PHASE MODIFICATIONS IN TONGUE MOVEMENTS ACROSS SPEECH RATE VARIATIONS: INFLUENCE OF CONSONANTAL ARTICULATION.

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ABSTRACT

A corpus of CV_1CV_2 sequences is analysed in order to emphasize the concept of synergy among gestures in speech production. The vertical movements of tongue dorsum were measured for V_1=[a] and V_2=[u], and for two consonants [d] and [g] which production recruit respectively this articulator at two quite different levels. Results are interpreted in terms of changes of (1) the consonant-vocalic and (2) the peak velocity phasing, for raising and lowering gestures.

1. INTRODUCTION

Speech production implies a spatial and temporal coordination of different articulatory gestures. The concept of synergy, introduced by Haken [3] in the field of motor control, could be appropriate to characterize and predict some articulatory patterns of speech production. In their work, Kelso et al. [5] explained the jump from the production [ipip] to the production [pipi] as the speech rate strongly increases, within this theoretical framework. They introduced the concept of intergestural phasing, and identified this jump as an obvious phasing restructuration between lip and glottal gestures.

In the present study, we propose to analyse this synergy phenomenon in a quite different paradigm. The behaviour of the consonant-vowel phasing in CV_1CV_2 sequences is observed for consonants involving different articulators. This paper presents preliminary results for two consonants [d] and [g].

2. METHOD

2.1 Experimental procedure

The corpus studied is designed for the observation of the vertical movements of tongue dorsum. It consists in the repetitions of isolated productions [au], [dadu], [gagu], for which we assume that tongue dorsum movement is pertinent to describe the [a] to [u] articulation. The consonants [d] and [g] are chosen, because of their two extreme behaviours towards this articulator: [d] production does not recruit the tongue, whereas the [g] articulation recruit mainly the tongue dorsum. Thus, in a [gagu] sequence, the vocalic and consonantal gestures are produced with the same articulator.

The task consisted in 10 repetitions of each sequence, produced at normal and fast speaking rates by a French male speaker. Tongue dorsum displacement was monitored at an 1 kHz rate with a computerized ultrasound transducer system (see [4]). Simultaneously the acoustic speech signal was recorded at the same rate.

2.2 Data collection

As data are available for one articulator only, namely the tongue dorsum, the choice of temporal events defining the vocalic and consonantal phases was not obvious: the events related to consonantal gestures were detected on the speech wave. In all cases the reference is the underlying vowel-to-vowel movement, divided into two components, the raising gesture ([a]-[u]) and the lowering gesture ([u]-[a]). For the first component, the consonantal movement towards the

occlusion is in the same raising direction as the vocalic movement; the release movement is in the opposite direction. In the second component ([u]-[a] transition), the relations are reversed. It is thus interesting to detect these two consonantal events (closion and release) inside the vocalic phase. For each vocalic transition ([a]-[u] and [u]-[a]) the boundaries of the vocalic phase correspond to the points of zero velocity of the tongue dorsum raising gesture (See Fig. 1). We define so for each movement (raising and lowering) one vocalic phase and two consonantal phases, the "occlusion phase" and the "release phase".

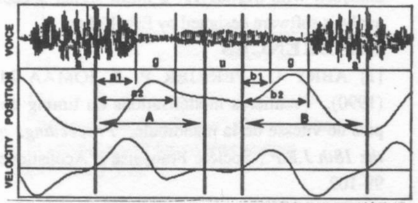

Fig.1 shows ultrasound recorded movement and velocity profile of tongue dorsum and the corresponding acoustic speech signal, during the production of /gagu/, at normal speaking rate. Duration A determines the raising gesture for the transition [a]-[u], in which a1 ("the occlusion phase") and b2 ("the release phase") are plotted in percentage. Duration B determines the lowering gesture for the transition [u]-[a], in which the same phases ("the occluion phase"=b1) and ("the release phase"=b2) are plotted.

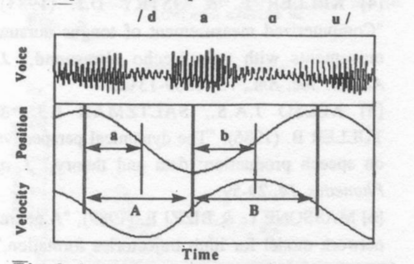

Fig.2 shows ultrasound recorded movement and velocity profile of tongue dorsum and the corresponding acoustic speech signal, during the production of /dadu/, at fast speaking rate. Duration A and B were measured assessing that points of zero velocity determine the initiation and termination of the gesture. The acceleration phases, duration a and b are plotted in percentage.

The second point of our study focuses on the kinematic changes of the raising and lowering gestures depending on the consonant and on the speech rate. In this aim and according to different studies that advocate the importance of velocity profiles in motor control analysis (see [1], [2] and [6]), the occurence of the velocity peak between two successive points of zero velocity is measured (see Fig. 2).

3. PRELIMINARY RESULTS AND DISCUSSIONS

3.1. Consonantal-vocalic phasing

The data obtained for the raising gesture are presented in Fig. 3 and 4. The examination of the time proportion of the release phase for [dadu] (Fig.3), reflects obviously no significant modification with changes in speech rate (mean values: 74.9 vs 74.2); on the contrary, for [gagu], we observe an obvious increase of this time proportion for the fast rate. Such a behaviour can easily be explained by a time constraint on the consonantal hold: this durational value must be sufficient for a good perception of the consonant; hence the vocalic durations are more affected by the change in speech rate than the consonantal one. This phenomenon becomes indeed more obvious, when vowel and consonant are produced with the same articulator. At the same time the proportion of the occlusion phase decreases in fast rate for both consonants (Fig. 4). Moreover, whereas the differences between [d] and [g] are not significant (α>0.10) at normal rate, they become highly significant at fast rate (α<0.01), which means that the articulation of the consonant induces different behaviours when speech rate increases. As the raising vocalic gesture ([a]-[u]) and the consonantal raising occlusion gesture occur simultaneously, the delay between the onsets of these two gestures tends to decrease significantly, especially when the same articulator is recruited. These results attest, in the case of a monoarticulator production, a tendency towards synchronization of the two raising gestures, when the speech rate constraints are strong. Hence, it supports the idea of a synergetic production.

The same kind of observations can be made for the release phase in the lowering vocalic transition. For both consonants, the proportion of the release phase increases (Fig. 5), as the proportion of the occlusion phase decreases (Fig. 6). But these behaviours are hardly significantly different for the occlusion phase ($\alpha > 0.05$) and highly significantly different for the release phase ($\alpha < 0.01$). The delay between the onsets of the lowering vocalic gesture and the consonantal one remains important, due to the constraints on the consonantal hold duration; but a tendency towards synchronization of these two gestures could well furnish a reliable explanation for the more important reduction of the consonantal hold, in the case of a monoarticulator production. This phenomenon supports the hypothesis of synergy among consonantal and vocalic gestures.

3.2. Kinematic changes

This investigation is essentially based on the duration of the lowering and raising gestures in which the occurence of peak velocity is observed (see Fig. 2). In both gestures, these acceleration phases are plotted in Fig.7 & 8. At normal rate, and for both gestures, our results show an important dispersion of the data for [au] and [dadu]; the constraints seem obviously stronger for the [gagu] production. For fast speech rate, the data converge towards the same value in all cases: the velocity profile tends to become symmetric as in optimized movements minimizing the jerk (see [7]). This variation is however less important in [gagu]. An increase in speech rate seems thus to produce an optimization of the coordination between vocalic and consonantal gestures. This optimization is already perceptible for [gagu] at normal rate.

3.3. First conclusions

These two kinds of data seem to attest the existence of synergy between consonantal and vocalic gestures when the same articulator is recruited: (1) the consonant-vowel phasing is specific for this kind of production; (2) in this last case, the kinematic properties reflect a tendency towards optimization. These results and conclusions are preliminary. A further study will be made with other consonants as [R], [b], [k], to confirm the assumptions resulting from the observation of [d] and [g].

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REFERENCES

[1] ABRY C., PERRIER P. & JOMAA M. (1990), "Premières modélisations du timing des pics de vitesse de la mandibule," *Proceedings of the 18th J.E.P.*, Société Française d'Acoustique, 99-102.

[2] BULLOCK D. & GROSSBERG S. (1988), "Neural dynamics of planned arm movements: Emergent invariants and speed-accuracy properties during trajectory formation," *Psychological Review, 91*, 1, 49-90.

[3] HAKEN H. (1977), "*Synergetics: an introduction. Nonequilibrium phases transitions and self-organization in physics, chemistry, and biology,*" Heidelberg, Springer-Verlag.

[4] KELLER E. & OSTRY D.J. (1983), "Computerized measurement of tongue dorsum movements with pulsed-echo ultrasound," *J. Acoust. Soc. Am., 73*, 1309-1315.

[5] KELSO J.A.S., SALTZMAN E.L. & TULLER B. (1986), "The dynamical perspective on speech production: data and theory," *J. of Phonetics, 14*, 29-59.

[6] MASSONE L. & BIZZI E. (1989), "A neural network model for limb trajectories formation," *Biol. Cybern.*, 1-9.

[7] NELSON W.L. (1983), "Physical principles for economies of skilled movements," *Biol. Cybern.*,46,135-1470.

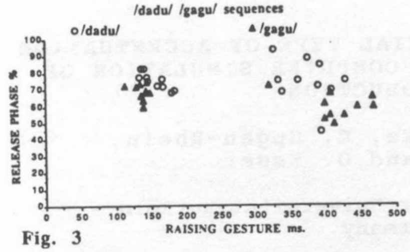

Fig. 3

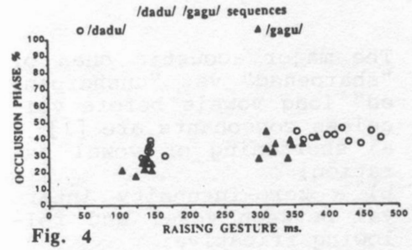

Fig. 4

Fig. 3 & 4
"Release" and "occlusion" phases plotted in percentage of the raising gesture (see text § 3.1)

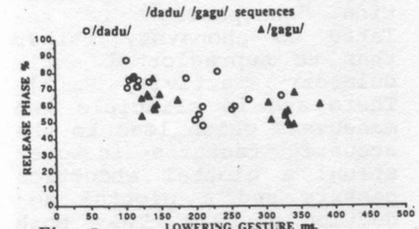

Fig. 5

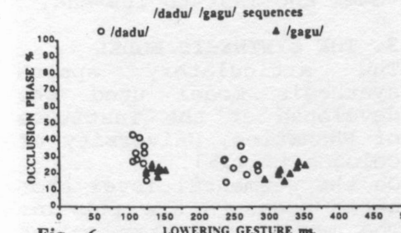

Fig. 6

Fig. 5 & 6
"Release" and "occlusion" phases plotted in percentage of the lowering gesture (see text § 3.1)

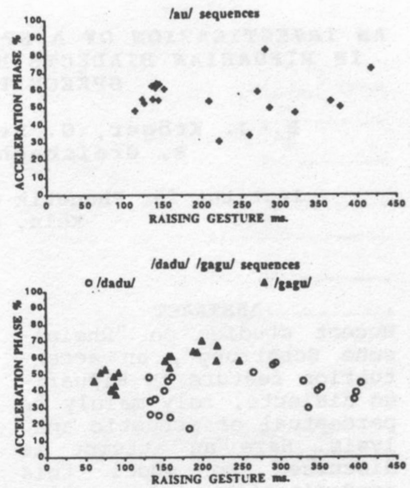

Fig. 7
"Acceleration phase" plotted in percentage of the raising gesture (see text § 3.2)

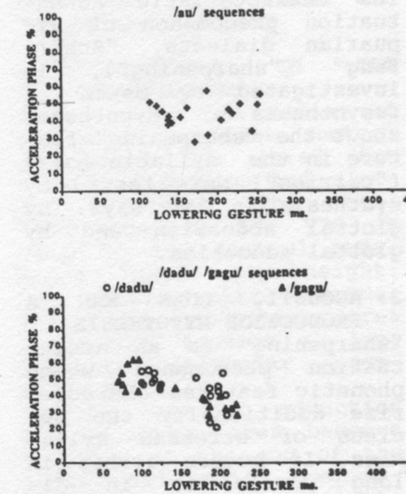

Fig. 8
"Acceleration phase" plotted in percentage of the lowering gesture (see text § 3.2)