An EPG study of alveolar to velar coarticulation in fast and careful speech: some preliminary observations

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1. Introduction

This paper is concerned with the articulatory details of a connected speech process - the assimilation of a word-final alveolar nasal to a following velar plosive, under conditions of varied speech rate.

A commonly observed phenomenon in a number of different languages is the so called 'instability' of alveolar sounds /t, d, n/. These sounds tend to assimilate to following velars and bilabials /k, g, p, b/ - that is, alveolars can take on the place of articulation characteristics of an adjacent segment and either change into or become more like it.

Traditionally, the phonological account of this coarticulatory phenomenon favours a simple binary description reflecting the perceived presence or absence of an alveolar: e.g. *tin can* /tɪn # kan/ → /tɪŋ # kan/. However, studies with electropalatography (EPG), a technique which records spatio-temporal patterns of tongue-palate contact, have established that this description does not capture the full range of patterns that actually occur. Hardcastle and Roach (1979) and Wright and Kerswill (1989) looked at articulation of alveolars in cluster sequences and found that a continuum of patterns across subjects occur ranging from full alveolar closure to 'complete' assimilation (no evidence of tongue-tip/blade contact or lateral contact beyond that which characterises an EPG description of a lexical velar). Varying degrees of 'residual' or 'partial' assimilations occupy the area in between. Hardcastle (1994) found that alveolar nasals are more susceptible to assimilation than plosives. The assimilatory behaviour of alveolar nasals remains a relatively under-researched area.

Nolan (1992) tested the perceptual response of listeners to this continuum of articulations in order to discover what the perceptual correlates of articulatory gradualness might be. He found that while the identification of complete alveolar closure with lexical alveolars is highly reliable, the identification of residual alveolars with lexical alveolars is ambiguous. Furthermore there is no conclusive evidence that listeners are able to recover an alveolar from a 'completely' assimilated alveolar-velar sequence. However, when naive listeners were asked to identify these when presented as a pair with lexical velars, they scored rather better than when presented with them unpaired. If listeners are to some extent able to match a residual phonetic trace of an alveolar stop to their mental lexical representation of that place (and therefore 'restore' it), then it would be reasonable to suggest that speakers too have a more detailed mental lexical representation than is otherwise assumed.

It has long been suggested that differences in lexical phonological form such as 'assimilatory' [ŋ] and lexical [ŋ], will always result in distinct articulatory or acoustic forms, at least for this type of optional assimilation (Nolan, 1992, although the author has since distanced himself from this hypothesis). Reliable evidence for this in EPG studies is not forthcoming although it is possible that studies using alternative instrumentation may establish the existence of a utilisable trace of the alveolar at some level. If not, the prospect of gestural deletion in this context provides a challenge to the theory of Articulatory Phonology where it is claimed that place assimilation is mainly the result of gestures overlapping and the perception of these as a single gesture. For instance, Browman and Goldstein (1990) consider a casual realisation of the phrase *hundred pounds*. They propose that if the /p/ is superimposed on it, the /d/ gesture is still maintained: 'The bilabial closure gesture may increase its overlap with the preceding alveolar gesture, rendering it effectively inaudible. The overlap of voicing onto the beginning of the bilabial closure yields the [bp] transcription' (p.361). Jun (1996) in his study on place assimilation in *pk* clusters in Korean and English argues that gestural overlap cannot be the sole factor behind place assimilation. He also argues that gestural *reduction* 'is speaker-controlled; it does not result directly from physical constraints on speech-production mechanisms' and therefore is the source of the variability in place assimilation.

Variation in speech rate/style is known to have an effect on assimilation. Other influencing variables include syntactic structure, stress and informational load. Rate has a more significant effect on coarticulation than syntax (Hardcastle, 1985) and a general if not unsurprising finding common to all research in this area is that coarticulation and connected speech processes tend to be applied at fast rather than slow speaking rates. The other tendency is for speaker-specific strategies (different responses to the demands on the articulators of increased rate) to emerge. This dimension of assimilation has only been explored with subject groups as small as two or three - the study reported here is a more systematic, larger scale effort. The robust correlation of rate with connected speech processes is not, however, straightforward. Brown (1990) has demonstrated in an auditory study that assimilation does occur in a 'careful' style of speech. Also, Barry (1985) and Kerswill (1985) using EPG found that while at a faster rate subjects tended to make less alveolar contact, when required to speak fast but 'carefully' this tendency could be overridden.

Durational variations can occur when an articulatory organ does not have sufficient time to complete a given target and so has to 'undershoot' it. This is the basis of Lindblom's 'duration dependent undershoot' model (1963) which was developed from acoustic evidence of vowel reduction. He proposed that articulatory and acoustic undershoot of vowels is a function of *reduction of movement* towards the vowel target due to physiological limitations. This assumes though, that segments in connected speech are reduced equally in duration at fast rates. Another articulatory outcome is an increase in movement velocity (Lindblom, 1990) although this can combine with undershoot (spatial reduction) to give rise to a further strategy (Gay, 1981).

Place assimilation behaviour is not a universal phenomenon. Lindblom (1983) views assimilation as a language specific grammatical rule which represents a categorical change unlike coarticulation which is a continuous motor process. Provisional confirmation of the view that alveolar-velar assimilation in Russian is nowhere near as extensive as it is in other languages, has been provided in an EPG study by Barry (1988). Most interestingly, Farnetani and Bùsa (1994) found that in Italian the alveolar-velar assimilation in /nk/ clusters is always categorical. On the basis of an auditory study of Durham English, Kerswill (1987) notes either an absence or near absence of place assimilation in contexts where it might reliably be predicted to occur in other varieties of English. Once the distribution of place of assimilation behaviour across many languages and accents comes to light we can fully conceive of it as something over which speakers have control. This could have ramifications for theories that are concerned with the precise level of phonetic detail that is specified in speakers' mental representations or phonetic plans.

2. Method

2.1 Stimuli

Speech material was devised so that consonantal combinations would capture potential sites of alveolar assimilation in addition to neutral velar control contexts. These experimental combinations were embedded in the sentences: *"I can't believe the ban cuts no ice "* /n#k/ and *"I've heard the bang comes as a big surprise"* /ŋ#k/. Further material was devised to capture two other consonantal combinations: /n#t/ *"I'm not surprised the ban touched a raw nerve"* and /ŋ#t/ *"I reckon the bang toughened her resolve"* the results from which are not reported here.

The vocalic environment was kept as consistent as possible. Bordering vowels were /a/ & /ʌ/ and the /a/ vowel was preceded by a bilabial stop to eliminate the possibility of any lingual coarticulatory effects on the target consonants. This latter control will be particularly advantageous in the light of a planned EMA experiment using similar test stimuli where the only source of coarticulation on tongue trajectories will be the tongue tip and dorsum themselves. Low vowels were used to flank the consonants because vocalic tongue-palate contact (characteristic of high front vowels for instance) would be minimal. Also it was predicted that a rather 'front' velar occlusion would be achieved after /a/, more easily observed on EPG printouts. Voiceless plosives were selected to follow the nasal in all experimental sentences so that the offset of voicing for the nasal could be directly measured in relation to the transition from nasal stop to oral stop. This is especially useful in those cases where phonetic differences are sought between 'assimilatory' /ŋ/ to /k/ and lexical /ŋ/ to /k/, *...ban cuts.../...bang comes...*, even though these are not strictly minimal pairs.

A further 4 'filler' sentences of no experimental interest were added to the original 4 to distract the speakers from the presence of near minimal pairs. 10 repetitions of each test item were produced.

2.2 Speakers

10 speakers with EPG palates were recorded. All but 2 of the subjects were female and overall the subject group represented a fairly wide range of regional accents. 4 of them spoke what might be called Standard Southern British, one was Australian, one was Northern Irish, one spoke a variety of North Eastern English and the remaining 3 spoke Scottish English from 2 different regions.

2.3 Data collection

The technique of electropalatography (EPG) was used to record the timing and the location of tongue contact with the hard palate during continuous speech. During the course of the recording each speaker wore an artificial palate embedded with 62 silver electrodes which are activated when contact occurs. The details of contact are then stored on computer. The palate can be roughly divided into three zones: alveolar region (rows 1 and 2), palatal region (rows 3-5) and velar region (6-8). Although palates are custom made for speakers these regions follow predetermined anatomical landmarks which target phonetically significant areas. The sampling rate of this system is 100 frames per second and the acoustic signal is 10kHz.

Before the experiment speakers wore their palates for an hour to adjust, although they in fact required little acclimatization. Most of the subjects were experienced wearers of EPG palates and had been involved in other experiments using the technique.

The experiment fell into two parts. The aim of the first part was to elicit careful speech and all subjects were instructed to read each sentence *slowly and clearly*. No particular instruction was given with respect to prosodic phrasing. The aim of the second part was to elicit fast/casual speech although genuinely casual speech is notoriously difficult to acquire under laboratory conditions. The material for this part was identical to the first but the 80 sentences were arranged in groups of 3 and filler sentences were purposely distributed to avoid 'clustering' of experimental sentences. Subjects were instructed to read out each group of sentences in a *rapid and casual style* one after the other avoiding obvious pauses in between each sentence. A time limit of 5 seconds was imposed on the delivery of each group of sentences and time was allowed for subjects to practice both the fast groups and the individual careful sentences. The time constraint automatically ruled out any attempt on the part of speakers to impose too complex an intonational structure on each sentence. All subjects perceived this time limit as a challenge so it was an effective measure against over-awareness of the test items. The sentences in the first half of the experiment and the groups in the second were individually cued during recording with a pause between each.

2.4 Data analysis

Electropalatographic measurements were taken from the EPG trace and acoustic measurements were taken from the waveform/spectrogram. For all experimental sequences annotation points were made from the onset of the vowel before the word boundary (/a/ in all cases) up to onset of the vowel after the word boundary (/ʌ/ in all cases).

5 annotation points were made for sequences where a single place of articulation was achieved i.e. /ŋ#k/ *...bang comes...* in fast and careful rate and /n#k/ *...ban cuts...* in the fast rate, where there was a complete absence of alveolar contact or it was insufficient to justify annotation. It was also predicted that, for some speakers, a careful articulation of this latter sequence would motivate an assimilation of this sort. 7 annotation points were made for sequences where there were 2 clearly observable adjacent places of articulation. That is, in the context /n#k/ in the careful and fast speech rate where the alveolar target was achieved. A database was created which stores the EPG frame corresponding to each annotation point and its time value.

Figure 1 below shows a waveform, spectrogram and EPG display of one canonical repetition of *...ban cuts...* in the careful speech condition. The numbered annotation points are indicated on the spectrogram and the timing of these in relation to tongue-palate contact during the sequence is marked on the EPG display below (in each frame of EPG data the top of the schematic plan is the alveolar ridge and the bottom row approximately corresponds to the junction between the soft and the hard palate). These annotation points are defined in Table 1 below.

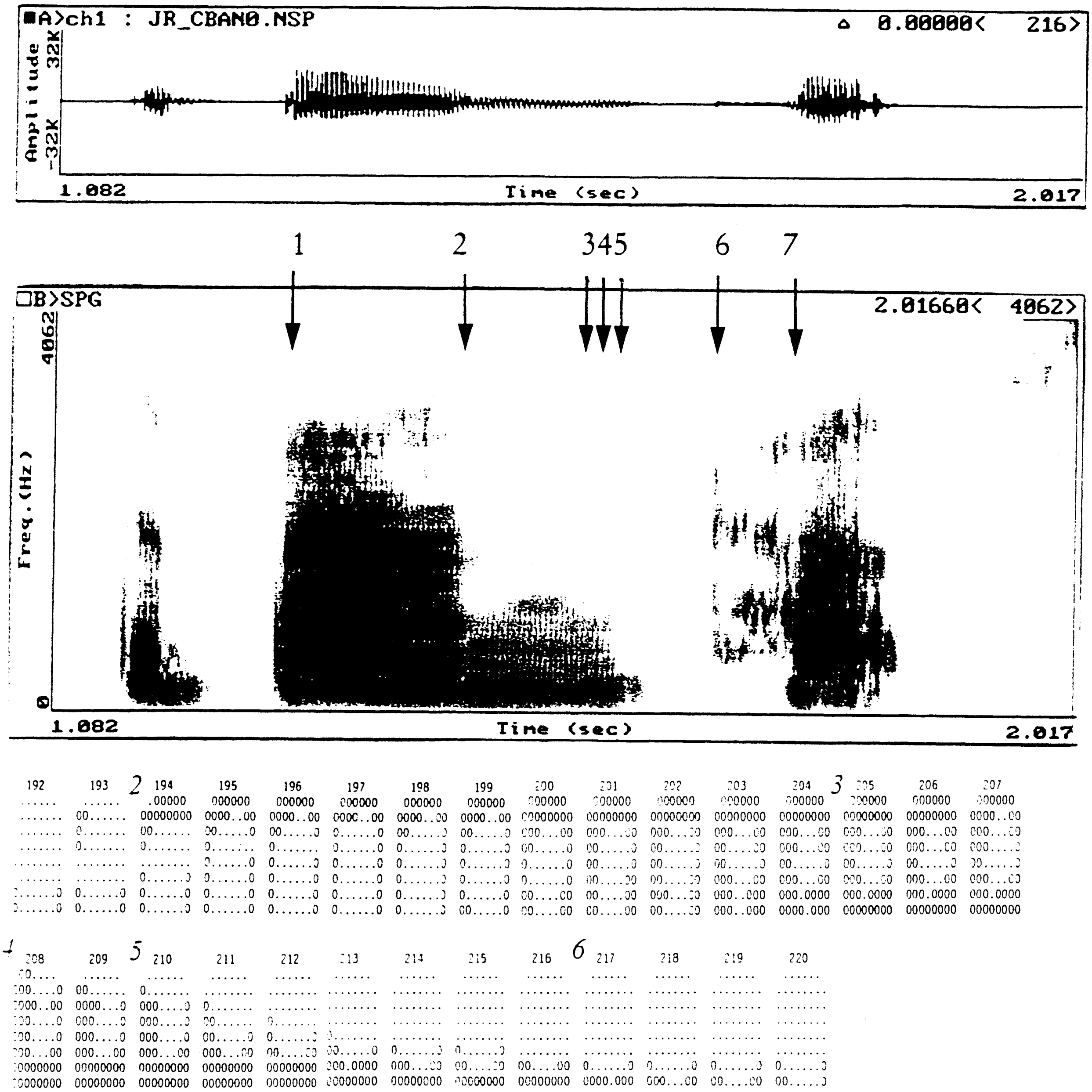


Figure 1: waveform, spectrogram and EPG display of...*ban cuts*... careful speech (subject JR). Numbered arrows represent acoustic and EPG-defined annotation points.

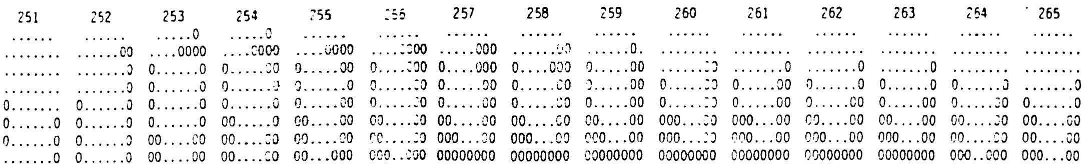
TABLE 1. Definition of annotation points: acoustic and EPG

no.	type	definition
1	acoustic	Onset of periodicity for the vowel /a/
2	EPG	Onset of mid sagittal contact in first 3 rows for alveolar /n/
3	EPG	Onset of complete or maximum constriction in row 8 for velar /k/
4	EPG	Earliest appearance of loss of contact for release of /n/
5	acoustic	End of nasal formant structure for /n/
6	EPG	Earliest appearance of loss of constriction for velar /k/
7	acoustic	Onset of periodicity for the vowel /ʌ/

N.B. The order of annotation points as they appear in the example in Fig.1 & Table 1 is, obviously, subject to variation. For example, formant structure for /n/ can end before the alveolar closure is released.

For analysis of the /n#k/ data a clear distinction had to be made between a 'canonical' alveolar or allophone of an alveolar and an assimilation of an alveolar. For a preliminary indication of the assimilatory trends, partial assimilations were subsumed into the general category of assimilation. To be classed as an alveolar, a pattern had to show mid sagittal contact in the first three rows of the EPG palate. Thus according to this definition, in Figure 2 (a) we see an allophone of /n/ while in (b) we see a partial alveolar articulation which here would be labelled an allophone of /ŋ/.

2(a)



2(b)

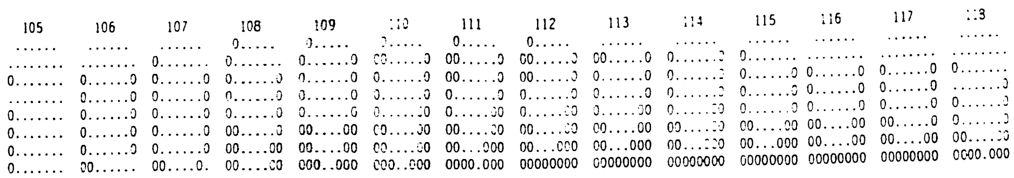
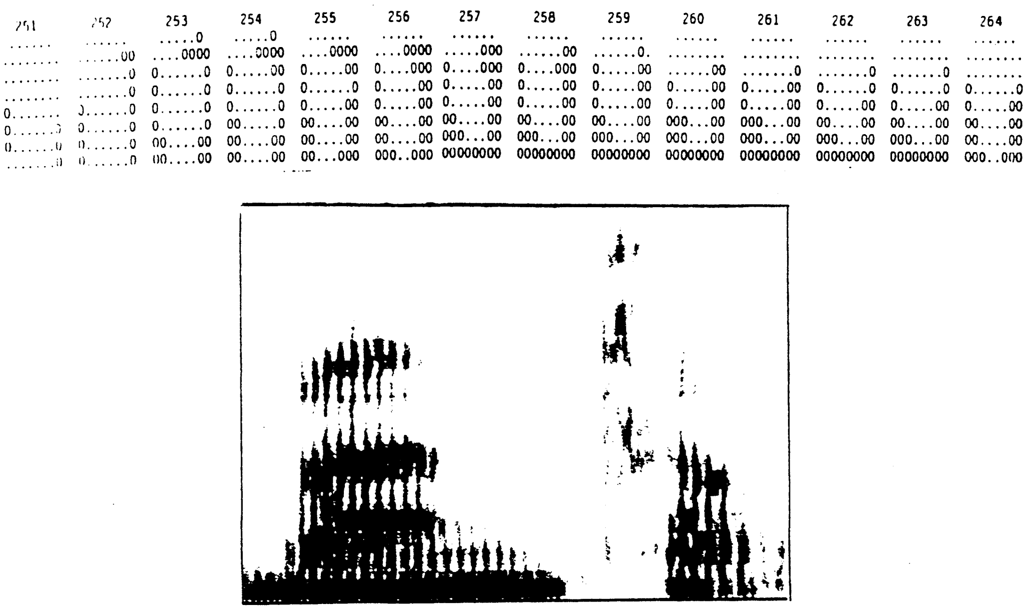


Figure 2 EPG patterns for...*ban cuts...* fast speech 2(a) annotation of an alveolar stop (JSC) 2(b) no annotation of an alveolar stop (WCM)

Although Fig.2 (b) is not classed as an alveolar articulation, the tongue has made the supporting lateral gesture for /n/ and as a result of tongue-tip raising, an acoustic correlate similar to one of a full alveolar might be expected. Figure 3 shows spectrograms for (a) a partial closure at the alveolar ridge and (b) a complete assimilation for *...ban cuts...* fast rate. F2 in (b) stays level while in (a) it drops slightly as the tongue tip makes contact. Notice also the lack of transition in (b) for the velar constriction. More thorough acoustic analysis of complete assimilations in this context and their comparison with lexical velars is planned.

3(a)



3(b)

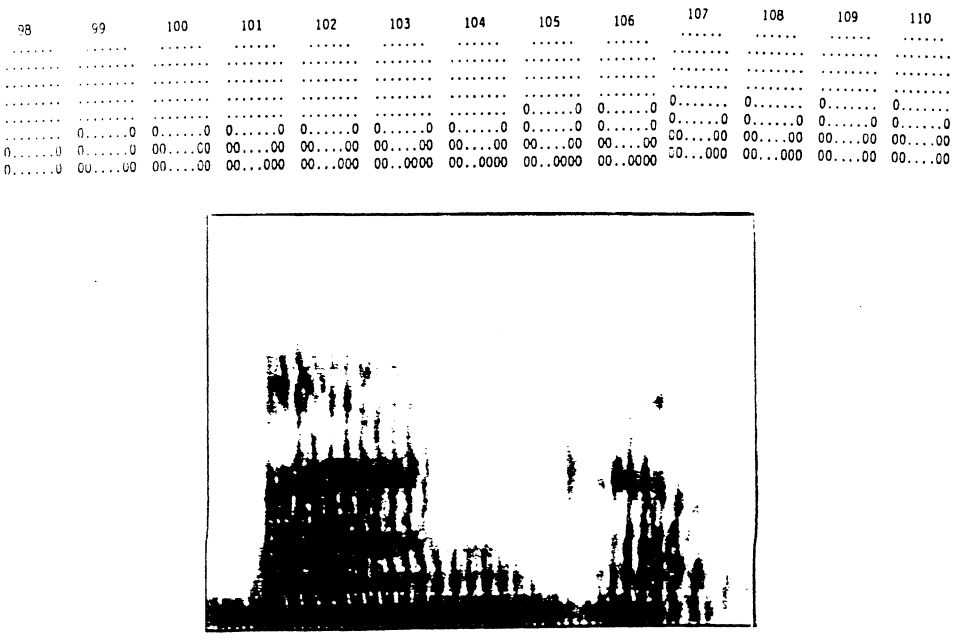


Figure 3 Spectrograms and EPG patterns for (a) incomplete alveolar closure (b) assimilated alveolar. Subject JSC

3. Preliminary Results and Discussion

The distribution of assimilations for /n#k/ in both fast and careful speech for all subjects are shown in Table 2.

TABLE 2

	careful speech	*fast speech*
assimilated	**3**	**56**
non-assimilated	**97**	**44**

The first thing to notice is that there are surprisingly few assimilated alveolars in the careful speech condition. These were produced by 2 subjects JF and SW who rather appropriately happened to be subjects who produced 100% assimilations of the same sequence in the fast rate. This might suggest that their systems are more predisposed to connected speech processes than others. The other thing to note from Table 2 is that although there are more assimilations in the fast rate as might be predicted, they by no means dominate the picture.

A breakdown of the results for fast speech /n#k/ for each subject is shown in Figure 4 below. There is considerable gross variation between speakers with regard to occurrence of assimilation. 2 subjects never assimilated in fast speech and 3 subjects always did (one subject assimilated for 9 out of 10 repetitions). The picture becomes more complex, however, if the patterns for the subjects in the middle of the graph are considered in more detail. Subjects FG, WCM, JSC, TH sometimes 'assimilated' and sometimes did not. But the graph does not tell the whole story, of course, since partial assimilations are not represented here. While the values for subjects JSC and TH appear the same on the graph they do in fact use entirely different reduction strategies as interpreted from the EPG contact patterns.

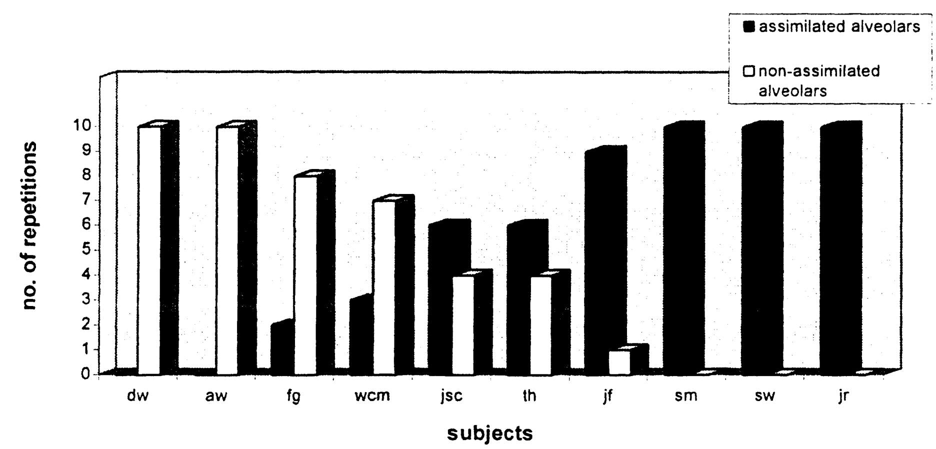


Figure 4 Distribution of assimilations for all 10 subjects ...*ban cuts*...fast speech

The EPG patterns for TH and FG suggest the adoption of a binary segmental strategy. That is, either full alveolar contact is achieved for target /n#k/ or there is segmental substitution with something that looks very similar to /ŋ/. The latter appears to be a restructuring option that precludes gradient partial alveolar assimilations. But partial assimilations *are* tolerated by JSC and WCM. Figure 2 shows the type of 'undershoot' articulations made by these subjects.

On the basis of this observation it would appear that not all speakers have the same 'allophone tolerance' for /n/ in this phonetic environment and in the articulatory domain at least. TH and FG behave here as speakers whose mental representation of /n/ specifies only a single alternative articulatory target. JSC and WCM are, however, speakers for whom permissible realisations are not categorical but include presumably unlimited graded intermediate articulations. One wonders how the contents of a mental lexical representation for these speakers might be expressed. It was thought possible that the discreteness of the two groups in this respect is a function of one of the groups speaking at a faster rate than the other. Target undershoot as a possible manifestation of inertial effects on the articulators is probably more closely associated with fast speech rate than segmental substitution, since the latter is known to occur even at careful rate. Measurements of duration of the sentences did not show JSC's and WCM's fast speech rate to be significantly faster than that of TH and FG (see Figure 5 below). Furthermore, the variability range for the fast speech repetitions for one group is not broader or narrower than for the other.

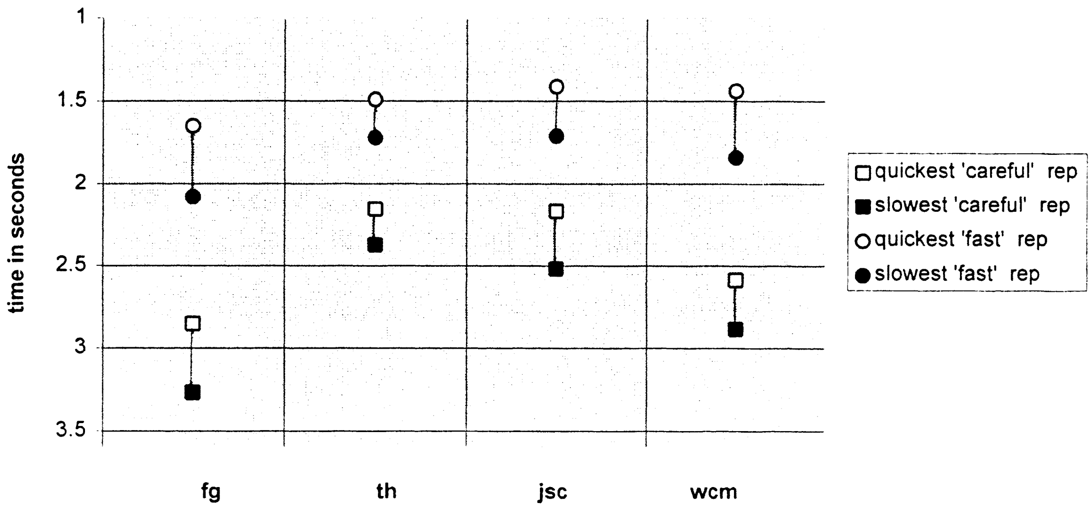


Figure 5. Duration ranges of careful and fast speech sentences for 4 subjects.
N.B. quickest utterance times at the top end of the graph.

Residual alveolars of the type that showed up in the data for JSC and WCM were almost completely absent in the data for the other 8 subjects. JSC and WCM were the only speakers whose alveolar-velar articulations were clearly gradient. They are, incidentally, both from West Scotland.

Figure 6 shows the EPG patterns for all 10 repetitions of *...ban* cuts...fast rate, for subject JSC. Each line shows a single repetition and captures the realisation of /n#k/. They are ordered to show a gradation from full alveolar contact to complete assimilation via consonant shortening of /n/ and target undershoot.

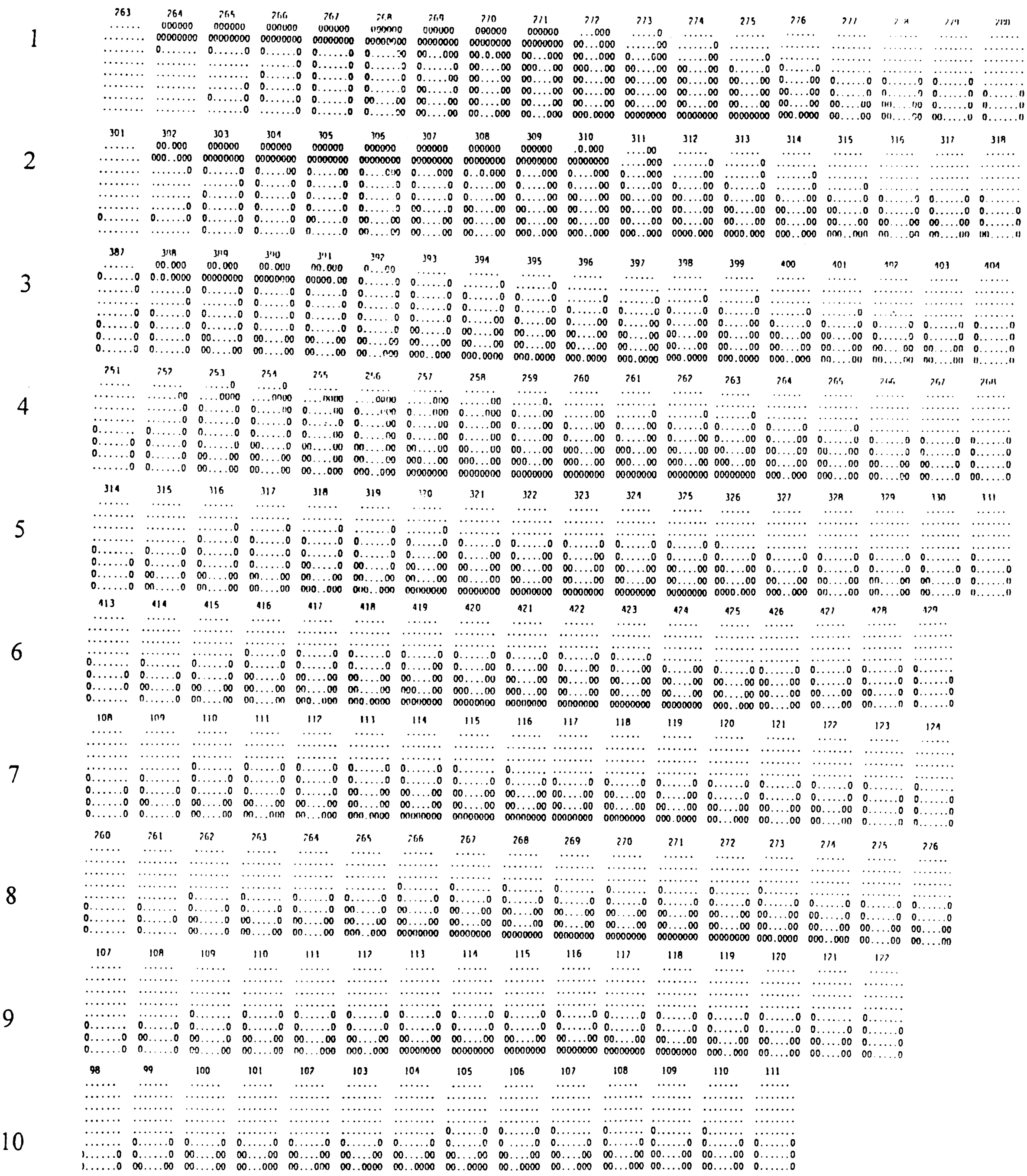


Figure 6 EPG patterns for all 10 realisations of /n#k/ sequence in *...ban cuts...*fast speech. (JSC)

The EPG contact 'totals' profiles for the patterns shown in Figure 6 are plotted in Figure 7 (a) below. Contact totals for all 10 repetitions from the beginning of the vowel /a/ are superimposed on a single graph. For each repetition there are two curves representing the amount of electrodes contacted on the palate frame by frame in the alveolar region (front 3 rows) and the velar region (back 3 rows). 7 (b) shows 10 realisations of the sequence...*ban cuts*...for fast speech by subject AW. 7(c) shows 10 realisations of the same sequence by AW but for careful speech.

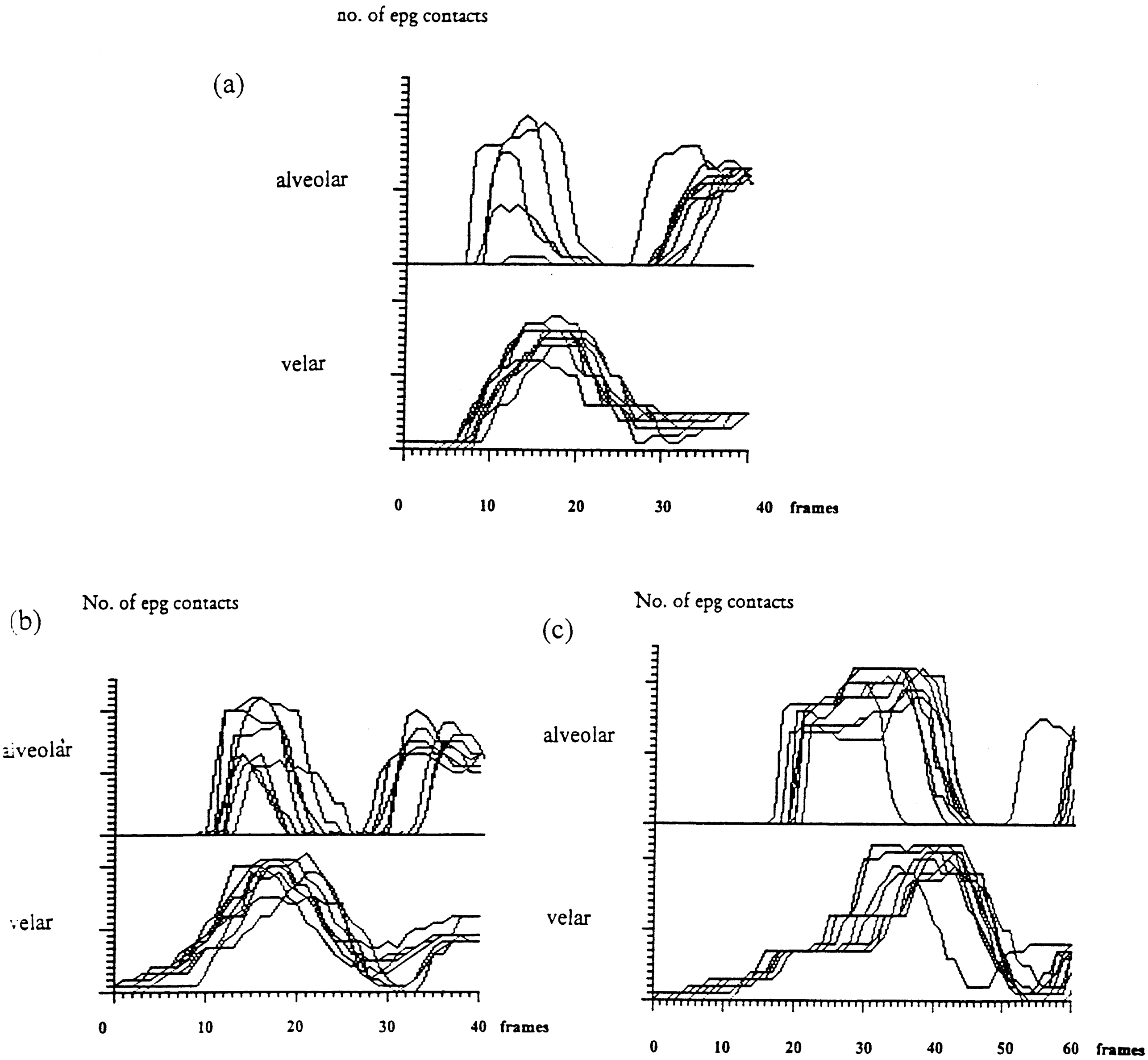


Figure 7 EPG 'totals' graphs showing tongue-palate contact in both alveolar and velar regions for sequence /n#k/ in ...*ban cuts*...The x-axis represents time in frames. 7(a) fast speech, subject JSC; 7(b) fast speech, subject AW; 7(c) careful speech, subject AW

In 7(a), the curves describing residual alveolar articulations are plotted. The shallowest curve of all represents repetition number 5 on Fig. 6 where for 5 EPG frames one electrode was contacted in the third row. The next shallowest curve is the fourth repetition on Fig. 6 where only a partial occlusion is formed and with a slightly more gradual onset than reps 1-3. Of course only 5 'alveolar' curves are shown on this graph because there was no alveolar gesture discernible on the EPG trace for the other 5 repetitions.

AW was one of only two subjects who produced no assimilations for /n#k/ in either careful or fast speech. This subject was quite variable in the fast rate, however, with respect to timing and especially to amount of total contact for /n/ (b). The main reduction strategy adopted was consonant shortening which was sometimes combined with reduction of alveolar contact. This combination produced the variability in alveolar curves in (b), an effect less apparent in (c) for the careful rate. Notice that compared to JSC, the alveolar gesture in (b) is initiated later. Also, the timing relationship between maximum closure for the alveolars and velars for AW in (b) is not the same as that for JSC in (a). AW frequently produced double articulations in careful speech and so maximum contact for each region was often simultaneous. JSC, however, tended to avoid double articulations as illustrated in Fig 6. Kinematics of tongue tip/blade and dorsum are maximally contrasted in 7(c) regarding time interval between initiation of gesture and maximum tongue-palate contact for that gesture. Here for AW velar contact builds up during the markedly less gradual tongue-tip articulation for each repetition. Timing of the release of the alveolar and velar in (c) is likewise consistent apart from one repetition. Of course, in the careful rate (c) the whole sequence up to the complete loss of contact for the /k/ takes around 50 frames whereas for fast speech (a) it takes around 30 frames.

A quite different reduction strategy altogether is used by 3 subjects occupying the right-hand side of the graph in Figure 4 - SW, SM, JR - who all speak Standard Southern British. For all their /n#k/ fast sequences there was a complete absence of alveolar closure and little evidence of lateral contact further forward than that characterising a lexical velar. If lateral contact was in evidence, then for the token to be classified as a residual alveolar according to the definition adopted in this paper, there would be contact along the sides of the palate least one row further forward than for a lexical velar produced by the same speaker under the same speech rate condition. When to compared to the EPG patterns for these subjects' fast all-velar sequences ...*bang comes*..., the 'assimilated' /n/ to /k/ patterns are very similar. It would appear that /n/ has been deleted in this context.

For one subject in particular there was even less EPG contact in the velar region for the 'assimilatory' velars than for lexical velars. In other words the habitual posterior tongue placement is more retracted. Some examples are shown in Figure 8 below.

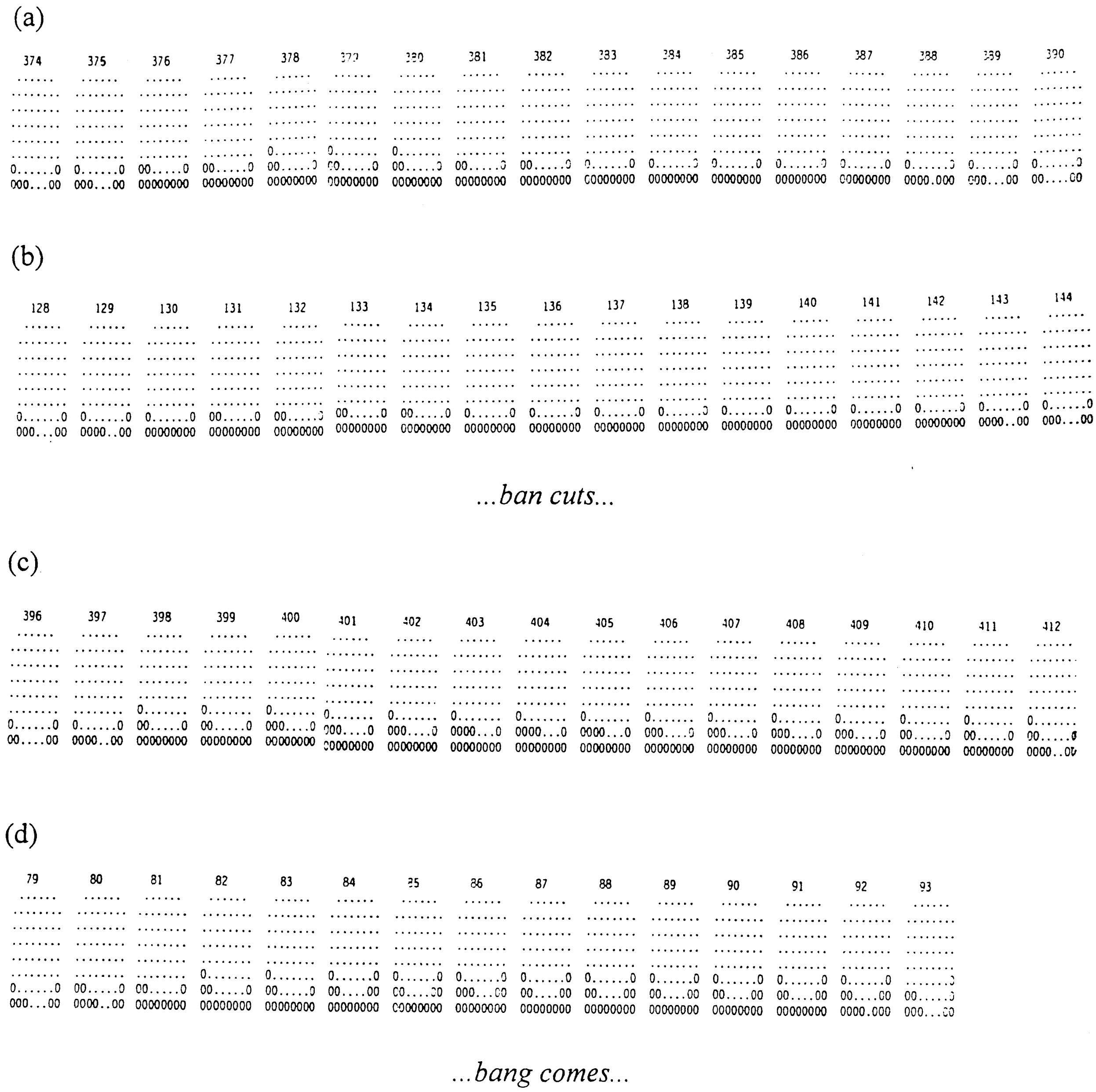


Figure 8 fast speech EPG patterns showing (a) & (b) velar tongue position for complete assimilation in 2 repetitions of...*ban cuts*.... contrasted with tongue position for 2 repetitions of all-velar control sequence in...*bang comes*...(c) & (d). Subject JR

There has been some speculation that this retracted assimilatory velar pattern, far from being an extreme form of complete assimilation, is residual evidence of a tongue body configuration appropriate for tongue tip elevation.:

> ...as the tongue tip moves up towards the alveolar ridge, the blade and pre-dorsum become concave, which reduces the amount of lateral contact in the pre-velar area. At the same time, this tongue shape will cause the velar contact itself to be more retracted.
>
> (Wright and Kerswill, 1989)

If this was the case, place assimilation here could be accounted for by Articulatory Phonology where gestures can reduce in magnitude and overlap, often to the extent that place of articulation is lost, although segments are never 'deleted'. If so-called complete alveolar assimilation is not necessarily incompatible with tongue tip elevation then the next question is whether the tongue tip is raised for some or all of the habitual complete assimilations illustrated in Fig 8 (a) & (b). But for those residual articulations produced by JSC and WCM where the tongue is making quite advanced contact with the sides of the teeth leaving less area of the tongue-tip /blade to manoeuvre, it might be the case that tongue-tip elevation is somewhat inhibited. But since the tongue-tip can function as a semi-independent articulator in relation to the tongue dorsum, it is possible that the tongue-tip is still able to describe a substantial raising (and looping?) trajectory although not of the same magnitude as that which, it is suggested, may give rise to the type of retracted velar seen in Fig 8 (a) & (b).

4. Conclusion

The two most interesting questions raised from this study have resulted from the identification from this data set of four broad inter-speaker reduction strategies (namely, one which reduces the consonant but avoids assimilation; one which avoids non-assimilation, one which involves binary variation and one which involves non-binary variation). Firstly, why does the distribution of residual alveolar gestures for this data set concentrate around only 2 subjects? While JSC and WCM produce full alveolars and 'complete' assimilations *aswell*, for subjects TH and FG the production of either of these is the result of a categorical binary option, intermediary articulations being somehow 'blocked'. To what extent can this distinction between these two groups of speakers be attributed to the absence or presence of something in their mental representation?

Electropalatography is a technique which can provide useful information about tongue-palate contact during connected speech leading us to the formation of important research questions. It cannot, however, provide information on proximity of the tongue to passive articulators and does not give an indication of which part of the tongue is involved in contact. In order to confirm or challenge the limited interpretations of the EPG data presented here, a combined EMA/EPG experiment using similar stimuli is planned involving a subject from each of the two groups. EMA tracks the movement, in the x-y plane, of sensors attached to the mid-line of the tongue and provides complementary information to EPG on tongue-dynamics and the overall configuration of the tongue during connected speech. The complete assimilations produced by the 'binary' subjects and those produced by the 'non-binary' subjects will hopefully be distinct in terms of tongue-tip elevation. The hypothesis is that the complete assimilations of the former group will involve less or no tongue-tip elevation compared to the latter, since for the latter the EPG evidence suggests that contact with the alveolar ridge is still being targeted. Clear, if reduced coronal trajectories, falling short of contact could be in evidence some of the time or on a more consistent basis. Kühnert (1993) in her study of the assimilatory behaviour of voiceless plosives reported that in cases of EPG-defined complete assimilation, clear coronal elevations are sometimes present and sometimes are not. Speaker-specific reduction strategies as reported here could prove to be the cause of this variability. The second question which could be answered by EMA observations of tongue-tip movement during assimilation, evolves from the type of data shown in Fig 8 (a) & (b).

These speakers are either consistently preserving the raising gesture part of the alveolar target, which could explain the retracted velar position and lack of lateral contact, or they are producing an extreme form of assimilation, or possibly alternating these articulations. The identification of habitual articulations from EPG data may not be mirrored in EMA data for the same sequences.

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