THE INFLUENCE OF PROSODIC POSITION ON VELIC AND LINGUAL ARTICULATION IN FRENCH: EVIDENCE FROM EPG AND AIRFLOW DATA.

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ABSTRACT
Prosodic position influences the articulation of the consonants [t] and [n], observed for one French subject. Both lingual and nasal articulations for [n] are affected by the position of the consonant. The higher the prosodic position of the consonant, the less nasal flow [n] has and the more lingual contact [n] and [t] have. This variation in articulation distinguishes 3 to 4 prosodic levels depending on the articulators (and/or the technique).

RESUME

INTRODUCTION
Various aspects of prosody have been found to influence articulation. For example, the effect of lexical, phrasal or emphatic stress on articulatory gestures is relatively well documented [e.g., 1]. But another aspect of prosody is phrasing. By phrasing, we are referring to the grouping of segments into prosodic domains and/or marking junctures (boundaries) between these domains. The strength of the juncture will depend on the prosodic level of the constituents (e.g. stronger between 2 words than between two syllables within a word). Prosodic position (or the position of a segment relative to these boundaries) has been found to influence the timing of articulatory movement, relative to the preceding segment (i.e. anticipatory coarticulation). When preceded by a major prosodic boundary (such as a syntactic sentence or clause), the onset of anticipatory coarticulation tends to be delayed. These results have been shown for the velum [2] and to a smaller extent for the tongue [3].

Prosodic position influences not only the articulation of a segment relative to its neighboring context, but also influences the articulation of a segment compared to other segments in the speech chain (syntagmatic) or in other sentences (paradigmatic). For example, several studies have shown that articulations are weaker in word- or syllable-final positions compared to initial ones [4, 5, 6, 7, 8].

More recently, attention has been directed to the influence of the position in higher prosodic domains, raising the question of whether particular changes in articulation may cue prosodic phrasing by marking prosodic boundaries. For example, in English [9] and in Korean [10], VOTs of aspirated stops have been found to be longer when the stop is initial in a large phrase (e.g. an Intonational Phrase), than if it is initial in a hierarchically lower prosodic domain or if it is medial in that domain. Most recently, Fougeron & Keating [11] have shown that the strength of oral articulation depends on phrasal position. Measured with electropalatography, the amount of linguopalatal contact for [n] in English is larger in prosodic domain-initial positions (Word-, Minor Phrase- and Major Phrase-initial positions) compared to medial or final ones. This phenomenon is called an "initial strengthening". Comparison of different prosodic levels shows that the degree of strengthening cues 2 or 3 levels of prosodic boundaries depending on the speaker.

The experiment presented here examines whether prosodic position influences the articulation of the consonants [t] and [n] in French. For the nasal consonants, prosodic effects are observed on both lingual and nasal articulations (in 2 separate experiments) in order to evaluate whether prosodic conditioning of articulation may be a general phenomenon in speech or is restricted to some articulatory subsystem.
EPG offers us a direct measurement of the amount of linguopalatal contact, and airflow recordings give us an indirect observation of the velopharyngeal aperture.

METHOD:
The amount of nasal flow and linguopalatal contact was observed for the nasal coronal [n]. In the airflow experiment, the consonant was placed in 2 vocalic contexts which vary in oral impedance: [a-a] and [i-i]. In the EPG experiment, only the open vowel [a] was used in order to minimize the occurrence of linguopalatal contact that is not directly related to consonant articulation. Amount of linguopalatal contact was also observed for the oral coronal [t] in the context [ö_ö].

The corpus consists of meaningful sentences with a test consonant in 5 different prosodic positions. Table 1 gives the sentences designed for the sequence [ana] along with their prosodic labeling. Note that although prosodic boundaries are manipulated across the sentences, the test syllable remains in the same position in the sentences. In (1), [n] is initial in the highest prosodic group considered: the Utterance (Ui). It is separated from the preceding utterance by a long pause. In (2), [n] is initial in an Intonational Phrase (IPi). This prosodic domain is defined by a big pre-boundary lengthening, a long pause and a major pitch excursion. In (3), [n] is initial in the lower prosodic domain defined by intonation in French, the Accentual Phrase [12] (APi). It is marked by a small final lengthening and a minor continuation rise. In (4), [n] is medial in the Accentual Phrase “Tata Nadia” and is initial in the word “Nadia” (Wi). In (5), [n] is word medial and is also syllable initial (Wm). For the test consonant [t], similar sentences were constructed with a combination of “tonton” [tööö] that allows a quite productive word formation in French.

For the [n] corpus, the nasal and oral flow were recorded directly onto a Kay-CLS with a Rothenberg split mask. In a separate session, recordings of linguopalatal contact were made with the Kay Palatometer for [n] in the context [ana], and for [t]. The custom made pseudopalate has 96 electrodes (see Fig. 2). The coverage of the electrodes extends toward the middle of the incisors which allows the dental articulation of French [n] and [t] to be captured. One Parisian French subject (the first author) was recorded for 10 repetitions of each sentence in the 4 corpora.

Measurements were taken at the maximum of nasal flow and the maximum of linguopalatal contact (in %) for the consonants. Acoustic energy was calculated from the acoustic signal of the EPG experiment. The difference between the average energy (RMS) in the consonant relative to the average energy in the following vowel was measured.

Table 1: Stimuli designed for the sequence [ana]

<table>
<thead>
<tr>
<th>Prosodic positions</th>
<th>Sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td>2- Intonational Phrase-initial (IPi): “La pauvre Tata, Nadia et Paul n’arriveront que demain.” (Poor Tata, Nadia and Paul will arrive only tomorrow)</td>
<td></td>
</tr>
<tr>
<td>3- Accentual Phrase-initial (APi): “Tonton, Tata, Nadia et Paul arriveront demain.” (Tonton, Tata, Nadia and Paul will arrive tomorrow)</td>
<td></td>
</tr>
<tr>
<td>4- Lexical Word-initial (Wi): “Paul et Tata-Nadia arriveront demain matin.” (Paul and Tata-Nadia will arrive tomorrow morning)</td>
<td></td>
</tr>
<tr>
<td>5- Lexical Word-medial (Wm): “Tonton et Agabelle arriveront demain matin.” (Tonton and Anabelle will arrive tomorrow morning)</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS:

1. Nasal flow experiment:
As shown in Fig. 1, the amount of nasal flow in [n] is affected by the prosodic position of the consonant. In general, the higher the prosodic position, the less nasal flow [n] tends to have.

Three out of five prosodic positions are distinguished by the amount of nasal flow:

Wm > APi > IPi

The differences between Wm, Wi and APi follow the same trend but are not significant. Utterance initial positions are not significantly different from other positions.

2. EPG experiment:
The percent of linguopalatal contact is shown in Fig.2 for [n] and [t]. As for nasal flow, lingual articulation is affected by the prosodic position of the consonant. For both [n] and [t], consonants in higher prosodic positions have more linguopalatal contact than in lower positions.

This variation in the amount of linguopalatal contact can distinguish 4 prosodic positions:

Wm < Wi < APi < [IPi, Ui]
All consonants have a full closure (as seen in the sample of EPG profiles given for [n]), but as the position of the [n] goes higher in the prosodic hierarchy, the contact increases as a result of modification in tongue blade orientation and/or tongue body height.

Initial positions in the higher prosodic domains (IP or U) have a similar amount of contact. The increase in linguopalatal contact is correlated with a lengthening of the stop closure for both [n] ($r^2=0.74$) and [t] ($r^2=0.64$). But the duration of the closure alone does not allow as many distinctions of prosodic levels and those vary depending on the consonant:

- $\{Wm, Wi\} < \{API, Ui\}$ for [n]
- $Wm < \{Wi, APi\} < \{IPi, Ui\}$ for [t]

3. **Energy:**

RMS calculation over the duration of [n] relative to that of the following vowel is presented in Fig. 3.

Only two prosodic levels can be distinguished by energy. Consonants that are initial in an AP or higher domain are more distinct from the following vocalic nucleus in terms of energy (around -7 dB difference) than consonants in AP-medial positions, both Wi and Wm (around -4 dB difference between [n] and the following vowel).

**DISCUSSION and CONCLUSION**

In this study we have shown that magnitude of oral and nasal articulation are influenced by the prosodic position of the segments.

Consonants in higher prosodic positions (that is when the consonant is preceded by a strong prosodic boundary) have less nasal flow and more linguopalatal contact than in lowest prosodic positions. However this influence needs to be examined with several subjects. Previous experiments involving 3 to 4 subjects have shown that prosodic influence on both nasal airflow in French [13] and lingual articulation in English [11] vary depending on the subject. Although almost every subject showed distinctions between the more extreme prosodic levels, the number and the nature of the prosodic positions distinguished by articulation was a function of the subject.

In this study, the influence of prosodic position has been shown to apply to two remote articulatory subsystems. This finding suggests that prosodic information may be a high-level component of speech production control. As a consequence, we feel the need of a prosodic tier in a model of speech production in order to account for the articulatory characteristics due not only to prosodic prominence (stress or accent), but also to particular prosodic positions. Only differences in magnitude of articulatory movements have been discussed here, but prosodic position may also affects the timing of articulatory gesture as suggested in the coarticulation experiments presented in introduction.

Comparison between the results obtained in the two experiments showed that nasal flow makes less distinctions between
prosodic positions than linguopalatal contact does. This result can be interpreted in two ways. (1) It could be that velum articulation distinguishes fewer positions than lingual articulation. A difference in degrees of freedom between the two articulators may prevent the velum from varying too much without endangering the velopharyngeal opening required to maintain nasality. For the tongue, greater variation in tongue height is allowed behind the seal as shown in the EPG profile. (2) The difference in the sensitivity of the techniques (aerodynamic recording and EPG) could also explain the difference in the number of distinctions.

Lingu al and velar articulation show patterns that at first glance may appear to be opposite. In higher prosodic positions, the contact of the tongue against the palate is strengthened for coronal consonants, whereas the velopharyngeal opening of nasal consonants seem to be reduced. These modifications seem to be contradictory if we looked at the effect of position as initial "strengthening" of articulation. But from an acoustic or perceptual point of view, this increased magnitude of oral articulation and decreased magnitude of nasal articulation may contribute to the same goal: the increase of the consonantality, and more generally the salience, of the consonant in "strong" prosodic positions. Manuel [14] suggested that the reduction of velopharyngeal opening (therefore nasal flow) for nasal consonants in word initial positions contributes to the reduction of the sonority of the consonant. In our study, we tried to examine this variation in sonority by examining the energy-distinctiveness of the consonant relative to the following vowel in the different prosodic positions. Results show only a binary distinction between high (above AP) and low prosodic levels. Therefore acoustic consequences of this articulation need to be further examined.

The results presented here also suggest that some variation in articulation may be controlled, explained or understood if looking at the prosody of the speech materials. Therefore, awareness of prosodic differences between utterances can turn some apparently random variation into predictable regularities of speech production.

Moreover, articulatory variation may be a valuable source of information in understanding the prosodic organization of speech. The possible acoustic and perceptual relevance of these position-dependent variations needs to be defined and tested, but from a production point of view, variation in articulation can follow the prosodic hierarchy and therefore cue prosodic phrasing.

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