A study of the effect of speech rate on the articulation of labiovelar stop consonants in fongbe: an EPG and aerodynamic approach

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Introduction

Notes on Fongbe and studies on labiovelar stop consonants

Attempts have been made to describe some of the uncommon sounds that occur in the languages of the world. One such sound is a stop consonant which is referred to with terms as varied as: double articulation, doubly articulated stop, labiovelar stop, double articulated plosive, coarticulated stop, labiovelar articulation, labial-velar double articulation, labial-velar stop. Indeed, the sound in question is a stop consonant, an oral stop consonant. The most common of its type is made on an egressive pulmonic airstream mechanism. It can be voiceless as well as voiced.

It is the purpose of the present study to investigate the nature of the labial-velar stops in Fongbe. Fongbe is the language of the Fon people in South Benin (West Africa). It is one of five sections into which the Gbé continuum has been broken down. Gbé is classified under Kwa languages which, in turn, belong to the Niger-Kordofanian family.

This will be done in the light of previous research and experiment that have been undertaken by some investigators (such as Sarah Garnes and Peter Ladefoged) and whose object has been to make statements on both the articulatory and acoustic characteristics of labial-velar sotps in languages like Yoruba and Ibibio. As far as plain oral stops are concerned, they are produced in the following way : the soft palate is raised so that the nasal cavity is closed. There is an articulatory closure, the location of which depends upon the active and the passive articulators involved, which in turn effect the quality of the oral stop concerned. It can be labial, dental, alveolar, retroflex, palatal, velar, uvular, glottal. Therefore the airstream is completely obstructed. Pressure then builds up behind the closure and an oral stop is formed. When the articulators come apart, the airstream is released in a burst which is not always audible. This processus is best explained by the three-phase distinction which is found in phonetic theory literature. Abercrombie (1967:147) for example, speaks of the three phases in the production of oral stops and says that this distinction is important in the function of stops in connected speech.

The three phases are :
– *phase i = the shutting phase, leading to*
– *phase ii = the closure phase, followed by*
– *phase iii = the opening phase.*

We can see, in the Fongbe consonant chart, that plain oral stop consonants occur in the language. Those have been clearly described as using the same airstream mechanism, that is the egressive pulmonic airstream mechanism. They then display much of the pattern described in plain oral stops in the languages of the world. The sounds concerned are : / p, b, t, d, ɗ, c, j, k, g /, that is nine plain oral stops in number.

As to /kp/ and /gb/ which also appear in the stop inventory of Fongbe, little is known about the mechanism of their production apart from tentative, uncommitted descriptions (Akoha, 1991 ; Capo, 1993). We can only note that Fongbe has both voiceless and voiced double articulated stops, which at first seem to be in contrast with voiceless bilabial /p/ and voiced bilabial /b/ respectively and also in contrast with voiceless velar stop /k/ and voiced velar stop /g/ respectively.

General surveys of African languages often list a series of traits which are said to be characteristics of sub-sahara Africa as a linguistic area. These enumerations tend to include, among other things, phonological features such as tone, click sounds, implosives, labial-velar stops and the prevalence of open syllables. Of the characteristics many are in fact found in other world areas. For instance, a preference for open syllables or tone. A few, however, are confined to Africa such as click sounds which are not of wide distribution since they are found only in South Africa. Others are common in Africa and are found in other places. An example is labial-velar stops which are the sounds under discussion here. Phoneticians often compare labial-velar stops with plain stops with a view to working out any significant similarities or differences ; Welmers, quoted by Greenberg, states that :

"There is an interesting geographical distribution of doubly articulated stops in Africa. They occur primarily in languages grouped in a strip from the Atlantic into the Central African Republic across the West African bulge and somewhat farther east." (Greenberg, 1983:5).

Ian Maddieson (1984) for his part, observes that stops occur in the inventory of all known languages and have appropriately been regarded as the optimal consonant (Jakobson and Halles, 1956:42). But he goes on to observe that labial-velar stops are only found in twenty languages and represent 6.3 per cent of the languages investigated and mostly in African languages such as Ibibio and Yoruba.

Greenberg (1970) says that here is an area outside of Africa in which these sounds are found and that is the Kate ono group of non-Austronesian (Indo-Pacific) languages in north-eastern New Guinea and some Autranesian languages of Melanesia have the sounds. In this respect, this remark by Greenberg seems important which says that :

"Moreover for many languages we still have only word lists. In the absence of systematic phonology the non-occurrence of these sounds cannot with certainty be deduced from their absence in a specific list, only their existence from their occurrence." (Greenber, 1983:5).

Hypothesis

One trend in the phonetic literature is to regard and treat the structure of labiovelar stop consonnant as behaving like clusters. In this respect, attempts have been made to explain the patterns of the gestures involed in the production of these complex articulations.

One such attempt is the use of the EPG technique correlated with aerodynamic technique to account for the spatio-temporal organization of articulatory gestures during the production of labiovelar stop consonants.

It is well accepted nowadays that the EPG technique is used to obtain quantitative and qualitative data on patterns of lingual contacts with the hard palate during continuous speech (Hardcastle *et al.* 1989). The technique indicates the presence of contact while not providing any direct information on the nature of the contact of the tongue with the palate.

Because of the limitation of the EPG technique, one has to resort to an aerodynamic technique to acquire information on labial and velar or post-velar gestures to complement information obtained using EPG. So, this is very appropriate when investigating coarticulatory effects in a VCV environment. Previous studies reporting on gestural timing in terms of EPG patterns and /or air pressure include Ladefoged (1962) who accounts for the behaviour of labiovelar stops in some African languages. D. Silverman and Jongho Jun (1994) investigate stop consonant clusters using aerodynamic techniques only. As to Marchal and Meynadier (1995), they investigated coarticulation in /kl/ sequences in French using a multisensor approach involving EPG and oral airflow. Demolin (1992) examines labiovelar stops found in some central African languages and he draws on aerodynamic parametres of oral airflow and pharyngeal pressure as well as video images showing the lips and lower jaw movement to account for the characteristics of labiovelar stops in three central African languages. His conclusions as drawn from the pharyngeal pressure traces, are that in the articulation of these complex sounds, there is a front - back movement of the tongue body accompanied sometimes by a lowering of the larynx on the one hand and a specific lower jaw movement different from the one involved in simple velar or bilabial stops. Finally Connell examines the status of the sole voiceless labiovelar stop /kp/ found in Ibibio, a Nigerian language and he provides acoustic, aerodynamic, laryngographic as well as EPG accounts, stating that the labial release is achieved subsequent to the velar one.

In the present study, by means of EPG and aerodynammic techniques, we investigate the effect of speech rate on the spatio-temporal organization of the labiovelar stop consonants /kp/ and /gb/ in Fongbé. To our knoweledge, no previous study has reported on this factor. To account for the degree of this effect, we consider as relevant : i/ timing of the tongue body and of the labial closure and release together with the articulatory phase durations as indicated by onset, closure and release corresponding to the volume or rarefaction of air pressure and airflow relative to plain velar consonants, ii/ magnitude of the velar constriction in both /kp/ and /gb/, that is in terms of the number of activated electrodes as compared with simple velar counterparts.

Material and Method

Subject, recording and data acquisition

The sole subject was an adult male who is a native speaker of the Ouidah dialect of Fongbé. Eight Fongbé real words were embedded in a carrier sentence. They were repeated ten times at normal speech rate and at fast speech rate yielding 160 tokens. The words were : gì, gbì, kì,ìkplìlɛ, gè, gbè, kè kpè. Each word was preceded by vowel /i/ or /e/ so that the vocalic symmetric context obtained is of the /CiC/ or /CeC/ pattern where C is either a velar consonant or a labiovelar consonant. Syllables containing the velar or labiovelar consonant have either a low or high tone and carries the sentence stress. Only data for five repetitions were segmented.

The multisensor, multichannel system developped in Reading (Hardcastle *et al.* 1989 ; Gibbon *et al.*, 1993) was used to acquire EPG, intraoral pressure, pharyngeal pressure, oral airflow as well as acoustic data. The sound signal was sampled at 20 khz using a Sennheiser MK 40 P48 microphone with simultaneous recording on a Sony DAT DTC - 1000ES. For this study we only processed the data supplied by the audio, EPG, intraoral and pharyngeal pressure channels. A signal editor named Phonedit was used to simultaneously and synchronously display the various articulatory and aerodynamic parameters and to carry out both segmentation and labelling.

Segmentation and labelling

Because of the nature of the data, segmentation was done in the following way: segmentation of /k/ and /g/ was based on the EPG frames and information on the labial release part of /kp/ and /gb/ was drawn from the variations in both the intraoral and pharyngeal pressure as well from the oral airflow trace. So the following phases were identified and labelled : the onset of the closure, the complete closure, the release of the closure. A script was specially designed which permitted us to observe and quantify the activated electrodes in each phase corresponding to the completing of the velar gesture.

The EPG data was segmented using the following labels :

– ACE (or 1) which identifies the Approach to the Closure and which indicates the approach of the articulatory target (the velar occlusion). It is placed at the point where the first electrode or group of electrodes start coming together from each side at various places on the palatogram in order to achieve the closure in the posterior rows.

– SCE (or 2) which identifies the exact moment when the stop closure is achieved. This label is placed on the first palatographic image where there is complete closure, which corresponds to the presence of a horizontal bar of activated electrodes in one or more posterior rows.

– SRE (or 3) is the label we used which marks the stop release of the closure as it is measured from the EPG data. It is placed on the last EPG frame showing a complete closure.

As a matter of fact, measurements were taken from both the oral airflow trace and intraoral and pharyngeal pressure trace and correlated with those taken from the EPG data.

Results and discussion

Timing of closure and release/Articulatory phase duration

Measurements of the total duration of both simple /k/ and /g/ and complex /kp/ and /gb/ show a specific pattern for each speech rate.

Consequently, /k/, in normal speech rate, has a mean duration of 165 ms and /kp/ has a mean duration of 172 ms. This is significant of the fact that both /k/ and/kp/ are programmed simultaneously and that, as Sara Garnes says, /kp/ articulation constitutes a single unit of timing.

In fast speech rate, /k/ has a mean duration of 53 ms and /kp/ has 64 ms with a standard deviation of 14.5. This clearly shows the effect of hypoarticulation which yields reduction and causes the overall duration of the consonant to be shorter than in the case of normal speech. Tables I and II show the duration of consonants and figures 1, 2, 3 and 4 show speech signals and spectrograms for /igi/, /igbi/, /iki/, /ikpi/ for both normal and fast rates of speech.

Table I. Showing the mean duration (in milliseconds) of the simple velar and labiovelar consonant in /e/ context

Consonants	Normal	Fast
/k/ [kɛ̀] "hernia"	148	53
/kp/ [kpè] "charm"	146	65
/g/ [gè] "toes"	125	50
/gb/ [gbɛ̀] "voice, speech"	110	48

Table II. Showing the mean duration (in milliseconds) of the simple velar and labiovelar consonants in /i/ context

Consonants	Normal	Fast
/k/ [kì] "bamboo"	165	76
/kp/ [ikpìlɛ] "place name"	172	75
/g/ [gì] "maize paste"	174	106
/gb/ [gbì] "to defy"	142	39

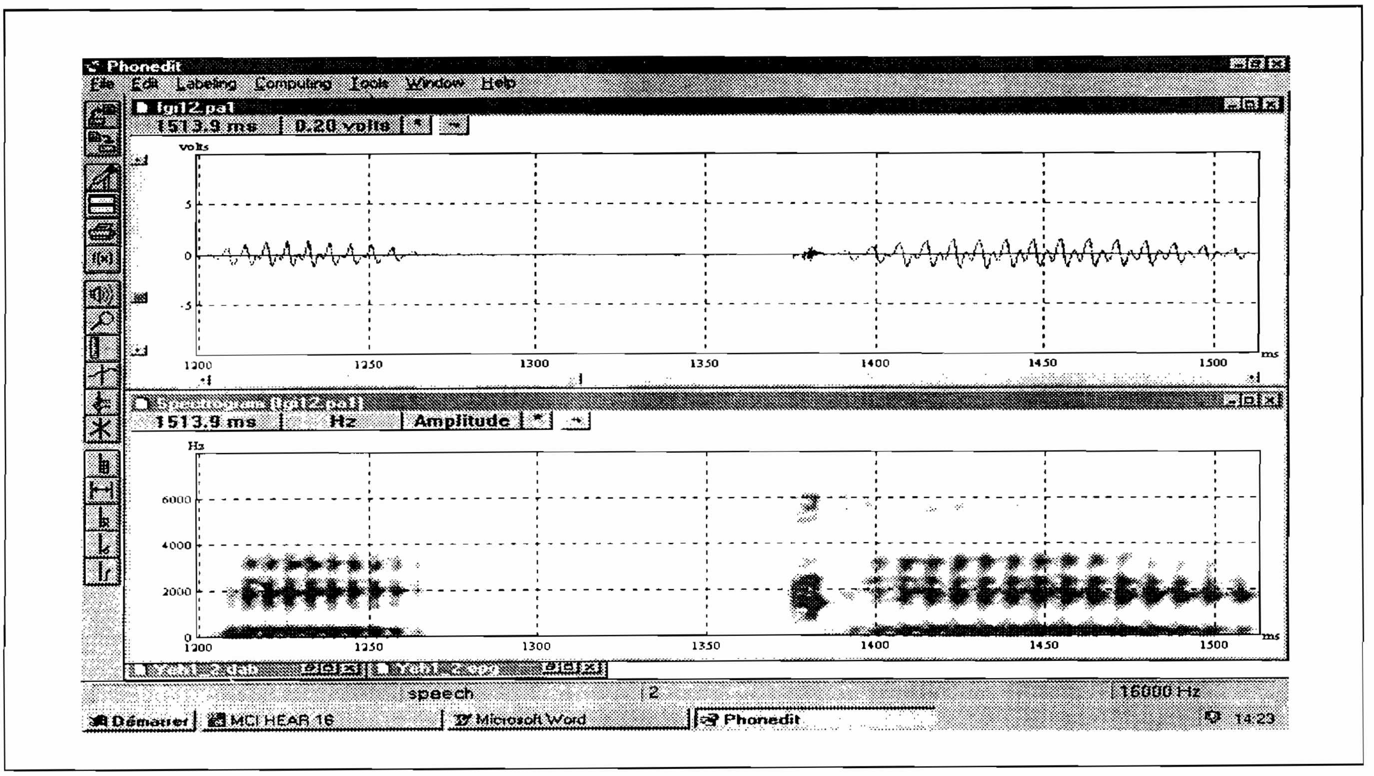

Figure 1: showing spectrogram of /igi/ in normal rate of speech.

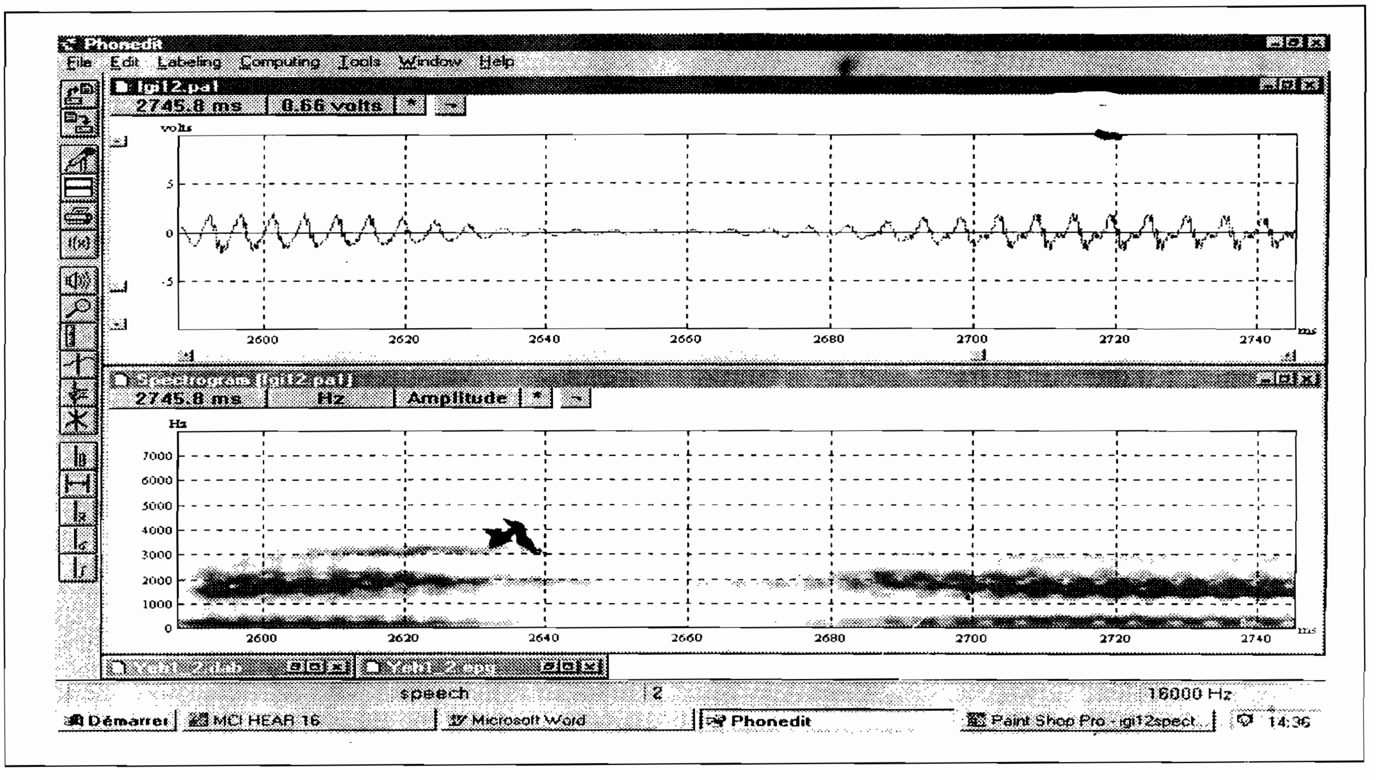

Figure 1 (bis) : showing spectrogram of /igi/ in fast rate of speech.

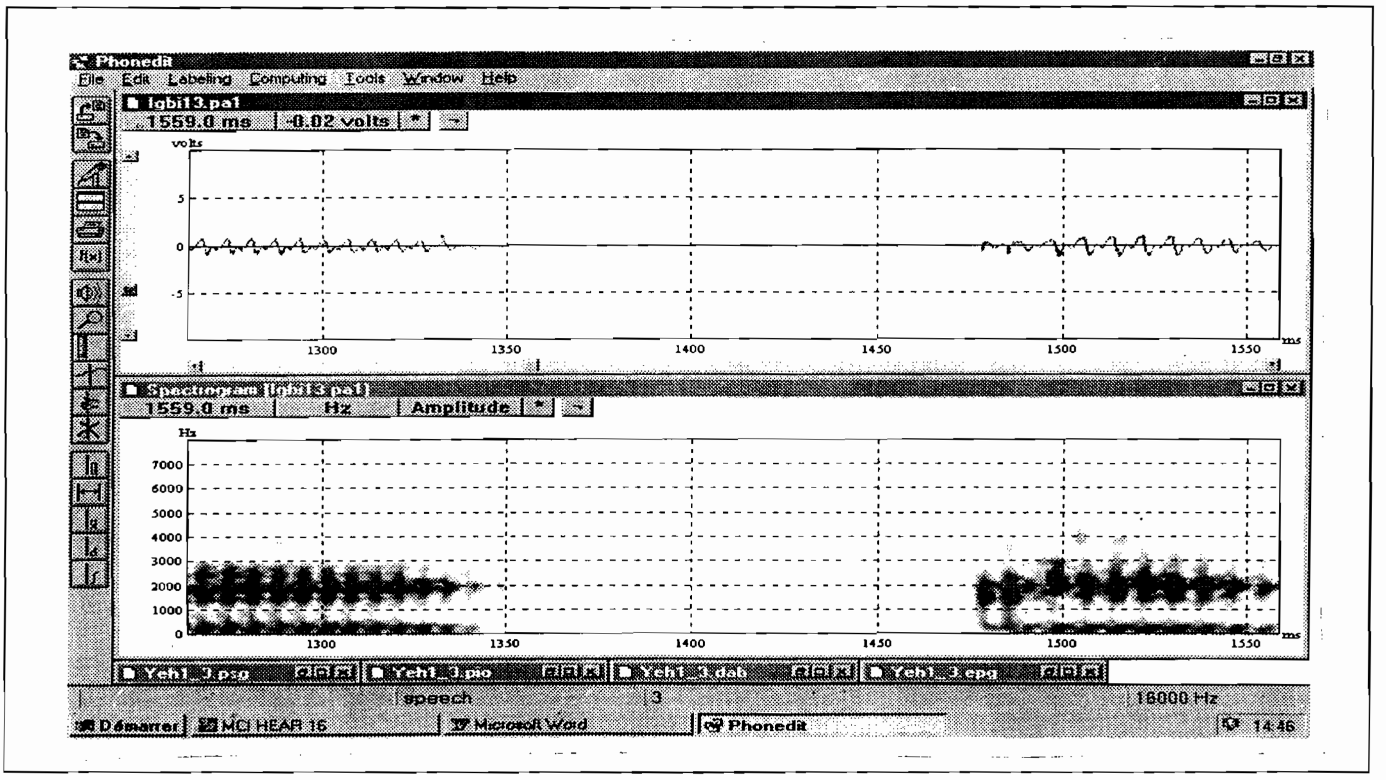

Figure 2 : showing spectrogram of /igbi/ in normal rate of speech

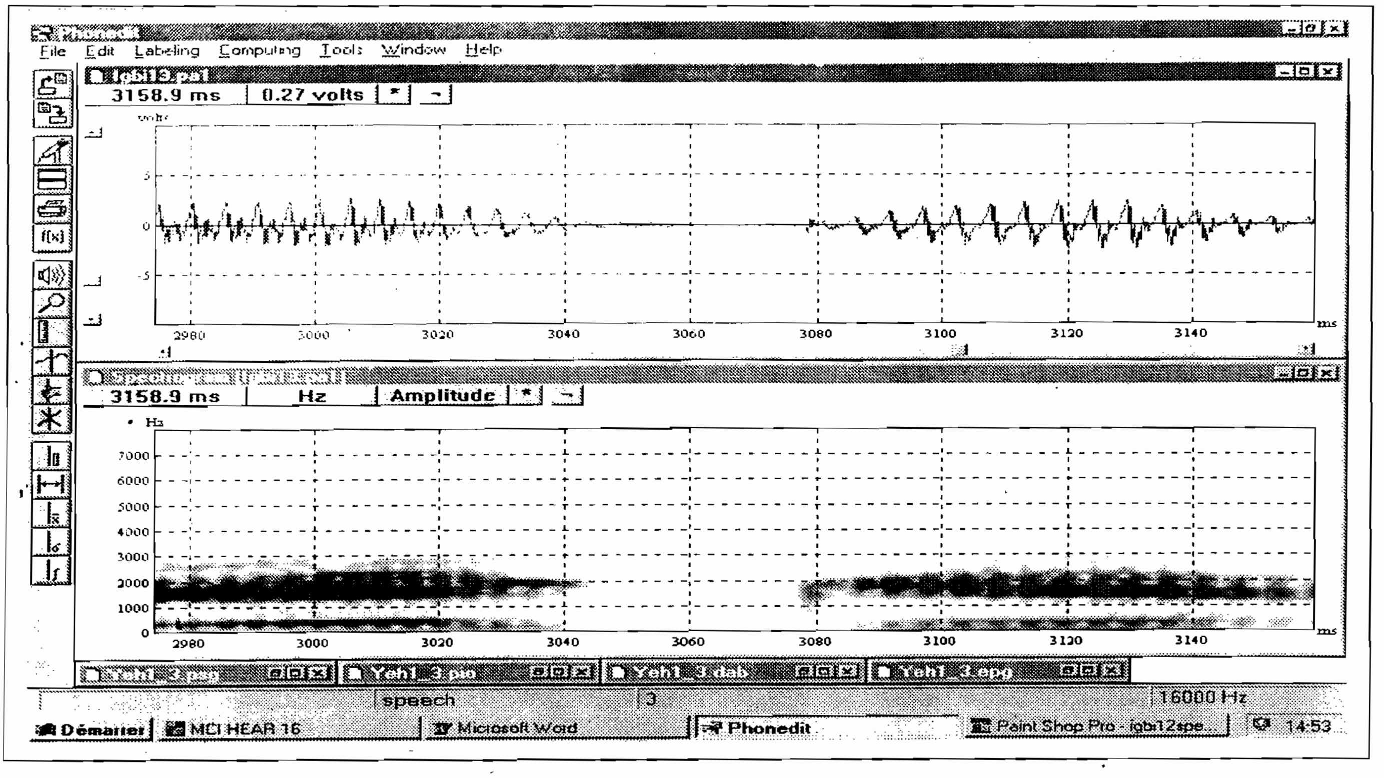

Figure 2 (bis) : showing spectrogram of /igbi/ in fast rate of speech

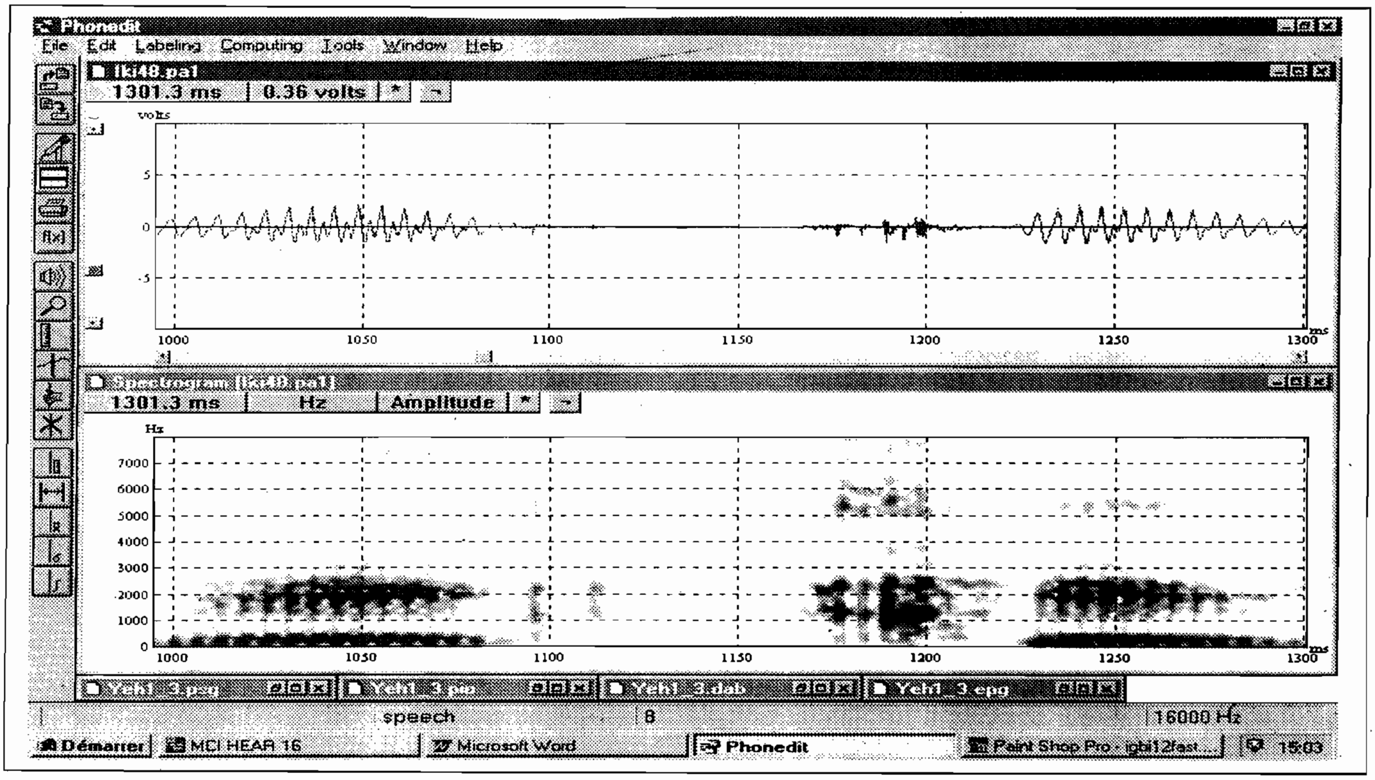

Figure 3 : showing spectrogram of /iki/ in normal rate of speech

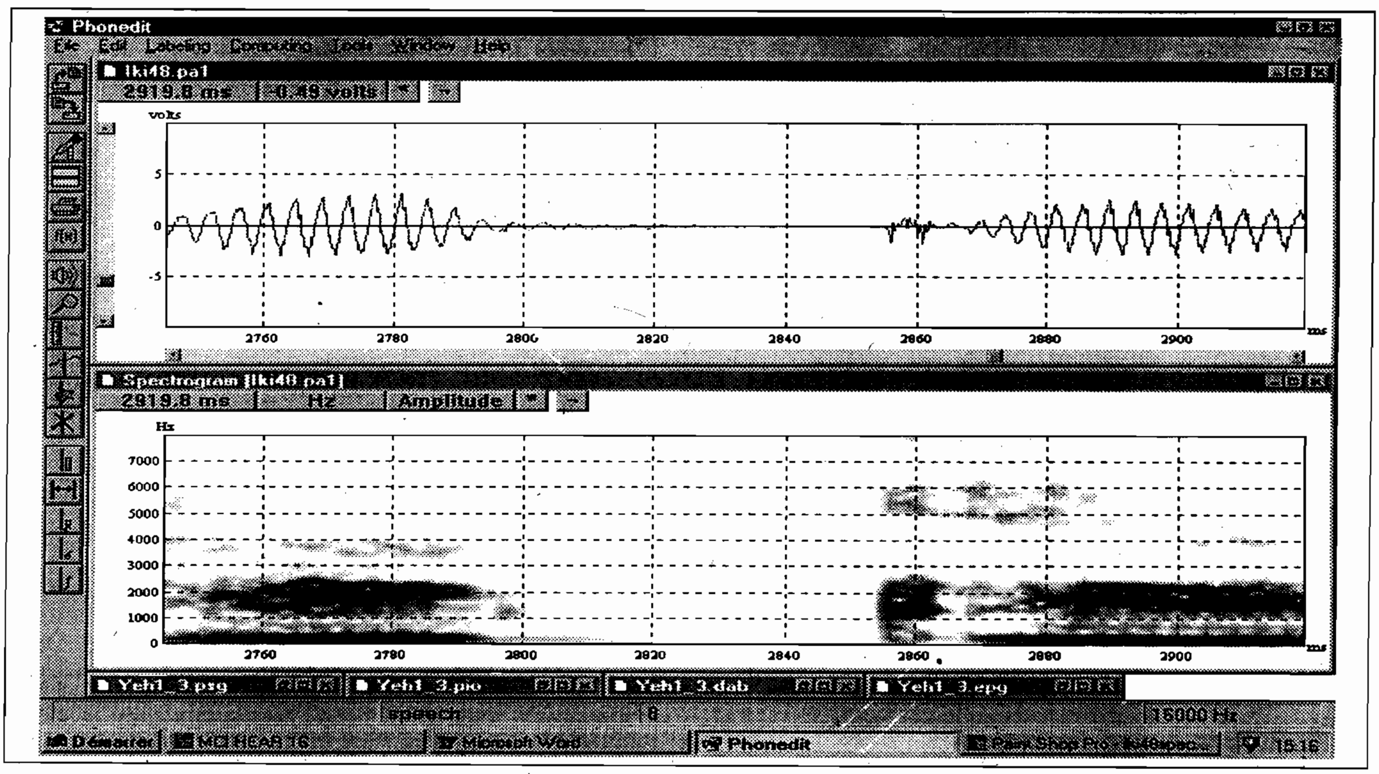

Figure 3 (bis) : showing spectrogram of /iki/ in fast rate of speech

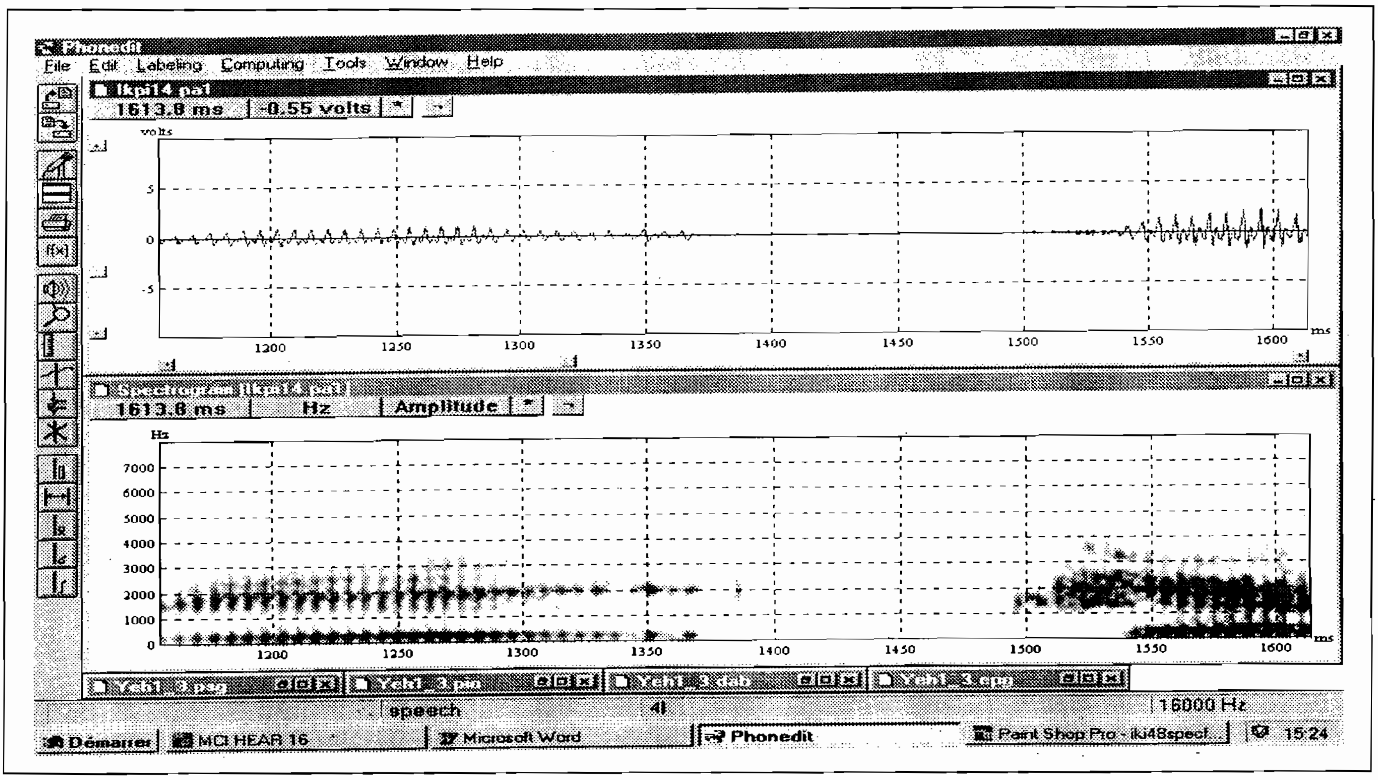

Figure 4 : showing spectrogram of /ikpi/ in normal rate of speech

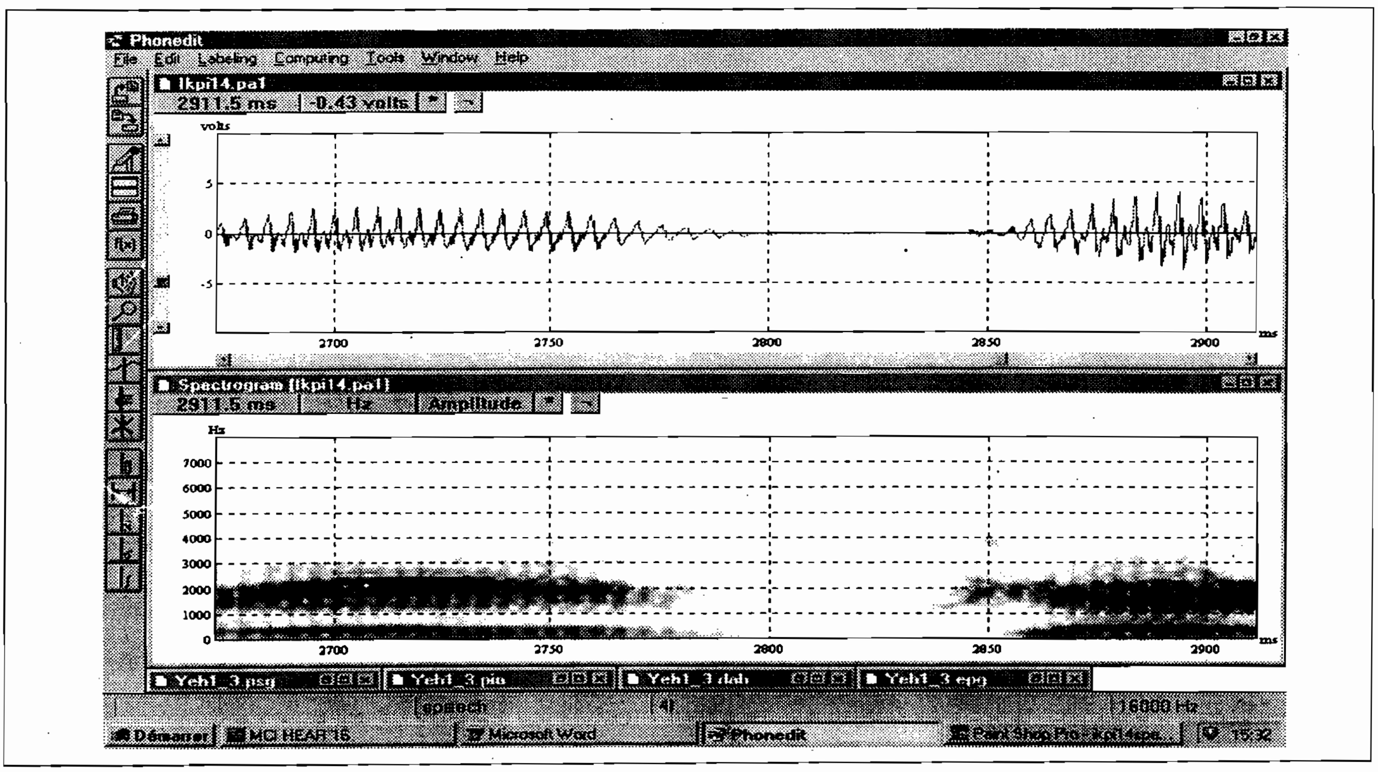

Figure 4 (bis) : showing spectrogram of /ikpi/ in fast rate of speech

As shown for Ibibio and Mangbetu by Connel and Demolin respectively, our data also provide evidence for the existence of asynchrony in the closure and release of the articulation of Fongbe /kp/ and /gb/. This is indicated by acoustic data which shows that F2 transition associated with the release of the labio-velar stop is negative and then is a typical labial transition. In fact, the consonant release occurs at a frequency lower than the adjacent vowel frequency. It is thus clear that the labial release is achieved after the velar one has occurred. Further evidence of the asymmetry of the two gestures is provided by the combination of EPG and aerometric techniques. This is seen when we consider the period of velar closure as shown by the velar contact on the EPG frames and the period of closure for the entire stop consonant as associated with the speech signal. There is a substantial difference between the velar closure duration (62 ms) and the total duration of the stop consonant (130 ms). When we consider aerometric data, the velar part of /kp/ or /gb/ shows a closure duration of 62 ms (measured from /gbe/ as we take into account the duration of positive pharyngeal pressure) and the volume of oral air flow whereas the total duration of the stop consonant is estimated at 174 ms as measured from the speech signal. Further evidence is seen in the decrease in the intraoral pressure as shown in figures 5 and 6.

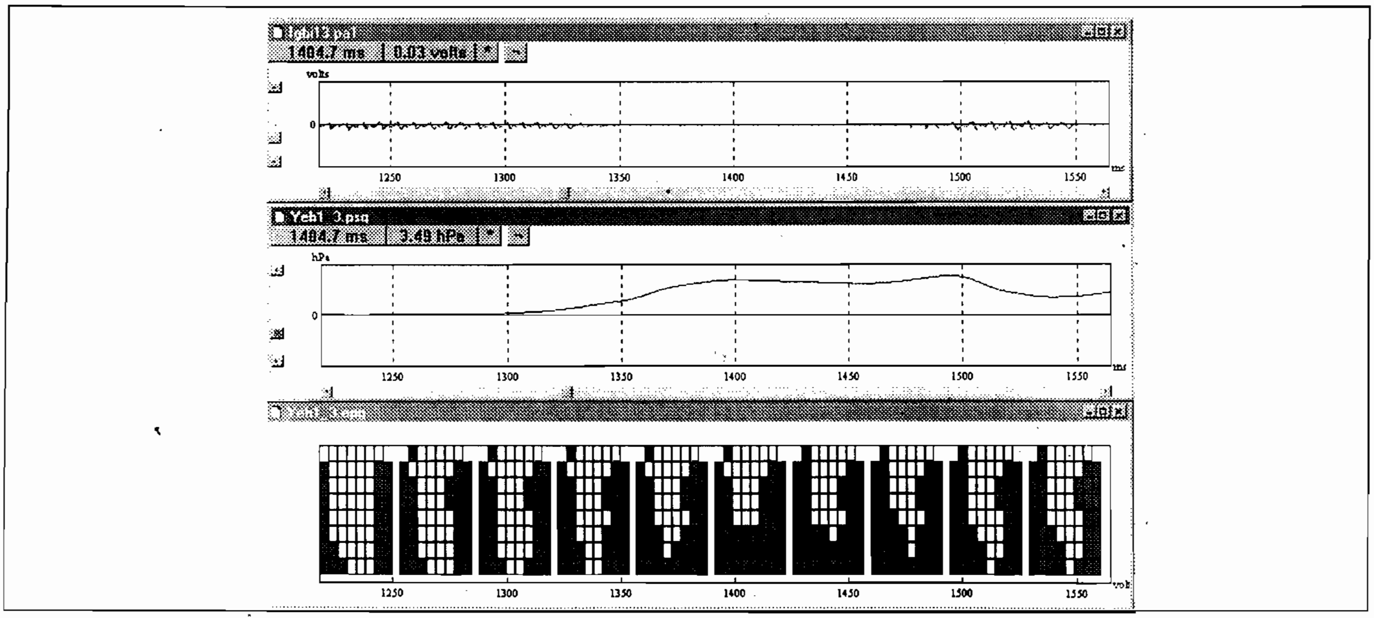

Figure 5 : showing speech signal, pharyngeal pressure for /gb/ in normal rate of speech in /i/ context

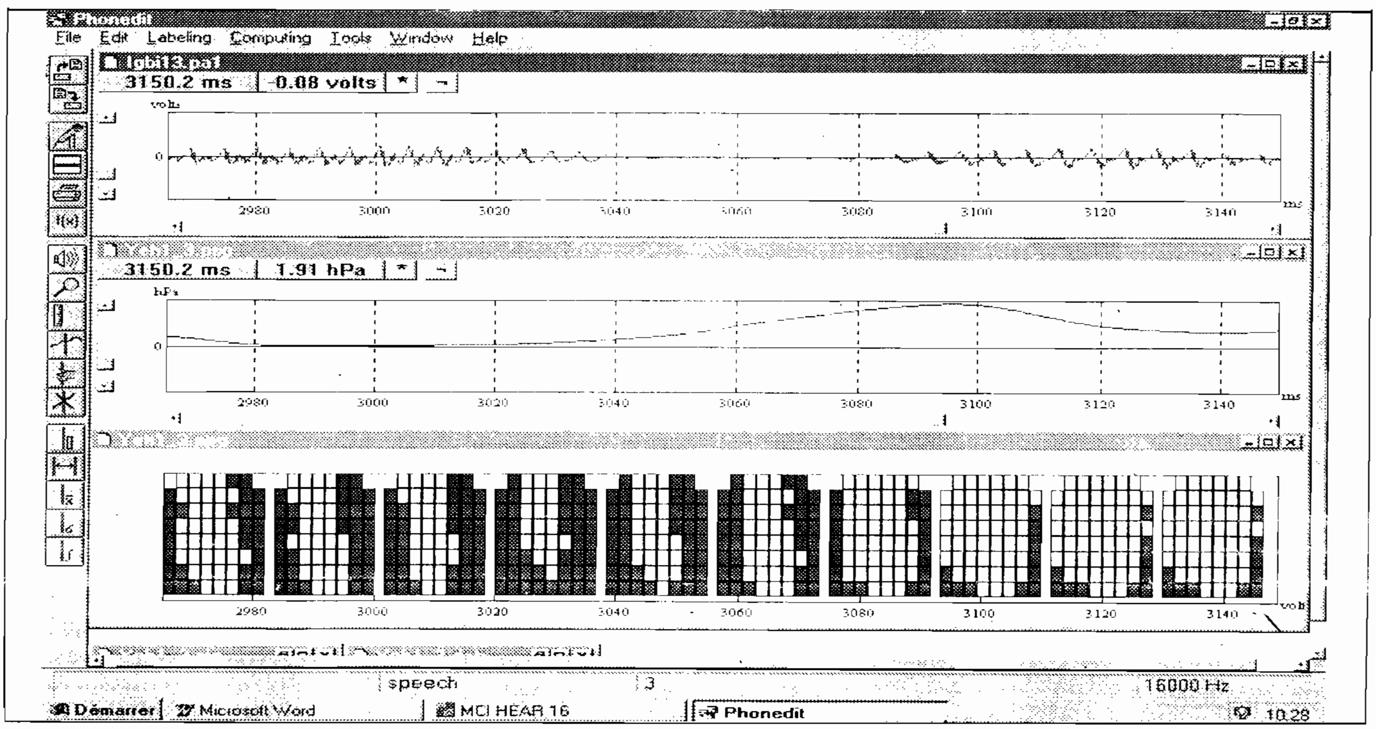

Figure 5 (bis) : showing speech signal, pharyngeal pressure for /gb/ in fast rate of speech in /i/ context

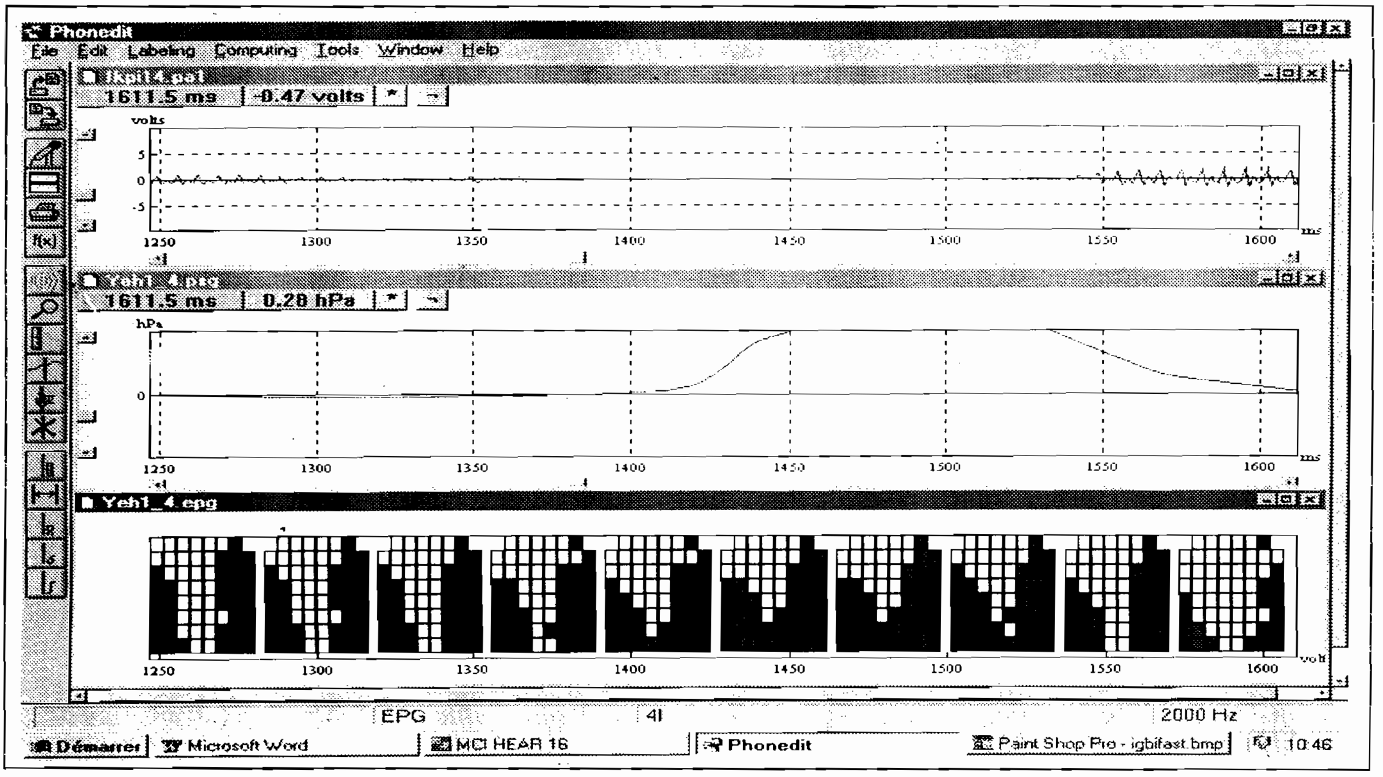

Figure 6 : showing speech signal, pharyngeal pressure for /kp/ in normal rate of speech in /i/ context

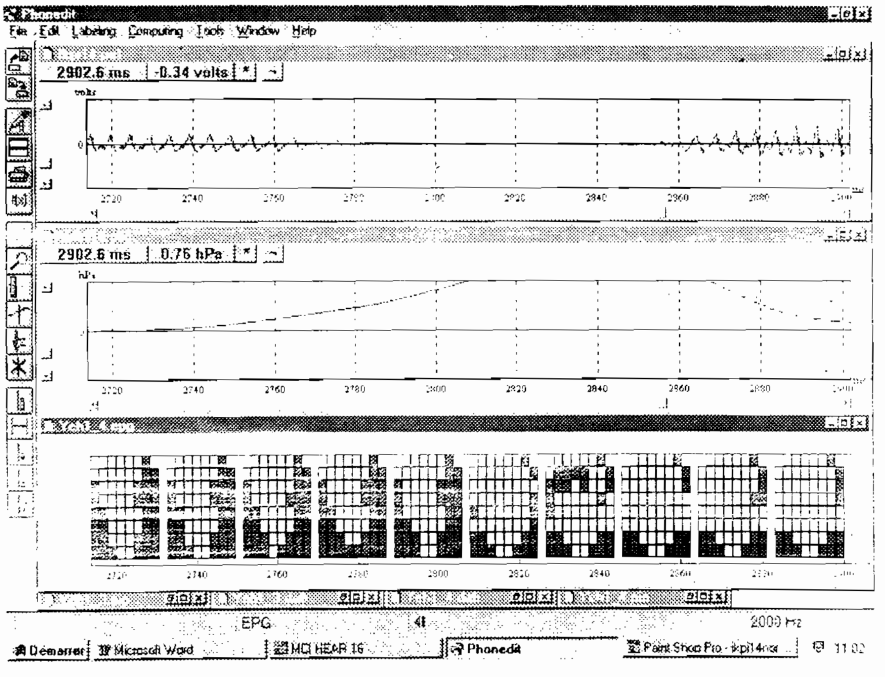

Figure 6 (bis) : showing speech signal, pharyngeal pressure for /kp/ in fast rate of speech in /i/ context

Magnitude of velar constriction

The use of the EPG technique has been decisive in accounting for the lingual contact with the palate during the articulation of our test consonants. Although the artificial palate only covers the pre-velar region of the roof of the mouth, we were able to observe the following :

In the context of high front vowel /i/ and mid high front vowel /e/, contact with the pre-velum and the back of the tongue was clearly visible. This was consistent with all velar and labio-velar consonants at normal rate of utterance.

Comparing simple velar and /k/ and /g/ with the simple velar part of /kp/ and /gb/ respectively, we saw little difference as to the patterning of the articulatory gesture. In both cases, we segmented and labelled the three phases (onset, complete closure (corresponding to maximum number of activated electrodes) and offset phase as specified in 2b.

In both consonantal contexts, complete closure was materializied by the horizontal bar of activated electrodes. There is also presence of lateral contact which is less consistent for /k/. Figures 7 illustrate complete closure (maximum closure) normal rate of speech.

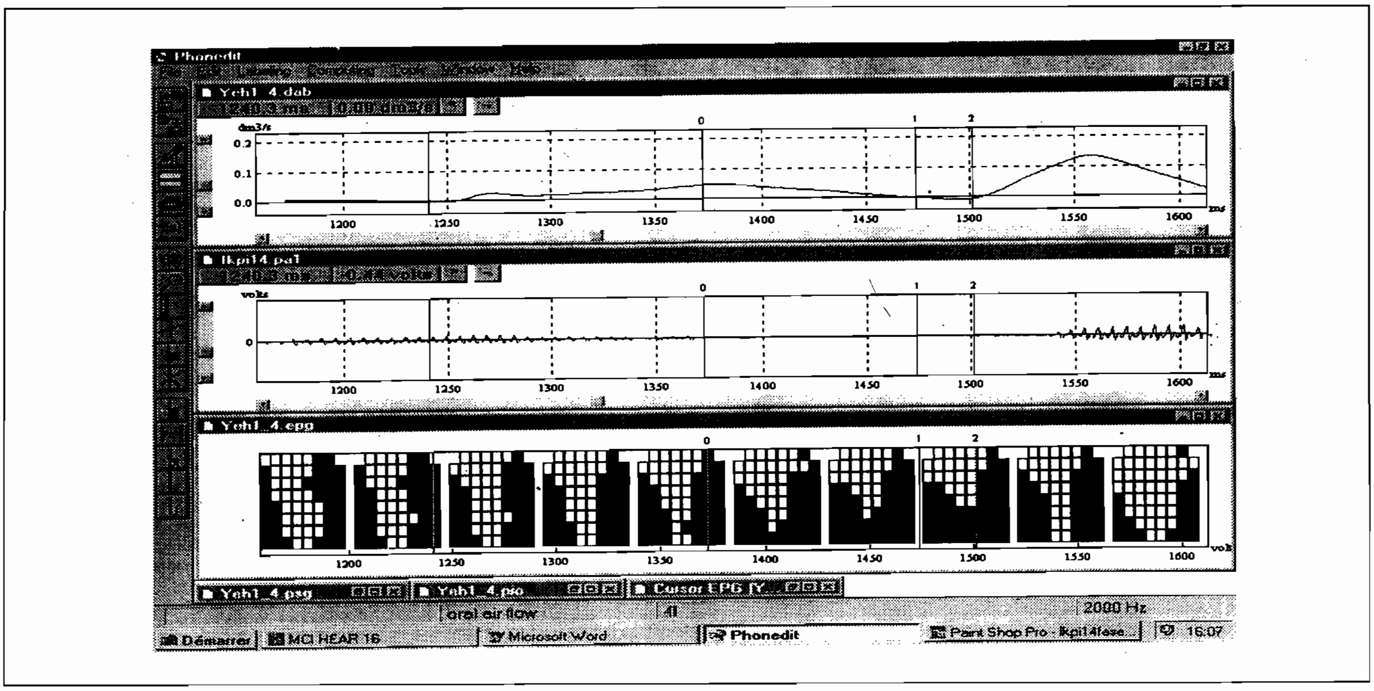

Figure 7 : showing EPG frame illustrating maximum closure for /ikpi/in normal rate of speech.

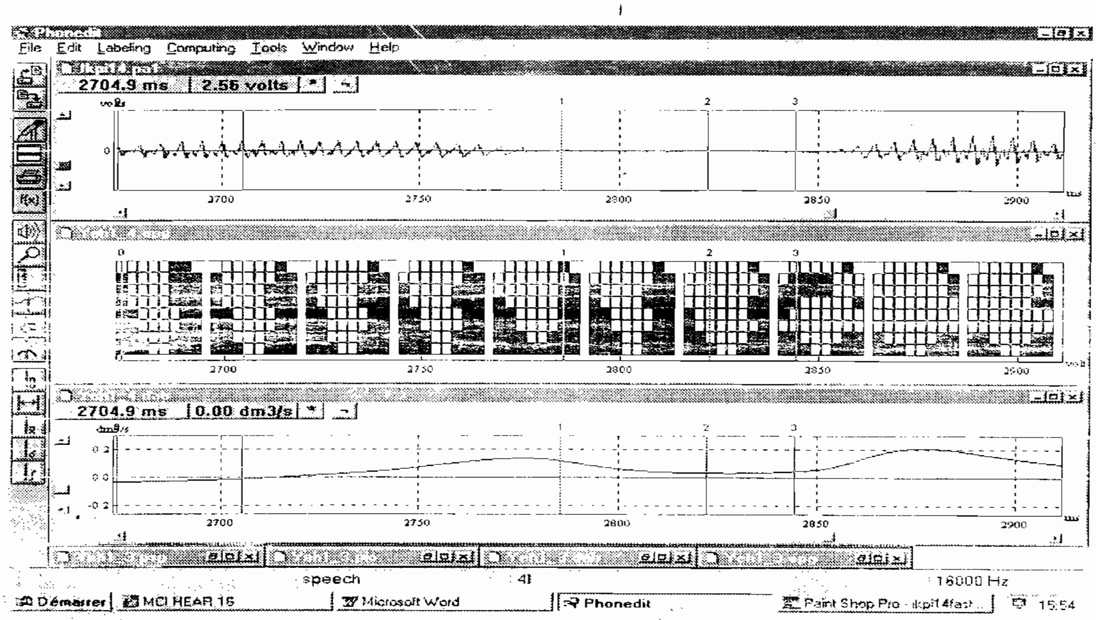

Figure 7 (bis) : showing EPG frame illustrating maximum closure for /ikpi/in fast rate of speech.

These patterns indicate that there exists some similarity between simple velar /k/ and complex consonant /kp/ and is a further piece of evidence that both consonants are programmed similarly and constitute a single unit of timing consequently a single articulary gesture. This result is in accordance with Connell who observed, for Ibibio, that there is a similairy between these two consonants with regard to their dynamics.

As a matter of fact, a different pattern is obtained in the case of fast speech rate. As was predicted, the EPG technique is appropriate in that it helps to see that the total duration of complete closure (maximum closure) is significantly shorter than in the case of normal speech and is averaged at 50 ms. Table III shows the duration of closing phase for normal rate of speech and for fast rate of speech. Besides, a look at EPG frames reveals the presence of a gap in the posterior row as a central electrode is not activated while contact persists in the lateral part of the palatogram.

Table III : showing the mean duration (in milliseconds) of maximum closure as measured from EPG data consonant in /i/ context

Consonants	Normal	Fast
/k/ [kì] "bamboo"	145	45
/kp/ [ìkpìlè] "place name"	102	44
/g/ [gì] "maize paste"	145	79
/gb/ [gbì] "to defy"	51	32

As it appears, our data reveal changes in the magnitude of lingual - palatal contact as well as in the duration of contact. This means that the rate of utterance contributes to the spatial and temporal reduction of /kp/ and /gb/. Consequently, temporal displays (contact profiles) corresponding to /kp/ an /gb/ as compared to /k/ and /g/ respectively show the number of electrodes contacted in the back region of a sequence of frames over time. The duration of lingual palatal contact in the back region for the environment investigated is estimated in terms of an articulatory index which corresponds to the sum of activited electrodes relative to the total number of electrodes. For /kp/, it is evaluated at 38 electrodes in the case of normal rate of utterance and 31 electrodes in the case of fast rate (/i/ context) ; whereas /gb/ shows the following : 39 electrodes for normal rate of utterance and 31 electrodes for fast rate.

As shown by Hardcastle (1985) investigating phonetic and syntactic constraints on lingual coarticulation in /kl/ sequence, our data seem to reveal that the rate of utterance exerts some influence on the degree of coarticulation.

Besides, it may be inferred that there is a specific gesture organization at work here which is dependent on the rate of utterance and which results in gestural overlap due to the change in the duration of the closure. This brings us back to our initial statement as regards the tendency of some phoneticians to treat labiovelars as a cluster of consonants.

One may then suggest that, because of the relative asymmetry of velar and labial gestures in the articulation of labiovelar stop consonants in Fongbe, the gestural overlap model can help to describe and account for the sequence of gestures and consequently the timing of the phases involved. This view is supported by D. Byrd (1992) although this author remarks that labiovelar stops are distinguished from to sequences by the principle that single complex segments have duration comparable to that of simple segments of the same phonetic class as was shown in *Timing of closure and release/Articulatory pase duration.*

With the EPG data, we were able to see that the Fongbe velar and labiovelar consonants /kp/ and /gb/ are subject to coarticulation and we do not notice any backward movement of the dorso-velar contact during the phase of complete closure. This may be interpreted as an evidence that Fongbe simple velar /k/ and /g/ on the one hand, and the velar part of Fongbe labiovelar /kp/ and /gb/ are articulated in the velar region as indicated by our data. The gap might be the evidence of incomplete velar the due to aerodynamic constraints as well as to the temporal organization of the articulatory gestures.

Conclusion

The significance of the present study rests entirely both on the methodology used and the results achieved. It enabled us to test and confirm the theoretical hypothesis as to the principle of phonetic gesture economy which seems to be particularly applicable when we compare normal rate of speech with fast rate of speech. The EPG technique, when it is correlated with aerodynamic as well as acoustic data, made it clear that, as far as the articulation of labiovelar stop consonants is concerned, the temporal organization of articulatory gestures is dissimilar and thus specific to each of the speaking situations investigated. Evidence is then given for the existence of context specific constraints in terms of the effect of speech rate on complex consonant articulation. In other words, our data provided evidence concerning the velar articulatory gesture and we were able to account for the relative timing of the labial and velar gestures. Despite the tendency for incomplete velar closure as may be inferred from the gap noticed in the posterior row of the palatogram, it is clear that the velar place of articulation is maintained. This is in line with Carré and Mrayati (1990) whose production model supports the view that in fast speech rate, phonetic gestures may be incompletely achieved although the targeted place of articulation does not change. It appears that, at least for our subject, speech production comes down to a process whereby a speaker adapts his articulation to speaking situation. However, we must be cautious and not lose sight of the fact that our corpus was read. We then need to investigate spontaneous speech with more subjects in order to see if the observations made with our subject are idiosyncratic or constitute a feature of the labiovelar stop consonants in Fongbe. ❐

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Abstract

The timing of both lingual and labial gestures in the production of labiovelar stop consonants is investigated in this paper. Evidence is provided as to the effect of speech rate (normal and fast) on the complete or partial realization of the gestures. Articulatory as well as aerodynamic cues show the presence of specific constraints in each case. Consequently EPG readings for /ikpi/ and /iki/ or /ege/ and /egbe/ show more activated electrodes in the posterior row in normal speech rate than in fast speech rate as both intraoral and pharyngeal pressures and oral airflow readings are used to monitor the bilabial closure and release relative to the velar gesture.