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CONNECTIONS BETWEEN NASALITY AND VOWEL DURATION AND HEIGHT: ELUCIDATION OF THE EASTERN ALGONQUIAN INTRUSIVE NASAL

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In certain Eastern Algonquian languages a nasal vowel developed from the long low vowel /a:/, regardless of consonantal context. A series of experiments showed that longer vowels (regardless of height) were perceived as more nasalized than shorter ones, but only when some nasalization was actually present. Further experiments showed no evidence of an increase in nasalization for long vowels in oral contexts. If some nasalization was nonetheless introduced (either randomly or by a general increase in nasalization) into these languages, the vowels most likely to be perceived as nasalized were the long ones. This perceptual process may have been responsible for this unusual historical development.*

Introduction

1. Sound change has long been recognized to be constrained by the physical mechanisms of human speech production and the reorganization imposed by the perceptual system (Whitney 1867, Verner 1877, Passy 1890, Paul 1891, Jespersen 1921). While earlier discussions often devolved into undecidable questions of what constitutes a 'natural' evolution, recent applications of experimental evidence have proved fruitful (e.g. Ohala 1974, 1981, 1983, Chen & Wang 1975, Hombert et al. 1979, Labov 1981, Janson 1983, Beddor et al. 1986). Even though it is not possible to examine the various stages of languages as they evolve, the behavior of modern listeners can often provide a rationale for changes whose detailed articulations and acoustics are lost to us. While some proposed avenues for change are unintuitive, the phonetic motivation behind other sound changes is uncontroversial. One such case is the development of distinctively nasalized vowels, which have almost universally evolved from sequences of oral vowels and nasal consonants. The physiological basis of this change is evident: crosslinguistic studies using a variety of techniques (e.g. Clumeck 1976, Henderson 1984) have shown that the opening movement of the velum necessarily overlaps the articulatory configuration of the neighboring vowel(s), though the extent of the overlap is determined by a variety of factors, including rate, vowel quality, and syllable structure. The large number of languages that lose a nasal consonant distinction (in certain environments) only to replace it with distinctive vowel nasalization indicates that this overlap can be perceived and then exploited by language users (Kawasaki 1986). That is, the distinction becomes one in which the velar port is

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deliberately open throughout the vowel, rather than being linked to the consonant closure.

This development is so frequently the source of distinctively nasalized vowels that it has, in the past, been claimed to be their only source (Ruhlen 1978). However, at least a few well-established counterexamples exist. In Iroquoian languages, for example, distinctive vowel nasalization apparently arose from earlier sequences of vowels and glides (Lounsbury 1953:15, Williams 1976, Dahl 1980). Ohala 1974 and Matisoff 1975 have observed that (allophonic) vowel nasalization can be conditioned by glottal and pharyngeal consonants, as in Thai, Lao, Lahu, Lisu, and various Semitic languages. Some other instances can be attributed to the presence of affricates, aspirates, or fricatives (Ohala 1980:88–89, 1987:220–21). A final example, and the focus of this paper, is the development in some of the Eastern Algonquian languages of a distinctively nasalized vowel from a long oral vowel (Goddard 1965, 1971)—that is, nasalization without ANY consonantal conditioning. Through a series of experiments, we will examine the link between nasality and vowel duration and quality. We will then use the results to provide a rationale for the Eastern Algonquian[1] change and to highlight secondary effects in the more typical cases of nasal vowel development, where the presence of a nasal consonant is the primary factor.

THE EASTERN ALGONQUIAN CHANGE

2. The Eastern Algonquian (EA) languages form a subgroup in Algonquian, as seen in a number of shared morphological innovations, a complex treatment of final vowels, and, most importantly for the present work, a reshaping of the vowel system (Goddard 1971, 1979:96–102). The Proto-Algonquian (PA) vowel system had four long and four short vowels, */i: e: a: o: i e a o/, but the length contrast was restructued in Proto-Eastern-Algonquian (PEA, the ancestor of the Algonquian languages formerly spoken from Nova Scotia to North Carolina). Two short vowels (**i* and **o*) generally merged with the corresponding long vowels (**i:* and **o:*), a change that eliminated distinctiveness for relatively few lexical items (Goddard 1979:112, n. 23). Also, PA **e* became PEA **ə*, leaving a six-vowel system */i: e: a: o: ə a/ with only one vowel (**a*) having the same quality in both long and short versions. In western EA languages, **e:* subsequently shifted to /a:/. In these languages (along with some dialects of Eastern Abenaki),**a:* became nasal, thereby maintaining the distinction between the vowels (Goddard 1965, 1971). This nasalization was, in at least some of the languages, accompanied by a quality shift to ɔ (a fairly common shift for ã; cf. Beddor 1982). This system, still with two short vowels and four long vowels, one of which is nasal, is that of Massachusett (Goddard 1981). In other languages (e.g. Western Abenaki) there was a further loss of the length distinction, with short oral /a/ and long oral /a:/ collapsing.

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[1] We will refer to this as the Eastern Algonquian change, although not all EA languages were affected.

The nasalization of **a:* took place in all contexts, regardless of the presence or absence of adjacent nasal consonants. For example, PA **šeka:kwa* 'skunk' > W. Abenaki /sək5kw/ (compare Cree [Central Algonquian] /sika:k/). Similarly, PA **aθa:m* 'underneath' > W. Abenaki /al5m-/ (Cree /ata:m-/). The earlier descriptions of this change (Geary 1945, Silver 1960) mentioned only the environment before stop consonants. The fact that this was not a nasal consonant environment was so unexpected that Haas 1963 was led to posit a PA nasal element whose main reflex was the EA intrusive nasal vowel. However, the distribution of this nasal element is highly restricted, occurring only after /a:/ and before stops (cf. Haas 1966:103–104, n. 17). The later work of Goddard 1965, 1971 showed that environments before segments other than stops occurred in more than half of the forms. Further, the loss of a nasal element happens not to be a likely source of nasal vowels for these languages, since in all of them the nasal consonant of original NC clusters was generally lost (Goddard 1971:130–31), and this loss did not give rise to a series of nasal vowels. The motivation for the nasalization therefore remains a puzzle. Our intent is to find evidence in modern language users that this change is not, in fact, arbitrary.

EXPLANATIONS TO BE TESTED

3. The EA change could have been due to internal or to external causes. An internal motivation for the change may have been the shift from **e:* to /a:/. If this shift were the original change, then **a:* may have changed simultaneously, to avoid merger. But this would not be a sufficient explanation for the result, as we still need to explain the nasalization of the shifted vowel. Whether the change of the PEA **e:* to /a:/ was the cause, the result, or an unrelated change, the nasalization of **a:* still needs its own motivation. The most likely phonetic motivations for this nasalization are (1) a tendency for long vowels to be perceived as more nasalized than short ones, and (2) a tendency for long vowels to be produced with greater nasalization. These, of course, are not mutually exclusive, though they are distinct. These factors can be tested more or less directly, as will be seen in §4 and §5.

The most promising nonphonetic source of this change would be diffusion from neighboring languages with nasal vowels. The possible areal feature is 'hard to consider irrelevant' (Goddard 1971:140), since those EA languages which developed the nasal vowel bordered on Iroquois languages, which have two nasalized vowels each. However, as we will show in §6, there is insufficient sociolinguistic evidence to permit a definite establishment of diffusion from Iroquois to EA.

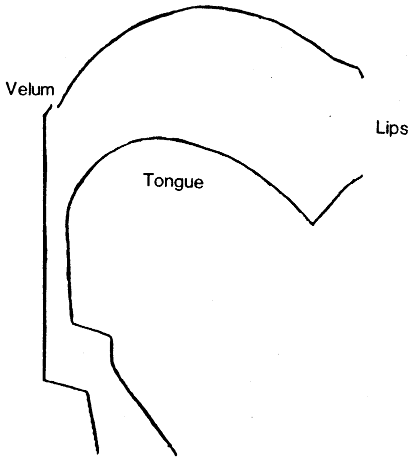
Our first six experiments will show that there is a perceptual link between duration and nasality, though with important restrictions. The last two experiments will show that it is not universally necessary for there to be more nasalization in long vowels than in short ones and, more tentatively, that an increase may not even be preferred. This raises a paradox which may be resolved by the areal feature.

ARE LONGER VOWELS PERCEIVED AS MORE NASALIZED?

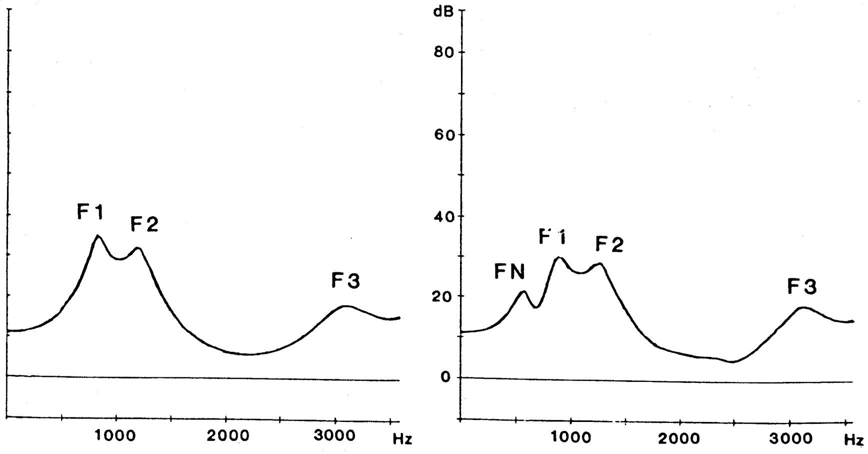
4. The phonological literature contains numerous references to the fact that nasal vowels are longer in duration than their oral counterparts. Although this difference is generally attributed to lengthening of the nasal vowel as compensation for nasal consonant loss (Delattre 1954, Straka 1955, Ruhlen 1978), some phonologists have suggested that vowel lengthening may be a direct phonetic manifestation of nasalization (Foley 1975, de Chene & Anderson 1979). Such correlations between two phonetic properties can usually be manipulated experimentally, so that the correlated property can affect the perception of an ambiguous segment (see Repp 1983 for a review). Thus, if nasalization and vowel duration are phonetically correlated, we would then expect—in appropriate circumstances—that longer vowels would sound more nasalized than shorter vowels. Such a perceptual equivalence is amenable to a direct test.

The first test of the influence of length on nasality was conducted by Delattre & Monnot 1968. Using the Pattern Playback hardware speech synthesizer, they created a syllable /lɛd/ whose vowel was intermediate between an oral and a nasal vowel in terms of F1 amplitude. (Delattre 1954 had previously found that a reduction in F1 amplitude increased the perceived nasality of a vowel.) They made nine versions of this syllable, differing only in duration, and presented them to both French and American English speakers. The French speakers heard shorter vowels predominantly as oral, while longer vowels were perceived as nasal. However, the English speakers gave almost identical results, with a crossover value in the middle of the range. It is thus not obvious that nasality had been correctly perceived, since the same results would probably have been obtained if subjects had been asked to judge length instead. Our technique included more degrees of nasalization, thus allowing us to find out whether subjects were successfully hearing nasalization itself.

4.1. LONGER SYNTHETIC *a*'S ARE PERCEIVED AS MORE NASALIZED. In order to test for a link between duration and nasality, we had listeners rate vowels of various lengths for nasality. Since shifts in the major resonances for vowels (the formants) are likely to contribute to perceived nasality (cf. Stevens et al. 1987), natural productions seemed too variable. Our strategy for controlling as many facets of the test utterances as possible was to use the articulatory synthesizer of Rubin et al. 1981. With this synthesizer, we could maintain a single position for the oral articulators and generate the complex acoustic consequences of nasalization by the adjustment of a single parameter, velar port opening. Figure 1 shows the schematic vocal tract used by the synthesizer to produce speech. The configuration of tongue, lip, and jaw that is shown produces [a], and is the configuration we used in our experiment. In the figure, the velar port is open 36.0 mm^2, resulting in a perceptually heavily nasalized [ã]. At the bottom right of the figure is the transfer function for this vowel, showing three oral formants (F1, F2, and F3) plus a nasal formant (FN). At the bottom left is the transfer function for this configuration when the velar



SYNTHESIZER VOCAL TRACT



Oral

Most Nasalized

TRANSFER FUNCTIONS

FIGURE 1. Schematic, midsagittal view of the vocal tract shape used by the synthesizer to generate the stimuli (top). The velar port is open 36 square millimeters, which results in the spectral transfer function on the bottom right. The spectral shape on the bottom left results from the same vocal tract shape with the velar port closed.

port is completely closed. The two main differences between these functions are the addition of the nasal formant and slight shift upward of the oral formants (F1 by about 40 Hz, F2 by about 50 Hz) introduced by velar port opening.

We constructed a listening test using the single oral configuration for [a] at five durations (50, 100, 150, 200, and 250 msec) and six degrees of velar port opening (0.0, 7.2, 12.0, 16.8, 24.0, and 36.0 mm^2), ranging from 'oral' to heavily nasalized. (The degrees were those used by Krakow et al. 1988.) Six repetitions of these thirty stimuli were presented in random order to twelve speakers of American English. Although these listeners were not phonetically trained and did not have a native language with distinctive vowel nasalization, none had any difficulty learning to rate these vowels for nasality after a brief familiarization set. This set consisted of twenty presentations of vowels with the middle duration (150 msec) with various velar port openings. Subjects were asked to rate each presentation from 1 ('least nasalized') to 5 ('most nasalized'). We did not label the endpoints 'oral' and 'nasal' since synthetic speech often strikes listeners as nasalized in the best of circumstances, as will be discussed further in §4.4. In the familiarization set, the first five answers were provided on the answer sheet, with '1' corresponding to the 0 mm^2 stimulus and '5' to the 36 mm^2. These first five vowels were drawn from the extremes so they could be given values; subjects assigned their own values to the rest of the familiarization items. After this, any questions the subjects had were answered and the test tape was played. The first of the six repetitions was treated as further warm-up and therefore was not scored for analysis.

Figure 2 shows the average nasality rating for each of the 30 stimuli collapsed across the twelve subjects. There are two major findings. First, the rating goes up as the velar port opening increases. Of the six functions shown, the lowest is the one without any opening, the highest has the most, and the intermediate degrees fall appropriately in between. Port opening, as expected, was a highly significant factor in an analysis of variance ($F(5,55) = 32.68$, $p < .001$).

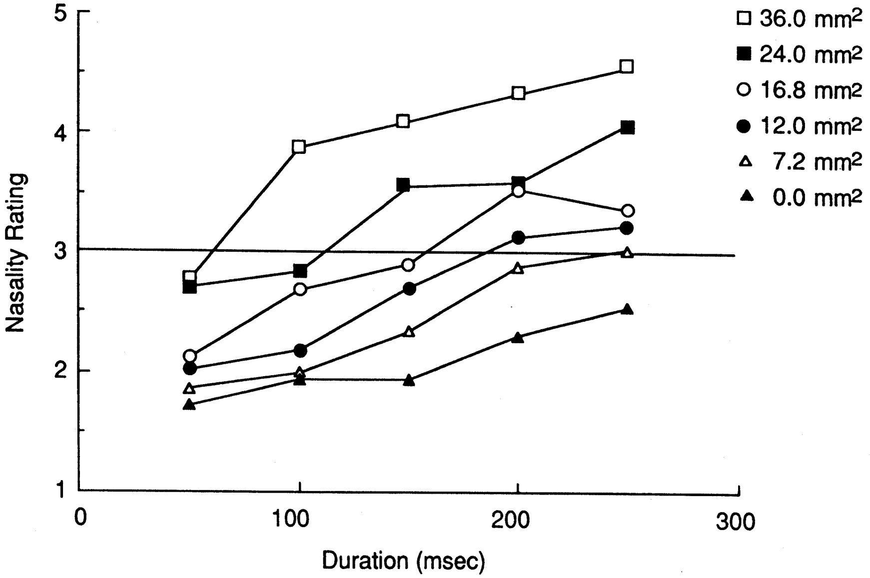


FIGURE 2. Averaged responses of twelve subjects to a synthesized with six degrees of nasalization at five durations. The horizontal line drawn at the value '3' indicates the midpoint of the range, and a conceivable boundary between oral and nasal.

The second major result is that all the functions in Fig. 2 tend upward from left to right. This indicates that the perceived nasality did indeed increase as duration increased. Thus duration, like port opening, was a highly significant factor ($F(4,44) = 9.53$, $p < .001$).

The two factors were not completely independent, however, as indicated by a significant interaction ($F(20,220) = 2.20$, $p < .01$). This seems to be due to the unexpectedly low rating given to the 50-msec duration of the stimulus with the largest port opening. (If we remove the 50-msec duration from the analysis, the interaction disappears.) It is unclear why this extreme effect should occur only with the greatest opening.

Despite their inexperience in judging nasality, our listeners consistently judged longer vowels as more nasalized. These judgments corresponded to actual velar port opening. In fact, if we treat the value '3' as the boundary between oral and nasal (see the horizontal line in Fig. 2), then all but the smallest degree of opening have 'oral' judgments at the short end of the continuum and 'nasal' ones at the long end. These findings suggest that long /aː/ could have been perceived by Algonquian speakers as nasalized while short /a/ was perceived as oral, even without any differences in velar opening.

4.2. THE DURATION LINK IS NOT DUE TO THE HEIGHT, F0, OR AMPLITUDE OF *a*. Having established a link between duration and nasality for *a*, we needed to see if that link occurs only with that vowel. In EA languages, only the low vowel gave rise to the distinctively nasalized vowel. A correlation between low vowels and distinctive nasalization is not uncommon crosslinguistically: low vowels are likely to nasalize before other vowels in the development of nasal vowels (Chen 1973, Ohala 1975, Ruhlen 1978, Hombert 1986; but see also Entenman 1977). This is probably connected with the lower position of the velum found for low vowels (Czermak 1857, Fritzell 1969, Ohala 1971, Henderson 1984). It may be that the height of *a* is responsible for the link between duration and nasalization. Alternatively, other phonetic correlates of *a*, such as its high amplitude or its low fundamental frequency relative to that of other vowels, may influence the perceived nasality of this vowel. We tested each of these correlates separately.

4.2.1. LONGER SYNTHETIC *i*'S AND *u*'S ARE PERCEIVED AS MORE NASAL. The correlation between vowel height and velar height may predispose low vowels towards sounding nasalized, in which case the link between duration and perceived nasality could be restricted to these vowels. To address this possibility, we investigated the perceived nasality of two high vowels.

Again using the articulatory synthesizer, we generated an oral configuration appropriate to [i], and another corresponding to [u]. Each vowel was synthesized at the five durations used in the previous experiments with, in this case, three degrees of velar port opening (0.0, 12.0, and 24.0 mm^2). Given the clear-cut effects found for *a*, we felt we could use fewer values and still obtain the same effect with less strain on our listeners' patience.

Twelve native speakers of English (two of whom had participated in the earlier study) listened to two tapes, one of *i* and one of *u*. Like the previous tape, these tapes consisted of both a familiarization block, again with five answers already entered, and a test block. The same rating scale was used.

The results for *i*, shown in Figure 3, are quite similar to those for *a*. The three degrees of port opening gave different nasality ratings, ranging appropriately from lowest to highest for the smallest to largest openings ($F(2,22) = 4.96$, $p < .05$). Duration affected perceived nasality quite reliably ($F(4,44) = 26.92$, $p < .001$). In this case, there was no hint of an interaction between duration and velar opening ($F(8,88) = 0.54$, n.s.), indicating that the duration effect did not depend on any particular degree of nasalization. As with most of the functions for *a*, each function had values below '3' at the short end and above '3' at the long end.

The results for *u* (Figure 4) are similar in that increasing duration increased the nasality judgment for each degree of velar opening. The three degrees of port opening were, however, less consistently distinguished than they were for *a* and *i*, leading to a nonsignificant effect of velar opening ($F(2,22) = 2.30$, n.s.). Duration, however, affected perceived nasality as with *i* and *a* ($F(4,44) = 10.38$, $p < .001$). There was no interaction of duration with velar opening ($F(8,88) = 1.37$, n.s.). We again see that each function was below '3' at the short end of the continuum and above '3' at the long end.

The results for *i* and *u*[2] are such that we can confidently conclude that the link between duration and perceived nasality found in §4.1 is not a function of vowel height. These results leave us without an answer to the question of why it was that **a*: was the only PEA vowel to nasalize. Before speculating on the effect of the structure of the PEA vowel system or on the possibilities of links in production between low vowels, length, and nasality, we tested two other phonetic correlates of *a* that might have been at work: its low fundamental frequency (F0) and high overall amplitude compared to those of other vowels. The amplitude and F0 differences are only present relative to other vowels in similar environments, since the changes in them due to stress, rate, intonation, etc., are much greater in magnitude than the intrinsic differences. Still, these correlates of *a* are consistent and robust across languages. Thus it is possible that regular, relative correlations could have precipitated the change in PEA **a*: while leaving other vowels untouched.

4.2.2. F0 CHANGES DO NOT AFFECT NASALITY JUDGMENTS IN THIS EXPERIMENTAL PARADIGM. Low vowels are generally accompanied by a relatively low F0 (Crandall 1925, Peterson & Barney 1952), probably due to an effect of jaw position on the position of the larynx and tension of the vocal folds (Honda 1983). It is possible that a low F0 also affects perceived vowel nasality, as suggested by the clinical findings of Hess 1959 (but see Dickson 1962 for some

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[2] The results for *u* are slightly complicated, due to the inconsistent effect of velar opening on perceived nasality. Spectral analysis of our synthetic *u*'s suggests why this was the case: even the largest opening we used did not result in an identifiable nasal formant, and the shifts in the formant values induced by opening were slight. (This negligible effect of velar opening on the *u* spectrum was an artifact of the synthesis parameters used, since natural *u* can be nasalized.) Thus the actual velar opening was not easily recovered by our listeners, though the duration effect was the same as in those cases where the degrees of velar opening were well differentiated.

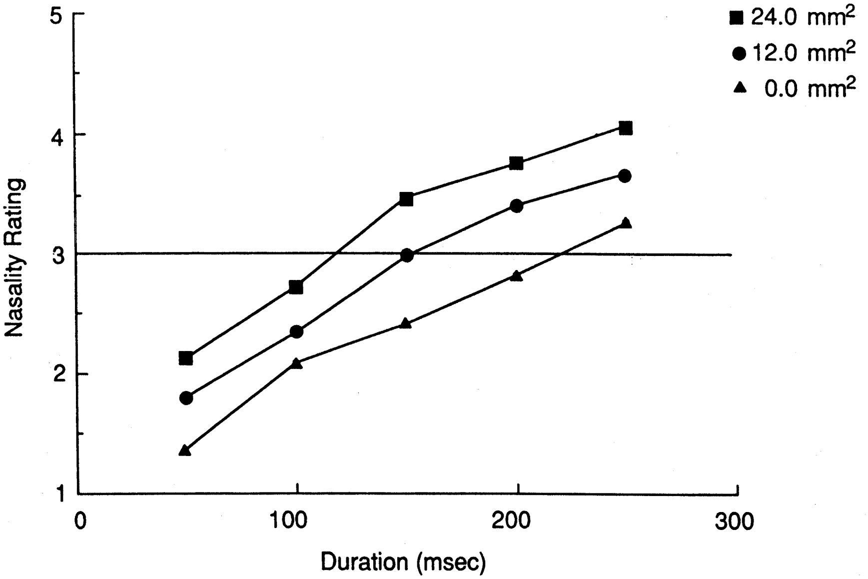

FIGURE 3. Averaged responses of twelve subjects to *i* synthesized with three degrees of nasalization at five durations. The horizontal line drawn at the value '3' indicates the midpoint of the range, and a conceivable boundary between oral and nasal.

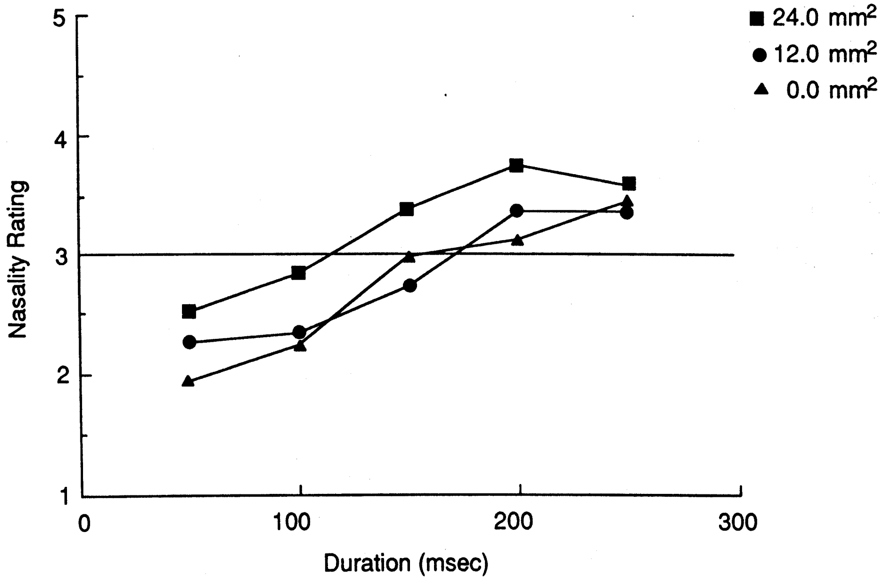

FIGURE 4. Averaged responses of twelve subjects to *u* synthesized with three degrees of nasalization at five durations. The horizontal line drawn at the value '3' indicates the midpoint of the range, and a conceivable boundary between oral and nasal.

reservations). While there is no clear physiological or physical basis for a lowering of F0 with increased velar port opening, our own analysis of Western Abenaki /a/'s in oral vs. nasal consonant contexts (see §5.1) shows, in fact, that this (contextual) nasalization is accompanied by a relatively low F0. However, Di Cristo & Hirst 1986 find a relatively high F0 for French nasal vowels. If perceived nasality is nonetheless enhanced by a relatively low F0, it could help explain why only the long **a:* of PEA nasalized.

The synthetic stimuli involved the oral configuration for [a] used in the first experiment (§4.1). Fifteen versions of this vowel were generated—three degrees of velar port opening, each with five different F0's. The F0 ranged around the original value of 111 Hz in 5-Hz steps (101, 106, 111, 116, and 121 Hz). This range is approximately the same as the 17-Hz difference between the F0 of [ɑ] and [u] reported in Peterson & Barney 1952 for English. Vowel duration was set at 150 msec. Since the synthesizer will only generate complete pitch periods, the resultant stimuli varied in duration from 154 to 163 msec. Based on the results of our previous experiments (especially Fig. 2), we could expect this difference to change the judgments by 0.045 on the nasality scale, an amount unlikely to affect the outcome. The subjects who listened to *i* and *u* also heard this test, which was preceded by its own familiarization block.

The results are shown in Figure 5. The functions for the three degrees of velar opening are distinct for the two lowest values of F0, but not at the higher three. This, plus sizable variability, caused the velar opening factor to miss significance (F(2,22) = 2.88, p < 0.10). Since the points at 111 Hz represent

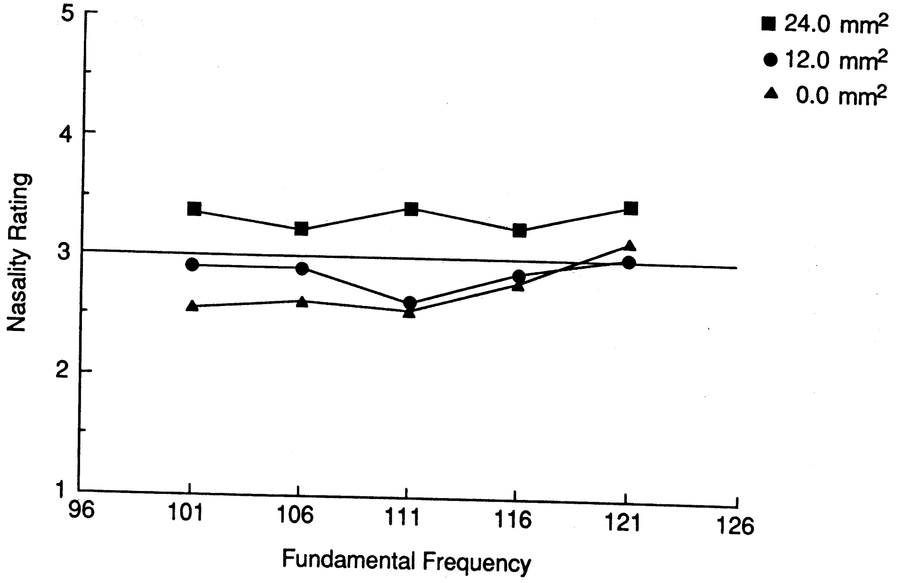

FIGURE 5. Averaged responses of twelve subjects to *a* synthesized with three degrees of nasalization at five values of F0. The horizontal line drawn at the value '3' indicates the midpoint of the range, and a conceivable boundary between oral and nasal.

data where the functions were well separated in the first experiment (Fig. 2), it is not clear why this failure occurred. Further, F0 had no consistent effect on nasality judgments, and there was no interaction between degree of port opening and F0.

While it is not possible to conclude that F0 does not affect perceived nasality, we can contrast the lack of an F0 effect with the presence of a duration effect for the same subjects (with the *i* and *u* stimuli). Since the same number of judgments and the same listeners were involved, we know that, if there is an effect of F0, it must have been obscured by some other factor. Indeed, since we know that subjects from the same population were able to differentiate these same degrees of velar opening for this same vowel and yet the present subjects did not do so reliably, there must have been contradictory information about nasality in the continuum. It could be that with the F0 variation subjects had no reliable value to anchor their responses and therefore shifted their criteria as the test proceeded. Another possibility is that the nasal formant was more or less prominent depending on its proximity to a harmonic, but the acoustics of the stimuli do not show any obvious differences in this regard. Whatever is the case, it is still true that subjects were behaving somewhat differently with these stimuli than before, since degree of nasality was poorly distinguished even when the F0 value was the same as that used previously.

4.2.3. AMPLITUDE CHANGES DO NOT AFFECT NASALITY JUDGMENTS IN THIS EXPERIMENTAL PARADIGM. The other acoustic correlate of [a] that we tested was amplitude. Since [a] is generally of greater overall amplitude than other vowels, this greater amplitude might result in an intensification of the effect of duration on perceived nasality. Lintz & Sherman 1961, in fact, suggested that the more prominent a vowel is, the easier it is to hear the nasality in it. On the other hand, nasalized vowels have in fact been found to have less overall amplitude than their oral counterparts (Smith 1951, Delattre 1954, House 1957, Jenson 1967). This would lead us to expect the opposite, namely, that more intense vowels would sound LESS nasalized. Either way, the correlation of amplitude with vowel height is well established, and the effect on nasality can be tested.

The twelve listeners from the preceding two experiments also participated in this experiment, after completing the F0 test. They were not given a familiarization set, since they were by now well acquainted with our synthetic *a*. The *a* of 150 msec duration, with three degrees of velar opening, served as the model. Amplitude was left unchanged for one level and reduced by 1 dB steps for each of other four levels. This range is similar to the difference between English [ɑ] and [u] found by Lehiste & Peterson 1959.

Figure 6 gives the results in a similar fashion to the previous figures. Degree of velar opening is perceived in the appropriate relative order, as seen by the clear separation of the three functions ($F(2,22) = 14.10$, $p < .01$). Amplitude changes, on the other hand, had no effect on subjects' nasality rating.

The lack of an effect of amplitude changes on the nasality rating suggests that, if overall vowel amplitude influences perceived vowel nasality, then vowel amplitude may need a surer reference point than was present in our experiment.

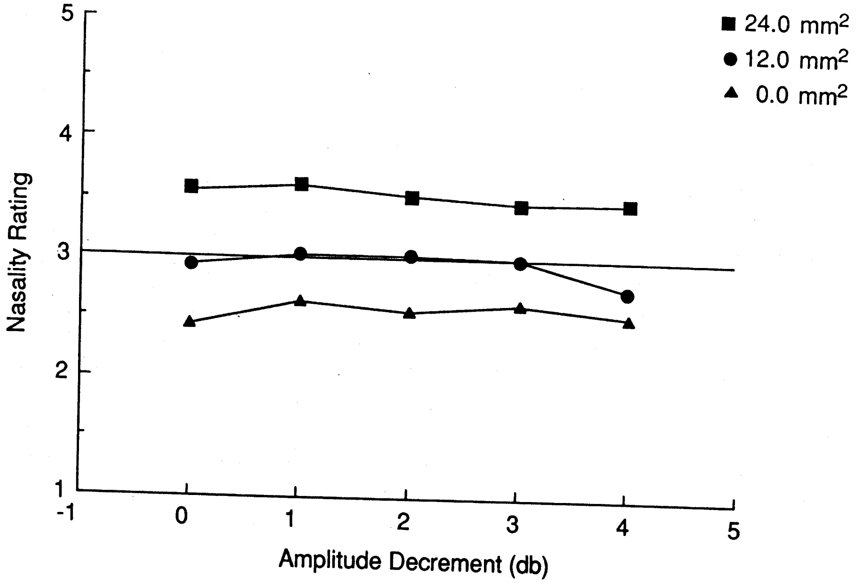

FIGURE 6. Averaged responses of twelve subjects to *a* synthesized with three degrees of nasalization at five levels of amplitude. The horizontal line drawn at the value '3' indicates the midpoint of the range, and a conceivable boundary between oral and nasal.

That is, it may have been difficult for listeners to know, from trial to trial, if a token had more or less amplitude than expected. The range of amplitude used was similar to that found in natural speech, but it may not have been large enough for an experimental context. Also, the changes in amplitude (and, indeed, F0) were of a magnitude appropriate for intrinsic differences. In contrast, the duration manipulations were of a magnitude appropriate for changes in distinctive length. If we had instead used a range found for, say, stress or pitch accent, our results might have been different. However, the intrinsic variations attributable to *a* were the ones of interest in the present context. Within that range, it appears that vowel amplitude does not affect perceived nasality, making it unlikely that this phonetic correlate of *a* was responsible for its being the vowel to be nasalized in EA.

4.3. THE EFFECT OF DURATION DISAPPEARS WITH UNAMBIGUOUS NASALITY. The results so far have shown a clear link between increasing duration and increasing perceived nasality. Since the stimuli were synthetic speech, one concern is that the relation may be connected with the unnaturalness that tends to accompany synthesis. As mentioned, even the vowels synthesized with a closed velar port sounded somewhat nasalized, so it could be that the 'nasal' perception is actually a conflation of a true nasality judgment and an unnaturalness judgment. ~~This~~ argument does require that subjects are confounding two judgments in their nasality ratings, since they were quite successful at hearing the synthesized degrees of velar opening appropriately. However, it is true that even linguists attribute the term 'nasal' to voice qualities which do not depend on velar opening (see the discussion in Laver 1980 and the clinical findings of Lock & Seaver 1984). It has been suggested (Lintz & Sherman 1961:395) that 'any deviant voice quality becomes more conspicuous' as amplitude and duration increase. This might account for our previous results on duration, but it does not predict the lack of an effect of the amplitude manipulation. In any event, we felt it important to examine the duration effect with natural speech.

Our stimuli for this experiment were tokens of oral [a] and nasal [ã] produced in isolation. We recorded the first author, a male speaker of English with a Southwestern American dialect from which most regional features have been stamped out by exposure to the Northeast. Two tokens of isolated [a] and [ã], matched reasonably well for amplitude and F0, were selected. From these, sections of 50, 100, 150, 200, and 250 msec duration were selected by the scheme illustrated in Figure 7. From the 250-msec section, two sections of each of the four shorter durations were cut, one beginning at the onset of the longest stimulus (the 'early' portion) and one ending at the offset (the 'late' portion). This ensured that any changes in velar opening during the natural production would be represented at each duration. The excising was deliberately done without regard to placement within the pitch period so that the shorter sections would be the likeliest to have editing artifacts. If the judgment is really about deviance, this would make them more nasalized rather than less.

Twelve new subjects listened to a sequence similar to those used previously. A familiarization block of 20 items was given, with the first five answers filled in, using '1' for the oral and '5' for the nasal tokens. Then five repetitions of

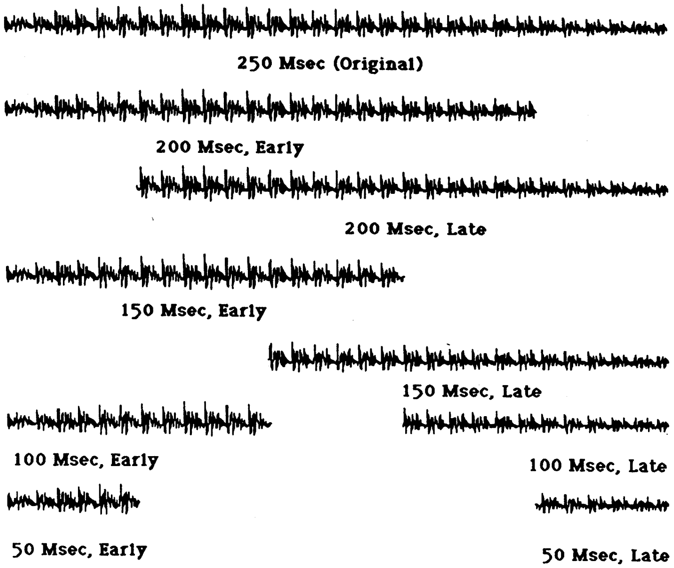

FIGURE 7. Scheme for creating natural stimuli of different durations (the vowel shown is the second oral token of *a*). Each shorter segment was excised from the original 250-msec vowel (top). At each duration, a version was taken from the beginning ('early') or the end ('late').

the stimuli in random order were presented (i.e., the warm-up repetition was omitted). There were two types of utterances (oral and nasal), two tokens of each type, and nine sections (the full 250-msec section and the 'early' and 'late' versions of each of the four shorter sections), yielding 36 stimuli.

The average ratings are shown in Figure 8. Subjects reliably heard the nasality, as seen by the separation between the two groups of functions (F(1,11) = 30.34, p < .001). Duration, however, did not show an effect (F(1,11) = 0.74, n.s.). There were interactions of duration, nasality, token, and location. Basically, all the interactions reduce to the fact that the late portion of nasal token 1 showed a highly consistent effect of duration, while no other segments did.

At first blush, these results seem to indicate that judgments on our previous, synthetic stimuli reflected some combination of nasality and deviance. That is, when the strangeness of the source was remedied, the effect of duration disappeared. However, there are considerations that blunt this conclusion. First, there were no intermediate levels of nasalization in this natural speech experiment, and this fact may have allowed subjects to focus on velar opening more narrowly than when some of the stimuli are ambiguous with respect to nasality. Second, there is the intriguing behavior of the late portion of the first nasal token. The late section of the first nasal vowel appears to have been (unintentionally) intermediate in its nasalization: spectral analysis revealed that all tokens, even the oral ones, had measurable nasal formants, located at approximately 200 Hz for the oral vowels and 230 Hz for the nasal. However, the relative prominence of the nasal formant differed for oral and nasal vowels. The difference between the amplitude of the nasal formant and F1 was −10

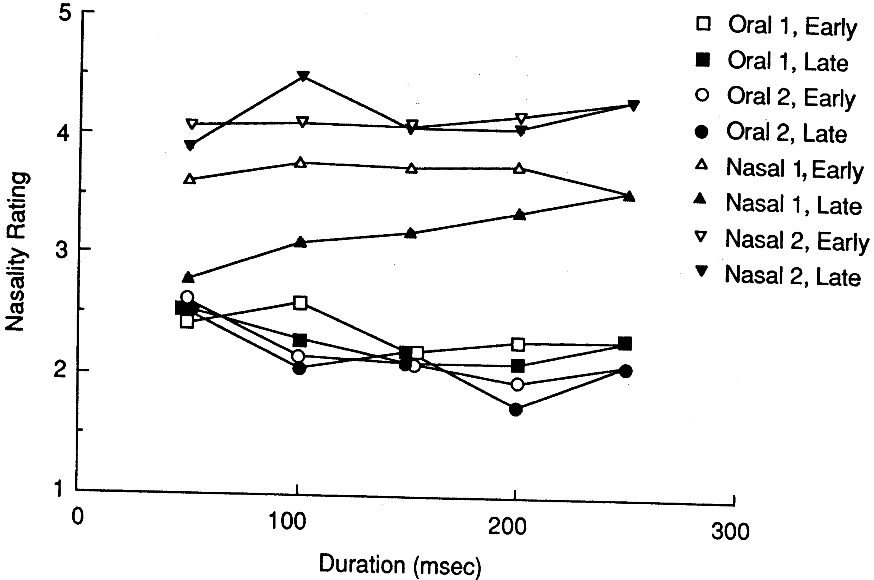

FIGURE 8. Average responses of twelve subjects to the naturally-produced [a]'s and [ã]'s, made to vary in duration. The two tokens of each vowel are shown separately.

dB for the oral vowels and −2 dB for three of the four nasal vowel segments. But this difference was −6 dB for the late portion of the first nasal vowel token. In addition, that nasal segment lacked a strong F4, like the oral vowels and unlike the other nasal segments. (These acoustic measures of nasality are valid only in this restricted context—the fact that we can make the comparison in acoustic terms here does not mean that nasality can be predicted from acoustic measurements in general.) It appears that only the last 50 msec of the vowel was intermediate in these ways, since the removal of that segment resulted in a single nasality rating (see the 'Nasal 1, Early' function of Fig. 8). Note that this final 50-msec segment affected the nasality rating of all five stimuli in which it was present, and that the effect increased as that segment constituted more of the stimulus. That is, the 'Nasal 1, Late' function declines from right to left. This result shows that the nasality judgment is affected by the nasality of the entire stimulus and is not dependent on duration simply for 'salience'. While of interest in itself, this result does not help us determine whether the lack of an effect of duration in this experiment was due to the naturalness of the stimuli or to their lack of ambiguity. The next experiment further addresses this issue.

4.4. ITERATED PITCH PERIODS OF NATURAL NASALIZED VOWELS SHOW THE DURATION EFFECT. To test another aspect of the naturalness question, and as a preliminary to our final set of experiments (which examined the degree of nasalization in natural productions), we ran a further experiment using the naturally-produced vowels of the previous section. The technique we wanted to use involves the iteration of pitch periods from naturally-produced vowel tokens. The primary usefulness of this technique is only apparent in the next section. Of more immediate interest is that repeating pitch periods in this way introduces unnaturalness or 'deviance' into natural productions: while acceptable vowel-like stimuli are created, there is often a 'buzzy' quality as well. Comparison of results using these stimuli with the results of both our synthetic speech experiments and our natural speech experiments will help us make further distinctions between judgments of nasality and judgments of deviance.

We selected a pair of pitch periods from the middle of each of the longest vowel tokens of the previous experiment. New stimuli were created by iterating those periods until the desired duration had been obtained. The durations used were those of our previous experiments (50, 100, 150, 200, 250 msec), and were made exact whether or not that resulted in a partial pitch period at the end of the stimulus. A familiarization block and then five repetitions of each of the twenty tokens (2 (oral/nasal) × 2 tokens × 5 durations) were presented to the subjects who had just heard the natural test (of §4.3) for the same nasality rating.

The results are shown in Figure 9. Both tokens of each category (oral and nasal) are shown. There is a clear separation between the two oral and the two nasal tokens ($F(1,11) = 34.60$, $p < .001$). Duration also had a significant effect ($F(1,11) = 2.83$, $p < .05$). There was, as well, an interaction between these two factors ($F(1,11) = 5.78$, $p < .001$), which indicates that the two nasality categories behaved differently with regard to duration. Separate analyses of

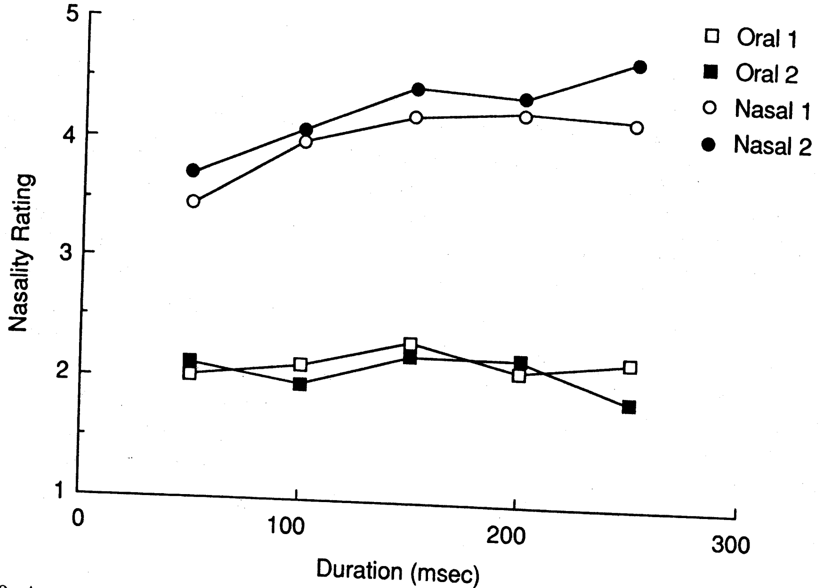

FIGURE 9. Average responses of twelve subjects to the vowels created by iterating pitch periods of the naturally-produced [a]'s and [ã]'s of Figure 8. The iterated vowels varied in duration. The two tokens of each vowel are shown separately.

only the oral and only the nasal tokens revealed that, while there was no effect of duration on the oral vowels (F(1,11) = 0.36, n.s.), there was a highly significant effect with the nasal vowels (F(1,11) = 10.90, p < .001).

These results show several things. First, the hope that iterated pitch periods would allow us to examine the degree of produced nasalization was fulfilled—subjects were accurate in their perception of the original nasality.

Second, we can see that at least one type of deviance does not contribute to nasality judgments at all. Iterated vowels, though quite identifiable, often sound buzzy or otherwise artificial. Nonetheless, with the oral vowels, this had no bearing on the nasality rating. Thus, although the unnaturalness introduced by iteration is quite different from that of speech synthesis, these results are consistent with our previous assessment that subjects were responding, at least in part, to nasality rather than deviance.

Finally, the lack of a duration effect on the oral vowels shows that the link between duration and nasality depends on the presence of some degree of nasalization. A possible explanation is that the duration effect is a type of summation, but there must be something there to sum before any effect will be found. Our results do not allow us to specify in either acoustic or articulatory terms what must be present for summation. The acoustics of our stimuli suggest that a nasal formant is neither necessary nor sufficient for perceptible nasalization. Our synthetic tokens with no velar port opening had no measurable nasal formants, yet nasality summed with duration. While we can speculate that the perceived nasality of these vowels is related to formant bandwidths, this has not been systematically manipulated (but see Hawkins & Beddor 1985). Articulatorily, the degree of velar port opening needed for perceptible nasalization is probably dependent on vowel quality. The spectra of the naturally-produced oral vowels of §4.3 showed low-amplitude nasal formants, indicating nasal coupling. With other vowels, the amount of coupling indicated by the amplitude of the nasal formant might have been sufficient for summation. But for low [a], this amount was apparently not sufficient to generate an effect of duration on the nasality rating. In the present experiment, the difference between the oral and nasal vowels indicates that nasalization will summate perceptually with increasing duration only when a sufficient degree of nasal coupling is present.

4.5. SUMMARY OF THE PERCEPTUAL RESULTS. Vowels with some degree of velic coupling are perceived as more nasalized in long versions than in short ones. This is true for high vowels as well as for low vowels; it is also true for both synthetic speech and iterated natural speech. In our first experiment with natural speech, the unambiguity of the nasalization apparently overrode any effect of duration on the nasality ratings. Increased duration leads to a summation of some sort in the stimuli with nasalization, though the mechanism for that summation cannot be determined from these results. The connection, however, is clear: longer vowels with some appropriate degree of nasalization sound more nasalized than shorter vowels of the same spectral shape. Thus the possibility exists that the development of the EA intrusive nasal was perceptual in origin.

Our perceptual studies also addressed the question of why it was only the long LOW vowel of EA that nasalized. The results do not support the speculation that acoustic correlates of low vowels, such as relatively low F0 or high amplitude, influence perceived nasality. These findings, together with the finding that the perceived nasality of high vowels increases with increased duration, fail to provide an account of specifically low-vowel nasalization. It may be that the structure of the vowel system of PEA supplied an impetus, since only the low vowel showed distinctive length without quality changes. Yet such paradigmatic pressures do not seem sufficient, since many languages have shifted vowel quality without introducing nasalization into the system. Alternatively, it may be that the degree of coupling or the percentage of utterances produced with coupling correlates with intrinsic velar height. The lower velar position for [a] would then lead us to expect that it would be the vowel to nasalize. We return to this possibility below.

ARE LONGER VOWELS PRODUCED WITH MORE NASALIZATION?

5. Although we have established a relation between duration and nasality in perception, a relation might exist on the articulatory side as well, with long vowels showing greater velar lowering than the corresponding short vowels. This might be particularly true for open vowels, which have been found to exhibit a somewhat lowered velum even in oral contexts (e.g. Czermak 1857,

Fritzell 1969, Ohala 1971, Henderson 1984). Various articulators have larger movements when their segments are relatively long, due, for example, to speaking rate or lexical stress (Kelso et al. 1985, Munhall 1985). There is no direct evidence to show that the intrinsic velar height varies in this same way, but it may well do so. If phonemically long PEA vowels also had a lower velar position than short vowels, then the nasalization in the EA languges may have been at least partly articulatory in origin.

The possibility that we have raised, then, is that the intrinsically low position of the velum for [a] increased with increased duration. However, while we are addressing produced nasalization, the relationship of concern here is more a perceptual one than an articulatory one. This is because a lower velum does not necessarily generate greater nasalization: closure can be attained even in this lower position, and changes in the vocal tract shape can change the degree of velic coupling. Hence, neither physiological measures of velar position during vowels of different lengths nor acoustic measures of such vowels would correspond directly to perceived nasality. And to explain the change in EA, we need to find evidence of perceptible nasality, since we assume that listeners will only adopt changes that they can hear. To overcome this drawback in production studies, we chose a perceptual test.

The next two experiments again used a nasality rating, but in this case the goal was to look for perceptual evidence of the produced nasality. The stimuli to be presented were always of the same duration. However, they were created by iterating pitch periods from naturally-produced vowels which differed in duration. If the stimuli created from the originally longer vowels are judged to be more nasal than those from the originally shorter vowels, this would be taken as evidence of articulatory differences in the nasalization of long and short vowels.

The most direct test of whether the long vowels of PEA tended to be nasalized would be to use utterances of that language. Unfortunately, we are a couple of millennia too late for that. As substitutes, we looked at two contemporary languages. The first, Western Abenaki, has one nasal and four oral vowels, with vowel quality (i.e. vowel height and backness) differing in all five vowels. Next we looked at the Iroquoian language Cherokee, which has six vowel qualities, five oral and one nasal, and distinctive vowel length for each of these. These languages fit the main criteria for our study, namely, a small vowel inventory with no contrast which depended solely on nasality. The small inventory was desirable since a crowded vowel space might inhibit nondistinctive nasalization: in some cases nasalization can change a vowel's height to the point where it will be perceived as a different phoneme (Ohala 1975, Beddor et al. 1986). Direct contrasts in nasality for vowels of the same quality were even less desirable. Our assumption was that, if there is a universal connection between vowel length and nasality, then these languages would show it. In addition, if the connection is not rare but also not universal, then languages historically associated with such a link might (but, of course, need not) be more likely to exhibit it.

5.1. Western Abenaki has a weak relationship between nasality and duration. One surviving language of the EA family is Western Abenaki, with four phonemically oral vowels /i e a o/ and one nasal vowel /ɔ̃/ (Day 1964). It has lost the phonetic manifestation of distinctive vowel length, though some phonological patterns still give evidence of the old distinction. We wanted to see if there was a tendency for vowel nasalization to increase as vowel duration increases. For this purpose, we examined only /a/, thus excluding the nasalized vowel. To obtain variation in velic coupling, we used both /a/'s in utterances without nasal consonants and contextually nasalized /a/'s, that is, /a/'s that occur between two nasal consonants.

Our stimuli came from a recorded word list collected from A. Obomsawin in 1958 by Gordon Day, who also kindly allowed us to make a copy of the tape. This list consisted of 68 utterance types which had been repeated three times each. There were 18 instances of /a/ in utterances that had no nasal consonants at all. Six /a/'s occurred between nasal consonants. The three repetitions of each of these items gave us a base of 54 oral and 18 contextually nasalized /a/'s. From these, we selected 36 oral and 14 nasalized vowels, using a restricted range of F0. (Pretests had indicated that the variability in F0 was distracting.) Each stimulus was created by iterating a pair of pitch periods from the middle of the vowel until a duration of 150 msec was obtained. The advantage was two-fold. First, the iterated stimuli were made uniform in duration. Second, any F0 contour in the original was eliminated, though static differences in F0 remained. The original duration of the vowels (including voiced transitions for adjacent consonants) ranged from 60 to 248 msec with a mean of 138.

The twelve subjects from the first experiment (§4.1) also heard this tape. They were presented with a familiarization block of twenty items, randomly selected from the fifty stimuli. No answers were given, since there was no predefined 'right' answer, and the subjects did not write any responses. They were instructed to treat these stimuli as filling the range of nasality from 1 (least) to 5 (most). In the subsequent test session, all fifty stimuli were presented six times in random order, with the first 'warm-up' repetition being excluded from the analysis. The average rating for the five repetitions of each stimulus for each listener was then submitted, along with the token's F0, F1, original duration, and original amplitude, to an all-possible-subset regression analysis. This analysis finds the best possible description of the dependent variable (nasality rating) from combinations of the independent variables (the four just mentioned).

Figure 10 shows the average rating for the twelve subjects for each token. Two regression lines are shown, one for the oral context only and one for the nasal context only. Since there was not much variation in the degree of nasalization, the ratings tended toward the midpoint, with a great deal of variability in the judgments. (The standard deviation was 0.84.) When the oral and the nasal contexts were analyzed separately, there was a large difference in the correlations of rating with original duration (r = .04 for the oral, .23 for the nasal). Simply put, duration had no relation to nasality for the vowels from

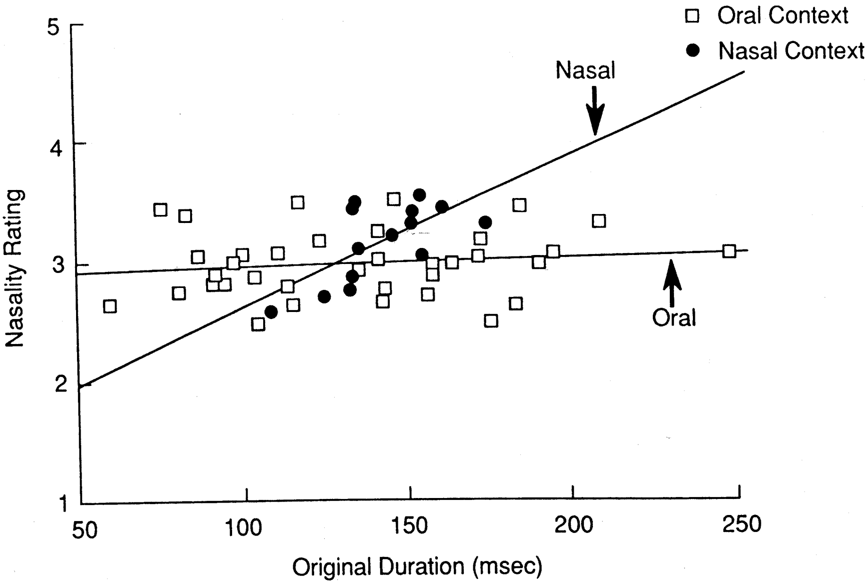

FIGURE 10. Average responses of twelve subjects to the vowels created by iterating pitch periods of the *a*'s from Western Abenaki. The vowels were originally produced in either oral or nasal contexts. Duration of the original production is shown on the x-axis, although the duration of the iterated stimuli was always 150 msec. The tokens of each vowel are shown separately. Fitted regression lines are shown for just the oral and just the nasal stimuli.

oral contexts, and it had a small but significant one for the vowels from nasal contexts.

Of the four factors in the regression analysis, the rating correlated best not with duration (r = .09) but rather with F1 (r = .19). This is more of a cautionary note than it is an indication of relative strength: since the phonetic contexts were not controllable, there was enough variability in formant values to make interpretations difficult. This also helps account for the fact that rating did not correlate well with nasal context (r = .09)—note the overlap in distribution of the oral and nasal tokens in Figure 10. The overall rating difference between oral and nasal contexts was slight (2.98 vs. 3.16), as would be expected by the small correlation. Nonetheless, there was a difference between the oral and the nasal environments in perceived nasality.

Assuming that perceived differences in the nasality of originally long and short vowels reflect differences in produced nasalization for these vowels, these results suggest an articulatory link between duration and nasalization, but only in the context of nasal consonants. A vowel becomes somewhat nasalized between nasal consonants, and the longer it is, the more nasalized it becomes. The increase in nasality may be due to an increase in the magnitude of the movement of the velum for the vowel itself. Alternatively, increased nasality could be due to an increase in the velic gesture for the adjacent nasal consonants. That is, since only the contextually nasalized /a/'s show a relation between original duration and nasality, it may be that the trajectories for the velum associated with the nasal consonants are sensitive to the duration of the syllable and therefore increase in magnitude as syllable (and vowel) duration increases. If so, then there might be no general tendency for nasalization of oral vowels to increase with increased duration. Rather, only contextual nasalization would be sensitive to duration. In this case, there would be no evidence that longer vowels are inherently more nasalized.

5.2. CHEROKEE DOES NOT INCREASE NASALITY FOR PHONEMICALLY LONG VOWELS. As a final check on possible correlations between produced variations in duration and nasality, we looked at Cherokee, another language with a small vowel inventory. In Cherokee the oral vowels *i e a o u* and the nasal vowel *ə̃* all occur in long vs. short contrastive pairs. The one nasal vowel, *ə̃*, does not contrast with an oral vowel with the same quality. Any universal tendency to increase nasal coupling in phonemically long (low) vowels would presumably show up in Cherokee and could also have been present in PEA. Any general Iroquoian tendency might also have been a factor if some traits entered PEA through diffusion from neighboring Iroquois languages.

Two tokens of phonemically long /a:/ and phonemically short /a/, from nasal and oral contexts, word-initially and after [tʃ], were selected from pedagogical recordings of Robert Bushyhead (Bushyhead & Cook 1979). Two pitch periods from the middle of each of these sixteen vowels were iterated (as with the Abenaki vowels in the previous experiment) to a duration of 150 msec. (The ratio of the original durations for long /a:/ to short /a/ was 3 : 1.) A familiarization block consisting of one presentation of each of the sixteen stimuli was played for the subjects, though they did not write any responses to them. The subjects had just heard the tapes based on English (§4.3 and §4.4) (except for one who was unable to complete the session). They rated five repetitions of the Cherokee iterated vowels.

The average ratings for each token are given in Figure 11. As with the Abenaki ratings, there is little separation due to nasal context, the average overall oral rating being 2.98 and the nasal being 3.33, though the difference is significant in an analysis of variance ($F(1,10) = 5.92, p < .05$). Phonological length is also a significant factor ($F(1,10) = 9.27, p < .05$), although the effect on the nasality rating is in the opposite direction from that predicted. Short vowels, whether from nasal contexts or not, received higher ratings (3.48 vs. 2.83 for the long).

To the extent that Cherokee shows any relation between vowel nasalization and phonemic length, it is the reverse of that needed to explain the EA vowel change. This does not indicate that there is less velic coupling with long vowels. Clumeck 1976 found that contextually nasalized long vowels in Swedish had longer stretches of coupling (in terms of absolute duration) than did short vowels, but this coupling covered proportionally less of the long vowel. So when measured from vowel onset, anticipatory nasalization started later in long vowels than in short vowels. Since we took our samples from the middle of the vowel, it could be that we did not select just that portion where a difference in degree of nasalization would be evident. Using vowels embedded between

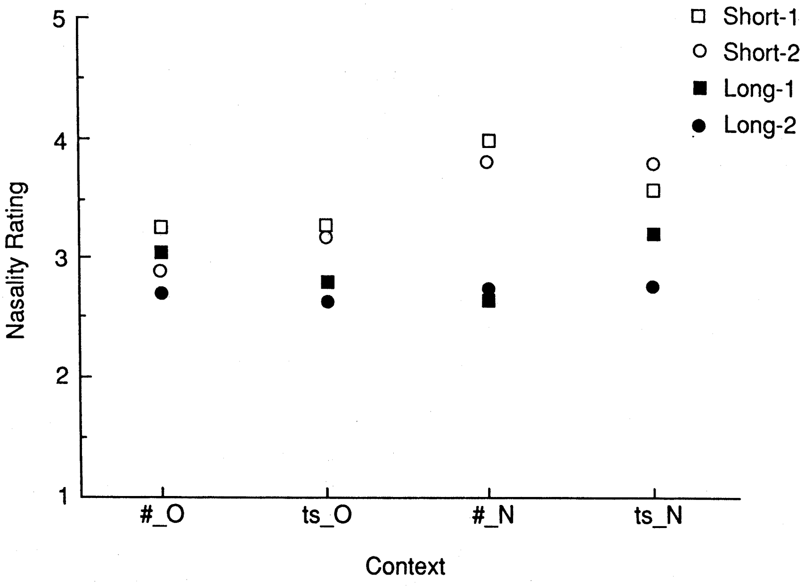

FIGURE 11. Average responses of eleven subjects to the vowels created by iterating pitch periods of the a's from Cherokee. The vowels were originally produced in either oral or nasal contexts. The original context is shown on the x-axis. The iterated stimuli were 150 msec in duration. The two tokens of each vowel are shown separately.

nasal consonants (as we did with Abenaki) may have avoided this problem, but our Cherokee corpus was too limited for that. Another source for a restriction on increasing nasalization may be the fact that Cherokee nasalizes ANY vowel in final position (Walker 1975), so nasalization may be suppressed utterance-internally to avoid signaling the end of the utterance. Regardless of such limitations, the Cherokee findings point toward the following conclusion: there is not a strong universal tendency to introduce nasalization into phonemically long low vowels. This suggests, albeit tentatively, that phonemic vowel length did not affect the intrinsic velar height of these low vowels—at least not to a perceptible degree.

DISCUSSION AND CONCLUSION

6. Our tests that manipulate duration have shown that there is a link between duration and perceived nasality: tests with synthetic vowels showed that longer vowels are perceived as more nasalized than shorter ones. This correlation is not restricted to low vowels. Two acoustic correlates of low vowels, relatively low F0 and relatively high overall amplitude, did not influence perceived nasality. The experiments with naturally-produced vowels, though, place an important restriction on the duration/nasality link: some degree of perceptible nasality must be present in the signal. This suggests that some sort of perceptual summation of nasality over time may be responsible for the link.

Our tests based on productions of different durations suggest that there is no absolute, universal requirement for (phonemically) long vowels to be produced with greater velic coupling (at least at the midpoint of the vowel). The Abenaki data suggest that, to the extent that there is a vowel-length effect, it seems to emerge only in a nasal context. The historical change in EA, however, did not require a nasal context (Goddard 1965, 1971). Therefore, our evidence does not support a role for an articulatory link between duration and nasalization in this change.

This leaves us with the following paradox: the EA vowel change by which PEA long **a*: became a nasalized vowel could be perceptually based, but only if there was some nasalization to begin with. To resolve this paradox, we need to posit some nasalization for EA. While we lack direct evidence for this nasalization, it would seem that there are two ways in which it could have come about: either the Algonquian vowels became nondistinctively nasalized, and long **a*: was then perceived as being intentionally and distinctively nasalized, or the Algonquian vowel was simply borrowed from neighboring Iroquois speakers. We will examine these two possibilities in the reverse order, beginning with a brief discussion of the areal feature itself.

Goddard 1971 and Sherzer 1972, 1976a have taken the EA nasal vowel to be an areal feature related to the Iroquoian languages. While quite plausible, this explanation forces us to postulate a certain social environment at the time of this development. One sign of contact, massive lexical borrowing, is totally lacking in the EA languages (Goddard 1978). While areal features can exist without massive borrowing of lexical material in the changed language (Jakobson 1938, Haas 1969, Cassano 1972), the evidence from the cultural diffusion of folktales throughout the Northeast indicates a general lack of contact, leading Sherzer (1976b:154) to this conclusion: 'Bilingualism was probably rather rare'. On the one hand, the diffused trait we are dealing with is neither very profound nor widespread: the number of shared features is paltry compared with linguistic areas in India or the Pacific Northwest. On the other hand, we would need some evidence of extensive bilingualism before we could claim diffusion from Iroquois to EA with any confidence.

It may be that the millennium or so that separates our cultural data from the time of the phonological change has hidden relations that once existed (cf. Hopkins 1980). The most likely EA tribe to show the conditions under which nasalization took place is the Mahican. In historical times, they were adjacent to the Iroquois Mohawks; they were surrounded by Iroquois speakers or speakers of the languages showing the intrusive nasal; and they showed several Iroquois traits in their social organization. Most enticingly, there are hints that the Mahicans may have developed into a matrilineal society, like the Iroquoians and unlike most other Algonquians (Proulx 1983). However, if they did so, it was accomplished without any borrowing of Iroquois kinship terms, which would have shown the influence directly. Also, similar indications of matrilineality exist for the Delaware (Murdock 1965, Goddard 1973) and Narragansett (Simmons & Aubin 1975), while only the latter exhibited the intrusive nasal. As Trigger 1981 has stated, it may be that only archaeological evidence will allow reliable estimations of precontact social structure.

To summarize the areal feature issue, while there may be enough evidence to postulate an early stage in which there was some Iroquois bilingualism among Algonquian speakers, evidence for general bilingualism is lacking. While this makes it possible for the EA nasal vowel to have been a diffused trait, it does not seem likely that it was borrowed directly. Cases of direct borrowing seem to involve massive bilingualism, which we can reasonably assume did not exist. Additionally, the Iroquoian vowel system has been reconstructed with two nasal vowels, *ẽ and *õ (Lounsbury 1978). PEA had the oral counterparts of both of those vowels, and either or both of them would seem to provide a better vehicle for directly modeling a phonetic change than does **a:*. Rather, it seems that the nasalizing EA languages were amplifying trends within their own phonemic inventories. We now turn to some explications of what those trends were.

As mentioned in §4.2 and §5, the position of the velum is relatively low for low vowels, and this cannot be ignored, since the only vowel to nasalize in the EA languages was **a:*. While we do not have data on velar height for any Algonquian languages, the relationship between velar height and vowel height holds true in all languages studied to date, and is true whether the language in question has distinctive nasalization or not (Czermak 1857, Fritzell 1969, Ohala 1971, Henderson 1984). The most common explanation for this relationship depends on the notion of economy: speakers will keep their velums just high enough to prevent unwanted consequences. Most accounts contend that the unwanted consequence in question is nasalization itself (House & Stevens 1956, Lubker 1968). These explanations fail to account for a significant portion of the available data and are directly contradicted by the physiological measurements in Henderson 1984.

If the velum is kept just high enough to avoid nasalization, we would expect that all vowels should be equally likely to be nasalized. That is, if a small change in velar position for any vowel would produce noticeable nasality, then random perturbations should occur equally for all heights. House & Stevens 1956 go further and argue that high vowels should be especially subject to nasalization, since their vocal-tract models showed that a relatively small amount of nasal coupling was necessary for high vowels to sound nasalized. Their results are initially suspect, given that they were unable to generate an oral *æ*. Their claim about high vowels is also at variance with the evidence of the linguistic evolution of nasal vowels, since low vowels are more likely to nasalize before other vowels.[3] Intrinsic velar height, then, does not seem to be due to an avoidance of vowel nasalization.

The production evidence of Henderson 1984 suggests an alternative rationale for the relation of vowel height to velar height—namely, that some aspect of vowel production is responsible. Her measurements of velar height in Hindi, which has distinctive vowel nasalization, showed that the difference in the minimum velar position for low [a] versus [ã] was less than that between the

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[3] The tendency for low vowels to nasalize before others apparently competes with a strong tendency for vowel systems to become symmetrical. A majority (62%) of the languages with nasal vowels surveyed in Maddieson 1984 are reported to have nearly identical distributions of oral and nasal vowel quality.

oral and nasal version of the nonlow vowels, as seen in Fig. 12. This figure, which is adapted from Fig. 16 of Henderson 1984, shows velar position (measured by a fibre-scope in the nasal cavity) through utterances of various types. Each panel shows the position of the velum, averaged over two speakers and at least ten tokens each, for three oral (thick line) and three nasal (thin line) vowels before an oral stop. The '0' time is the release of the utterance-initial /t/. When the velum is high (toward the top of the graph), nasalization is minimal. As the velum lowers, nasalization increases. In this case, even though the position of the velum was lowest for the low vowel, this vowel showed the smallest difference in velar height between oral and nasal versions. The relatively low position of the velum with low vowels apparently requires less low-

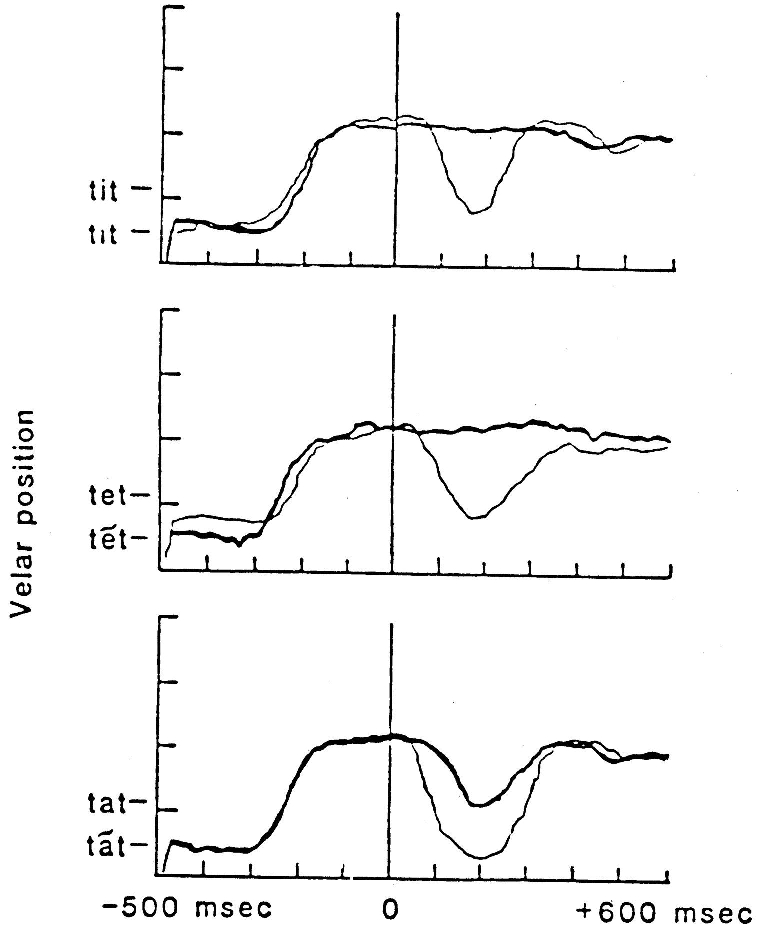

FIGURE 12. Plots of velar height versus time in Hindi utterances (from Henderson 1984). These represent average data for two Hindi subjects with at least ten repetitions per vowel per subject. The zero line-up on the time scale corresponds to the release of the initial *t* of the syllables. Velar height was measured in relative units based on individual subjects and is thus plotted in arbitrary units.

ering to attain coupling, while the high position with high vowels seems to require a larger change in position before coupling is attained. Additionally, Henderson 1984 and Bell-Berti et al. 1979 report that vowel effects on velar height occur even during adjacent nasal consonants, indicating that the anticipation of the vowel affects velar height even when nasal coupling has already been attained for the nasal consonant. These measurements, together with the apparent universality of intrinsic velar height, suggest that intrinsic velar height depends on the articulation of the vowel itself, not on active control of the velum. Indeed, the results of Shelton et al. 1970 indicate that it is not possible for speakers to control velar height consciously in the small degrees apparent in intrinsic velar elevation.

The present results lead us to believe that the apparent tendency for low vowels to nasalize more readily (historically and synchronically) is not due to the inherent duration difference between low and high vowels. Despite consistent duration differences among these vowels, the magnitude of the difference is not sufficient (based on our perceptual experiments) to contribute to making nasality distinctive. The duration difference for [a] versus [i] is on the order of 60 msec in English (Peterson & Lehiste 1960) and is somewhat smaller in Swedish (Lindblom & Rapp 1973). Our experiments show that such differences would give a rather small effect due to perceptual summation of nasality. Apparently, only the large differences of duration due to distinctive vowel length are sufficient to contribute to distinctive nasalization. In fact, there is some evidence that long vowels in nasal contexts become distinctively nasalized before short vowels in similar contexts (as in the Teke group of Bantu languages; cf. Hombert 1986).

In sum, longer vowels are perceived as being more nasalized than shorter ones if there is some nasalization present. Low vowels, and [a] in particular, seem (from both articulatory and typological data) to be susceptible to nasalization, at least in part because they require a relatively small change in velar height to achieve nasalization. If we assume a general increase in nasalization in EA, possibly influenced by the Iroquois languages' nasal vowels, these results indicate that the development of the EA nasalized vowel without a consonantal conditioning environment is, though unusual, understandable.

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