Tongue palate contact patterns of velar stops in normal adult English speakers

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ABSTRACT

This paper provides a more detailed description of normal tongue palate contact patterns for the occlusion phase of velar stops than currently exists. The study used electropalatography (EPG) to record seven normally speaking adults' contact patterns of voiceless velar stops in nine VkV contexts. A variety of EPG indices measured: percent complete closures across the palate; place of articulation; articulatory distance between /k/ and /t/; and amount of contact. Complete closure occurred in the majority (81%) of tokens. Some speakers almost always had complete closures regardless of context, whereas other speakers produced them only with high front vowels. As expected, place of articulation and amount of contact were heavily influenced by vowel context. The most fronted and most contact occurred in /i/ contexts and the most retracted and least contact in /a/ contexts. There was considerable interspeaker variability on all measures, particularly in the precise location of velar placement and articulatory distance between alveolar and velar placement. The implications for diagnosing and treating abnormal velar articulations are discussed.

Keywords: velar stops, electropalatography, EPG, articulation.

1. INTRODUCTION

Recent studies have reported the benefits of using electropalatography (EPG) to diagnose and treat abnormal articulations of velar stops /k/ and /g/ in people with speech disorders associated with a variety of conditions, including cerebral palsy (Gibbon & Wood, 2002), Down's syndrome (Gibbon, McNeill, Wood & Watson, 2003), cleft palate (Gibbon & Crampin, 2001), hearing impairment (Crawford, 1995) and functional articulation/phonological disorders (Friel, 1998). A recent survey showed that /k/ was targeted in nearly a third of individuals (n=60) who received EPG therapy in Scotland over a 10 year period (Gibbon & Patterson, 2006). Furthermore, the Gibbon and Patterson study showed that /k/ was the fifth most commonly targeted sound in EPG therapy after /s/, /t/, /ʃ/ and /d/. The main reason for using EPG to investigate and treat velars is that these sounds usually register measurable amounts of tongue palate contact, which is located in the posterior region of the hard palate (Hardcastle & Gibbon, 1997).

Although EPG patterns for velars is broadly characterised by contact in the posterior region, the relatively frequent use of EPG for abnormal velars is somewhat surprising; contact patterns for these sounds are highly variable even in normal speakers and productions of /k/ have minimal amounts of contact. Variability of tongue palate contact in normal speakers is due to factors both between and within speakers. For example, patterns are likely to vary between speakers due to the physiological factors such as the different shapes of people's hard palates (Hiki & Itoh, 1986) and upper/lower jaw relationships. Factors such as these have an impact on the overall amount of contact exhibited by different speakers. For example, recent studies reporting normative data have shown that although different speakers have broadly similar contact patterns for the same target, some speakers have up to twice as much contact as other speakers (Gibbon, Lee & Yuen, 2007; Gibbon, Yuen, Lee & Adams, 2007; Liker, Gibbon, Wrench & Horga, 2007).

As well as variation between speakers, contact patterns for velars produced by the same speaker vary due to the phonetic context in which they occur. Velar articulations are profoundly affected by the vowel environment and assimilation processes (Gibbon, Hardcastle & Nicolaidis, 1993; Ellis & Hardcastle, 2002). To illustrate this point, EPG studies have shown a more forward place of articulation of velars where they occur in high/front compared to low/back vowel contexts (Gibbon et al., 1993; Dagenais, Lorendo & McCutcheon, 1994; Gibbon & Nicolaidis, 1999; Nicolaidis, 2001; Recasens & Pallares, 2001). The more retracted placement for velars in some vowel contexts can lead to incomplete closure being registered on the artificial plate. This is often due to the occlusion occurring further back than the most posterior row of electrodes, which are normally located on the junction between the hard and soft palate (Hardcastle & Gibbon, 1997). The lack of complete closure is a limitation of the technique itself because in these cases it is not possible to know from EPG data alone where the main occlusion for the velar stop is located.

A number of previous EPG studies have reported and discussed the difficulties of interpreting contact patterns that exhibit incomplete closure during velars. Nicolaidis (2001) used EPG to study Greek spontaneous speech. She showed that 59 out of 94 velar tokens (63%) were produced with incomplete velar closure. Nineteen out of 59 incomplete closures showed silence in the acoustic signal, but incomplete EPG closure, which was the evidence of closure occurring behind the EPG palate. Additional 12 incomplete velar closures had friction in the acoustic signal as well as incomplete EPG closure, which suggested a reduction of the velar gesture itself. The remaining 28 out of 59 incomplete velar closures in her study showed full closure on EPG data, but were still tagged as incomplete closures, because there was evidence of friction in the acoustic signal during /k/. The author, therefore, assumed that the occlusion was not complete and that there was a lateral release of airflow at a location behind the most posterior row of electrodes which caused the friction in the acoustic data. Another explanation, not offered by the author, could be that a small opening in the closure occurred between two electrodes in posterior rows of the EPG palate and was therefore not recorded in the EPG data. This explanation is supported by the fact that contact separation in the palatal and velar region is greater (more than 3 mm) than that in the alveolar region (less than 3 mm) on the Reading EPG palate (Wrench, 2007), making it possible for the opening to occur between two electrodes. Stephenson (2003) in a study of alveolar to velar assimilation in normal speakers of Australian English reported the presence of incomplete closures during velar stops in her data, but these were in a potential alveolar to velar assimilation site so it is not known how often to expect incomplete closures in non-assimilated velars in normal speakers.

In addition to knowing about the range of normal EPG patterns for velars, it is also important to know the relative articulatory distance in placement between velars and other target sounds, particularly alveolar stops. The importance of articulatory distance was discussed in a recent study by Liker et al. (2007). These authors estimated distance by using the “centre of gravity” (COG) index, based on EPG data. (For further details of the COG measure see Gibbon & Nicolaidis, 1999; Baken & Orlikoff, 2000). The purpose of the COG measure is to identify the location of the main concentration of contacted electrodes on the EPG plate, and as such it estimates relative place of articulation on the hard palate from alveolar to velar. A high COG value represents a forward, i.e., anterior placement typical of alveolar and post-alveolar sounds whereas a low COG value reflects a posterior placement typical of velar sounds. Liker et al. found that placement of the occlusion phase of /t/ and /tʃ/ varied considerably between speakers. Despite this variability in placement, the COG measure showed that individual speakers consistently maintained a significantly more forward placement for /t/ compared to /tʃ/.

Another reason why the distance between alveolars and velars is important is because some individuals with speech disorders produce articulations that effectively either reduce or neutralise this distance. Reducing or neutralising the distance in placement between alveolar and velar targets has been found to be associated with speech errors such as substitutions, distortions and overall reduced speech intelligibility. Gibbon and Crampin (2001) studied articulatory distance in an adult with cleft palate who from a perceptual analysis produced all alveolars and velars as middorsum palatal stops. Based on the COG index, these authors found that the articulatory distance between these targets produced by this speaker was significantly reduced compared to the control speakers. Gibbon and Crampin found that normal speakers had COG values of around 5 for alveolar targets and between 1 and 2 for velar targets, giving an articulatory distance between these targets of approximately 3-4. In contrast, the speaker with cleft palate had a much reduced articulatory distance of less than 1. A limitation of the Gibbon and Crampin study was that it was based on only two control speakers. The high inter speaker variation in contact patterns, particularly velars, means that more EPG data is needed from a greater number of normal speakers in order to establish reliable COG norms for articulatory distance.

The aim of the current study was to better define the range of tongue palate contact patterns during the occlusion phase of /k/ in normal English speaking adults for the purpose of informing clinical practice when using EPG for diagnosis and treatment of abnormal /k/ articulations. The study additionally measured articulatory distance between velar /k/ and alveolar /t/ (the data for /t/ was recorded in the same vowel contexts and from the same speakers as /k/, and is reported in a previous study, Liker et al., 2007).

2. METHOD

2.1. Participants

The study analysed articulation data from seven normal adult speakers of English, ranging in age from 24 to 47 years and a mean of 36 years. There were four female (F1, F2, F3 and F4) and three male (M1, M2 and M3) participants. Participants were faculty members at the University of

Reading, UK. They had no history of speech, language or hearing difficulties and were all native speakers of English. In order to record the dynamic tongue palate contact patterns, each speaker had an artificial plate (Reading EPG, Hardcastle & Gibbon, 1997) individually constructed to fit against the hard palate. The plate contained 62 electrodes, placed in eight horizontal rows according to well-defined anatomical landmarks. All participants underwent a desensitization period of four hours prior to recording to adjust their articulation to the presence of the artificial plate within the oral cavity. All participants were judged by the experimenter, a qualified speech and language therapist, to have normal undistorted speech with the palate in situ at the end of the desensitization period.

2.2. Speech material

Simultaneous EPG and acoustic data were recorded as the participants read out loud a set of nonsense VkV sequences in which V represented /i/, /a/ and /u/. Thus /k/ tokens were analysed in nine vowel environments (aa, ii, uu, ai, au, ia, iu, ua, ui), which were selected because they represented a high front, high back and low tongue position in British English dialects. Stress was placed on the first syllable and each speaker repeated the sequences 10 times, hence, a total of 630 tokens were analysed. Data recorded at the same time for alveolar stop /t/ targets produced by the same speakers in exactly the same vowel environments and reported in a previous study (Liker et al., 2007) were used to investigate articulatory distance between alveolar and velar stops within speakers.

2.3. Instrumentation & recording

The speech material was extracted from the EUR-ACCOR database (Marchal & Hardcastle, 1993). The data was recorded using the Reading Multi-channel System, with the EPG data sampled at 200 Hz and the acoustic signal at 20 kHz. Data were recorded in several channels, for this study only the audio signal (Sennheiser microphone MKH 40 P48) and tongue palate contact (Reading EPG system) were utilised. Data was imported into the Articulate Assistant software (Wrench, Gibbon, McNeill & Wood, 2002), which was used for segmentation, annotation and analysis.

2.4. Data segmentation, annotation and analysis

The EPG and acoustic data were displayed on a computer screen using the Articulate Assistant software version 1.12 (EPG software). In order to identify the articulatory characteristics of the velar stops, occlusion phase of velar stops was annotated (tagged):

(1) The beginning of the occlusion was identified as the first EPG frame showing full electrode activation on one or more rows;

(2) The end of the occlusion identified as the last frame of full electrode activation across one or more rows.

The annotated EPG frames at the beginning and end of segments usually coincided with the acoustic events marking the beginning and the end of the occlusion phase. These annotations are illustrated in figure 1.

Insert figure 1 about here.

Three measurements were made based on the annotations: percent of complete occlusions, place of articulation, amount of contact. When there was no full electrode activation on at least one row on the palate during velar occlusion (figure 1), the repetition was tagged “incomplete EPG closure” and annotation was performed according to acoustic events (silence in the acoustic signal). Percent of complete EPG closures for each speaker and each vowel context was calculated. Number of complete EPG closures was counted for each repetition and each vowel context, divided by the total number of repetitions (10) and multiplied by 100. The data for each vowel context were averaged across speakers.

Place of articulation was measured by means of a modified COG index, the PCoG (Posterior Centre of Gravity) at the frame of maximum contact (Gibbon et al., 1993). Like the COG, a higher PCoG value indicated a more fronted articulation, while a lower value indicated a more retracted articulation. The PCoG index was calculated on the central four mid-sagittal electrodes in the back four rows according to the following formula:

$$PCoG = \frac{(0.5xR8) + (1.5xR7) + (2.5xR6) + (3.5xR5)}{R4 + R3 + R2 + R1}$$

Articulatory distance between /k/ and /t/ was measured as the difference between two calculated index values, the PCoG and placement for alveolar stop /t/ measured using the ACoG index (Gibbon et al., 1993) and is reported in full in a previous study (Liker et al., 2007).

Amount of contact was also calculated at the EPG frame of maximum contact between the beginning and end of the occlusion. The calculation was expressed as a percent of a total number of contacts as a fraction of the whole palate (62 electrodes). So, the largest possible result was 100%, meaning all of the electrodes were contacted, whereas the lowest possible result was 0%, meaning none of the electrodes were contacted.

The statistical significance of differences between the variables was tested by means of heteroscedastic t-test.

3. RESULTS

3.1. Complete EPG closures

Figure 2 shows that the majority (81%) of velar stop tokens had complete closure across the EPG palate. There were at least some cases of incomplete EPG velar closures in all vowel contexts, however. The following vowel contexts are ordered from the highest (96%) to the lowest (59%) number of complete EPG closures: /ui/, iu/, /ia/, /ii/, /ai/, /ua/, /uu/, /au/, /aa/. The differences between vowel contexts, however, were not statistically significant ($p>0.05$). The speakers also varied considerably in the number of complete occlusions (F3 99%; M1 98%; F4 92%; M3 89%; F2 77%; M2 74%; F1 40%). Only speaker F1 differs significantly from other speakers ($p<0.05$). These percentages show that four of the seven speakers (F3, M1, F4 and M3) almost always produced complete closures, regardless of the vowel context in which /k/ occurred. For other three speakers (F2, M2 and F1), their productions of complete closures was dependent on vowel context, with closures in the context of a high front vowel.

Insert figure 2 about here.

3.2. Place of articulation

The results in figure 3 show that the place of articulation as measured by the PCoG index at maximum contact point during the velar occlusion varied depending on the vowel context. As expected, the most fronted velar occlusion was in the /i/ vowel context; /iki/ had an average PCoG value of 1.36, SD 0.54. The most retracted placement was in the /a/ vowel context; /aka/ had an average PCoG value of 0.5, SD 0.01. The following vowel contexts are ranked from highest to lowest PCoG index values: /ii/, /ia/, /iu/, /ui/, /ai/, /ua/, /uu/, /au/, /aa/. The following differ significantly ($p<0.05$): /ii/ from /ui/, /ai/, /ua/, /uu/, /au/ and /aa/; /ia/ and /iu/ from /ua/, /uu/, /au/ and /aa/, while /ui/ differs significantly from /aa/. This difference in placement depending on vowel context is illustrated in figure 4.

A high negative correlation coefficient ($r = -0.73$) shows that complete closure and place of articulation move together in an inversely proportional way. This means that the probability of complete EPG closure in the velar stop /k/ increased with in the context of higher vowels.

Insert figures 3 and 4 about here.

The articulatory distance between alveolar and velar stops /t/ and /k/ is shown in figure 5. The distance between the two occlusions is clear in all speakers, with M3 having the smallest distance (index difference of 4.81) and F1 having the greatest distance between the targets (index difference of 6.77). Average placement in velar occlusion for the different speakers was between PCoG values 0.51 and 1.29 (mean 0.88, SD 0.28) and in alveolar occlusion between ACoG values 5.98 and 7.28 (mean 6.63, SD 0.45). The differences between PCoG values for each speaker were all statistically significant ($p<0.05$), except between F2 and M3 as well as between F3 and M1.

Insert figure 5 about here.

3.3. Amount of contact

Amount of contact (figure 6) varied according to vowel context. The most (42%) contact during velars occurred in the /ii/ vowel context, with the least (22%) in the /aa/ context. Despite considerable interspeaker variation in overall amount of contact, all speakers followed the same general trend of having more contact for velar occlusion in a high compared to a low vowel context. The following ranks the various vowel contexts in terms of amount of contact from the most to least: /ii/, /iu/, /ia/, /ui/, /ai/, ua/, /uu/, /au/ and /aa/. The following reached statistical significance ($p<0.05$): /ii/ and /uu/, /ua/, /au/, /aa/, then /ia/ and /au/, aa/, then /iu/ and /uu/, /ua/, /au/, /aa/ and finally /ui/ and /aa/. As with the other variables, there were considerable interspeaker differences in amount of contact, with some speakers having almost twice as much contact as others (F4 22%, F1 23%, M2 26%, F3 36%, M1 36%, F2 39% and M3 42%). All the differences between speakers were statistically significant ($p<0.05$), except those between F1 and F4, F2 and M3 as well as F3 and M1. However, although overall differences between speakers were considerable, figure 6 shows that all speakers follow the same trend.

Insert figure 6 about here.

4. DISCUSSION

The results of this study show that across all vowel environments, the majority (81%) of velar occlusions had complete closure in the posterior region of the hard palate. Adjacent vowels heavily influenced whether complete closure occurred, however, with higher instances in /i/ compared to /a/ vowel contexts. There were also considerable differences between speakers in their tendency to produce closures; some speakers almost always produced complete closures regardless of vowel context, whereas other speakers tended to produce closures only in the context of high front vowels. In normal speakers, where the acoustic signal indicates the presence of a closure with no acoustic energy present in the waveform and the EPG trace shows incomplete closure, it is likely that an occlusion is occurring at a location behind the most posterior row of EPG electrodes.

The diagnostic implication is that incomplete closures during perceptually correct velar articulations are not unusual in normal speakers and therefore should not be regarded as abnormal patterns. One implication of this finding is that during EPG intervention that aims to facilitate correct articulation of velars, speech and language therapists might find it helpful for the individual with a speech disorder to try to produce velars in phonetic contexts that are most likely to have complete closures, at least in the first stages of therapy. A possible starting point would be to attempt to elicit correct velars in a high vowel context in words or phrases such as *a key*, *Mickey* or *beaker*. Further support for selecting these words or words in similar phonetic contexts is the finding from the current study that speakers produce about twice the amount of contact for velars in /i/ compared to /a/ environments. EPG intervention is based on providing visual feedback of tongue palate contact, so it is reasonable to suggest that patterns involving high amounts of contact provide more information to the client and are therefore better treatment targets than those with minimal or no contact. A final therapeutic implication of the results is that clients as well as speech and language therapists should be aware that so long as articulations are heard as correct velars, it is of no consequence whether the EPG patterns show complete or incomplete closure patterns. In a recent study Cheng, Murdoch, Goozée & Scott (2007) investigated normal development of tongue palate contact in four groups of participants with normal speech and hearing status: 6-to 7-year-olds, 8- to 11-year-olds, 12- to 17-year-olds and adults. In this large-scale study, the authors reported that each group demonstrated a high percent of incomplete velar closures during /k/ productions. Complete closures occurred as follows: 25% of complete closures in the 6-to 7-year olds, 58% in the 8-to 11-year olds, 27% in the 12-to 17-year-olds and 17% in adults. The differences between the age groups were significant. The study also showed that amount of contact for velar stop /k/ was about 15% (8.3 – 9.9 electrodes) and that differences between the age groups were not significant. These findings have important implications for treating abnormal contact patterns for velars in children, adolescents and adults. One reason for a relatively high percentage of incomplete closures and low amount of contact in /k/ might be a low vowel context in which /k/ was investigated (test word: *car*). The results of the present study have shown that the percent of complete closures and amount of contact are influenced heavily by vowel context. The reason for the differences between the two studies might also be in the fact that different speakers show different tendencies in velar stop production, as shown by this study. Different tendencies in different speakers might have also influenced the difference in the results between the four age groups in Cheng et al. (2007). Since coarticulatory performance develops with age, it remains to be seen how different vowel contexts influence velar closure in different age groups.

The results of this study provide useful guidelines for identifying abnormal contact patterns for velars in individuals with speech disorders. Despite considerable differences between speakers, it was possible to define a range of normal values for velars from the modified COG index and amount of contact measure. For instance, in terms of amount of contact, normal speakers exhibited between 22%-42% contact located primarily in the posterior region for the occlusion of /k/ across all vowel environments. Based on these values, abnormal EPG patterns for velars may be identified by contact that differs significantly from this range. Examples of abnormality might include contact that is not primarily confined to the posterior region, but instead involves extensive contact across the whole of the palate, or located primarily in the alveolar region, or contact that is minimal or absent. These abnormal patterns are likely to be associated with a wide range of perceptual errors such as substitutions, double articulations and distortions (Gibbon, 2004). In terms of therapy, normative data provide helpful guides when using EPG for visual feedback to remediate articulation errors affecting velar stops. More specifically, the normal EPG patterns will serve as targets that speakers with articulation errors will attempt to reproduce in order to produce velars with normal place of articulation.

The measures used in this study (i.e., modified COG and amount of contact) to investigate the normal velar contact patterns may prove to be valuable in assessing coarticulation in both young typically developing children and individuals with speech disorders. These measures were sensitive enough to detect the relatively small coarticulatory effects of vowels on velar placement, and as a result these measures could be applied to clinical cases and used as indicators of subtle speech motor control difficulties and the acquisition of articulation skills in typically developing children. Some researchers (Nijland, Maassen, van der Meulen, Gabreëls, Kraaimaat, & Schreuder, 2002; Nijland, Maassen, & van der Meulen, 2003) have found evidence from acoustic analysis that children with childhood apraxia of speech have subtle motoric difficulties that affect adversely this type of coarticulation. Katz (2000) reports on results of 13 studies investigating labial and lingual coarticulation in aphasic (apraxic) individuals. Eight of those studies show missing or delayed anticipatory coartioculation in people with aphasia (apraxia). On the other hand, five studies reported by Katz (2000) show no differences in the extent or magnitude of anticipatory coarticulation between nonfluent speakers with aphasia (apraxia) and controls. The COG index and amount of contact measures would provide important supporting evidence of this type of motoric deficit, which could occur in both developmental and acquired forms of dyspraxia. The ability to coarticulate also reflects articulatory skill, and so these measures could be used to gauge proficiency in using velars as a result of EPG therapy or during the course of typical development.

The results of the current study showed how the modified COG indices quantified the extent to which normal speakers separate alveolar from velar placement in terms of articulatory distance, with index differences of between 4.8 and 6.8. This normal range will prove valuable when identifying abnormal articulation errors that affect these categories of sounds. For example, the frequently occurring phonological processes of fronting velar targets to alveolars, or the opposite process of backing alveolar targets to velars, might be expected to result in reduced or neutralised articulatory distance. Likewise, the distance measure could be used to identify whether individuals with speech disorders were producing subtle phonological contrasts that could not be detected through perceptual analysis, so called covert contrasts (Hewlett, 1988; Edwards, Gibbon & Fourakis, 1997).

5. REFERENCES

Baken, R.J., & Orlikoff, R.F. (2000). *Clinical Measurement of Speech and Voice*. 2nd ed. San Diego, California: Singular Publishing Group.

Cheng, H.Y., Murdoch, B.E., Goozée, J.V., & Scott, D. (2007). Electropalatographic assessment of tongue-to-palate contact patterns and variability in children, adolescents, and adults. *Journal of Speech, Language, and Hearing Research*, 50, 375-392.

Crawford, R. (1995). Teaching voiced velar stops to profoundly deaf children using EPG: Two case studies. *Clinical Linguistics and Phonetics*, 9, 255-270.

Dagenais, P.A., Lorendo, L.C., & McCutcheon, M.J. (1994). A study of voicing and context effects upon consonant linguapalatal contact patterns. *Journal of Phonetics*, 22, 225-238.

Edwards, J., Gibbon, F., & Fourakis, M. (1997). On discrete changes in the acquisition of the alveolar/velar consonant contrast. *Language and Speech*, 40, 203-210.

Ellis, L., & Hardcastle, W. J. (2002). Categorical and gradient properties of assimilation in alveolar to velar sequences: evidence from EPG and EMA data. *Journal of Phonetics*, 30 (3), 373-396.

Friel, S. (1998). When is a /k/ not a [k]? EPG as a diagnostic and therapeutic tool for abnormal velar stops. *International Journal of Language and Communication Disorders*, 33 (supplement), 439-444.

Gibbon, F. E., & Crampin, L. (2001). An electropalatographic investigation of middorsum palatal stops in an adult with repaired cleft palate. *Cleft Palate-Craniofacial Journal*, 38, 96–105.

Gibbon, F., Hardcastle, W., & Nicolaidis, K. (1993). Temporal and spatial aspects of lingual coarticulation in /kl/ sequences: a cross-linguistic investigation. *Language and Speech*, 36 (2, 3), 261-277.

Gibbon, F., Lee, A., & Yuen, I. (2007). Tongue palate contact during bilabials in normal speech. *Cleft Palate-Craniofacial Journal*, 44, 87-91.

Gibbon, F.E., McNeill, A.M., Wood, S.E., & Watson, J.M.M. (2003). Changes in linguapalatal contact patterns during therapy for velar fronting in a 10-year-old with Down's syndrome. *International Journal of Language and Communication Disorders*, 38, 47-64.

Gibbon, F., & Nicolaidis, K. (1999). Palatography. In W.J. Hardcastle, & N. Hewlett (Eds.), *Coarticulation. Theory, data and techniques* (pp. 229-245). CUP.

Gibbon, F.E., & Paterson, L. (2006). A survey of speech and language therapists' views on electropalatography therapy outcomes in Scotland. *Child Language Teaching and Therapy*, 22, 275-292.

Gibbon, F.E., & Wood, S.E. (2002). Articulatory drift in the speech of children with articulation/phonological disorders. *Perceptual and Motor Skills*, 95, 295-307.

Gibbon, F., Yuen, I., Lee, A., & Adams, L. (2007). Normal adult speakers' tongue palate contact patterns for alveolar oral and nasal stops. *Advances in Speech-Language Pathology*, 9 (1), 82-90.

Hardcastle, W.J., & Gibbon, F. (1997). Electropalatography and its clinical applications. In M.J. Ball, & C. Code (Eds.), *Instrumental Clinical Phonetics* (pp. 149-193). London: Whurr Publishers.

Hewlett, N. (1988). Acoustic properties of /k/ and /t/ in normal and phonologically disordered speech. *Clinical Linguistics and Phonetics*, 2, 29-45.

Hiki, S., & Itoh, H. (1986). Influence of palate shape on lingual articulation. *Speech Communication*, 5, 141-158.

Katz, W.F. (2000). Anticipatory coarticulation and aphasia: implications for phonetic theories. *Journal of Phonetics*, 28, 313-334.

Liker, M., Gibbon, F., Wrench, A., & Horga, D. (2007). Articulatory characteristics of the occlusion phase of /tʃ/ compared to /t/ in adult speech. *Advances in Speech-Language Pathology*, 9 (1), 101-109.

Marchal, A., & Hardcastle, W. J. (1993). ACCOR: Instrumentation and database for the cross-language study of coarticulation. *Language and Speech*, 36, 137 – 153.

Nicolaidis, K. (2001). An electropalatographic study of Greek spontaneous speech. *Journal of the International Phonetic Association*, 31 (1), 67-85.

Nijland, L., Maassen, B., & van der Meulen, S. (2003). Evidence of motor programming deficits in children diagnosed with DAS. *Journal of Speech, Language, and Hearing Research*, 46, 437-450.

Nijland, L., Maassen, B., van der Meulen, S., Gabreëls, F., Kraaimaat, F. W., & Schreuder, R. (2002). Coarticulation patterns in children with developmental apraxia of speech. *Clinical Linguistics and Phonetics*, 16, 461-483.

Recasens, D., & Pallares, M.D. (2001). Coarticulation, assimilation and blending in Catalan consonant clusters. *Journal of Phonetics*, 29, 273-301.

Stephenson, L. (2003). An EPG study of repetition and lexical frequency effects in alveolar to velar assimilation. *The Proceedings of the 15th ICPhS in Barcelona*, 1891-1894. Also on CD.

Wrench, A.A., Gibbon, F.E., McNeill, A.M., & Wood, S.E. (2002). An EPG therapy protocol for remediation and assessment of articulation disorders. In: J.H.L. Hansen, & B. Pellom. (Eds.), *Proceedings of ICSLP-2002*, 965-968. Also on CD-ROM.

Wrench, A.A. (2007). Advances in EPG palate design. *Advances in Speech-Language Pathology*. 9 (1), 3-12.

Figure captions

Figure 1. EPG printout to illustrate incomplete EPG closure in /aka/ realised by speaker F1 (top) and complete EPG closure also in the /aka/ sequence realised by speaker F3 (bottom). Beginning, end and maximum contact point are marked by encircled letters B, E and M respectively. Below each EPG printout annotated velar closure is marked on the waveform.

Figure 2. Percent of complete EPG closures during /k/ in nine vowel contexts.

Figure 3. PCoG index at the EPG frame of maximum contact during velar occlusion in nine vowel contexts.

Figure 4. EPG printout illustrating the difference within speakers in amount of contact in different vowel environments. In this example, the speaker is F3, and shows that velar closure in /iki/ (top) has 47% contact at maximum contact frame 107 versus /aka/ (bottom) which has 27% contact at frame 43.

Figure 5. Articulatory distance in place of articulation, as measured by ACoG index for /t/ and PoG index for /k/, at maximum contact in seven speakers.

Figure 6. Amount of contact at maximum contact measured in nine vowel contexts for each speaker.

Figure 1.

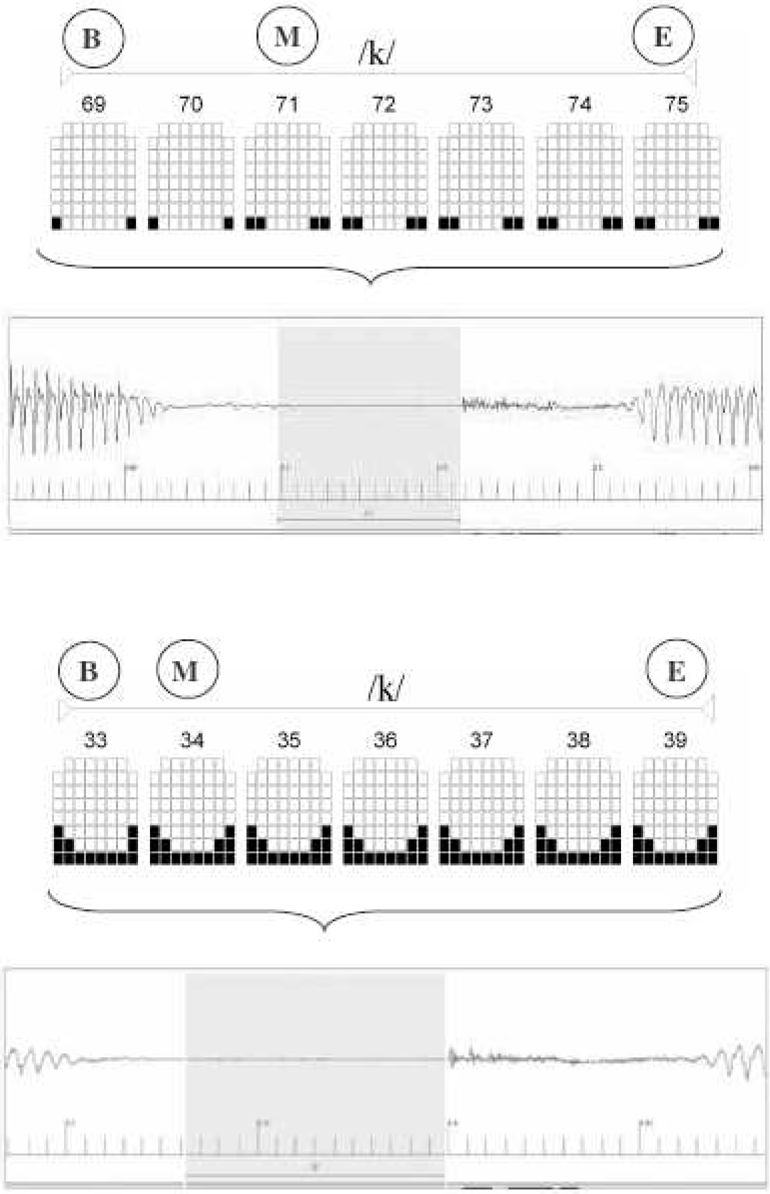


Figure 2.

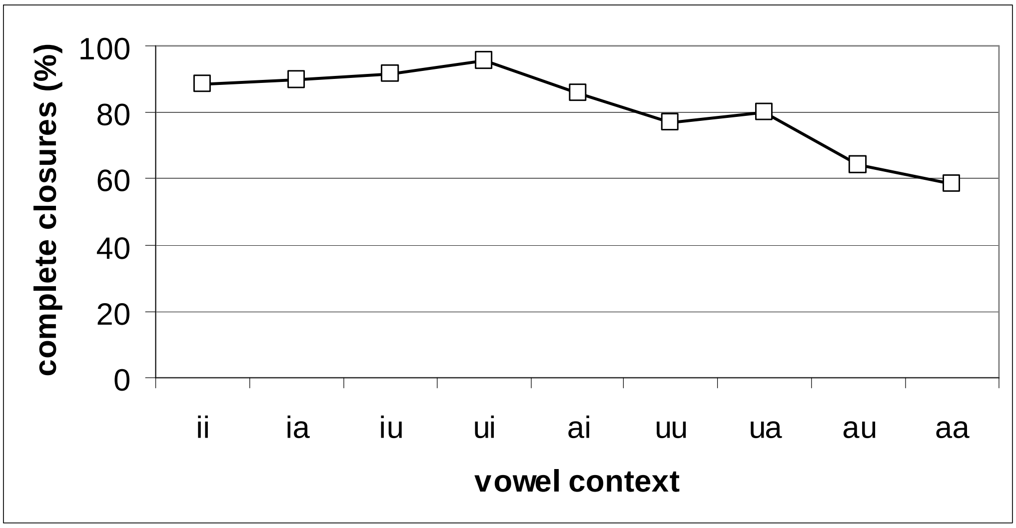

complete closures (%)
100
80
60
40
20
0
ii
ia
iu
ui
ai
uu
ua
au
aa
vowel context

Figure 3.

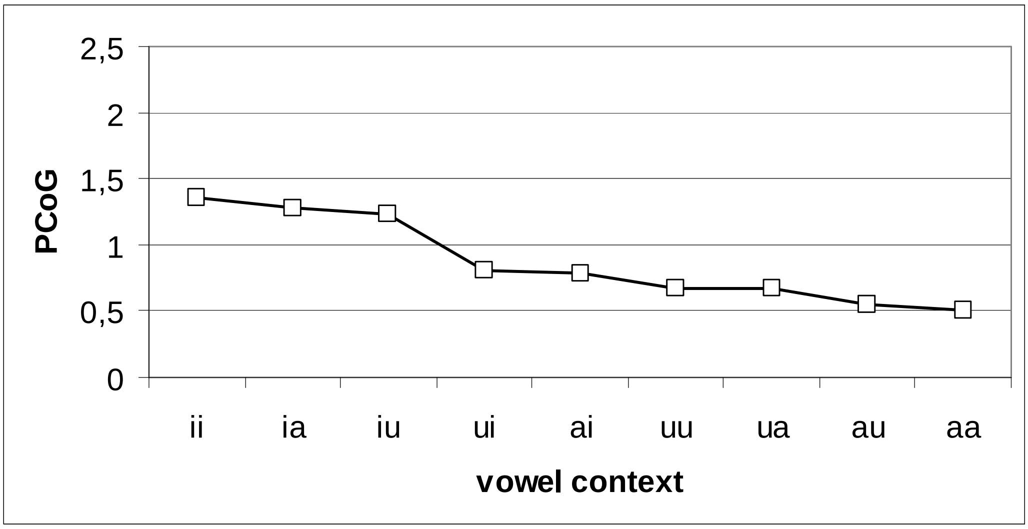


Figure 4.

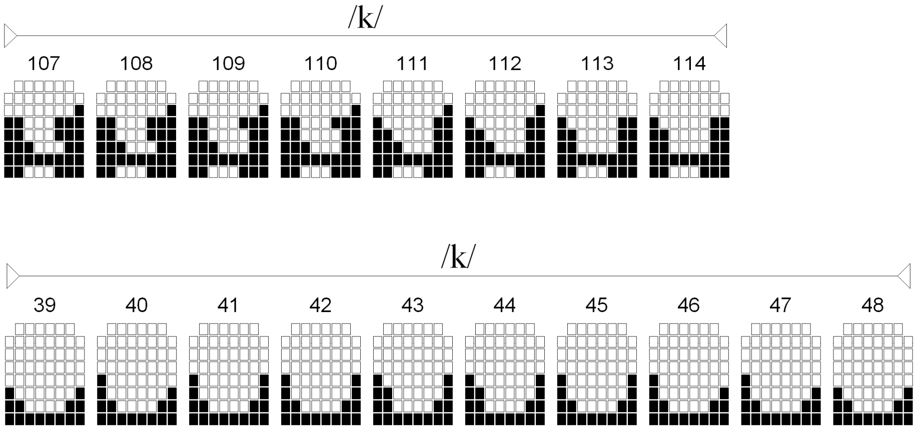


Figure 5.

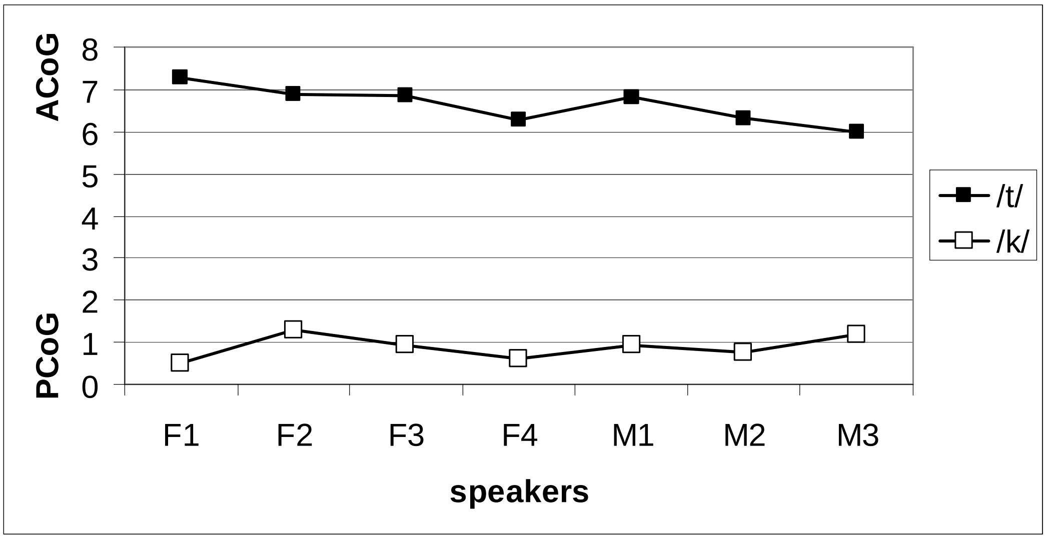
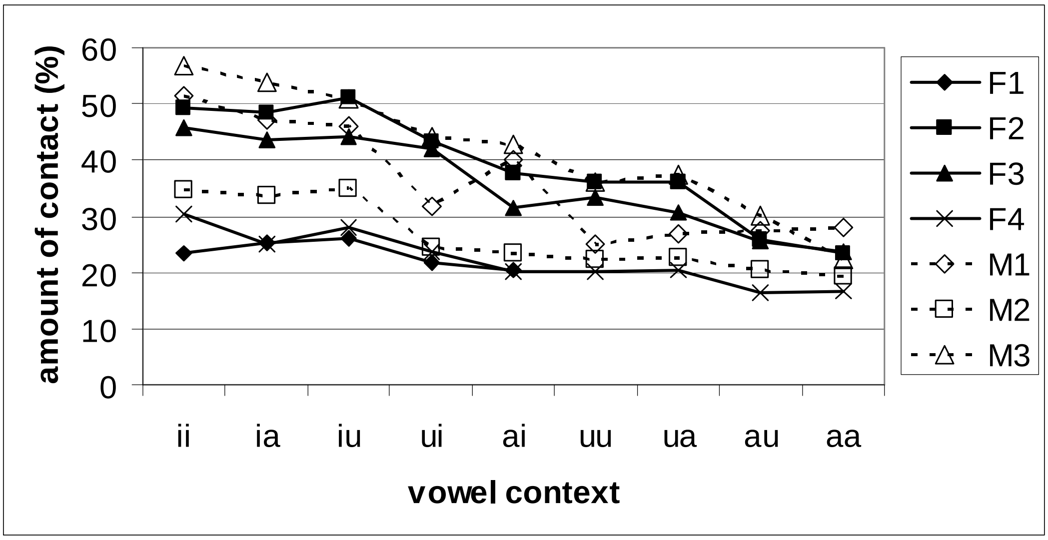


Figure 6.


amount of contact (%)
60
50
40
30
20
10
0
ii
ia
iu
ui
ai
uu
ua
au
aa
vowel context
F1
F2
F3
F4
M1
M2
M3