# AN EPG STUDY OF PALATALISATION IN FRENCH

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**ABSTRACT**

This paper studies palatalisation gestures that are present in the realisation of phonemes /t/ and /d/ in French. Production of these consonants in different vowel or approximant contexts by four Belgium French speakers is compared with that of /t+ʃ/ and /d+ʒ/ sequences by the same speakers. This study deals with temporal aspects (based on acoustic output and EPG), articulatory patterns (EPG) and devoicing phenomena. Influence of the environment on the place of articulation is studied to establish coarticulation patterns. Results are examined in terms of co-ordination patterns to explain variations of realisation and palatalisation in two French variants (Belgium, and Quebec, where palatalisation leads to affricated realisations), these patterns being shown to result from biomechanical constraints on the articulators. Results are also compared with diachronic data to propose explanations to French evolution patterns.

## 1. INTRODUCTION

The aim of this paper is to study palatalisation and to suggest hypotheses about the control on articulatory gestures and about the strategies implemented during the production of the consonants studied. Temporal, articulatory and devoicing patterns are linked to conclude about gestures co-ordination processes. The main idea of this study is that the organisation of articulatory gestures reflects inherent control processes, and that the interactions between gestures give clues about this organisation.

By comparing palatalisation traces (/t/, /d/, Belgium speakers) with stop + fricative sequences (/tʃ/, /dʒ/, Belgium speakers) and affricated stops (/t/, /d/, Quebec speakers [1]), this study aims at explaining co-ordination patterns as resulting from biomechanical constraints on articulators. This paper also compares these results with diachronic data, showing that biomechanical constraints and their consequences on realisation can explain both synchronic variants and diachronic evolution patterns, in the sense that variations of realisation, present because of mechanical reasons, can be considered as resources for the direction of sound change patterns.

## 2. METHOD

Short sentences containing 71 V(#)-t/d-(A)V (1st corpus) and 21 V(#)-tʃ/dʒ-V (2nd corpus) items were produced by each subject (4 subjects). Right vocalic environments are described in table 1.

| | i | y | oe | a | u | e | ɥ | jV | ˌV |
|---|---|---|---|---|---|---|---|---|---|
| 1st c | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 12 | 5 |
| 2nd c | 5 | -- | -- | 5 | 5 | 2 | 4 | -- | -- |

Table 1: number of items for each type of vowel following the consonants in the 1st (/t/ and /d/ grouped) and 2nd (/tʃ/ and /dʒ/ grouped) corpuses.

The experiment was conducted via the Physiologia workstation [11], which allows to deal simultaneously with acoustic signal, electropalatography (EPG), aerodynamic data and electroglottography (EGG). The EPG system is Reading's EPG2. It uses an acrylic 0,8mm-thick plate of 62 contact electrodes. The EGG system is Fourcin's laryngograph.

Several parameters are examined for this study. Temporal measures on consonants combine EPG and acoustic information. Closure duration is the interval between first total closure (first EPG frame showing a complete row contacted) and closure release (first EPG frame showing an opening of the closure). "Friction" (1st corpus) or fricative (2nd corpus) duration is the interval between this second moment and the beginning of the following vowel (based on acoustic data). The term "friction" is used in the 1st corpus because it represents the interval where a turbulence noise can occur due to a constriction (cf. § 4.4.).

Different EPG patterns are examined: first closure frame (I), maximum closure frame (II), closure release frame (III) and end of friction frame (IV) (i. e. beginning of the following vowel) for the 1st corpus, or the most stable constriction frame for the 2nd corpus (IV). EPG data are described in terms of graphs giving the articulatory patterns as contact profiles with the number of electrodes contacted (Y axis) for each row (X axis). The first row is the most anterior one and has 6 rather than 8 electrodes.

## 3. RESULTS

### 3.1. Temporal aspect

Table 2 shows mean duration (4 subjects) of stop closure and following friction (1st corpus) or fricative (2nd corpus) of the voiced and voiceless consonants.

| | V t V | V tʃ V | V d V | V dʒ V |
|---|---|---|---|---|
| Closure | 85 | 97 | 79 | 88 |
| Frict. | 50 | 106 | 18 | 56 |
| Total | 135 | 203 | 97 | 144 |

Table 2: mean duration (n=4) in ms of closure and friction or fricative parts of the voiceless and voiced consonants in the 1st and 2nd corpuses.

Several temporal relationships can be noticed. For both experiments the voiceless consonants have a longer duration than their voiced equivalents. The friction following the voiceless stop in the 1st corpus also has a more important duration than the one following the voiced stop. These results match those mentioned in Calliope [4].

In the 1st corpus, closure duration is longer than the following friction duration. This is less the case for the items with an approximant following the stop, especially the voiceless stop. Table 3 shows duration difference (closure duration – friction duration “cl-fr”) first as a mean value for all items (for /t/ and for /d/), and then as a mean value for the items with a following approximant. For these items, the difference is smaller (friction duration being more important), or even negative (friction duration being longer than closure duration).

| | cl-fr: t (n=36) | cl-fr: tj (n=6) | cl-fr: t̡ (n=3) | cl-fr: d (n=35) | cl-fr: dj (n=6) | cl-fr:d̡ (n=2) |
|---|---|---|---|---|---|---|
| ms | 35 | 8 | -5 | 55 | 33 | 53 |

Table 3: mean duration differences (closure – friction) of the voiceless and voiced stops in all contexts (/t/: n=36, /d/: n=35) and followed by approximants.

In the 2nd corpus, the stop in the voiceless sequence is shorter than the following fricative, while the stop in the voiced sequence is longer than the following fricative. The average duration relationship is thus, from the shorter to the longer: ʒ<d<t<ʃ. These results also match those mentioned in Calliope [4] and those of Hardcastle and Clarke [6] about fricatives.

### 3.2. Devoicing phenomenon

Some of the productions of /d/ in the 1st corpus present a more or less important devoiced part. This phenomenon affects only female subjects (69% of devoiced /d/ for S1 and 26% for S2), and can affect the end of friction, the whole friction, the end of closure and the whole friction, or the whole consonant. The third type (end of closure and whole friction) is the most common (58% of devoiced items for S1 and 88% for S2).

The mean duration (2 subjects) of a devoiced /d/ (70+27=97ms) is only slightly longer than that of a voiced /d/ (72+21=93ms), whereas it is considerably shorter than that of a /t/ (91+50=141ms), regarding both closure and friction durations. This suggests that the difference between the voiced and voiceless consonants can be made by means of duration differences.

In the 2nd corpus, some productions of the /dʒ/ sequence are also devoiced. This affects the female subjects (73% of devoiced /dʒ/ for S1, 80% for S2) more than the male subjects (27% for S3, 36% for S4). The most common type of devoicing is also the third type (end of closure and whole fricative), which rates 52% of the devoiced items for the four subjects.

The duration of the devoiced /dʒ/ sequence (93+63=156ms) is longer than that of the voiced /dʒ/ sequence (81+48=129ms) but is shorter than that of the voiceless /tʃ/ sequence (97+106=203ms), especially regarding the fricative part. This duration difference should allow correct identification.

These temporal results also suggest that these phenomena could be due to mechanical constraints on the realisation of a voiced consonant (cf. § 4.2.).

### 3.3. EPG: Influence of the vowel following the consonant

Figure 1 shows the contact profiles (number of contacts per row) for the release of closure (III) of subject S3 in the 1st corpus, according to the following vowel. The results are grouped according to the items having the same following vowel, and do not take into account the voiced/voiceless feature of the stop.

The vowel's influence can be noticed from the release frame, sometimes from the maximum closure frame and from this time on. Figure 1 only shows moment III, but the four moments will be discussed. The differences between the configurations of the consonants according to the following vowel are first noticeable in the posterior part of the palate, consonants followed by /i/, /y/ or by their corresponding approximants or by /u/ showing more (lateral) contacts in this area than those followed by /oe/, /a/ and /ɥ/. Those followed by /e/ are close to the mean result.

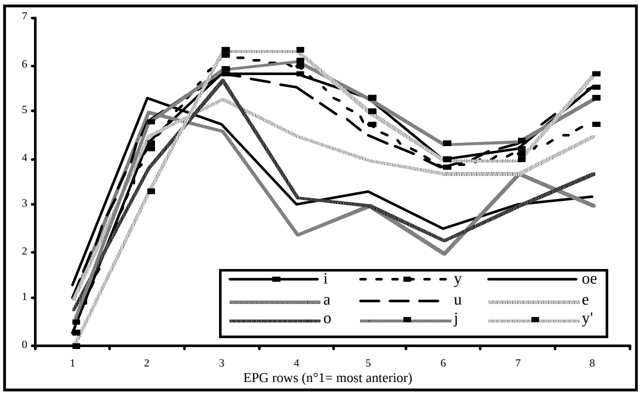


Figure 1: contact profiles (1st corpus, S3) for the release of stop closure according to the following vowel (items with /t/ and /d/ are grouped). (o is /ɥ/, and y' is /̡/).

At the end of the release, the same tendencies extend to the front part of the palate. Contact in this area is more important for the stops followed by /i/, /y/, /j/ and /̡/, and are less important for those followed by /oe/, /a/, /u/ and /ɥ/. At the back of the palate, contact is more important for the stops followed by /i/, /j/, /y/, /̡/ and /u/, while those followed by /oe/, /a/ and /ɥ/ show less important lateral contact.

The influence of the vowel following the stop on the stop's articulatory pattern across time can be summarised in this way. The vowel modifies the production of the preceding stop in the second part of its realisation and its influence consists of anticipating the position of the tongue for this vowel, which, for high front vowels and approximants, results in maintaining an important constriction after the release. The stops in that kind of environment show important lateral contact as early as at maximum closure.

In the 2nd corpus, figure 2 (moment III for subject S3) shows no particular influence of the following vowel on the production of the sequence. The differences noticeable are rather due to the preceding vowels, which were not controlled so that their influence be neutralised. This leads to conclude that the production of the fricative consonants does not vary and is independent of the nature of the following vowel, and that fricatives are resistant to coarticulation. This matches what Hoole et al. [7] show, saying that fricatives set heavy constraints on the general position of the tongue because of its more important implication of the back of the tongue. The following vowel has no stable or important influence on the production of the stop because of the presence of a fricative, which resists coarticulation.

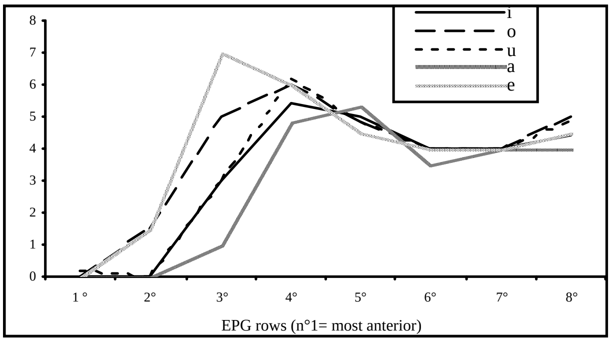


Figure 2: contact profiles closure (2nd corpus, S3) for the release of stop according to the following vowel (items with /tʃ/ and /dʒ/ are grouped). (o is /ɥ/).

## 4. DISCUSSION

### 4.1. Temporal aspect

Table 2 shows that closure and fricative (2nd corpus) durations are longer than their equivalents in the 1st corpus. This seems due to the fact that the tongue maintains longer contact because of the constriction to be made for the fricative rather than the less constrictive position of a vowel. This matches the results of Mair et al. [9], which show that the /t/ closure is released more quickly than that of /tʃ/. The release of the stop is slower when it is followed by a fricative rather than by a vowel. The constrictive part is also longer and released more slowly. These results are consistent with those of Fletcher [5], which show that the affricate release action is slowed down or even stopped.

This is also consistent with the results shown in table 3. The friction interval is longer when the stop is followed by an approximant because it involves a constriction gesture which makes the tongue release more slowly than it would in its opening movement for a following vowel. (cf. § 4.4.).

It is interesting to notice that similar results are obtained for affricates in English and two-phoneme sequences in French. Rather than revealing a monophonematic nature in French, these results more likely give clues about coarticulation phenomena. The duration of /t+ʃ/ sequence (97+106=203ms) is shorter than that of an intervocalic /t/ added to that of an intervocalic /ʃ/ (136+144=280ms). This tends to show that the stop and fricative gestures are reorganised in order to reduce the V-to-V interval rather than just being the sum of two isolated consonant gestures.

### 4.2. Devoicing phenomenon

The temporal results about devoiced consonants show that their production is not identical to that of voiceless consonants. The devoicing of voiced stops seems due to mechanical reasons, namely sub-glottal and intra-oral pressure becoming equal, which stops the laryngeal vibrations. The duration of a /d/ is therefore shorter than that of a /t/, in order to prevent this devoicing phenomenon. The closure and friction durations of a devoiced stop remain shorter than those of a voiceless stop, because in the latter case, the activity of the vocal folds is submitted to commands controlled by the speaker, which take time to be executed. In the former case, devoicing is purely mechanical and uncontrolled. There is no such command to activate, because the controlled activity of a devoiced /d/ is the same as for a voiced /d/, which has a shorter duration.

In the case of the stop + fricative sequences, the devoicing phenomenon can be explained to result from a compensation mechanism, which is mechanical and uncontrolled. Again, the duration of a devoiced /ʒ/ is more similar to that of a voiced /ʒ/ than to that of a voiceless /ʃ/, which is longer because it is easier to maintain. Indeed, maintaining the turbulence noise that characterises a fricative implies a minimal level of oral airflow, which the adduction position of the vocal folds does not always allow. It can be compensated by opening the glottis, which entails a devoicing mechanism.

### 4.3. EPG: lingual constriction gestures

Figure 3 shows the contact profiles of subject S3, comparing moments I (first closure) and II (maximum closure) in the 1st corpus with those of the 2nd corpus.

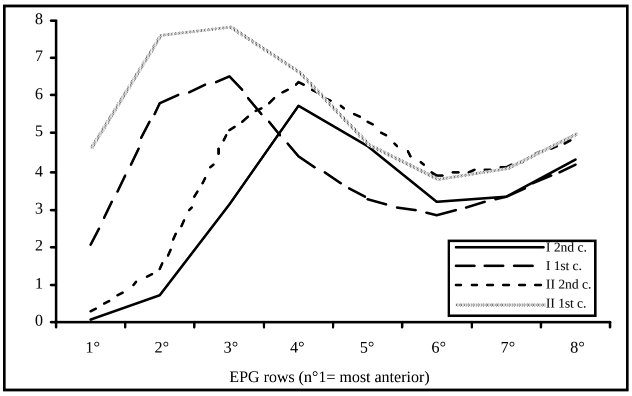


Figure 3: contact profiles (S3) for moments I (first closure) and II (maximum closure) of the 1st (/t/ and /d/ grouped) and 2nd (/tʃ/ and /dʒ/ grouped) corpuses.

Moments I and II show that the closure location is more posterior in the 2nd corpus, when the stop is followed by a fricative. This is due to the fact that during the production of the stop, the tongue anticipates the position for the fricative. Indeed, the place of articulation of a /t/ followed by a fricative is similar to that of an intervocalic fricative. Thus, the fricative modifies the place of articulation of the stop.

Reorganisation of gestures occurs according to the type of adjoining gestures. The fricative does not vary and sets heavy constraints on the position of the tongue. Its target is more precise and has to be carefully reached because the acoustic result depends on a precise position of the articulators [3]. It shows less variation than the stop, which allows more instability because different articulatory patterns are not acoustically perceived [2]. The place of the stop is thus assimilated to the place of the fricative because the gesture with a more precise target will have a more complete execution.

### 4.4. EPG: Influence of the vowel following the consonant

The production of the stop varies according to the following vowel, this modification consisting of anticipating the position of this vowel. In the case of a high vowel, this anticipation is more demanding since an important constriction has to be maintained, as seen in the massive lateral contact.

The results and conclusions already mentioned help to bring closer the two French variants and show how traces of palatalisation gestures (in Belgium French) are similar to the affrication phenomenon in Quebec French. When an alveolar stop is followed by a high vowel or front palatal approximant, an important constriction is made and maintained after the release as an anticipation of the high position of the tongue for that type of vowel. The channel through which the air passes after the release burst is narrow and can entail an automatic turbulence noise. Affricates are stops with a prolonged transitory friction after the release [8]. It can thus be shown here to result from a coarticulation phenomenon, namely the tongue anticipating high front vowels.

### 4.5. Perceptual and diachronic aspects

Articulatory results about the influence of a following high vowel or approximant and temporal results about stop + approximant sequences can be linked to describe the nature of co-ordination patterns and to explain synchronic variants as well as diachronic data. The friction interval following a stop is longer when an aproximant follows the stop, especially in the case of a voiceless stop. What happens is that the approximant shares the voiced/voiceless feature of its preceding stop. The long friction part, characteristic of the release of a stop in such a context, is thus voiceless after a /t/, and, since it is easier to maintain, also has a longer duration.

This explains why voiceless affricated stops are more frequent than voiced ones in Quebec French [1]. A voiceless friction is easier to produce and has a more important turbulence noise, which should make it more easily identifiable. Once again, explanations given to a French variant without recognised affricated stops are likely to apply to another French variant. This is because Quebec affrication is due to biomechanical constraints and will automatically appear in a particular context.

This affrication phenomenon and the causes of its existence also allow to explain some diachronic data in the evolution from Latin to French [10]. Palatalised dental and velar consonants were palatalised in Latin when they preceded /j/, /i/ or /e/. Then (II and III c. AD) they were segmented by an anterior tongue movement during production, leading to an affricated realisation. By 1200, the plosive part disappeared, leading to a palatalised constrictive consonant.

The results of this study allow to suggest explanations to this evolution pattern. During the production of an alveolar stop, the tongue anticipates its position for a high vowel or approximant, because this position has to be reached more precisely than that of the stop. The increase in lateral contact narrows the air channel to an important constriction, which creates an automatic turbulence noise, leading to an affricated release. The perceptive saliency of a voiceless constrictive as opposed to a stop should explain the later stage in this evolution. The affricated realisation present in Quebec French and in the evolution pattern can be explained by results from the production of Belgium French speakers, because this explanation is based on constraints resulting from the co-ordination of gestures simultaneously active during the production of the studied sequences.

## 5. CONCLUSION

The influence of a following fricative or high front vowel or approximant on the production of an alveolar stop has been shown to explain synchronic variants as well as diachronic data by revealing the nature of the co-ordination of adjoining articulatory gestures. Gestures with contradictory targets come into conflict, which leads to coarticulation. Articulation patterns reflect movement traces directed each to a unique target. The gesture with the most precise target is the one whose acoustic result depends most heavily on a precise position of the articulators. This kind of gesture thus sets the heaviest constraints on the articulators, and its realisation will be the most completed. A gesture co-ordination aphorism would be that the most demanding gesture tolerates less coarticulation but provokes it to less demanding adjoining gestures.

The phenomena described in this study have been shown to result from biomechanical properties of articulators and the constraints they are submitted to, as regards the status of the glottis and the patterns of tongue movements. But if these constraints explain why a phenomenon is present in a particular context, it does not explain why it is more present or salient in a language variant than in another. A unique phenomenon can be normalised and ignored by speakers of one variant (Belgium French in this case), or be preserved, amplified and recognised as typical by speakers of another variant (Quebec French). Co-ordination and coarticulation phenomena depend on universal neuro-muscular constraints as well as on the structure of the phonological system in which they appear.

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