli containing [tu]. Not surprisingly, "k" responses were considerably more frequent following [s]-like noises than following [f]-like noises. More detailed examination of the data showed that "k" responses remained at a constant level as long as the fricative was identified as "sh", but increased rapidly as noises identified as "s" became more and more [s]-like. In
conjunction with Experiment 2, these results show that within-category effects of fricative spectrum may differ quite radically from study to study—an impression that Experiment 3 confirmed.

EXPERIMENT 3

Experiment 3 examined the nature of within-category effects of fricative noise spectrum on stop identification and, in addition, tested whether the way a given fricative noise is labeled affects identification of the following stop. To that end, this study included several fricative noises ambiguous between [ʃ] and [s]. Thus it tested whether, in addition to the spectral effects demonstrated in Experiment 2, there is a categorical component to the context effect.

This experiment was previously reported by us as Experiment 3 in Mann and Repp (1979a). However, we subsequently discovered that our data analysis had used an incorrect procedure. Reanalysis produced a somewhat different pattern of results, so that our conclusions had to be modified. We also extracted some additional information not previously presented. Our present, complete account of this experiment supersedes that given in our earlier paper.

Method

Subjects. Ten adults served as subjects. They included eight paid volunteers and both authors.

Stimuli. The 25 FCV stimuli used in this experiment were formed by pairing each of 5 fricative noises with each of 5 CV stimuli, separated by a constant 75-msec period of silence. The stimulus components were similar to those employed in Experiment 2 of Mann & Repp (1979a). The fricative noises included the two unambiguous ones employed earlier and three noises ambiguous between [ʃ] and [s]. The ambiguity of these three additional noise stimuli was known from an earlier study of the [ʃ]-[s] distinction (Mann & Repp, 1979b); they were stimuli 4, 5, and 6 from a nine-member noise continuum. The CV stimuli were drawn from a [ta]-[ka] continuum (Mann & Repp, 1979a). They included the two endpoint stimuli and the three stimuli (4, 5, and 6) most ambiguous between [ta] and [ka].

Five randomized sequences of 55 stimuli were recorded directly from the synthesizer. Within each sequence, stimuli that contained two unambiguous components were presented once, stimuli that contained one ambiguous component were presented twice, and those that contained two ambiguous components were presented three times.

Procedure. Each subject participated in a single 1-hour session, in which the test tape was presented twice. Thus, each subject gave a total of 30 responses to stimuli in which both components were (more or less) ambiguous. The task was to identify the fricative-stop cluster as "st", "sk", "sht", or "shk".
Results

The results for stop consonant identification are shown in Figure 3. The left panel displays standard labeling functions for the CV stimuli, separately for each preceding fricative noise. It is obvious that stop identification was as strongly affected by the preceding fricative as in the previous studies, \( F(4,36) = 13.2, p < .0005 \). The frequency of "t" responses declined steadily as the fricative noise became more [s]-like. To examine whether that decline can be accounted for entirely by the changes in noise spectrum, we turn to the right panel of Figure 3, which displays the overall percentages of "t" responses contingent on whether the fricative was identified as "sh" or "s". (Contingent percentages were calculated for each individual subject and stimulus combination before averaging; our failure to do this was responsible for the artifacts in our earlier analysis.) There we see that, although "t" responses declined within each fricative category, there was a sizeable break at noise stimulus 5, the one most consistently ambiguous between [ʃ] and [s]; when this particular noise was called "sh", "t" responses were more likely to follow than when it was called "s". This categorical effect was shown by seven of the ten listeners and, due to the very large effects shown by some subjects, was significant, \( F(1,9) = 7.0, p < .05 \).

In contrast to Experiment 2, the present data show declines in "t" responses within both fricative categories. In fact, the decline within the "s" category (not obtained in Exp. 2) was more consistent across subjects, \( F(2,18) = 9.3, p < .005 \); that within the "sh" category did not reach conventional levels of significance due to large individual differences, \( F(2,18) = 3.2, p < .10 \).

These results demonstrate that, for the majority of listeners, the fricative context effect has both a categorical and a continuous component. However, there are some listeners who seem to lack the categorical component, whereas others show an effect that is almost entirely categorical.

Examination of the fricative identification results revealed an effect of the CV portion, \( F(4,36) = 6.7, p < .0005 \). As Figure 4a shows, however, this effect was very small compared to that of the fricative on stop identification; it was primarily due to CV stimulus 1, which led to somewhat more "sh" responses than the other CV portions. This reciprocal effect exhibits the same contingencies as that of the fricative on stop identification: "sh" goes with "t", and "s" with "k". To see whether there is any categorical component to the reciprocal context effect, fricative identification was analyzed contingent on stop identification. The results are shown in Figure 4b. There were two consistently ambiguous CV stimuli (4 and 5), giving a good opportunity to observe categorical effects. However, the effects obtained were rather small (due in part to the small size of the total effect) and fell short of significance, \( F(1,9) = 4.5, p < .10 \). The decline in "sh" responses within the "t" category was significant, \( F(2,18) = 7.9, p < .005 \); there was no significant effect within the "k" category.

Discussion

Experiments 2 and 3 showed that the effect of the fricative on stop perception depends on perceived fricative category as well as on fricative
Figure 3. Effect of five different fricative noises on stop identification (panel a), and the continuous and categorical components of that effect (panel b).
Figure 4. Effect of five different CV portions on fricative identification (panel a), and the continuous and categorical components of that effect (panel b).
noise spectrum. There is also a smaller, reciprocal effect of the stop on fricative perception, "s" responses being more frequent in conjunction with "k" responses, and—although the evidence is weak here—this effect may likewise have two components. The within-category effects of fricative noise spectrum on stop identification varied from study to study, even though highly similar stimuli were involved.

The finding that the context effect studied here is partially categorical and partially continuous makes it impossible to rule out any of the candidate theoretical explanations (discussed in detail by Mann & Repp, 1979a). Rather, we seem to need different explanations for the two components of the effect. Neither auditory contrast nor noise-offset cues to place of stop occlusion can explain the observed categorical effect; however, either of them may account for the somewhat elusive effects of noise spectrum within fricative categories. On the other hand, the categorical effect does fit a response bias hypothesis. Elsewhere, we have argued (Mann & Repp, 1979a) that the categorical effect does not derive from a simple response preference. We also have new evidence (Repp & Mann, Note 1) that subjects, when presented with isolated fricative noises and asked to guess the following stop, show no preference for "k" to go with "s" responses; this supports our argument.

It still seems plausible to us that the increased number of velar stop responses in the context of [s] may arise from listeners' implicit knowledge of certain variations (as yet not confirmed by acoustic measurements) in the transitions for velar and alveolar stops with the nature of the preceding fricative, reflecting a forward shift in the place of tongue-palate contact following [s]. Similarly, the effect of the stop on fricative identification may be due to the absence in our stimuli of appropriate transitions at the offset of the fricative noise. Since coarticulatory effects, such as the ones just referred to, are invariably assimilatory in character, perceptual compensation for them will favor contrasts; hence, listeners' preference for reporting combinations of fricatives and stops with opposite polarities on the place-of-articulation dimension. That the perceptual effect is partially categorical, partially continuous, may indicate that the compensatory mechanism operates both before and after phonetic category decisions. Thus, it seems that reference to articulation still provides the most parsimonious explanation of our results.

At present, we do not have any solid measurements demonstrating that there are, in fact, coarticulatory dependencies of stop consonants on preceding fricatives. However, we do have some perceptual evidence for the existence of such coarticulatory effects (Repp & Mann, Note 1). In the case of the reciprocal effects of stops on fricative identification, the existence of coarticulation in the form of spectral changes in the fricative noise is well-known, but we do not know whether these transitions affect the identification of the fricative itself. This possibility is not implausible, however, since the end of the noise seems to be more important for fricative identification than its beginning (Mann & Repp, 1979b).

It is possible that the perceptual effects investigated here reflect a very general principle of speech perception: a tendency to differentiate successive phonetic segments along the place-of-articulation dimension (cf. Repp, 1978). Such a tendency would compensate for the general assimilatory
nature of coarticulation, regardless of whether or not coarticulation occurs in a specific instance. We suspect, however, that the tie between speech perception and production is much more specific, with perceptual context effects occurring only when corresponding coarticulatory dependencies are in fact observed. Our present results may be an instance of such a relationship.

REFERENCE NOTE


REFERENCES