Acoustic-perceptual factors in phonological assimilations: A study of syllable-final nasals

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Among the more common phonological assimilation patterns in the world's languages is assimilation of syllable-final nasals to the place of articulation of a following consonant. This study investigated acoustic-perceptual factors that might underlie this phonological pattern. Previous perceptual studies of the role of syllable position and manner of articulation in assimilatory phenomena have reported very different patterns of results in terms of the type (assimilatory or random) and likelihood of perceptual errors on syllable-final nasals, leaving open questions concerning the nature and strength of any contribution of perception to the phonological pattern. Two perceptual experiments were conducted in which original homorganic NC sequences were manipulated to create three stimulus conditions: homorganic NC (e.g. [zɪmbə]), heterorganic NC (e.g. [zɪmdə]), and final N# (e.g. [zɪm]); stimuli were presented to listeners for identification. Across the two experiments, identification error rate was 15% for final nasals (N#), 18% for nasals in homorganic clusters, and 48% for nasals in heterorganic clusters, with the majority of errors in the heterorganic condition involving place assimilation to the following oral stop. These results indicate that, although nasal place cues were not regularly overridden by following oral place cues, place in syllable-final nasals was perceptually unstable. This unstable perceptual situation appears to be consistent with the phonological situation, in which nasal place assimilation in NC clusters is linguistically widespread but not universal. Viewing the perceptual findings in light of the acoustic properties of nasals, it is suggested that the acoustic factor underlying the perceptual instability may be the relative gradualness of spectral change in syllable-final nasals*.

1. Introduction

The notion that diachronic and synchronic phonological phenomena can be attributed in part to phonetic factors has a long history within linguistics (Whitney 1867; Verner 1877; Paul 1886; Sweet 1888; Jespersen 1922; Hill 1936; Jakobson 1941; Martinet 1952, 1955). In recent decades, technological advances have both enabled and challenged researchers to replace speculative claims regarding phonetic constraints on sound systems with experimental evidence of these constraints. Increasingly, the trend is to derive specific articulatory or perceptual constraints from quantitative models of the human speech mechanism.

The focus of the present study is the class of phonological phenom-

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ena involving assimilation of consonantal place of articulation, especially nasal place assimilation.[1] A general assumption in our approach to the phonetic study of phonological structures is that phenomena which recur across geographically distant and genetically distinct languages have a phonetic basis; that is, such phenomena are at least in part the result of characteristics of the system used by humans to produce and perceive speech. A more specific assumption in our approach is that the more narrowly we constrain the phonological phenomena to be 'explained', the more we force a phonetic account of these phenomena to be precise. For example, in the case of phonological assimilations, certain assimilatory processes are cross-linguistically more common than others, a fact noted in many phonology texts (e.g. Hyman 1975; Sloat et al. 1978; Hawkins 1984; Lass 1984; Katamba 1989). If articulatory or perceptual models are to explain (even in part) phonological assimilations, it is not sufficient that they predict that assimilatory processes will occur in the world's languages; rather, they must differentiate between processes which are more or less likely to occur.

The challenge in the present study is to provide phonetic data which address two asymmetries in consonantal place assimilations in languages of the world. First, in clusters of two consonants (C_1C_2) involving complete oral obstruction (i.e. oral stops or nasals), it is more likely for C_1 to adopt the place of C_2 than the reverse (e.g. Ohala 1990; Manuel 1991). Second, such place assimilations are especially common when C_1 is a nasal consonant (see the phonology texts cited above; see also McCarthy 1988; Ohala & Ohala 1993). English, for example, exhibits this phenomenon in certain morphological contexts: the nasal in the negative prefix /ɪn/ is realized as [m] in bilabial contexts (as in *impatient*), as [n] in alveolar (and vocalic) contexts (as in *intolerant*), and as [ŋ] next to a velar stop (as in *incongruous*, at least for some speakers). Other languages in which nasals assimilate (sometimes under restricted conditions) to the place of articulation of a following (often oral stop) consonant include Swedish, German, Yiddish, Russian, Spanish, Sanskrit (and many modern Indic languages), Classical Greek, Finnish, Swahili (and numerous other Bantu languages), Nzema, Javanese, Chamorro, Malay, Tagalog, Peruvian Quechua, Zoque, Tequistlatec, Western Basque, Ainu, Japanese, Korean, Khalka Mongolian, various Tungusic languages, and Chinese (sporadically at morpheme boundaries), to list but a small subset.[2]

Thus the question to be addressed here is why nasals (as opposed to oral stops) are particularly predisposed to undergo place assimilation in clusters, especially in syllable coda position. While it is not unlikely that nasal place assimilations are the consequence of both articulatory and acoustic-perceptual factors, let us consider separately what wholly articulatory or wholly perceptual accounts might look like. An ease-of-articulation account might postulate that place assimilation in clusters is particularly likely when the cluster involves a nasal consonant because it is difficult or costly to coordinate the velic gesture responsible for nasalization with the oral gesture responsible for place of articulation. That is, in clusters involving complete oral obstruction, two supralaryngeal gestures are required in non-homorganic NC or CN clusters (where N is nasal and C is oral), as opposed to only one in CC clusters. To explain the propensity of syllable-final nasals to assimilate (e.g. VnbV frequently becomes VmbV, but VbnV becoming VbmV is much less common), this approach might be extended to claim that coordination of oral lip or tongue movements with the velic *raising* gesture is particularly costly.

An acoustic-perceptual account of nasal place assimilations might argue that place distinctions are perceptually less salient for nasal consonants than for oral consonants, with place distinctions being especially confusable in syllable-final nasals. To account for the *assimilatory* nature of the place shifts (over more random shifts in nasal place of articulation), an acoustic-perceptual approach would presumably argue that the nasal place cues are overridden by the more salient place cues for the following oral stops.

If we consider how these accounts fare on the basis of the existing literature, the acoustic-perceptual one appears to come out ahead. Nelson et al. (1984) and Ohala (1990), among others, have argued that a general problem with 'articulatory effort' explanations is that a satisfactory account of 'economy' or 'ease' is generally lacking. It may indeed be difficult to coordinate velic with tongue or lip gestures, and the epenthetic oral stops sometimes found in the productions of phonological nasal + fricative clusters (as in English *prince* [pɹɪnts] or *warmth* [wɔɹmpθ]) point toward difficulties in temporal coordination (Harms 1973; Ohala 1974), but independent evidence of such difficulties from articulatory modeling is generally lacking. Kohler (1990) has suggested that place assimilations in German, where alveolars but not bilabials or velars assimilate in clusters, is due to the high cost of relatively precise tongue tip articulations over more global tongue body or lip gestures. Unfortunately, the opposite argument might also be made (i.e. that movement of the large extrinsic tongue muscles costs more than movement of the smaller intrinsic muscles).

Lindblom (1990) has suggested that articulatory effort might be quantified in part in terms of a model of articulatory cost that measures peak velocities (see also Nelson et al. 1984). Syllable-final and syllable-initial nasals do appear to exhibit different patterns of velic velocity. Kuehn (1976) reported that the velocity of velic raising in NC sequences is greater than the velocity of velic lowering in CN sequences (although both velocities are great relative to velic velocity in NV and VN sequences; Bell-Berti 1993). Consistent with the general finding that higher velocities are associated with longer distances (Kuehn & Moll, 1976), velic position has been found to be lower in syllable-final nasals than in syllable-initial nasals (Ohala 1971; Kuehn 1976; Fujimura et al. 1977; Krakow 1989). Viewing these findings in terms of phonological place assimilations, it might be argued that syllable-final nasals undergo place assimilation because it is difficult to coordinate tongue/lip movement (for place) with the high-velocity velic raising gesture in NC sequences. However, such an account seems weak in that if the constraint is to 'minimize peak velocity', it should be the *velic* (rather than the place) gesture that undergoes change in NC sequences. But, phonologically, the nasality of the nasal consonant in these clusters remains robust.

Two types of acoustic-perceptual studies provide evidence in support of the 'lack of perceptual salience' account of nasal place assimilations. First, perceptual measures indicate that place is less clearly differentiated in nasal stops than in oral stops. For example, American listeners' ratings of the relative similarity of naturally produced consonants showed that nasal [m n ŋ] were judged to be closer to each other than were oral [b d g] (Mohr & Wang 1968). Moreover, recent evidence indicates that syllable position influences the perceptual salience of nasal place information. In a series of experiments, Repp found that American English listeners' accuracy of identification of the [m]-[n] distinction was poorer for nasals in VN syllables (Repp & Svastikula 1988) than in NV syllables (Repp 1986). Interestingly, identification accuracy of murmurs and vocalic formant transitions extracted from the original syllables did not differ for syllable-initial and syllable-final nasals, suggesting that syllable-final nasals do not involve 'degraded' place information in either of these two components. A current view of the perceptual correlates of place of articulation in nasal consonants is that, while the spectral characteristics of the nasal murmur and vocalic transitions both contribute to place perception, place cues are at least in part *relational*, involving the difference in spectral structure between the nasal consonant and the adjacent vowel (Kurowski & Blumstein 1987; Repp & Svastikula 1988; Seitz et al. 1990; for a comprehensive review see Kurowski & Blumstein 1993) (this view of nasal place perception is in keeping with the claim for stop consonants that place perception is based on relative spectral change in regions of high information, e.g. Kewley-Port 1983; Lahiri et al. 1984). Repp and Svastikula (1988) speculated that poorer identification of the nasals in their original VN syllables may be due to a less abrupt change in spectral

structure in VN than in NV syllables. Acoustic evidence of these spectral change differences is provided by Seitz et al. (1990) and Manuel (1991).

The second type of perceptual study relevant to explaining phonological nasal place assimilations directly tests the perception of place in nasals when the nasals are part of a consonantal cluster. Using tape-splicing techniques, Malécot (1956) spliced nasal murmurs onto the beginning of American English [bæ], [dæ], or [gæ] and the end of [æb], [æd], or [æg] (replacing the voiced closure with the murmur), creating homorganic and non-homorganic NCV (e.g. [mbæ], [nbæ]) and VCN (e.g. [æbm], [æbn]) sequences. Identification scores showed that homorganic responses to non-homorganic clusters predominated, with the place of the oral stop determining the perceived place of the nasal consonant. However, as the nasals in Malécot's study (which were adjacent to C) lacked any place information from vocalic transitions into or out of the nasal murmur, the results do not address the central question here of whether oral overrides nasal place information in more typical VNCV sequences.

In a study whose focus was the perception of place in consonantal clusters, Ohala (1990) used computer-editing techniques to create homorganic and non-homorganic VNCV (e.g., [ampa], [amta]) and VCCV (e.g. [appa], [apta]) clusters. Overall (results for NC and CC clusters were not reported separately), the second consonant of the cluster determined perceived place of articulation in 93% of the responses.

Most recently, Hura et al. (1992) also tested place perception in VNCV and VCCV clusters using cross-splicing methods. The second consonant of all clusters was one of [p t k]; the first consonant was one of [m n ŋ] in NC clusters and one of [p t k f s ʃ] in CC clusters. Identification results showed that place errors were highest in NC clusters, but Hura et al.'s error rates differed markedly from those reported by Ohala: 7% errors in NC clusters, 6% in oral stop -C clusters and 3% in fricative -C clusters. Equally importantly, the place errors in Hura et al.'s study were generally not assimilatory, indicating that oral place information did not override nasal place information.

The different pattern of results found by Ohala (1990) and Hura et al. (1992) is due at least in part to methodological differences. Hura et al. note that the temporal intervals between the consonants in their NC and CC clusters may have been relatively long, reducing the likelihood of assimilatory errors (Hura et al. recorded speakers reading nonsense names such as *Shanim Perry*; Ohala's speaker read nonsense disyllables such as *ampa*). This explanation of Hura et al.'s results is consistent with the findings of Repp (1977), which showed that stop consonant clusters in VC_1C_2V strings were heard as single consonants (primarily C_2) when cluster members were separated by a short temporal interval, but as two consonants when separated by a long interval. The studies by Ohala (1990) and Hura et al. (1992) also differed in the response alternatives offered to listeners. Ohala offered 3 choices for each stimulus, 2 being homorganic sequences and the third being 'other' (e.g. for *amta*, the choices were *ampa*, *anta*, *other*), which presumably encouraged homorganic responses. In contrast, Hura et al. asked listeners to identify only the first name in each stimulus (with a possibility of 9 responses – 3 each ending in a nasal, oral stop, or fricative), presumably focusing listeners' attention away from the second consonant of the cluster (but see discussion below).

The methodological differences are not entirely surprising given the different emphases of the two studies: Ohala addressed the possible perceptual influence of the second consonant in a cluster on the first, while Hura et al. focused on the relative perceptual salience of nasals, oral stops, and fricatives. But the different pattern of results leaves us without a clear picture of the possible role of acoustic-perceptual factors in diachronic and synchronic phonological tendencies involving consonantal place assimilations. Is the role of such factors weak at best, consistent with Hura et al.'s results which show less than a 4% difference in errors between phonologically robust fricatives and phonologically unstable nasals (e.g. Chomsky & Halle 1968), or so strong as to make nasal place in non-homorganic NC clusters nearly imperceptible, consistent with Ohala's high error rate? Furthermore, if perceptual data show syllable-final nasals to be susceptible to perceptual assimilation in the laboratory, is it possible to identify the spectral characteristics of syllable-final nasals that give rise to this laboratory finding (which in turn is presumably linked to their propensity to assimilate phonologically in languages of the world)?

In an effort to resolve some of this uncertainty, the experiments reported below further investigate the perception of nasal consonants in consonantal clusters. As in previous studies, original homorganic VNCV sequences were cut into two components, VN and CV, which were recombined to create cross-spliced non-homorganic and spliced homorganic VNCV sequences. Unlike previous studies, the initial component, VN, was presented separately to subjects for identification; these results could then be compared to the identification of the same VN token in VNCV sequences, allowing us to better assess the relative contribution of weak place cues in N, versus strong place cues in C, to nasal place errors. Another innovation was to use multiple vowels in the VNCV sequences. Earlier investigations of place perception of nasals in consonantal clusters used a constant vocalic context; however, studies of place perception of nasals in other contexts (i.e. absolute final and initial position) have varied vocalic context and found an influence on identification accuracy (e.g. Repp 1986; Kurowski & Blumstein 1987; Repp & Svastikula 1988).

The speakers and listeners used in the present study were native speakers of American English. English might appear at first to be an inappropriate language for testing the possible contribution of perceptual factors to phonological nasal place assimilations. As English phonology exhibits nasal place assimilation in both allophonic variation and morphophonemic alternations, English listeners' linguistic experience might influence the results. We do expect some influence of native language experience (see the General Discussion below), but we would also argue that English remains an appropriate testing ground in that place distinctions can be maintained in certain NC clusters, especially across morpheme boundaries (e.g. velar-bilabial in *springboard*, *dingbat*; bilabial-alveolar in *slammed*, *sometime*; velar-alveolar in *banged*, *springtime*; bilabial-velar in *camcorder*; and, for some speakers, alveolar-velar in *pancake*, *unkind*; alveolar-bilabial in *cranberry*, *sunburn*). English speakers are familiar with both homorganic and non-homorganic NC clusters.

2. *Experiment 1*

2.1. *Method*

2.1.1. *Stimulus materials*

Four native speakers of American English (females JE and RC, and males AC and MB) were recorded in a sound-attenuated room on digital audio tape using an AKG H17A microphone and a Panasonic SV-3500 digital audio recorder. Speakers produced multiple repetitions of disyllabic stimuli of the form [zVNCə], where V was one of [ɪ], [æ], or [ʌ], NC was one of the homorganic clusters [mb], [nd], or [ŋg], and stress was on the first syllable. The three vowels and three clusters were combined factorially to produce a total of nine stimulus types. Speakers read the stimuli from a printed word list in a constant carrier sentence which placed contrastive stress on the target word. Speakers were instructed to read at a comfortable pace.

Stimuli were digitized at 10 kHz and edited using a speech analysis package developed at Haskins Laboratories. The offset of the nasal murmur (as determined from synchronized waveform and spectrographic displays) was located in each token and the [zVN] and the [Cə] portions of each original stimulus were extracted. Six instances of each [zVN] syllable and one instance of each [Cə] syllable were selected from each speaker's extracted tokens, subject to the following constraints: (a) the place of articulation of the stop in each [Cə] syllable be easily identifiable (as determined in an informal listening test); (b) the [Cə] syllable selected not come from an utterance whose [zVN] portion was also used, but must come from an utterance with the same original vowel (e.g. [Cə] from a [zɪNCə] syllable must be spliced onto another [zɪN]); and (c) there not be noticeable amplitude or pitch discontinuities between the [zVN] and [Cə] portions of a stimulus. From these syllables three stimulus types were created, as shown in Tab. 1: monosyllables ending in a nasal, disyllables with homorganic clusters, and disyllables with heterorganic clusters.

Table 1. Test stimuli used in Experiments 1 and 2 created by splicing original [zVNCə] utterances

Final Nasal	Homorganic Cluster	Heterorganic Cluster	
zɪm	zɪmbə	zɪmdə	zɪmgə
zɪn	zɪndə	zɪnbə	zɪngə
zɪŋ	zɪŋgə	zɪŋbə	zɪŋdə
zæm	zæmbə	zæmdə	zæmgə
zæn	zændə	zænbə	zængə
zæŋ	zæŋgə	zæŋbə	zæŋdə
zʌm	zʌmbə	zʌmdə	zʌmgə
zʌn	zʌndə	zʌnbə	zʌngə
zʌŋ	zʌŋgə	zʌŋbə	zʌŋdə

2.1.2. Procedure

Stimuli were arranged into a series of test sequences, each sequence involving one of two stimulus conditions: an NC condition consisting of [zVNCə] disyllables containing heterorganic and homorganic clusters and an N# condition consisting of [zVN] monosyllables. Four N# test sequences were constructed, one for each of the 4 speakers. Within each N# sequence, there were 3 randomized sets of 18 test stimuli (3 nasals x 6 distinct tokens) plus one non-test 'warm-up' stimulus at the beginning of each set; stimuli in each of the 3 sets shared the same vowel. Taken together, the N# sequences consisted of a total of 216 test tokens (4 speakers x 3 vowels x 3 nasals x 6 tokens), plus 36 non-test tokens. The interstimulus interval in the N# condition was 2 s, with a 6 s pause at the end of each set of 19 stimuli.

Twelve NC test sequences were constructed, grouped by vowel and speaker (3 vowels x 4 speakers). Within each NC sequence, there were 54 test stimuli (3 nasals x 3 oral stops x 6 tokens) plus 6 non-test stimuli (the first 4 and last 2 tokens of the sequence). Stimuli were randomized

within each sequence. The 54 stimuli in the 12 NC test sequences yielded a total of 648 test tokens in the NC condition (plus 72 non-test tokens). The interstimulus interval in the NC condition was 2.5 s.

All 16 test sequences were output to digital audio tape and were presented over headphones to listeners in groups of up to 4 at a time. In the N# condition, listeners were asked to identify the final consonant of each stimulus as "m", "n", or "N" (the last representing the velar nasal and described as the final sound in English *bang* and *sing*). In the NC condition, listeners were asked to identify both consonants, the first as "m", "n", or "N" and the second as "b", "d", or "g". Test sequences were presented in a pseudo-random order, with the first sequence always being one of the N# sequences. Listeners were also tested on additional identification conditions (involving different versions of [zVN], [zVNCə], and [Cə] stimuli) that are not reported here. Testing involved two 1-hour listening sessions.

2.1.3. Subjects

Subjects were 15 native English-speaking undergraduate students recruited from introductory linguistics classes at the University of Michigan. No subject had more than rudimentary training in phonology or phonetics and none reported hearing or speaking deficiencies. Subjects were paid for their participation in the study. One additional subject was eliminated from the study for failing to consistently identify the place of stop consonants.

2.2. Results

2.2.1. N# condition

Our first concern is to establish that the nasal consonants used in this study were reliably identifiable. It is possible that the editing procedure in which the original [zVNCə] stimuli were spliced at the offset of the nasal murmur adversely affected place identification. The overall correct identification rate for nasals in the N# condition was 82% (84% for [m], 79% for [n], and 83% for [ŋ]). This is roughly comparable to the error rate reported by Repp & Svastikula (1988: Experiment 1), who found that unedited final nasals in VN syllables were correctly identified 88% of the time.

2.2.2. NC condition

Mean correct identification of nasals in the NC condition was 66%: 75% for homorganic clusters and 62% for heterorganic clusters (66% is the weighted mean of 216 homorganic and 432 heterorganic tokens). Comparison of the N# and NC conditions showed that nasal place identification was significantly poorer when the nasal occurred before an oral stop than when it occurred in absolute final position. This difference held not only when the nasal-stop clusters in the NC condition were heterorganic, but also when the clusters were homorganic. Three-way repeated measures analyses of variance with factors Nasal Place ([m], [n], [ŋ]), Speaker (JE, RC, AC, MB), and Context were performed on the number of correct nasal identifications. When the Context factor was N# vs. heterorganic NC, the analysis revealed a strong main effect of Context, $F(1,14) = 41.75$, $p < 0.001$. When the Context factor was N# vs. homorganic NC, there was again a main effect of Context, $F(1, 14) = 9.53$, $p < 0.01$, as well as a significant interaction between Context and Nasal Place, $F(2,28) = 3.46$, $p < 0.05$ (the interaction being due primarily to a relatively high error rate on the velar nasal in the homorganic NC condition). Neither analysis showed a main effect of Nasal Place or Speaker, and no other interactions were significant at 5%.

Of particular interest here is whether there was a difference in performance within the NC condition on the heterorganic and homorganic clusters. To evaluate the hypothesis that place cues in syllable-final nasals can be overridden by place cues of a subsequent oral stop at a different place of articulation, a third analysis of variance was performed with the same design as above except that the Context factor was heterorganic NC vs. homorganic NC. This analysis revealed a main effect of Context, $F(1, 14) = 6.97$, $p < 0.05$, with nasals in homorganic clusters identified significantly better than nasals in heterorganic clusters. In addition, there was an effect of Speaker, $F(3, 42) = 11.88$, $p < 0.001$, with male speakers' tokens being more easily identified than those produced by the female speakers. There was also a significant Speaker-Context interaction, $F(3, 42) = 6.13$, $p < 0.01$, indicating across-speaker variation in the degree to which identification accuracy changed from homorganic to heterorganic contexts; and a Nasal-Context interaction, $F(2, 28) = 4.02$, $p < 0.05$, reflecting the relatively strong effect of context on identification of [n] and the relatively weak effect of context on identification of [ŋ]. A significant Speaker-Nasal-Context interaction, $F(6, 84) = 3.75$, $p < 0.01$, indicated that the general pattern of context influencing [n] the most and [ŋ] the least did not hold for all speakers (e.g. the responses to JE's nasals showed the same magnitude of context effect for [m], [n], and [ŋ]).

The type of error on the heterorganic clusters is also of considerable interest here, as the current hypothesis predicts nasal responses to be homorganic with the following stop. Errors on NC clusters can in fact involve either nasal or oral stop misidentifications. Oral stops were misidentified less than 4% of the time (with many of these errors appearing to be random, although there was a slight tendency for the

errors to preserve the place of articulation of the preceding nasal). Nasals were misidentified 38% of the time. In analyzing the type of nasal errors, we have excluded from the analysis any NC response which involved misidentification of both the nasal and stop (due to difficulties in classifying such errors as assimilatory or not).

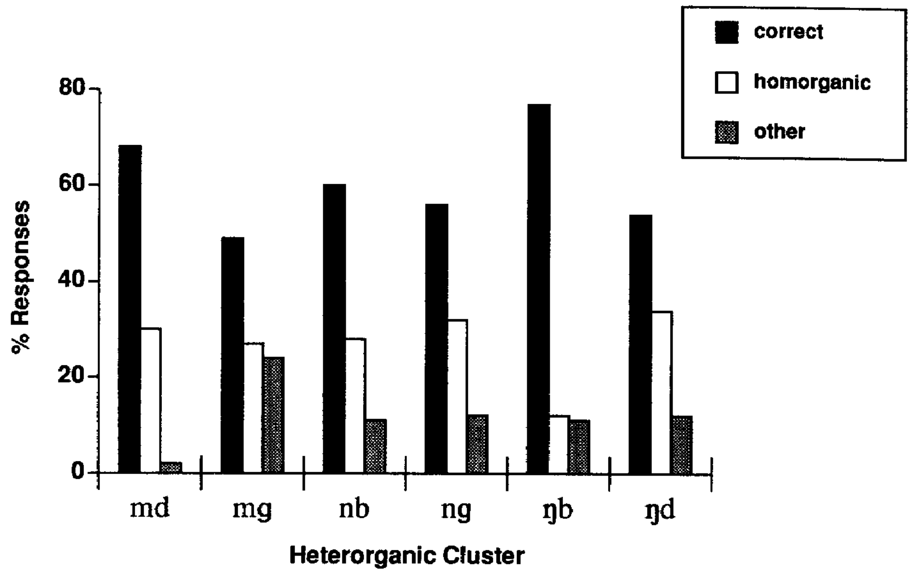

Figure 1. Experiment 1: Pooled responses to cross-spliced heterorganic NC clusters. Given 3 places of articulation ([m], [n], [ŋ]), 3 nasal responses were possible for each cluster: correct (black columns); incorrect and homorganic with the following stop (white columns); and incorrect but not homorganic, i.e. 'other' (grey columns). Responses in which the oral stop was misidentified were excluded.

Fig. 1 shows the percent correct (black bar), homorganic (white bar), and 'other' (grey bar) responses to each of the 6 types of heterorganic clusters. Of the three alternatives, the correct response was chosen the most often for all heterorganic clusters, followed by the homorganic response. The overall rate of homorganic (i.e. assimilatory) responses was 27%.

However, while 27% of the responses to heterorganic clusters were homorganic, it does not necessarily follow that all such responses involved nasal place assimilation to the following stop consonant. Certain of the identification data show clear response biases. In the most extreme case, JE's [n] tokens from the context [zɪ_bə] were identified as /m/ 58% of the time, as /n/ 41% of the time, and as /ŋ/ 1% of the time. This would appear to indicate a strong assimilatory influence of [b] on the perception of [n]. But these same nasals in the N# condition showed the same pattern of response: 57% /m/, 30% /n/, and 13% /ŋ/. Clearly, the addition of [b] did not have a strong assimilatory effect for JE's [n] tokens in the context of [ɪ], despite the fact that 'assimilations' made up over half of the responses here.

One way to separate response biases from assimilatory errors is to examine, not the actual number of homorganic responses, but the *change* in the response pattern from the N# to the NC conditions. Figure 2 indicates, for each heterorganic NC combination presented to listeners, the mean *difference* in percent identification of a nasal as /m/, /n/, or /ŋ/ between the N# and the NC conditions. The first column in each condition indicates the change in correct responses (e.g. /m/ responses to [md] compared to /m/ responses to [m#]), the second indicates the change in responses categorized as "homorganic" based on the NC condition (e.g. /n/ responses to [md] compared to /n/ responses to [m#]), and the third the change in "other" responses (e.g. /ŋ/ to [md] compared to /ŋ/ responses to [m#]). If there were perceptual assimilation, the first column should be negative (correct identification decreases), the second positive (assimilation increases), and the third either negative or at least not as large as the second ('other' responses either decrease, remain the same, or increase, but not as much as homorganic responses). This is exactly what happened for all 6 cluster types.

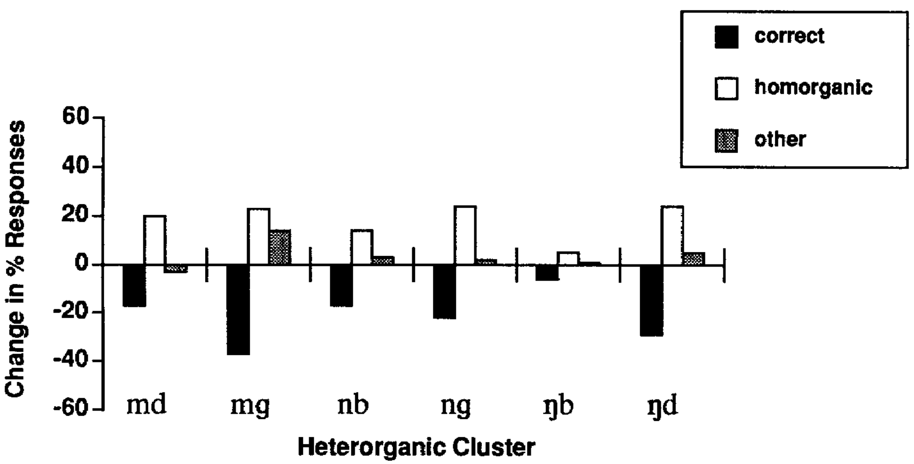

Figure 2. Experiment 1: Change in the type of nasal response between N# and heterorganic NC conditions, averaged across listeners. Each column represents the difference in the percent responses of a given type (correct, homorganic, or other) between the NC condition and the corresponding place of articulation in the N# condition (see text)

2.2.3. Cross-speaker variability

While the overall pattern of responses indicates a tendency for nasals to assimilate perceptually to the place of a following oral stop, the extent of assimilation differed for the different speakers in different conditions. Indeed, the range of assimilation rates across different speakers, vowels, and places of articulation was dramatic, ranging from an assimilation rate of 0% for MB's [zɪŋbə] stimuli to a high of 70% for JE's [zʌŋdə]'s. As an illustration of this variability, Fig. 3 gives the percent homorganic responses to heterorganic clusters according to speaker (one speaker per panel), nasal place, and vowel context (indicated on the abscissa). Black bars indicate the percent homorganic responses for nasals preceding [b], gray bars before [d], and the white bars before [g]. (Only two stops are specified for each vowel-nasal combination because only responses to non-homorganic clusters are given).

As a measure of perceptual assimilation, columns marked with an asterisk "*" in Fig. 3 indicate conditions in which there was both a significant decline in the number of correct responses from the N# to the NC condition (e.g. the percent /m/ responses to [m] was significantly lower in [md] clusters than in absolute final position), and significantly more homorganic errors than non-homorganic errors in the NC condition (e.g. the percent /n/ responses to [md] was significantly higher than the percent /ŋ/ responses). Significance was assessed at the 5% level using a series of Wilcoxon Signed Rank tests. That some speakers' nasals are more susceptible to perceptual assimilation than those of other speakers is indicated by the different number of significant conditions present in the four graphs (Speaker RC's tokens being the most likely to assimilate and Speaker AC's being the least likely). Also evident is the fact that the particular combinations of vowel, nasal, and stop which yielded assimilatory responses differed from speaker to speaker.

2.3. Discussion

Although there are strong speaker and vowel effects, the overall results indicate that syllable-final nasals are more poorly identified in pre-consonantal position than in absolute final position. The relatively high error rate on nasals in heterorganic clusters was predicted by the hypothesis that nasal place information might be overridden by conflicting place information for oral stops. However, the increase in error rates on nasals in *homorganic* clusters relative to nasals in absolute final position was *not* expected, as the place information for adjacent consonants was not in conflict. A possible explanation for this finding is that identification of place in syllable-final nasals becomes more difficult as

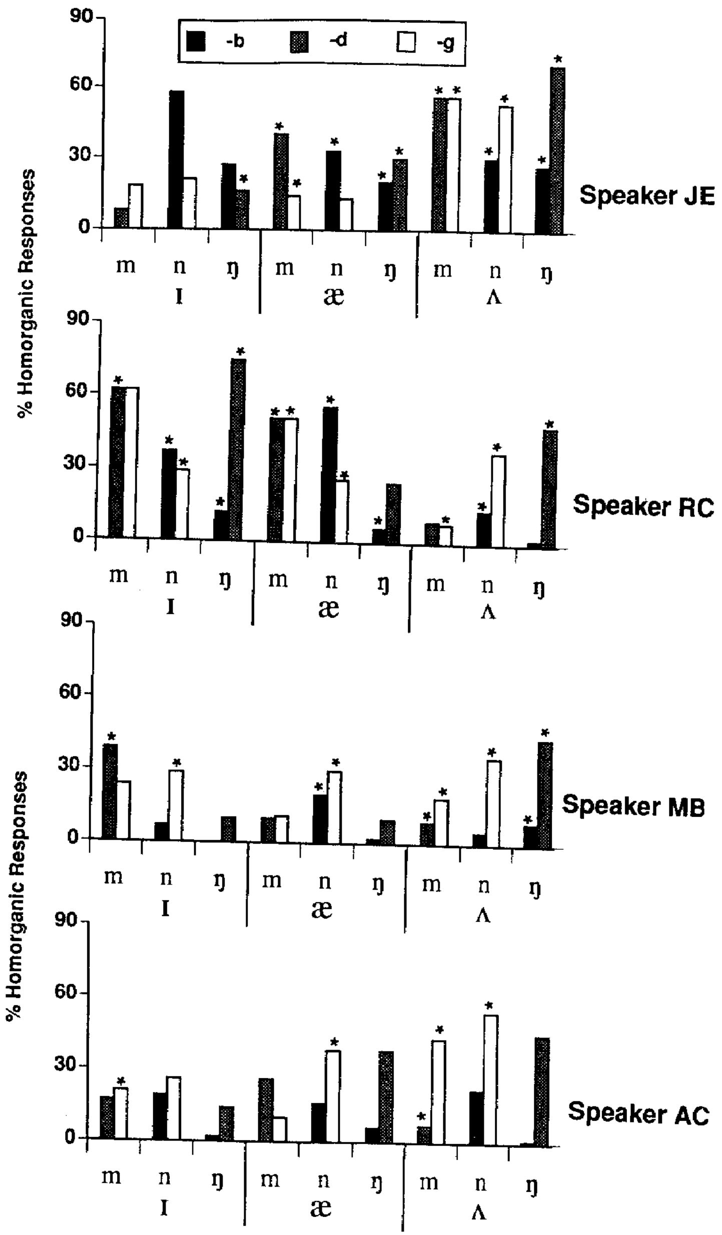

Figure 3. Experiment 1: Averaged homorganic responses of listeners to heterorganic clusters cross-spliced from the original tokens of 4 speakers: JE, RC, MB, and AC. Each column representes percent homorganic responses to a given VNC string, where V is [ɪ], [æ], or [ʌ]; N is [m], [n], or [ŋ]; and C is [b], [d], or [g] (black, grey, and white columns, respectively). Responses in which the oral stop was misidentified were excluded

the complexity of the stimulus increases. An alternative explanation, however, was that the increase in overall error rates is an artifact of the methodology employed here. As the N# condition required subjects to identify only one consonant, and the NC condition required that they identify two consonants in a relatively short period of time, it is possible that the difference between the N# and the NC conditions reflects at least in part the increased difficulty of the task in the NC condition.

To address this possibility, a second experiment was conducted in which listeners were asked to identify only the nasal, rather than both consonants, in the NC condition. This makes the listener's task in the NC and N# conditions more similar, and reduces the likelihood of a methodological source of any differences in results between the two conditions.

3. Experiment 2

3.1. Method

3.1.1. Stimulus materials and procedure

The stimulus materials and procedure used in Experiment 2 were identical to those used in Experiment 1, except for the instructions for the NC condition, which asked listeners to identify only the nasal in [zVNCə] stimuli. Moreover, the additional tasks from Experiment 1 (but not reported in this study) were not replicated, reducing the testing time of Experiment 2 to a single one-hour session.

3.1.2. Subjects

Ten native speakers of English participated in the study. Subjects were undergraduate students in introductory linguistic courses or were otherwise affiliated with the linguistics community at the University of Michigan.

3.2. Results

In the N# condition, mean correct identification was 91%. As in Experiment 1, nasals in absolute final position were reliably, but not perfectly, identified. In the NC condition, mean correct identification was 58%: 89% for homorganic stimuli and 42% correct for heterorganic stimuli. Thus, consistent with expectations, identification of nasals in homorganic clusters improved in Experiment 2 relative to Experiment 1. But, contrary to expectations, identification of nasals in heterorganic clusters was poorer in Experiment 2 than in Experiment 1.

The improved performance on the homorganic clusters resulted in a non-significant difference between the N# and homorganic NC conditions in Experiment 2. A three-way repeated measures analysis of variance on number of correct identifications with factors Nasal Place ([m], [n], [ŋ]), Speaker (JE, RC, MB), and Context (N#, homorganic NC) revealed a main effect of Speaker, $F(2, 18) = 3.91$, $p < 0.05$, but not of Nasal Place or Context.[3] There was a significant Nasal-Context interaction, $F(2, 18) = 13.22$, $p < 0.001$, reflecting a tendency for the addition of homorganic stops to influence identification of bilabial and alveolar nasals more than that of velar nasals; and a significant Nasal-Speaker-Context interaction, $F(4, 36) = 2.96$, $p < 0.05$, reflecting in part the relatively weak influence of context on the bilabial and alveolar nasals of Speaker JE.

Identification of nasals in heterorganic clusters, however, was significantly poorer than that of nasals in either absolute final position or homorganic clusters. A three-way repeated measures analysis of variance where Context was N# vs. heterorganic NC (and Speakers were JE, RC, MB) revealed an effect of Context, $F(1, 9) = 69.96$, $p < 0.001$ and Nasal Place, $F(2, 18) = 3.84$, $p < 0.05$. There were significant interactions between Context and Speaker, $F(2, 18) = 18.22$, $p < 0.001$ (Speaker RC's tokens showing a stronger effect of context than those of the other speakers) and between Context and Nasal Place, $F(2, 18) = 13.63$, $p < 0.001$ (the bilabial nasal exhibiting a particularly strong context effect). When the Context factor was heterorganic NC vs. homorganic NC (and Speakers were JE, RE, AC, MB), the analysis again showed a strong main effect of Context, $F(1, 9) = 80.27$, $p < 0.001$. There were also significant interactions between Context and Speaker, $F(3, 27) = 18.80$, $p < 0.001$, and Context and Nasal Place, $F(2, 18) = 7.62$, $p < 0.01$, with the source of these interactions being the same as in the previous analysis (i.e. Speaker RC's tokens and the bilabial nasal showed particularly strong effects of context).

To determine the source of the relatively high rate of nasal misidentifications in heterorganic clusters, the percentage of each response type (correct, homorganic, or other) is shown in Fig. 4. For four of the six cluster types, homorganic responses were the most frequent. This is unlike the results of Experiment 1, where correct responses predominated for all six clusters (compare Fig. 1). In both experiments, however, the [ŋb] cluster was the least likely to exhibit homorganic responses. Overall, the mean rate of homorganic (i.e. assimilatory) responses in Experiment 2 was 54% (compared to 27% in Experiment 1).

As in Experiment 1, the results of Experiment 2 exhibit response biases. These are factored out in Fig. 5, which shows change in the percent correct, homorganic, and 'other' responses to the heterorganic NC condition relative to the N# condition (see description of Figure 2

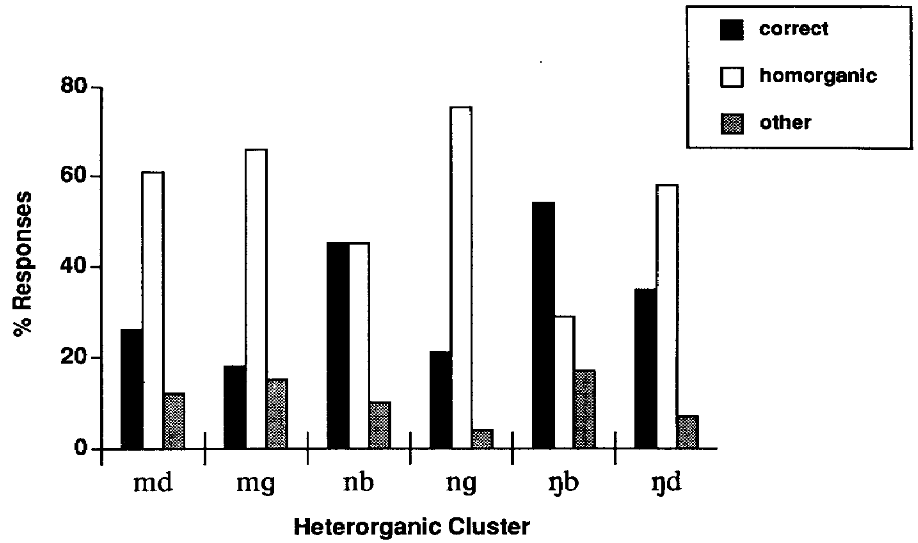

Figure 4. Experiment 2: Pooled responses to cross-spliced heterorganic NC clusters

above). We see here a more robust version of the pattern found in Experiment 1: compared to nasals in absolute final position, nasals in heterorganic clusters are more likely to be misidentified. Moreover, errors are due primarily to an increase in homorganic responses and not to a random increase in misidentifications.

There was once again considerable variation in responses to tokens produced by different speakers. Figure 6 shows the rate of homorganic responses to heterorganic stimuli for each speaker's tokens broken down by vowel, place of nasal, and place of stop. While the actual response rates differ, most of the general patterns observable in Experiment 1 are visible in Fig. 6. The speakers whose tokens yielded the highest number of significant conditions in Experiment 1 continued to yield the highest number, and, for the most part, those combinations of vowel, nasal, and oral stop that yielded unusually high or low percent homorganic responses continued to do so.

3.3. Discussion

Experiment 2 served in part as a replication of the N# condition tested in Experiment 1. In that condition, accuracy of identification was better in Experiment 2, although not markedly so (91% correct compared to 82% in Experiment 1).

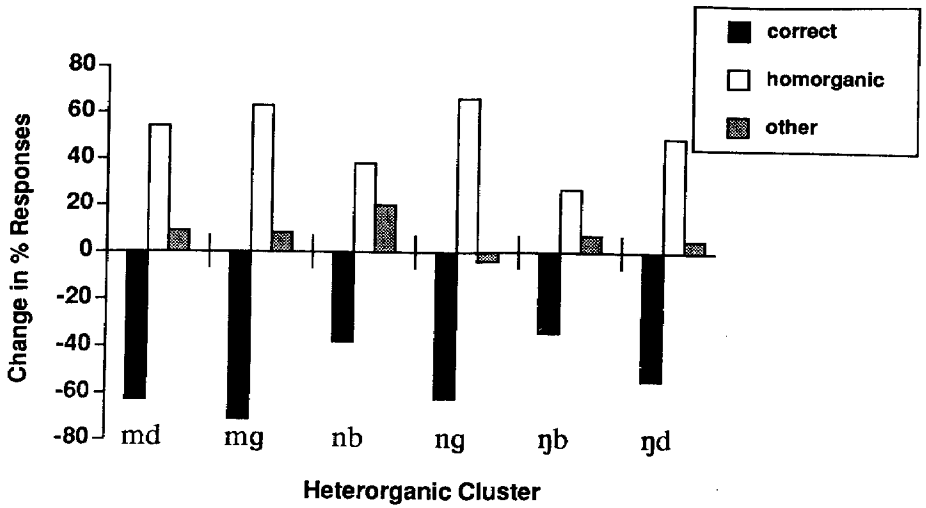

Figure 5. Experiment 2: Change in the type of nasal response between N# and heterorganic NC conditions, averaged across listeners

Experiment 2 was conducted primarily to determine whether the increase in misidentifications from the N# to the NC conditions in Experiment 1 was due to a methodological artifact (listeners being required to supply one response to each stimulus in the N# condition but two responses in the NC condition). Experiment 2, which addressed this issue by requiring only one (nasal) response to both conditions, yielded a surprising result. While we had expected errors on NC clusters to possibly decrease slightly, they increased (from 34% in Experiment 1 to 42% in Experiment 2). More striking, though, was the nature of the difference: errors on homorganic clusters decreased (from 25% to 11%), while errors on heterorganic clusters increased (38% to 58%), with a higher percentage of the heterorganic cluster errors in Experiment 2 being homorganic responses than was the case in Experiment 1.

Clearly, changing the task from identification of two stops to identification of one did not facilitate perception in the way we had anticipated. We speculate that this result may be linked in part to the different number of response alternatives in the two experiments. In Experiment 2, listeners had 3 alternatives (/m/, /n/, /ŋ/) and even listeners with high rates of perceptual assimilation would have used all 3 roughly equally. In Experiment 1, listeners had 9 alternatives (3 nasals x 3 oral stops); listeners with extremely high rates of assimilation would have used only 3 of these (/mb/, /nd/, /ŋg/). If listeners in Experiment 1 assumed

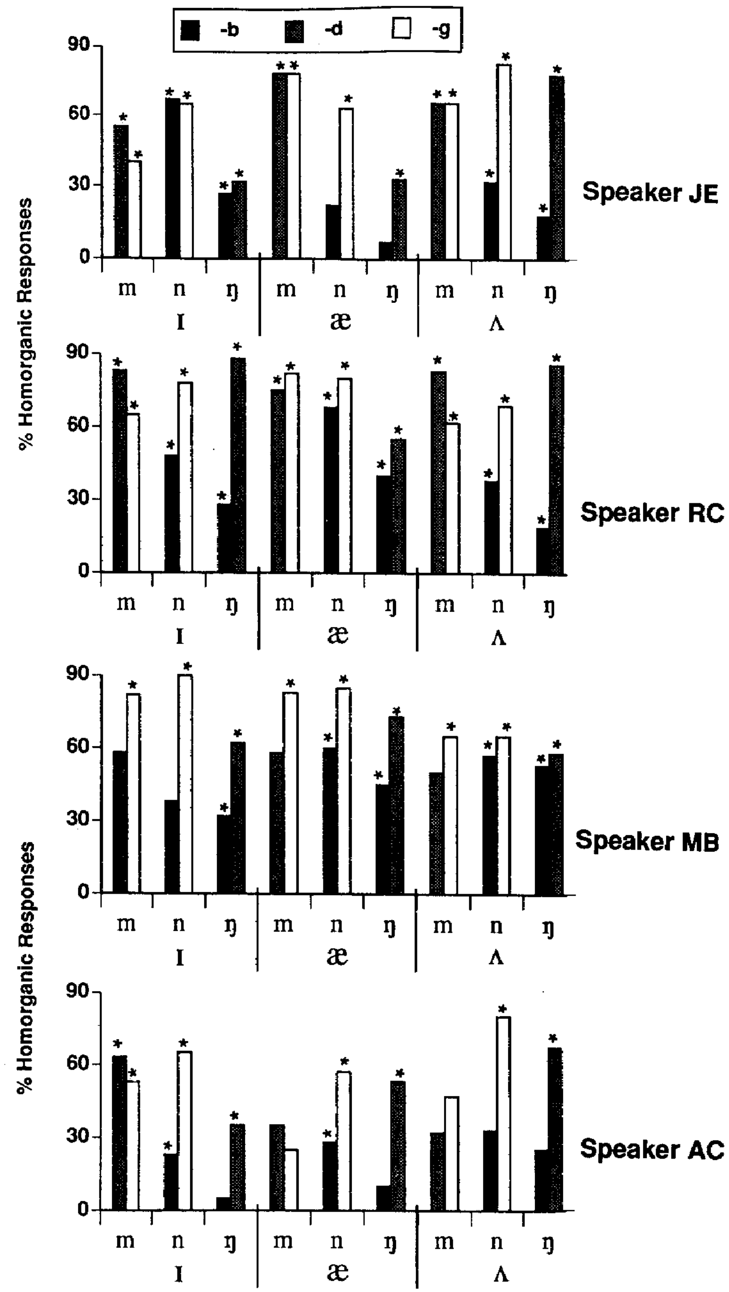

Figure 6. Experiment 2: Averaged homorganic responses of listeners to heterorganic clusters cross-spliced from the original tokens of 4 speakers, JE, RC, MB, and AC

(correctly) that all 9 alternatives occurred with approximately the same frequency, they should have been more likely than Experiment 2 listeners to supply heterorganic responses. Moreover, these heterorganic responses might be expected to occur not only on heterorganic clusters, but also on homorganic clusters. This suggestion is consistent with the relatively high error rate on homorganic clusters in Experiment 1. However, the fact that heterorganic responses were not randomly distributed across homorganic and heterorganic clusters suggests that listeners can succeed more often than not at making this distinction under appropriate testing conditions.

In general, however, the results of Experiment 2 support those of Experiment 1. Indeed, the results of Experiment 2 provide even stronger support of the hypothesis that perceptual factors might underlie phonological assimilations.

4. General Discussion

The results of Experiments 1 and 2 indicate that, overall, place of articulation in syllable-final nasals is not perceptually robust. Identification of place in nasals in absolute final position (N# condition) was less than perfect (85% across the two experiments). This finding is comparable to that of Repp & Svastikula (1988) for syllable-final nasals and contrasts with previous experiments with syllable-initial nasals reporting near-perfect identification scores (e.g. Repp 1986).

Accuracy of identification of syllable-final nasals in consonantal clusters (NC condition) was poorer than in absolute final position. In both experiments, addition of a voiced oral stop (plus [ə]) after the nasal murmur reduced the salience of nasal place information (although this was true only of heterorganic stops in Experiment 2). Moreover, the increase in place errors on nasals in consonantal clusters was due primarily to homorganic cluster responses, in which place cues for the nasal were apparently overridden by place cues for the oral stop.

However, the relative lack of salience of nasal place information and the assimilatory nature of nasal place errors in NC clusters should not be over-stated. Under the experimental conditions used here, nasals assimilated to the place of the following stop 40% of the time (averaged across the two experiments), indicating that in over half of the trials place information for oral stops did not override that for adjacent nasals. This finding falls between the two more extreme sets of data reported in previous studies, the assimilation rate obtained here being several times that obtained by Hura et al. (1992), but less than half that reported by Ohala (1990). We attribute this intermediate status in the error rate to

the intermediate nature of our methodology relative to theirs. The disyllabic stimuli selected here were more similar to those used by Ohala, but the relatively large set of response alternatives was more like that used by Hura et al. The predominantly assimilatory nature of the place errors in the NC condition (especially in Experiment 2) was unlike the more randomly distributed pattern of errors found by Hura et al. and corresponded more closely to Ohala's predictions.

Viewing these results within the acoustic-perceptual theory of place of articulation in nasals outlined in the introduction, we speculate that place information in nasals in the N# condition may have been poorly identified (compared to syllable-initial nasals, as reported in previous studies) due to relatively gradual changes in spectral structure in the transition from the vowel into the syllable-final nasal (Repp & Svastikula 1988; Seitz et al. 1990; Manuel 1991). Relative to the N# condition, perceptual errors presumably increased in heterorganic clusters because the robust place cues for voiced stops dominated the inherently ambiguous cues for nasals. This view is supported by analysis of the individual tokens: in general, the tokens that were most often misidentified in the N# condition were the most likely to assimilate in the NC condition.

5. Implications of the perceptual findings for sound change and synchronic phonological processes

How should the data reported here be interpreted in light of the original hypothesis that historical and synchronic phonological processes involving nasal place assimilation might be the consequence of acoustic-perceptual factors? The method we employed experimentally separated the possible contributions of perception and articulation to place assimilation. Using cross-splicing, the articulation of the nasal consonant was held constant while the context was manipulated. Our assumption was that if contextual manipulations altered perception of the nasal consonant, and misperceptions involved place errors that were homorganic with the following oral stop, then we could conclude that perception alone can induce place assimilations, at least in the laboratory.

The data do not support a strong version of the perceptual hypothesis in which the place of nasals in heterorganic NC clusters are predicted to be *consistently* misidentified. Nasals in heterorganic clusters were identified correctly more often than incorrectly. However, consistent misperception of nasal place should not be *expected* given a closer look at the phonological situation. Many languages do maintain place distinctions in NC clusters, at least under certain conditions (for example, it is not uncommon for languages, such as Russian and Tungusic languages, to show limited assimilation in which only a subset of nasal place distinctions is neutralized in NC clusters). If oral consonant cues for place were completely dominant (or nearly so) in NC sequences, languages which maintain nasal place distinctions in these sequences could not exist.

While not supporting a strong perceptual hypothesis, the data presented here are consistent with a weaker version which holds that nasals in heterorganic clusters have a *tendency* to be misperceived. Place in nasals in NC clusters was found to be perceptually unstable, with the degree of instability depending on speaker-dependent and context-dependent factors. That is, nasals produced by some speakers were markedly more susceptible to perceptual assimilation than those produced by other speakers, especially in certain vocalic contexts (speaking rate may also influence the salience of nasal place information, but the present data do not address this because a comparable rate was used by all four speakers).

Therefore, the experimental data suggest that the potential for misidentification of place in syllable-final nasals is reasonably high, especially in pre-consonantal position, indicating that perceptual factors alone are sufficient to induce assimilation in NC sequences which are unambiguously produced as heterorganic. These perceptual assimilations may in turn result in articulatory assimilations in speaker-listener exchanges: listeners (particularly learners) who have misperceived nasal place may articulate nasal place in the way that they heard it (this view of the articulatory consequences of misperception generally holds for studies which accept that perceptual factors may motivate sound change, and is discussed in detail by Ohala (e.g. 1981)).[4]

Does this view of the possible role of perceptual factors in phonological nasal place assimilations mean that articulation is *not* a factor in these assimilations? Not at all. Having tested only the contribution of perception, we cannot address the possibility of an articulatory component (although this also could be tested in the laboratory setting). Perceptual and articulatory factors may of course interact as an impetus to phonological place assimilations. A possible disadvantage of this view is that multiple phonetic explanations for phonological phenomena have been interpreted as a failure of phonetic accounts to isolate the motivating factor. Rischel (1991:251) noted that, in general, current applications of phonetic models to phonological structures allow for "too many degrees of freedom". However, certain phonological phenomena probably are the consequence of multiple phonetic factors. Indeed, in

light of the striking cross-linguistic frequency of place assimilation of nasals in NC sequences, it is tempting to suggest that sound change might be especially likely to occur under conditions in which the outcomes of perception and articulation (assuming 'an ease of articulation' factor in which one place of articulation is less complex than two) are compatible rather than in conflict.

Regardless of the possible contribution of articulatory factors to phonological place assimilations, of importance here is that available articulatory and perceptual data differ in the extent to which they predict the particular phonological patterns noted in the introduction. Current articulatory models fail to provide an account of the greater likelihood of syllable-final (over syllable-initial) consonants to assimilate place in consonantal clusters and the frequency of nasal place assimilations in languages of the world. On the other hand, the perceptual data reported here show that place in syllable-final nasals is perceptually unstable, especially in the context of conflicting place cues for an adjacent oral stop. If the hypothesis that crucial information for perception of consonantal place is encoded by relative spectral change over time is correct, then this perceptual instability may be attributed, at least in part, to the relative gradualness of spectral change in vowel-nasal consonant sequences. Further support for this account should, of course, be sought by testing additional sequence types. Most importantly, this account predicts that nasals in VCNV sequences should be less likely to be misperceived, and more resistant to assimilation, than nasals in the VNCV sequences tested here.

As just seen, the hypothesis that certain phonological patterns involving nasal place assimilations may be due in part to perceptual factors leads to predictions that can be tested in the speech perception laboratory. The reverse also holds. That is, if this account of perceptual factors underlying phonological place assimilations is on the right track, we should not only be able to use the 'relative spectral change over time' model of place perception as a post hoc account of observed phonological patterns, but also to generate a set of *predictions* concerning phonological structure. For example, we have focused here on the greater tendency of nasals to assimilate in NC than in CN clusters. But the model of place perception assumed here predicts that while nasal place information in VCNV sequences should be relatively robust (due to relatively rapid spectral change in the region of the nasal release into the vowel), such information should be less robust in VCN# sequences (i.e. with a final syllabic nasal). We would therefore expect that nasal place assimilations *should* occur in *final* CN sequences. The frequency of such assimilations is difficult to determine, as CN sequences are less common in final position than in medial position in the world's languages. There are examples, however: English, German, and Yiddish show assimilation of final syllabic nasals to the place of a preceding stop (e.g., English *happen* [hæpm̩]; German *haben* [habm̩] 'to have').

A second, more speculative prediction derived from the spectral change model of place perception concerns the possible relation between degree of vowel nasalization due to an adjacent nasal consonant and nasal place assimilation. Repp & Svastikula (1988) suggested that spectral change was less pronounced in VN than in NV sequences in part because of greater anticipatory vowel nasalization in English (see Manuel 1991, for a similar suggestion). If so, then languages with heavy perseverative vowel nasalization, such as languages with extensive nasal prosody, should exhibit poorly demarcated spectral changes in NV sequences. This acoustic situation should give rise to relatively non-salient nasal place cues in NV sequences and in turn might result in phonological place assimilations in VCNV sequences in languages with heavy perseverative nasalization. This prediction is extremely speculative, however, and has not been phonologically investigated. Our main point here is not so much the correctness of the claim but the bi-directionality of this approach: cross-linguistically recurring phonological patterns lead to certain phonetic predictions, but in turn phonetic models may give rise to well-defined phonological predictions (see Beddor 1991 for further discussion).

The limitations of this general approach are also noteworthy. One qualification is that the actual values obtained in the speech perception laboratory – in this case, the perceptual error rates for syllable-final nasals – cannot be taken as indicative of the extent to which speech sounds will be misperceived in natural language settings. On the one hand, misperceptions might be expected to be more common in natural settings, as the typically noise-free listening conditions of the laboratory would not be met. On the other hand, misperceptions might be less likely to occur as the discourse situation should provide information not available in the nonsense utterances often used in the laboratory (here again, whether or not the listener is a language learner enters into the picture). Furthermore, we would expect these values to change depending on the native language of the listener. For example, the error rates in heterorganic clusters would be expected to increase if the listeners' native language allowed only homorganic nasal-stop clusters, but to decrease if their native language consistently maintained nasal place distinctions in consonantal clusters. Consequently, these experimental perceptual findings simply point toward the *potential* for misperception in natural language settings.

A more important limitation of this approach is that our perceptual findings, together with the spectral change theory of place perception,

are not deterministic. In a now-classic study, Weinreich et al. (1968:102) proposed that an account of language change should be able to address the question: "Why do changes in a structural feature take place in a particular language at a given time, but not in other languages with the same feature, or in the same language at other times?". The acoustic-perceptual hypothesis offered here fails to answer this question. To borrow Ohala's (1987) terminology, the present account identifies the 'preconditions' for, but not the 'immediate triggers' of, sound change. This is not to say that the factors which trigger a sound change at a particular point in time in a particular language can never be identified, but rather that these factors will be at least in part, if not largely, non-phonetic.

6. *Summary and conclusion*

These results show that, under the laboratory conditions employed here, syllable-final nasals in articulatorily unambiguous heterorganic clusters may perceptually assimilate to the place of articulation of a following oral stop. We attributed the relatively weak salience of syllable-final nasal place cues (which are less than perfectly identified even in the absence of conflicting stop place information) to poorly demarcated spectral changes in the transition from the (possibly heavily nasalized) vowel into the nasal murmur. Compatible with the hypothesis that perception of place in orally obstructed consonants (i.e. nasals and oral stops) depends on relative spectral change, it would appear that the abrupt spectral changes at the release of oral stops may perceptually supersede the gradual, less pronounced spectral changes in an adjacent syllable-final nasal. If this interpretation is correct, then syllable-initial nasals should be less likely than syllable-final nasals to undergo perceptual place assimilation, and syllable-final non-nasals (e.g. oral stops) should also be less likely than syllable-final nasals to perceptually assimilate to an adjacent consonant (see Hura et al. 1992 for some experimental evidence in support of the latter claim).

The perceptual findings are consistent with the phonological patterns discussed here, specifically the striking frequency with which syllable-final nasals assimilate to the place of a following oral stop. While the possibility of a complementary role of articulatory factors in phonological place assimilations cannot be discounted, such factors appear unable to account for systematic asymmetries in phonological assimilations (Blumstein 1983; Kohler 1990; Ohala 1990; Manuel 1991; and Hura et al. 1992; among others, have also noted the limitations of articulatory explanations for assimilatory processes). In comparison, the strength of the particular perceptual account presented here lies in the specific predictions generated by spectral change models of place perception concerning the relative salience of place information, and the close link between the predictions which have been tested to date with the specific patterns of assimilation found in languages of the world.

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Notes

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1 In general, no systematic distinction will be made here between historical sound changes involving place assimilation and synchronic allophonic or morphophonemic assimilatory processes. Following Greenberg (1966) and Labov (1974), among others, it is assumed that the processes observable in currently spoken sound systems operated to produce the historical record.

2 Two qualifications should be noted here. First, as there are languages in which nasals are the only consonant which can appear in syllable-final position (see Beddor 1982 for examples), some languages allow VNCV (where N = nasal consonant and C = oral consonant) but not VCNV clusters. This restriction may contribute to the high frequency of nasal assimilations to a following consonant. Second, in a small number of the languages listed, nasals also assimilate to the place of a preceding consonant (e.g. German, Yiddish). However, as discussed below, in at least some cases there appear to be interesting restrictions on this direction of assimilation.

3 Due to a mechanical problem in one of the testing sessions, only a subset of listeners' responses was available for the tokens of Speaker AC in the N# condition. For this reason, statistical tests which involved this condition were performed on the data for three rather than four speakers.

4 The systematic incorporation of individual misperceptions / misarticulations into the phonological structure of a language – and hence the progression from 'sporadic error' to 'sound change' – is primarily a sociolinguistic issue and not a phonetic one.

References

ANDERSON J.M. & C. JONES, eds. (1974), *Historical Linguistics II: Theory and Description in Phonology*, Amsterdam, North Holland.

BEDDOR P.S. (1982), "Phonological and phonetic effects of nasalization on vowel height", Doctoral dissertation, University of Minnesota, Minneapolis (reproduced by Indiana University Linguistics Club, 1983).

BEDDOR P.S. (1991), "Predicting the structure of phonological systems", *Phonetica* 48:83-107.

BELL-BERTI F. (1993), "Understanding velic motor control: studies of segmental context", in HUFFMAN & KRAKOW (1993:63-85).

BLUMSTEIN S.E. (1986), "On acoustic invariance in speech", in PERKELL & KLATT (1986:178-193).

CHOMSKY N. & M. HALLE (1968), *The Sound Pattern of English*, New York, Harper and Row.

DRESSLER W.U., H.C. LUSCHÜTZKY, O.E. PFEIFFER & J.R. RENNISON, eds. (1987), *Phonologica 1984*, Cambridge, Cambridge University Press.

FUJIMURA O., J.E. MILLER & S. KIRITANI (1977), "A computer-controlled X-ray microbeam study of articulatory characteristics of nasal consonants in English and Japanese", Paper presented at the 9th International Congress on Acoustics, Madrid, Spain.

GREENBERG J.H. (1966), "Synchronic and diachronic universals in phonology", *Language* 42:508-517.

HARDCASTLE W.J. & A. MARCHAL, eds. (1990), *Speech Production and Speech Modelling*, Dordrecht, Kluwer Publishers.

HARMS R. (1973), "Some non-rules of English", Bloomington, IN, Indiana University Linguistics Club (also in JAZAYERY, POLOMÉ, & WINTER (1974)).

HAWKINS P. (1984), *Introducing Phonology*, London, Hutchinson.

HEILMANN L., ed. (1974), *Proceedings of the 11th International Congress of Linguists*, Bologna, Società Editrice Il Mulino.

HILL A. (1936), "Phonetic and phonemic change", *Language* 12:15-22.

HUFFMAN M.K. & R.A. KRAKOW, eds. (1993), *Nasals, Nasalization, and the Velum*, Orlando, FL, Academic Press.

HURA S.L., B. LINDBLOM & R.L. DIEHL (1992), "On the role of perception in shaping phonological assimilation rules", *Language and Speech* 35:59-72.

HYMAN L.M. (1975), *Phonology: Theory and Analysis*, Chicago, Holt, Rinehart and Winston.

JAKOBSON R. (1941), *Kindersprache, Aphasie und Allgemeine Lautgesetze*, Uppsala, Almquist and Wiksell.

JAZAYERY M., E.C. POLOMÉ & W. WINTER, eds. (1974), *Linguistic and Literary Studies in Honor of A.A. Hill*, The Hague, Mouton.

JESPERSEN O. (1922), *Language: Its Nature, Development and Origin*, London, G. Allen and Unwin.

KATAMBA F. (1989), *An Introduction to Phonology*, New York, Longman.

KEWLEY-PORT D. (1983), "Time varying features as correlates of place of articulation in stop consonants", *Journal of the Acoustical Society of America* 73:322-335.

KINGSTON J. & M. BECKMAN, eds. (1990), *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*, Cambridge, UK, Cambridge University Press.

KOHLER K. (1990), "Segmental reduction in connected speech: phonological facts and phonetic explanations", in HARDCASTLE & MARCHAL (1990:69-92).

KRAKOW R.A. (1989), "The articulatory organization of syllables: a kinematic analysis of labial and velar gestures", Doctoral dissertation, Yale University, New Haven, CT.

KUEHN D.P. (1976), "A cineradiographic investigation of velar movement variables in two normals", *Cleft Palate Journal* 13:88-103.

KUEHN D.P. & K.L. MOLL (1976), "A cineradiographic study of VC and CV articulatory velocities", *Journal of Phonetics* 4:303-320.

KUROWSKI K.M. & S.E. BLUMSTEIN (1987), "Acoustic properties for place of articulation in nasal consonants", *Journal of the Acoustical Society of America* 81:1917-1927.

KUROWSKI K.M. & S.E. BLUMSTEIN (1993), "Acoustic properties for the perception of nasal consonants", in HUFFMAN & KRAKOW (1993:197-222).

LABOV W. (1974), "On the use of the present to explain the past", in HEILMANN (1974:825-51).

LAHIRI A., L. GEWIRTH & S.E. BLUMSTEIN (1984), "A reconsideration of acoustic invariance for place of articulation in diffuse stop consonants: evidence from a cross-language study", *Journal of the Acoustical Society of America* 76:391-404.

LASS R. (1984), *Phonology: An Introduction to Basic Concepts*, Cambridge, Cambridge University Press.

LEHMANN W. & Y. MALKIEL, eds. (1968), *Directions for Historical Linguistics*, Austin, TX, University of Texas Press.

LINDBLOM B. (1990), "Explaining phonetic variation: a sketch of the H&H theory", in HARDCASTLE & MARCHAL (1990:403-439).

MALÉCOT A. (1956), "Acoustic cues for nasal consonants: an experimental study involving tape-splicing technique", *Language* 32:274-284.

MANUEL S.Y. (1991), "Some phonetic bases for the relative malleability of syllable-final versus syllable-initial consonants", *Proceedings of the 12th International Congress of Phonetic Sciences* vol. 5:118-121.

MARTINET A. (1952), "Function, structure, and sound change", *Word* 9:1-32.

MARTINET A. (1955), *Economie des Changements Phonétiques*, Berne, A. Francke.

MASEK C.S., R.A. HENDRICK & M.F. MILLER, eds. (1981), *Papers from the Parasession on Language and Behavior*, Chicago, Chicago Linguistic Society.

MCCARTHY J.J. (1988), "Feature geometry and dependency: a review", *Phonetica* 43:84-108.

MOHR B. & S.-Y. WANG (1968), "Perceptual distance and the specification of phonological features", *Phonetica* 18:31-45.

NELSON W.L., J.S. PERKELL & J.R. WESTBURY (1984), "Mandible movements during increasingly rapid articulations of single syllables: preliminary observations", *Journal of the Acoustical Society of America* 75:945-951.

OHALA J.J. (1971), "Monitoring soft palate movements in speech", *Project on Linguistic Analysis* (University of California, Berkeley) 13:JO1-JO15.

OHALA J.J. (1974), "Experimental historical phonology", in ANDERSON & JONES (1974:353-387).

OHALA J.J. (1981), "The listener as a source of sound change", in MASEK, HENDRICK, & MILLER (1981:178-203).

OHALA J.J. (1987), "Explanation in phonology: opinions and examples", in DRESSLER, LUSCHÜTZKY, PFEIFFER, & RENNISON (1987:215-225).

OHALA J.J. (1990), "The phonetics and phonology of aspects of assimilation", in KINGSTON & BECKMAN (1990:258-275).

OHALA J.J. & M. OHALA (1993), "The phonetics of nasal phonology: theorems and data", in HUFFMAN & KRAKOW (1993:225-249).

PAUL H. (1886), *Prinzipien der Sprachgeschichte*, 2nd edition, Halle, M. Niemayer.

PERKELL J.S. & D.H. KLATT, eds. (1986), *Invariance and Variability in Speech Processes*, Hillsdale, NJ, Lawrence Erlbaum Associates.

REPP B.H. (1977), "Perceptual integration and differentiation of spectral information across intervocalic stop closure intervals", *Haskins Laboratories Status Report on Speech Research* 51-52:131-138.

REPP B.H. (1986), "Perception of the [m]-[n] distinction in CV syllables", *Journal of the Acoustical Society of America* 79:1987-1999.

REPP B.H. & K. SVASTIKULA (1988), "Perception of the [m]-[n] distinction in VC syllables", *Journal of the Acoustical Society of America* 83:237-247.

RISCHEL J. (1991), "The relevance of phonetics for phonology: a commentary", *Phonetica* 48:233-262.

SEITZ P., M. MCCORMICK, I. WATSON & R.A. BLADON (1990), "Relational spectral features for place of articulation in nasal consonants", *Journal of the Acoustical Society of America* 87:351-358.

Sloat C., S.H. Taylor & J.E. Hoard (1978), *Introduction to Phonology*, Englewood Cliffs, NJ, Prentice-Hall.

Sweet H. (1888), *History of English Sounds*, Oxford, Oxford University Press.

Verner K. (1877), "Eine Ausnahme der Ersten Lautvershiebung", *Zeitschrift für Vergleichende Sprachforschung* 23:97-130.

Weinrich U., W. Labov & M. Herzog (1968), "Empirical foundations for a theory of language change", in Lehmann & Malkiel (1968:97-195).

Whitney W. (1867), *Language, and the Study of Language*, New York, C. Scribner.