LARYNGEAL MOVEMENTS AND SPEECH RATE
An X-ray investigation

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ABSTRACT

This is an investigation on the production of VCV sequences with special emphasis on the displacement of the unit larynx-hyoid bone. X-ray data obtained for two subjects at two speaking rates show: that there is a positive correlation between the displacement of the larynx and that of the hyoid bone; that larynx position is lower for high vowels compared with their lower counterparts; that the larynx adopts a higher initial position in fast speech. Varying speech rate allows to uncover robust laryngeal trajectories underlying the production of these VCV sequences.

INTRODUCTION

Elevation and lowering of the entire larynx is usually observed in the action of swallowing, but also during speech production for vocal pitch control and voiced *vs.* voiceless distinctions (Ohala & Eukel, 1978; Lindqvist *et al.*, 1973). In the production of ejectives and implosives (Maddieson, 1984), the entire larynx is not only elevated or lowered respectively, the amount of oral pressure during the production of the desired sound also plays a significant role. However, the contribution of such laryngeal movements in the production of the usual types of speech sounds still needs to be investigated.

This research thus deals essentially with the production of vowel-consonant-vowel sequences (VCV) in French, with particular focus on larynx and hyoid bone positions. The hyoid bone, an isolated structure in the human skeleton, is in fact linked not only to the tongue and the jaw, but also to the larynx through a complex system of muscles and ligaments. It is thus judicious to investigate the behaviour of the larynx in relation to that of the hyoid bone position in the production of VCV sequences (*cf.* e.g. Ladefoged *et al.* 1972; Bothorel, 1979). Data, related to larynx vertical movement in the production of vowels and consonants have been reported in the literature (*cf.* e.g. Perkell, 1969; Hirose, 1977; Barbier, 1979; Bothorel, 1979; Rossi & Autesserre, 1979). However, analyses of laryngeal displacements under speech rate conditions is indeed lacking. Speech rate is varied in this investigation as a perturbing factor of larynx and hyoid trajectories in the production VCV sequences. The present research is thus a contribution to knowledge on the control of robust larynx positions in obtaining vocalic and consonantal gestures across rate variations.

METHOD

X-ray data were obtained for two speakers (one female, MM and one male, AE), at two speaking rates, normal-conversational and fast.

The corpus consisted of 58 sentences (of 4 to 6 syllables) that embedded the target words. Some of these words were specifically chosen to study the production of V_1CV_2 sequences, where V_1 is the high vowel /u/ and V_2 corresponds to the low vowel /a/, and symmetrically, where V_1 is the low vowel and V_2 the high vowel. The medial consonant is either a voiceless or a voiced consonant. Place of articulation was also varied.

The following sentences are a few examples from the corpus:

Nous pâlissons /upa/	*vs.* Il **a pou**rri /apu/
Tout balancer /uba/	*vs.* Il **abou**tit /abu/
Couds ta chemise /uta/	*vs.* Elle **a tout** faux /atu/
Faut t**out da**ter /uda/	*vs.* Faut t'**adou**cir /adu/
Pour t**out ca**sser /uka/	*vs.* Pour **accou**rir /aku/
T'as t**out gâ**ché /uga/	*vs.* Tu y **as goû**té /agu/

The data reported here are thus based on 12 (out of the 58) sentences produced by two speakers at a normal conversational speaking rate and at a self-selected fast rate. Thus there were 6 conditions in all: 2 speakers (one male one female) X 3 places of articulation (bilabial, apical and velar) X 2 speech rates (normal and fast) X 2 voicing contrasts (voiced *vs.* voiceless) X 2 vowel heights (high *vs.* low) X 2 vowel positions (V_1 *vs.* V_2).

With the help of a grid (Bothorel *et al.*, 1986), measurement parameters for larynx and hyoid bone positions during the production of the sequences were determined. A tongue body measurement was also obtained.

RESULTS AND DISCUSSION

Results obtained from a frame-by-frame analysis (50 frames per second) of midsagittal profiles reveal the following facts:

- The position of the larynx is systematically lower for the high vowel /u/ than for the low vowel /a/. This is in line with results obtained by Bothorel (1975) for the dialect of Breton spoken at Argol. In the /upa/ and /apu/ sequences — where the tongue is not recruited for consonant production — the tongue body moves in a direction opposite to that of the unit larynx-hyoid bone: while the tongue body adopts a continuous lowering trajectory in the /upa/ sequences, the unit larynx-hyoid bone adopts a raising movement; patterns are symmetrically different for the /apu/ sequence. In both cases, the result is a maximum distance between tongue body position and larynx-hyoid bone position in the /u/ configuration, and a minimum distance between tongue body position and larynx-hyoid bone position in the /a/ configuration. This finding also holds in fast speech. Figures 1 and 2 show the change in larynx position across VCV trajectories, where V_1 is always the high vowel /u/ and V_2 the low vowel /a/. In Figure 1, at a normal speaking rate (left panel), the position of the larynx, of Speaker MM, during the /u/ configuration is 18 mm on average (frames 863 to 867); it attains a mean value of 24 mm in the /a/ configuration (frames 871 to 876). When speech rate is increased (right panel), the initial setting for the /u/ configuration (frames 544 to 546) now has a mean value of 23 mm that increases to 29 mm for the /a/ configuration (frames 550 to 555). Note that larynx position is higher in fast speech for both vocalic and consonantal configurations, compared with initial adjustments in normal speech. However, the amplitude of laryngeal displacements from the high vowel configuration to the low vowel configuration is comparable across speaking rates (6 mm on average). Also, the medial consonant does not seem to perturb the trajectory of laryngeal displacements from vowel-to-vowel configurations. Globally, these laryngeal adjustments for the different phonetic categories and in the different rate conditions are confirmed for Speaker AE, in Figure 2. Moreover, mean values are highly comparabled as regards the amplitude of laryngeal displacements (6 mm on average).

- The data also show a close relationship between the movement of the larynx and that of the hyoid bone. It should be noted that the displacement of the hyoid bone is diagonal in nature (an upward-backward movement), and that higher correlations between the vertical displacement of the larynx and the hyoid bone are obtained with the backward component of hyoid displacement. Figures 1 and 2 show similarities in the trajectories of the two structures, with a higher structural coupling between larynx displacement and hyoid bone horizontal movement. Here also, consonantal configurations do not seem to significantly perturb larynx and hyoid bone trajectories.

- As concerns consonant production, results on a whole, did not show any coherent behaviour related to voicing contrast or to place of articulation, for the 2 subjects investigated. However, correlations between the larynx and the hyoid bone are more consistent for lingual consonants.

CONCLUSIONS

Apart from corroborating earlier findings, these results show that overall patterns based on larynx and hyoid bone displacements are resistant to speech rate conditions. Such findings seem to indicate the robustness of the depicted trajectories in the production of VCV sequences. Nonetheless, the initial setting of the larynx and the hyoid bone at a higher position in fast speech, compared with that of the normal speech condition, seems to suggest that increasing speaking rate requires a different configurational setup presumably necessary for speeding up of the articulatory task. It would thus be worthwhile investigating the relationship between fast speech movements (and their kinematic properties such as velocity, acceleration...) and articulatory configurations.

As the set hyoid-larynx is inversely correlated with tongue body vertical displacement, and therefore with vowel height, the data systematically rejects the "tongue-pull hypothesis", at least in the version that relates tongue body raising with the hyoid bone and the hard tissues of the larynx.

Vowel-to-vowel trajectories of the larynx and the hyoid bone are never significantly perturbed by the medial consonant, even when the medial consonant requires a lingual gesture for its articulation. It is infact vocalic trajectories that seem to impose their movement characteristics on consonantal configurations (*cf.* e.g. Vaxelaire, 1993), thus confirming the robustness of vocalic gestures in comparison with consonantal ones (Öhman, 1966).

The acoustic consequences of the vertical displacement of the larynx and of the hyoid bone on the vocal tract are being examined in relation to perturbations in midsagittal and area functions.

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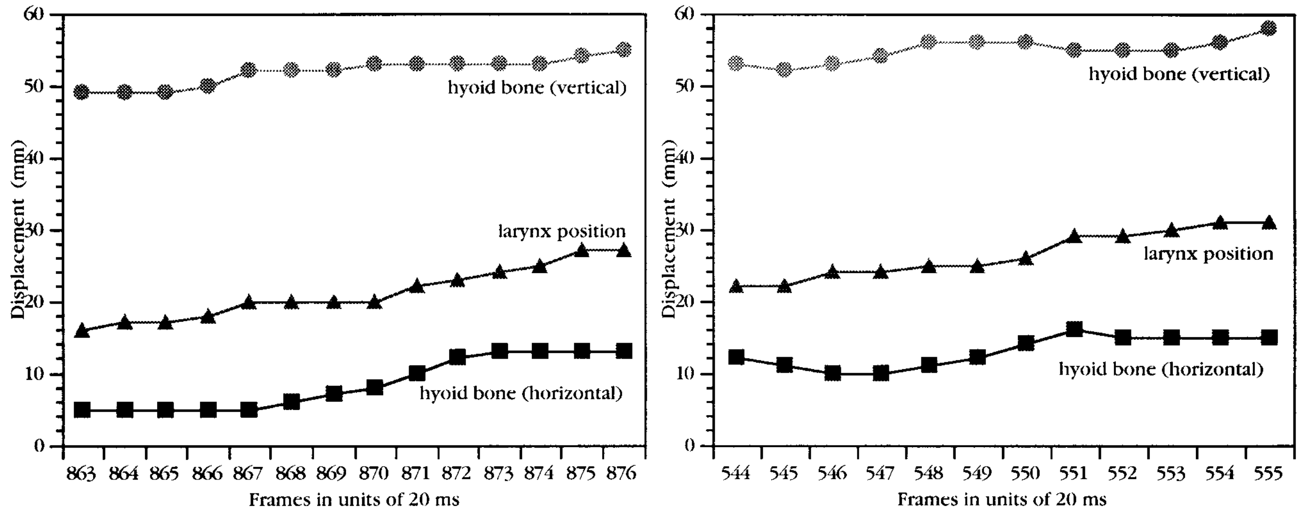

Figure 1: Frame-by-frame analysis of the sequence /uta/ in normal speech (left panel) and fast speech (right panel). Apical contact corresponds, respectively, to frames 868-870 in normal speech and to frames 547-549 in fast speech. Speaker MM.

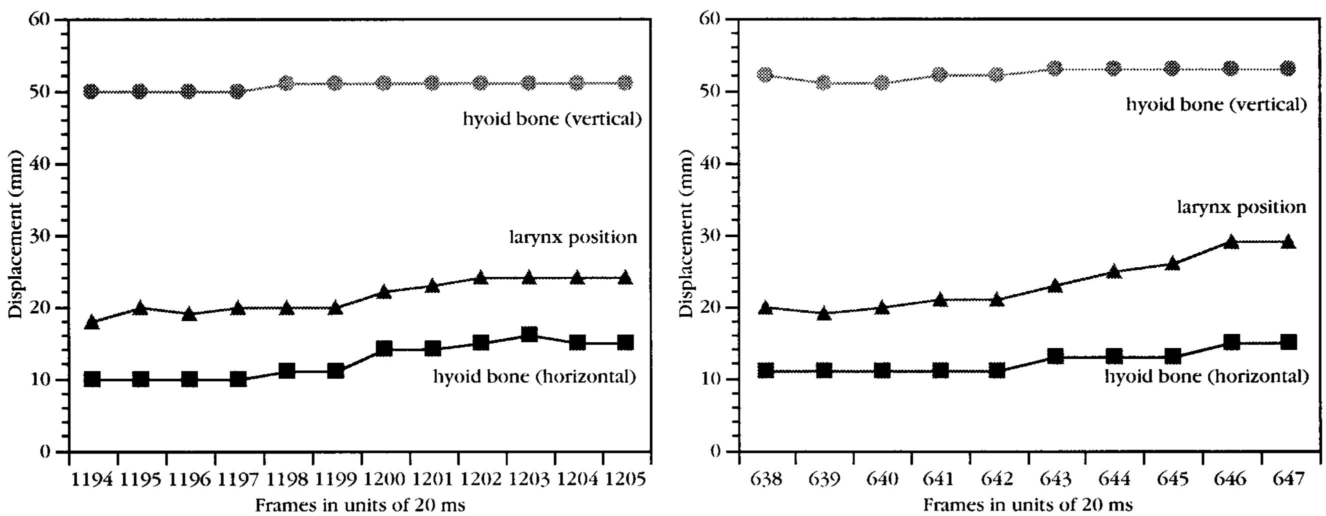

Figure 2: Frame-by-frame analysis of the sequence /uka/ in normal speech (left panel) and fast speech (right panel). Tongue dorsum contact corresponds, respectively, to frames 1197-1199 in normal speech and to frames 641-642 in fast speech. Speaker AE.