Anticipatory laryngeal movements: An X-ray investigation

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ABSTRACT

This investigation deals with the production of VCV sequences produced by French speakers, with particular focus on larynx position and trajectory. X-ray data are extracted from a database for four speakers, uttering sentences or VCV sequences at two speaking rates: normal-conversational and fast. Results obtained from a frame-by-frame analysis of midsagittal profiles reveal: (1) a high positive correlation between the larynx and the hyoid bone in their vertical displacements; 2) a confirmation of previous findings that the position of the larynx is lower for high vowels than for low vowels; (3) anticipatory laryngeal gestures in both /aCu/ and /uCa/ sequences; (4) that these anticipatory gestures are resistant to the behaviour of supraglottal structures, and also to speech rate conditions.

Keywords: anticipation, larynx, protrusion, lip-opening, speech rate, X-rays.

1. INTRODUCTION

Research related to larynx vertical movements in the production of vowels and consonants have been reported in the literature (cf. *e.g.* Perkell, 1969 [7]; Bothorel, 1979 [3]). However, the search for anticipatory laryngeal gestures, combined with the use of speech rate as a perturbing factor, are indeed lacking in the literature. The present research is thus, hopefully, a contribution to knowledge on the control and timing of larynx position in obtaining vocalic and consonantal gestures, across rate variations. Anticipatory laryngeal patterns eventually unveiled should contribute to efforts in understanding and modelling glottal and supraglottal anticipatory gestures (*cf.* works by Henke, 1966 [4]; Perkell & Chiang, 1986 [8]; Bell-Berti & Harris, 1981 [2]; Abry & Lallouache, 1995 [1] and Maeda, 1999 [5], among others).

One version of the *tongue-pull hypothesis* claimed the existence of a strong connection between tongue body elevation, the position of the hyoid bone and the rigid structures of the larynx. Thus there should be a high and positive correlation between displacements of these structures, where elevation of the tongue-body would provoke the vertical displacement of the larynx-hyoid bone complex. However, the proponents of this hypothesis had to discard it later, as data obtained for the larynx and the hyoid did not confirm the theory. In fact quite a few results revealed that the position of the larynx was lower for high vowels than for low vowels. This fact has been explained by Perkell (1969, [7]) as follows. There is interaction between behaviour of the jaw, the lips and larynx height. This is because *contraction* of the geniohyoid, the anterior belly of the digastric and the mylohyoid triggers elevation of the larynx-hyoid bone complex and jaw lowering. The result is shortening of the length of the vocal tract at the larynx, and opening of the oral cavity, as can be observed in the production of vowel /a/. Conversely, it is the *relaxation* of this group of muscles, combined with jaw elevation and contraction of infralaryngeal striated muscles that may be responsible for lengthening of the vocal tract, as is the case in the production of /u/. The jaw also influences the length of the vocal tract at the lips, since it carries the lower lip. Lip protrusion contributes to significant lengthening of the vocal tract for vowels like /u/, which has a low larynx and hyoid bone position. Inversely, absence of lip protrusion, as is the case in /a/, provokes reduction of the length of the vocal tract, the complex larynx-hyoid bone being in a high position.

With regards to this interaction between the behaviour of the jaw, the lips and larynx height, it is hypothesised that the data reported here should: (1) highlight displacement correlations between these structures; and (2) show anticipatory strategies for the larynx, the lips and the jaw in producing /aCu/ sequences.

2. METHOD

The corpus consisted of V_1CV_2 sequences and sentences that embedded target words. The words were specifically chosen to study anticipatory behaviour in the production of V_1CV_2 sequences, where V_1 is the low vowel /a/ and V_2 the high vowel /u/. Symmetrically, control V_1CV_2 sequences were also elicited, where V_1 is the high vowel /u/ and V_2 the low vowel /a/. The medial consonant is either /p/, /t/ or /k/.

The following sentences are a few examples from the corpus:

N**ous pâ**lissons. /upa/ *vs*. Il **a pou**rri. /apu/
C**ouds ta** chemise. /uta/ *vs*. Elle **a tou**t faux. /atu/
Pour t**out ca**sser. /uka/ *vs*. Pour **accou**rir. /aku/

All sentences were pronounced by two speakers (one male and one female), once at two self-selected speaking rates, normal-conversational and fast.

Similar V_1CV_2 sequences (nonsense words) were also read by two other speakers (one male and one female), once in each speech rate.

X-ray data are obtained for all 4 speakers (two females and two males) who uttered the sentences and the sequences once at two speaking rates, normal-conversational and fast. The speaker's head was firmly fixed to the back of an adapted seat in order to prevent head movements.

With the help of a grid (and software for the digitised data), measurement parameters for larynx and hyoid bone vertical positions during the production of the sequences were determined. Lip protrusion, lip-opening, tongue-tip, tongue-body and jaw displacements were also monitored and measured. Speech rate was varied as a perturbing factor, *i.e.* as a means of evaluating the robustness of the trajectories of the measured structures in the production of the different vocalic and consonantal phonetic categories.

3. RESULTS AND DISCUSSION

First of all, results for all four subjects confirm a high positive correlation between the larynx and the hyoid bone in their vertical displacements. The position of the larynx (and that of the hyoid bone) is systematically higher for the low vowel /a/ than for the high vowel /u/. Note that previous findings (Vaxelaire & Sock, 1997) involved only /uCa/ or /aCu/ sequences, in which the C was always the labial consonant /p/ whose production does not require an active involvement of the tongue (see Figure 1). In such cases, tongue body displacement adopts a trajectory opposite to that of the larynx. For example, while the tongue body constantly moves downwards to produce /upa/ sequences, the larynx continues its raising movement.

Here it was also found that the production of other consonants (/t/ and /k/), which recruit tongue movements actively, does not perturb the laryngeal trajectory as was observed in the /p/ context. In other terms, the raising tongue gestures necessary to produce /t/ and /k/ do not significantly influence the hyoid bone's movement, coupled with that of the larynx. In fact, in /atu/ and /aku/ sequences, if the respective tongue-tip and tongue-body raising gestures seem to reduce the steepness of the slope of the downward trajectory of the hyoid across /aCu/ sequences, that of the larynx remains quite abrupt, as in the labial consonant context.

These laryngeal settings and trajectories (and especially the vocalic ones) are all maintained in fast speech, thus suggesting their robustness in speech production. It should also be mentioned that in fast speech, the larynx and the hyoid bone have higher positions, compared with initial settings observed in normal speech (Figure 2 is a typical example). This result is true for all four subjects. It has been hypothesised elsewhere (Vaxelaire & Sock, 1997) that increasing speech rate requires such an initial configuration, presumably necessary for the articulatory acceleration task. This may also be related to a probable co-variation between fast speaking rate and intrinsic F0. However, complementary acoustic data are needed in order to verify such an assumption.

Secondly, the entire data highlight displacement correlations between the larynx-hyoid bone complex, the lips, tongue-body and the jaw (even if the hyoid bone and the jaw are not shown in Figures 3 and 4). The behaviour of all measured structures reveals a variable but certain degree of coupling: as the larynx goes downwards from vowel /a/ to /u/ across the consonant, lip-opening reduces, tongue body rises, while lip protrusion increases. One may conclude therefore that an interaction between the behaviour of these structures, regarding position and displacement, is proven.

Thirdly, the data reveal an anticipatory laryngeal movement for the /u/ in /atu/ and /aku/ sequences.
In the /atu/ sequence in normal speech (Figure 3), the larynx begins its anticipatory downward trajectory (frame 1115) before apical contact (frame 1116), and continues its descent gradually (from frame 1116 to 1121), before declining abruptly (by 5 mm) into the /u/ configurations (frames 1122 to 1125). Note that upper lip (frame1112) and tongue-body (frame 1113) gestures for /u/ are also anticipated well before apical contact.

As concerns the /aku/ sequence in normal speech (Figure 4), similar anticipatory patterns are observed. Here also, the larynx initiates its anticipatory lowering trajectory (frame 455), prior to tongue-tip contact (frame 456), drops quite remarkably (frame 457) and remains relatively stable through the /u/ configurations (frames 459 to 462). The upper lip and the tongue-body (the latter recruited for the /k/ contact too) also show anticipatory behaviour.

These patterns are robust, as they are structurally similar in fast speech, apart from the fact that movements in this speaking condition are accelerated, with reduced amplitudes.

It is interesting to recall that similar anticipatory laryngeal behaviours have been observed in /uCa/ sequences. Such a finding suggests that this category of anticipatory gesture is a real vowel-to-vowel glottal one. It is not at all harnessed to the anticipatory behaviour of supraglottal structures, such as lip protrusion and rounding, tongue-body constriction, jaw movements, etc. If such were the case, absence of anticipatory vocalic movements in these structures (as has been found for /a/ in /uCa/ sequences), would have meant absence or hindering of anticipatory laryngeal movements. Another look at Figure 1, however, shows that the larynx, in the /upa/ sequence in normal speech indeed starts moving upwards (frame 876) before bilabial contact (frame 877). The elevation of the larynx becomes remarkable at bilabial release (frame 879). The scenario is comparable in fast speech, where the anticipatory upward movement for the production of the /a/ begins in an /u/ configuration, at frame 474, before lip contact (frame 475), and is steep at release (frame 477).

In short, anticipatory movements of the larynx are detectable in both /aCu/ and symmetrical /uCa/ sequences. They seem to be independent of lip, tongue and jaw anticipatory movements.

4. CONCLUSIONS

From the experimental data analysed in this investigation, two main conclusions can be drawn. Firstly, with regards to interaction between the behaviour of the jaw, the lips and the tongue, displacement and positional correlations between these structures and larynx height have been revealed.

Secondly, such correlations cannot, however, be extended to anticipatory behaviour, since anticipatory laryngeal behaviour appears even when no anticipatory supraglottal gestures are observed.

Such results suggest that gestures that are coupled in given speech tasks, may no longer be correlated in anticipatory timing tasks, and therefore seem to pinpoint the specificity of anticipatory gestures in speech.

5. REFERENCES

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Figure 1: A frame-by-frame analysis of an /upa/ sequence at a normal speaking rate (left) and at a fast speaking rate (right). It can be noticed that relative timing of the tongue-body and laryngeal gestures are across speech rates. See text for details .

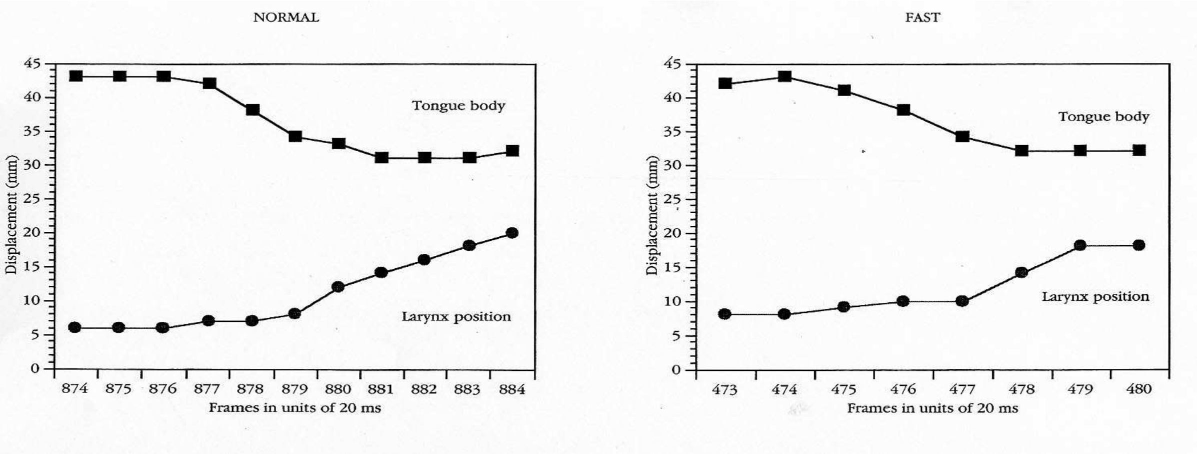

Figure 2: Profile tracings of the production of /u/ (left) and /a/ (right) at a normal speaking rate (continuous line) and at a fast speaking rate (dotted lines). Notice a higher position of the larynx and the hyoid bone in fast speech.

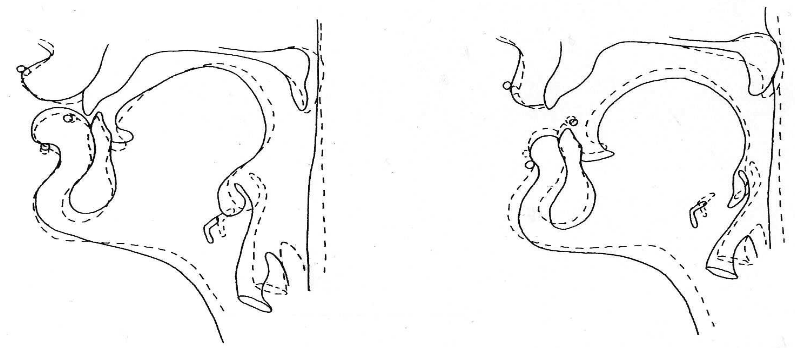

Figure 3: Trajectories of speech structures as a function of time for the /atu/ sequence (see text for details).

Figure 4: Trajectories of speech structures as a function of time for the /aku/ sequence (see text for details).