DIFFERENTIATING BETWEEN PHONETIC AND PHONOLOGICAL PROCESSES: THE CASE OF NASALIZATION

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ABSTRACT

The aim of this paper is to differentiate between hardwired or unintended phonetic processes and phonological or language specific processes. Cross-linguistic data on coarticulatory effects of *nasalization* across different *speech rates* in American English and Spanish were obtained. The data show that in American English vowel nasalization varies (inversely) with speech rate; whereas in Spanish nasalizations has a constant duration across speech rates. Spanish nasalization is modeled as a constant additive component (dependent on vowel height), and American English nasalization as a multiplicative component. It is argued that vowel nasalization in Spanish is an unintended, vocal tract constraint unaffected by higher-level speaking rate effects, and that nasalization in American English is a phonological effect, intentionally implemented by the speaker.

1. INTRODUCTION

The aim of the study is to devise a model that can quantify and differentiate between (i) "hardwired" phonetic processes due to the mechanics of speech, and (ii) phonological or language-specific processes intentionally implemented by the speaker. The model will be formulated on the basis of original data on coarticulatory effects of nasalization in Spanish and American English.

Cross-linguistic studies using a variety of techniques[1], [3], [5], [6] show that lowering of the velum necessarily overlaps the articulatory configuration of preceding vowels and that the period of overlap varies across languages. In the present study it is hypothesized that this variation is due to the different nature of nasalization in different languages. Thus, in some languages, such as Swedish or Spanish,vowel nasalization seems to be an online or hard-wired phenomenon, mechanically linked to the presence of a nasal consonant and by-product of the temporal organization of motor commands; whereas in some other languages, such as American English, vowel nasalization is not mechanical but intended, part of the linguistic organization of speech motor commands.

To differentiate between on-line and intended nasalization an experiment was conducted where rate of speech (i.e., *time* to achieve articulatory targets) was varied and its effects on velum movement (i.e., duration of vowel nasalization) were observed for Spanish and American English. This information will allow to determine which portion of the vowel (the oral or the nasalized portion) is affected when rate of speech is varied, and it will be possible to establish if the vowel is articulatorily specified as oral(with mechanical nasalization)or as nasalized. Speech rate is an intended, higher level adjustment. If the vowel is targeted as nasalized, and consequently nasalization is higher level, nasalization is expected to to vary (inversely) with speech rate. If the vowel is targeted as oral, nasalization will be due to vocal tract constraints, and the nasalized portion will not vary in different rates of speech (or it will vary as a function of the velocity of the articulatory gesture).

2. METHOD

Three speakers of American English and three speakers of peninsular Spanish read a randomized word list consisting of all possible combinations of $C_1V_1V_2C_2$, where C_1= t, n; V_1= i,ɑ; V_2= i,e, ɑ, C_2= t,n. The carrier sentence for English speakers was "Guess __soon". The Spanish carrier sentence was "Dos__son" ("They are two __"). The subjects were asked to read the 24 test sentences twice at five different speech rates: 1. overarticulated, overslow speech ("as if talking to a deaf person who was lip reading"), 2. careful, slow speech ("as if reading out loud to a formal audience in a big lecture hall"), 3. normal conversational speech, 4. fast speech, 5. underarticulated, overfast speech ("as fast as you possibly can"). The four most equidistant speech rates were studied for every speaker.

To track the time-varying positions of the velum a Nasograph (see [7] for a description) was inserted into the subjects' nasal cavity and pharynx and the traces of velopharyngeal port opening/closing and acoustic waveform were obtained on a Siemens Oscillomink chart recording device in the standard way [3], [7]. Measurements of vowel duration and timing of soft palate lowering before nasal consonants were done in [t^hVVN] sequences. The measurements of vowel duration were done 1) for the aspiration period [h], 2) for V1, and 3) for V2. The method used in determining onset of velum lowering was to consider movement to begin at the time when the velocity function (slope) crosses a noise band (defined as 10% of the highest peak velocities of the velar movement gestures for each speaker) around zero. For multistage velar gestures- usually those involving a low vowel- the first lowering gesture exceeded the noise band and, consequently, velum lowering due to vowel height was included in all cases. Measurements were done by hand on Osciloming traces.

3. RESULTS

The results for the measurements for American English are presented in Figs. 1 and 2, which show the mean duration of the oral and nasalized portion of the vowel sequence (including the aspiration period) for [iV] and [aV] sequences respectively. The onset of velic lowering is marked 0 on the abscissa and segments appearing right of 0 are the nasalized portions of the vowel sequence. Varying speech rates appear on the ordinate. Speech rate was plotted by determining the average duration for the vowel sequences. The oral portion of the [^{h}VV]English sequences in Figs. 1 and 2 corresponds to the aspiration period as obtained from the acoustic waveform (mean oral portion for speaker JJ= 59.9ms, AV=52.3ms, MN= 49.7ms; mean aspiration period for speaker JJ= 58.3ms, AV=61.5ms, MN=49.8ms). Furthermore, in some cases velic lowering begins during the aspiration period resulting in a nasalized aspiration,[h̃]. This indicates that in American English the voiced portion of the vowel sequence is completely nasalized.

Figs. 3 and 4 show the results for Spanish. It can be observed that the nasalization period in Spanish shows a roughly constant duration across different speech rates. Only in the fastest speech rates some speakers (MJ [iV]; PR [iV]; JR[iV], [aV]) succeed in reducing the nasalized portion. This indicates that under unusually fast speech conditions speakers might increase the *velocity* of the velic lowering movement.

Comparison of Figs. 3 and 4 shows a longer nasalization period for [aV] sequences than for [iV] sequences. It seems reasonable to suggest that nasalization has a constant duration in both cases and that differences are due to further low-level adjustements due to vowel height [1], [6], [7]. The fact that for [iV] sequences the constant nasalized period (k) across speech rates for the different speakers (MJ, k=91.6ms; PR, k=124.3ms; JR, k=97.6ms) is longer than the minimum transitional period (40ms for [ii] sequences) is due to the fact that the computed k value is the mean of the values for different V2. This indicates that the height of V2 also has an effect on velum lowering which is presently under study. This effect is less evident for [aV] sequences.

To sum up, the results in Figs. 3 and 4 suggest that nasalization is a constant value across speech rates, and that the oral portion of the vowel varies inversely as a function of speech rate. Thus, Spanish vowels can be said to be targeted as oral and nasalization is the result of a physiological time constraint.

4. MODELING NASALIZATION IN AMERICAN ENGLISH AND SPANISH.

In American English vowel sequences followed by a nasal are nasalized throughout. Thus vowel nasalization can be modeled as a multiplicative effect (multiplied by a factor of 1):

$a=d$

where a equals the nasalized portion, and d equals the total duration of the vowel sequence (excluding aspiration).

In peninsular Spanish the nasalized portion can be modeled as a constant value (k) which depends on the height of V1 (v) (and possibly V2). The oral portion can be

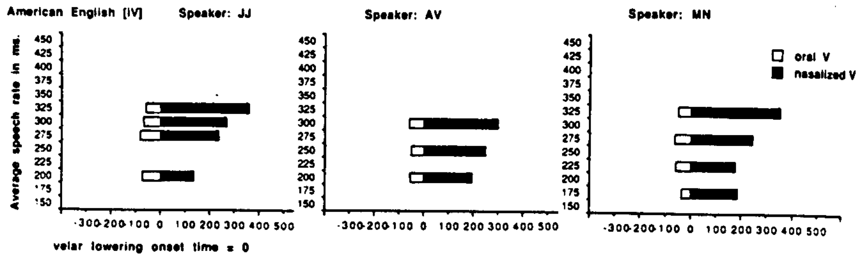

Fig. 1. Mean duration in ms. of the oral and nasalized portions of the vowel sequence [^{h}iV] for American English on the abscissa. Onset of velic lowering is marked time 0. Average spech rate in ms. appears on the ordinate.

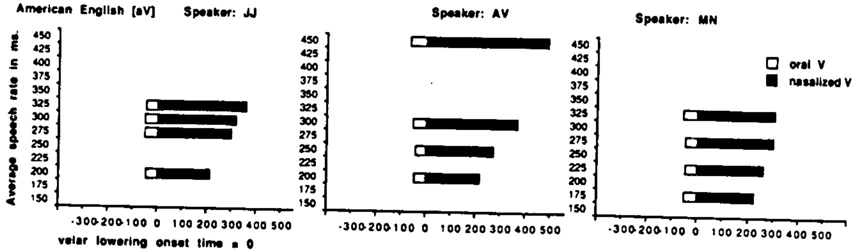

Fig. 2. Mean duration in ms. of the oral and nasalized portions of the vowel sequence [^{h}aV] for American English on the abscissa. Onset of velic lowering is marked time 0. Average spech rate in ms. appears on the ordinate.

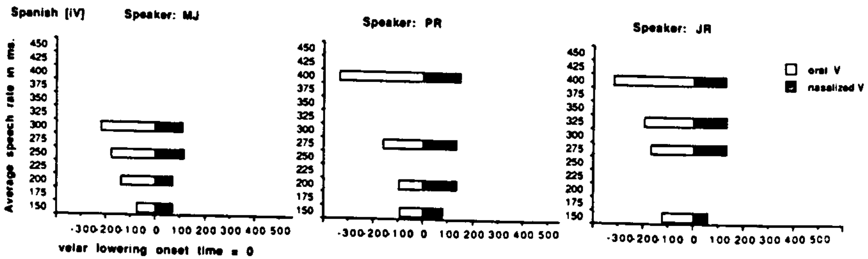

Fig. 3. Mean duration in ms. of the oral and nasalized portions of the vowel sequence [^{h}iV] for Spanish on the abscissa. Onset of velic lowering is marked time 0. Average spech rate in ms. appears on the ordinate.

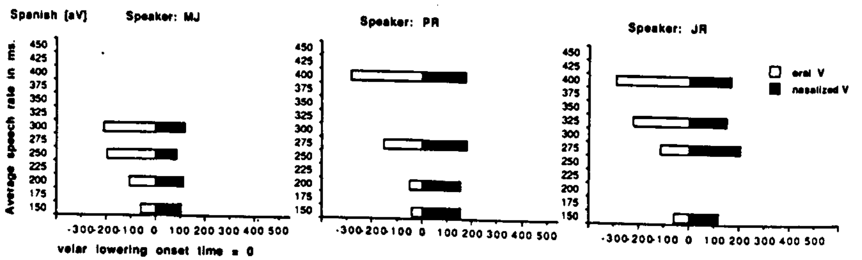

Fig. 4. Mean duration in ms. of the oral and nasalized portions of the vowel sequence [^{h}aV] for Spanish on the abscissa. Onset of velic lowering is marked time 0. Average spech rate in ms. appears on the ordinate

modeled as the vowel's duration minus k(v):

a=k(v)

b=d-k(v)

where a equals the nasalized portion of the vowel; k (v) equals a constant value (incompressible beyond 40 ms) which depends on the height of V1 (and V2); b equals the oral portion of the vowel, and d equals the total duration of the vowel sequence. Thus, vowel nasalization in Spanish can be modeled as a constant which is added to vowel duration after speaking rate effects have applied.

The working of the model for observed vs predicted values is currently under study.

5. DISCUSSION

The fact that nasalization in Spanish is an additive constant number of milliseconds indicates that it may take k(v)ms to establish the articulatory configuration for the nasal consonant. Thus, nasalization in Spanish can be considered as an unintended harwired effect which is added to higher level adjustments such as speaking rate. If speakers were using vowel nasalization distinctively one would expect that the nasalized portion in one rate of speech would differ from that in another rate by an amount proportional to the difference of the duration of the vowels, rather than by a constant number of milliseconds across all rates. This is the case for American English. It seems reasonable to hypothesize [2] that multiplicative effects are phonemic and occur prior to additive ones, which reflect constraints of speech production. Since no additive component was observed for vowel nasalization in American English, it can be deduced that nasalization does not occur automatically but that it has achieved the status of a phonological rule, intentionally implemented by the speaker.

The existing models on the timing of vowel nasalization [4], [8] do not target velum position for vowels, but just for preceding and following consonants (thus, a vowel in a [t__N] context is thoroughly nasalized in the transition between the two targets). According to our data these models are adequate for American English, where vowels are intentionally nasalized, but do not accurately simulate the behavior of Spanish vowels in the same context. This indicates that a timing model must be language specific.

6. CONCLUSION

The universality of vowel nasalization before nasal consonants demands an explanation that refers to some universal properties of human beings. The transition time in velic port opening is most likely the origin of vowel nasalization. However, the same phonetic effect might be unintended and low-level in one language (Spanish), and it might have been phonologized, and therefore be part of the language specific timing instructions in another language (American English). Moreover, the large number of languages (e.g. French, Hindi, Protuguese) that lose a nasal consonant distinction only to replace it with distinctive vowel nasalization indicates that phonetic nasalization can be perceived and then exploited by language users. The different nature of the same phonetic phenomenon proves the need to interpret phonetic data in terms of their phonological behavior if we are to provide an accurate account of the hardwired and softwired components of speech in different languages and implement them in automatic speech technology.

6. REFERENCES

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