Articulatory characteristics of the occlusion phase of /tʃ/ compared to /t/ in adult speech

[1]Marko Liker
[2]Fiona Gibbon
[2]Alan Wrench
[1]Damir Horga
[1]Department of Phonetics, Faculty of Humanities and Social Sciences, University of Zagreb
[2]Queen Margaret University College, Edinburgh

Abstract

This study used electropalatography (EPG) to investigate articulatory characteristics of /tʃ/ and /t/ occlusion in order to provide normative data to be used for the diagnosis and treatment of individuals with speech disorders. EPG data from the EUR-ACCOR database were analysed for nonsense VCV sequences containing /tʃ/ and /t/ in nine vowel contexts for seven English speaking adults. The main results of this study are that all speakers had a significantly more posterior placement for /tʃ/ compared to /t/ and that placement was stable during the occlusion phase of both /tʃ/ and /t/. For most speakers, the occlusion phase was longer for /tʃ/ compared to /t/, the occlusion phase generally involved more EPG contact and was slightly more variable in /tʃ/ compared to /t/, but these differences were not statistically significant for all speakers. The implications of the results for diagnosing and treating speech disorders are discussed.

Key words: stops, electropalatography (EPG), affricates, articulation disorder.

Introduction

Researchers and speech and language therapists are using electropalatography (EPG) increasingly for diagnosing and treating articulation disorders associated with a variety of pathologies such as: neuromotor disorders (e.g., cerebral palsy, Parkinson's Disease, stroke, Worster-Drought syndrome); structural abnormalities of the vocal tract (e.g., cleft palate, glossectomy); sensory deficits (e.g., hearing impairment); and cognitive deficits (e.g., Down's syndrome) (see Hardcastle & Gibbon, 2005, for a recent review). For the purpose of using EPG as a clinical tool, an understanding of the range of EPG patterns produced by normal children and adults is necessary to identify abnormal patterns and also to use EPG effectively as a therapy tool. Differentiating normal from abnormal patterns is not a straightforward task, however, due to the variability of normal patterns. For example, contact patterns between speakers will vary depending on the shape of the hard palate (Hiki & Itoh, 1986). In addition, an individual speaker's contact patterns for the same target will vary depending on the phonetic context. McLeod (2006) emphasised the need for normative data so that EPG users appreciate the range of intra and inter subject variability that exists in the normal population.

In terms of therapy, normative data is a helpful guide when using EPG for visual feedback to remediate articulation errors. More specifically, the normal EPG patterns will serve as targets that speakers with articulation errors will attempt to reproduce in order to produce target sounds with normal place of articulation. Although considerable normative EPG data exist for a range of lingual targets, there is relatively little normal adult data available for English affricates /tʃ/ and /dʒ/. This is a gap in the literature that needs to be filled because affricates are frequently produced as errors by individuals with articulation disorders and as a result these sounds are often targeted in EPG therapy (Gibbon, Hardcastle & Dent, 1995; Gibbon & Paterson, in press; Hardcastle, Gibbon & Scobbie, 1995; Hickey, 1992; Howard, 2001).

Although there is little normative adult data on English affricates, some EPG data for the voiceless affricate /tʃ/ have been reported by Fletcher (1989) in school aged children. He studied nine normal 6- to 14-year-old children and found that the affricates had clearly visible stop and sibilant portions, with the sibilant portion formed at the same place as singleton /ʃ/. As expected, Fletcher found that the stop phase of the affricate was retracted in comparison to /t/ and located at a place similar to /ʃ/. Although this study provided useful normative data for children, it did not investigate adult patterns. Furthermore, the data was acquired using the Kay system, which has an arrangement of electrodes on the palate that is different from the Reading EPG palates, so data gathered by the two systems are not directly comparable.

Ladefoged and Maddieson (1996) described affricates as ‘stops in which the release of the constriction is modified in such a way as to produce a more prolonged period of frication after the release’ (p. 90) and as a result they share some acoustic and articulatory features of both stops and fricatives. Affricates have been studied widely using acoustic analysis (Howell & Rosen, 1983; Stevens, 1993) and are characterised by a relatively rapid build up in acoustic energy at the release, although this build up is not as rapid as for plosives (Howell & Rosen, 1983). In terms of articulation, the affricate /tʃ/ is described as being produced by raising the blade of the tongue and producing an occlusion in the post alveolar region, a region generally more posterior than the occlusion of /t/. The affricate is not only at a different place of articulation compared to /t/, the active articulator is also different with the blade of the tongue (i.e. laminal) the active articulator for /tʃ/ and the apical region the active articulator for /t/. At the release of the affricate, turbulent noise is generated by the airflow through the central post alveolar constriction and impinging on the lower incisors (Stevens, 1993). In English, the affricates are usually accompanied by some lip rounding, as occurs for /ʃ/, with which the fricative component of the affricate shares many articulatory and acoustic features.

The post alveolar /tʃ/ is one of the most frequently occurring affricates – it is in 45 percent of the world’s languages (Maddieson, 1984). Affricate releases usually involve widening of the constriction of the stop, with the result that the fricative and stop components of affricates, such as /tʃ/, usually have identical place of articulation. Although often homorganic, some affricates involve a small movement backwards or forwards, an example of this phenomenon is the German /pf/. Although a change of placement is not reported in traditional phonetic descriptions of the English affricate /tʃ/, nevertheless Bernhardt, Gick, Bacsfalvi and Adler-Bock (2005) stated that they have observed using ultrasound and EPG that in some speakers the tongue moves ‘from a more forward (generally alveolar) position to a more clearly post-alveolar position for the affricate /tʃ/ (/t/ to /ʃ/)’ (p. 612).

The aim of this paper is to provide normative EPG data from adult speakers for the occlusion of the affricate /tʃ/ and the stop /t/. Based on traditional descriptions, it is predicted that placement for affricates will be posterior to that of the stop. Furthermore, it is predicted that placement will remain stable throughout occlusion of both affricates and stops.

Method

Participants

The study involved the analysis of 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 palate (Reading EPG, Hardcastle & Gibbon, 1997) individually constructed to fit against the hard palate. The palate contained 62 electrodes, placed in eight horizontal rows according to well-defined anatomical landmarks. All participants underwent a desensitization period of 4 hours prior to recording to adjust their articulation to the presence of the artificial palate 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.

Speech Material

Simultaneous EPG and acoustic data were recorded as the participants read out loud a set of nonsense VCV sequences in which V represented /i/, /a/ and /u/, while C represented /t/

and /tʃ/. Thus two consonants were analysed in nine vowel environments (aCa, iCi, uCu, aCi, aCu, iCa, iCu, uCa, uCi). These vowels were selected because they represent 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 nonsense sequences 10 times, hence, a total of 1260 tokens were analysed.

Instrumentation and Recording Procedures

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 was imported into the Articulate Assistant software (Wrench, Gibbon, McNeill & Wood, 2002), which was used for segmentation, annotation and analysis. EPG data was analysed at 100 Hz. 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.

Selected EPG frames during the affricate and stop segments were annotated for subsequent analysis. The beginning of the occlusion was identified as the first EPG frame showing complete closure (full electrode activation on one or more rows), with the end of the occlusion identified as the last frame of complete closure. The frame of maximum contact during the occlusion was also identified. Data from these frames were exported for analysis using the 'data export' function of the software. 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 points are illustrated in figure 1. Figure 1 shows full EPG printouts from one speaker for /t/ and /tʃ/. The occlusion phase is marked above the EPG frames.

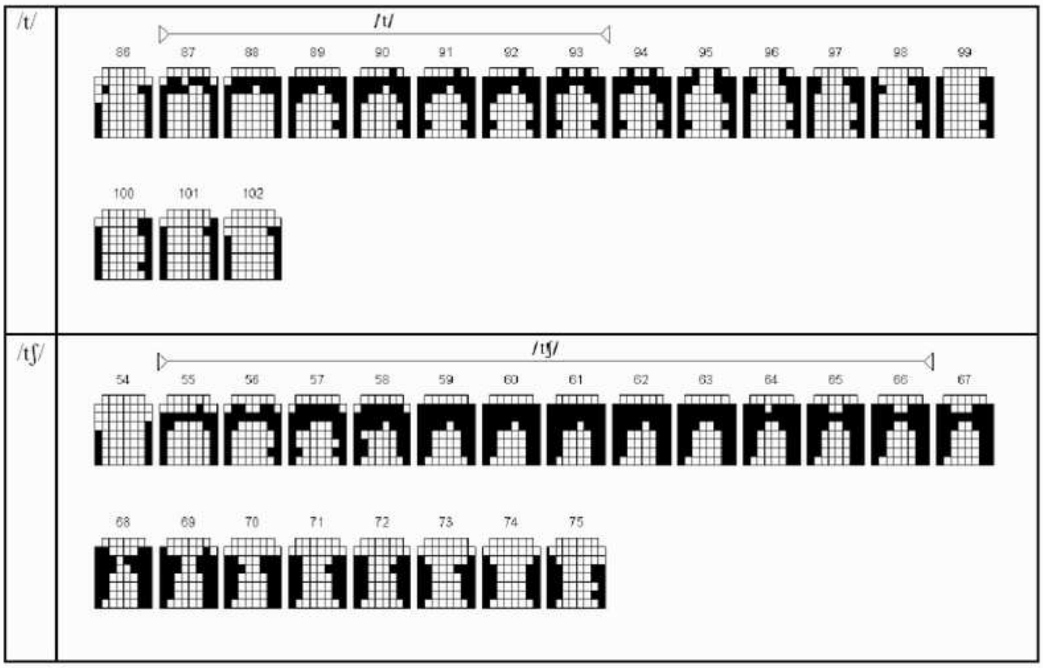

Figure 1. Full EPG printouts of /tʃ/ and /t/, with the occlusion phase marked above the EPG frames. Both EPG printouts are from the same speaker (F3) and the same vowel environment (aCa).

Data Analysis

Place of articulation during the occlusion phase of affricates and stops was measured by means of the ACoG index (Anterior Centre of Gravity) at maximum contact point in different vowel contexts (Gibbon, Hardcastle & Nicolaidis, 1993). The ACoG is a variation on the more widely used COG index, which is a well-established measure of placement on the hard palate and is reported in a previous study (Gibbon, et al. 1993). The index gives a single numerical value representing the position of the greatest concentration of activated electrodes across the palate in the front/back dimension. A high value represents a forward, i.e. anterior, place of articulation, whereas a low value reflects a posterior place of articulation. The ACoG index is calculated on the central four mid-sagittal electrodes in the front four rows according to the following formula:

$$ACoG = \frac{(4.5xR4)+(5.5xR3)+(6.5xR2)+(7.5xR1)}{R4+R3+R2+R1}$$ (Gibbon, et al. 1993).

Placement stability during occlusion was compared by means of the ACoG index measured at 10 equally spaced sample points during the occlusion phases of the stop and the affricate for each vowel context and each speaker. The shortest occlusion was approximately 60 ms and the longest was about 100 ms. Since the data was analysed at the sampling rate of 100 Hz, this meant that for occlusions shorter than 100 ms some sample points were at the same EPG frame. Although this decision made statistical comparison between the sample points in the two types of occlusion invalid, measuring the maximum number of sample points (10) had the advantage of making the trend lines as smooth as possible. The alternative would have been to measure the ACoG index at 6 equally spaced sample points (the shortest occlusion was about 60 ms), which would have ensured that each sample point was measured at a different frame. However, a smaller number of sample points would have resulted in a more crooked trend lines for longer occlusions, thus making visual inspection of the trend lines more difficult. A smaller number of sample points would have been more appropriate if we had wanted to conduct statistical analysis of the sample points and also if we had wanted to compare the trend lines mathematically. The results were presented as one trend line for the stop and one for the affricate per speaker, showing the stability of the ACoG throughout the occlusion. A shift in placement could be identified by observing whether the ACoG value changed during the occlusion.

The variability index (Farnetani & Provaglio, 1991) was used to quantify variability of tongue palate contact. To calculate the index, the percent frequency of activation of each electrode across repetitions is measured. 100% and 0% of activation frequency represent invariance and are assigned an index value 0. The index value increases as the contact frequency reaches 50%, when it is assigned an index value 50. Finally, the variability index can be calculated in two ways: 1. by summing the index values for all contacts with more than 0% contact and dividing by that number of contacts and 2. by summing the index values for all contacts and dividing by 62. In this paper the index values for all contacts were summed and divided by 62. Thus, a variability index value of 0 represents invariability and an index value of 50 represents maximum variability. The variability index was calculated at the maximum contact point for each vowel context for each speaker producing 18 variability index values per speaker.

The amount of contact was calculated at maximum contact, expressed as a percent and duration of occlusion was measured in ms as the time from the beginning of the first frame of complete closure to the last frame of closure.

The statistical significance of differences between the affricate occlusion and the stop occlusion in all variables was tested by means of a two-sample t-test assuming unequal variances (heteroscedastic t-test) with the alpha (p) of 0.05.

Results

Place of Articulation

Figure 2 shows that all speakers had a more posterior placement for /tʃ/ (mean placement = 5.82, standard deviation = 0.53) compared to /t/ (mean placement = 6.63, standard deviation = 0.54). This applied to all speakers, although there was inter subject variation in the exact location of the placement for the affricate and stop as well as the articulatory distance between them. The distance between targets represents the difference in the calculated ACoG values and it is not the actual distance. For example, speaker M1 had the greatest distance between the targets (1.48), whereas M3 had a much smaller distance (0.38) between placement for the occlusion of stop and affricate sounds. The speakers also varied in the location of placement for the stops and affricates, with F1 showing the most anterior placement for /t/ at 7.28, with M3 further back on the palate for this target at 5.98. Likewise, placement for the affricate varied from 6.36 (F1) to 5.38 (M1). Interestingly, placement for M3's /t/ was at a more posterior place than some speakers' (F1 and F3) placement for affricates. The important feature in all speakers however, was that they maintained a posterior placement for /tʃ/ relative to /t/ and statistical analysis revealed that the difference in placement for /t/ and /tʃ/ was significant in all speakers (F1 t = 1.9785, df = 129; F2 t = 1.9746, df = 163; F3 t = 1.9772, df = 139; F4 t = 1.9736, df = 175; M1 t = 1.9769, df = 141; M2 t = 1.9739, df = 172 and M3 t = 1.9754, df = 155). Average palates at maximum contact point are in appendix 1.

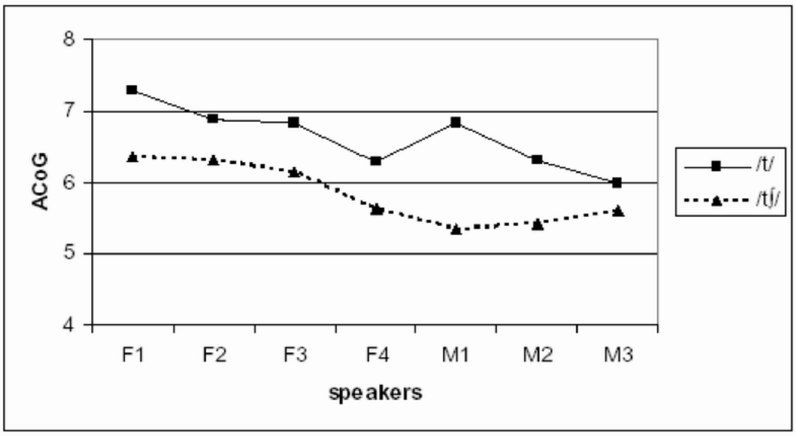

Figure 2. ACoG measured at maximum contact point in /tʃ/ and /t/ averaged for all vowel environments for each of the seven speakers.

Placement Stability during Occlusion

Figures 3 and 4 show trend lines for ACoG values at 10 equally spaced annotation points throughout the occlusion of /t/ and /tʃ/ for the seven speakers. Recall that ACoG measures place of articulation, with higher values indicating more forward placement. The trend lines aimed to identify whether placement moved backwards during occlusion (by a downward sloping line) or forwards (by an upward sloping line) or remained stable (by a horizontal line). Observations of figure 3 show almost horizontal trend lines for /t/, indicating stable placement during occlusion. The trend lines for /tʃ/ in figure 4 are likewise almost horizontal indicating similarly stable placement for the occlusion of the affricate.

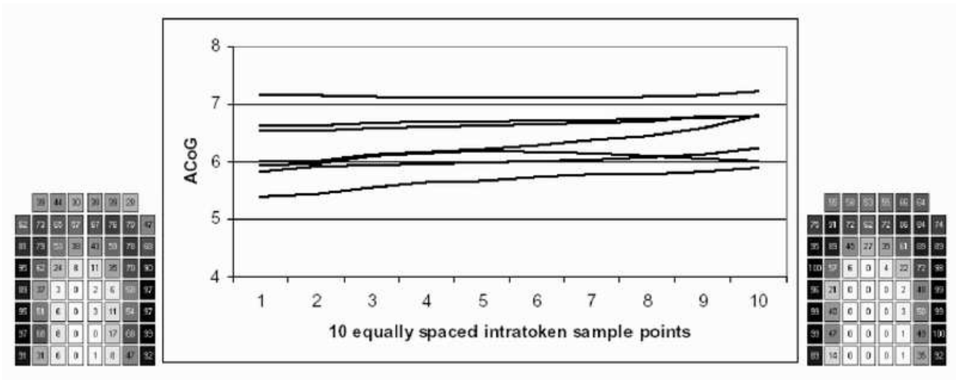

Figure 3. Placement stability during the occlusion of /t/ for each speaker (composite palates show the placement at the beginning of the occlusion – left, and at the end of the occlusion – right).

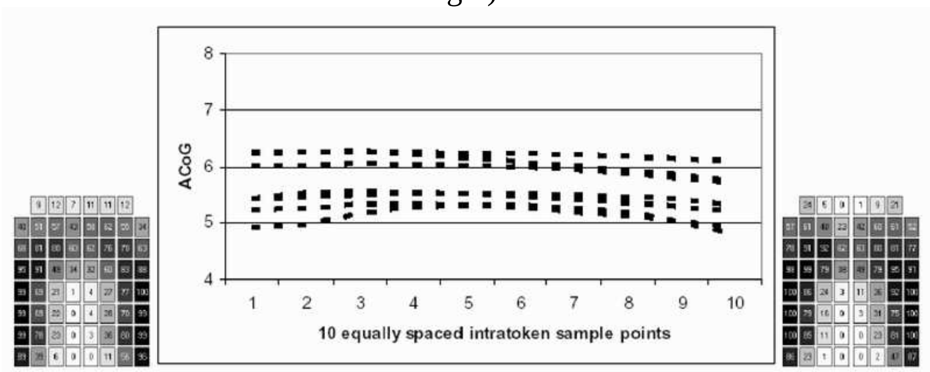

Figure 4. Placement stability during the occlusion of /tʃ/ for each speaker (composite palates show the placement at the beginning of the occlusion – left, and at the end of the occlusion – right).

Variability

The results of the variability index at the frame of maximum contact are shown in figure 5. The results show that there is greater variability in the affricate closure compared with the stop closure in five speakers, although a two sample t-test assuming unequal variances showed that the difference in variability between the stop and the affricate closure was significant for only three speakers (F1 t = 2.1604, df = 13; F2 t = 2.1199, df = 16 and F3 t = 2.1448, df = 14) and not statistically significant for the remaining four speakers (F4, M1, M2 and M3). Average variability for the affricate closure is 8.57 (standard deviation = 2.57) and for the stop closure 6.90 (standard deviation = 3.10).

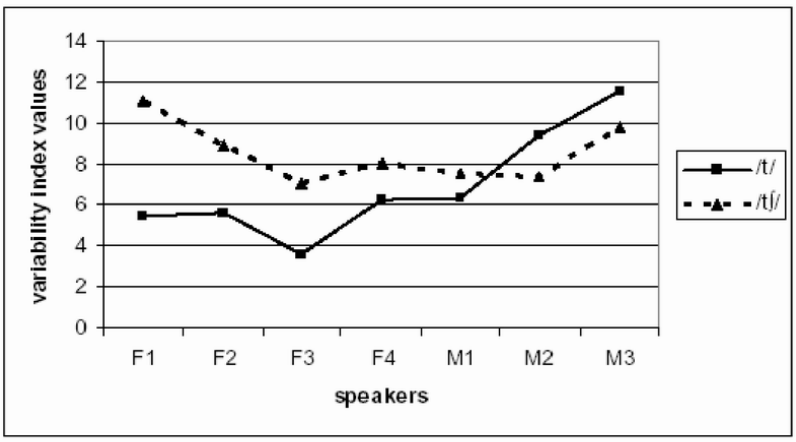

Figure 5. Variability of placement of /tʃ/ and /t/ for each speaker.

Amount of Contact

The results of calculating the total amount of EPG contact at the frame of maximum contact is shown in figure 6. This figure shows that the amount of contact for the affricate is higher than for /t/ in most speakers, with a two sample t-test assuming unequal variances showing that the difference in the amount of contact between the stop and the affricate was significant in five speakers (F1 t = 1.9743, df = 167; F2 t = 1.9744, df = 165; F3 t = 1.9744 df = 166; M1 t = 1.9744, df = 165 and M3 t = 1.9742, df = 168) and not significant for two speakers (F4 and M2). Average amount of contact for the affricate is 55.08% and for the stop it is 49.27%. The finding of higher contact for the affricate compared to /t/ in some speakers is illustrated in Figure 1.

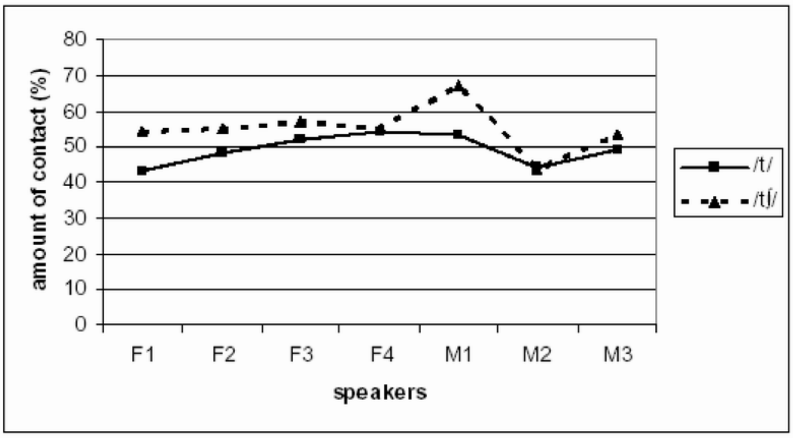

Figure 6. Amount of contact at maximum contact point in the occlusion of /tʃ/ and /t/ for each speaker.

Duration

The duration of the occlusion phase is shown in figure 7. The results show that the occlusion phase ranged approximately from 60-100 ms and was longer for /tʃ/ (mean = 78.64, standard deviation = 24.09) compared to /t/ (mean = 69.59, standard deviation = 23.42). A two sample t-test assuming unequal variances showed that the difference in the duration of the occlusion in the stop and the affricate was statistically significant in six speakers (F1 t = 1.9668, df = 347; F2 t = 1.9671, df = 336; F3 t = 1.9679, df = 300; F4 t = 1.9671, df = 332; M2 t = 1.9669, df = 343 and M3 t = 1.9684, df = 281) and not significant in one (M1). The finding of a longer occlusion duration for the affricate compared to /t/ in some speakers is illustrated in Figure 1.

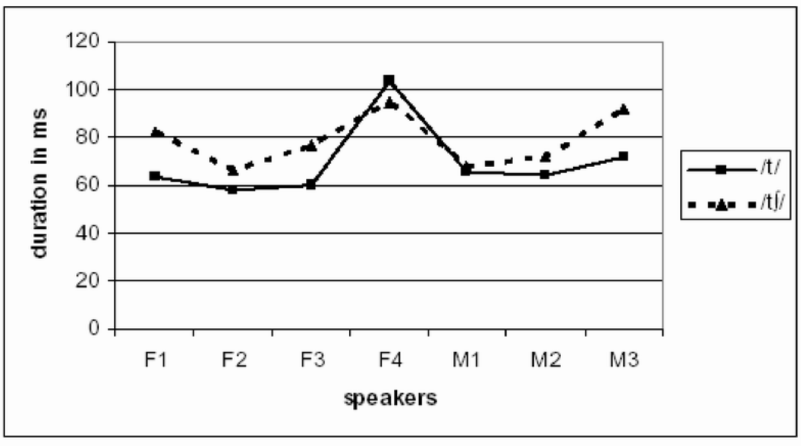

Figure 7. Duration of the occlusion in /tʃ/ and /t/ for each speaker.

Discussion

The main results of this study are that all speakers had a significantly more posterior placement for /tʃ/ compared to /t/ and that placement was stable during the occlusion phase of both /tʃ/ and /t/. For most speakers, the occlusion phase was longer for /tʃ/ compared to /t/, the occlusion phase generally involved more EPG contact and was slightly more variable in /tʃ/ compared to /t/, but these differences were not statistically significant for all speakers. The following sections discuss these results in the context of what is known about normal speech production and in relation to their implications for the management of individuals with articulation disorders.

As predicted, speakers produced a significantly more posterior placement for the occlusion phase of /tʃ/ compared to /t/ although the location of placement on the palate varied from speaker to speaker. Inter speaker differences in EPG contact patterns, particularly of alveolar stops, is a frequent finding in previous studies of normal speakers (Kohler & Hardcastle, 1974; McAuliffe, Ward & Murdoch, 2003; McLeod, 2006; Shockey, 1991). One explanation of these differences is to do with differences in shape and size of the hard palate. Hiki and Itoh (1986) gathered three dimensional measurements from plaster casts of the hard palates of fifteen adults and four children and related these measurements to EPG data produced during Japanese consonant production. The plaster casts varied considerably in terms of the length, width and height of the participants' hard palates and also the angle the front portion of the palate (the alveolar ridge) forms with the palatal vault. They found considerable inter speaker variation in the extent and location of EPG contact during /t/ and that the area of contact could be predicted to some extent when the shape of the palate was taken into account. The finding in the present study that speakers varied in the place of articulation for /tʃ/ and /t/ may be related to the shape of their palates. For example, it may be that speakers with narrower, more highly arched, palates had less tongue palate contact positioned more anteriorly compared to those with wider, flatter palates. In the present study, the speakers' palatal dimensions were not measured, so this explanation is speculative and requires further investigation.

The finding that speakers varied in the location on the palate for affricate and stop occlusion is important when using EPG in therapy. Specifically, it is relevant to take into account placement for /t/ and ensure that occlusion for the affricate is in a posterior placement relative to their alveolar stop. Aiming for a specific region on the palate for affricate placement may not be an effective strategy unless this is posterior to the stop. It is also important to take into account the individual's placement for /ʃ/. Hardcastle, et al. (1995) used EPG to study 10 school aged children with speech disorders, who produced perceptually normal /t/, but who produced /tʃ/ (among other sounds) as articulation errors. The EPG data from the children showed that there is a strict requirement for the affricate's stop phase to be homorganic with its fricative phase, irrespective of the place of articulation of /t/. But they also found that 'in those cases where /ʃ/ is retracted to a dorsal place of articulation, the occlusion phase of the affricate sometimes has a coronal component' (p. 248). These authors go on to suggest that the coronal component in the stop phase of affricates is inexplicable unless the children are aware at some level of a relationship between /t/ and /tʃ/. The influence of placement of /t/ means that for at least some individuals with speech disorders, production of a normal /t/ could facilitate 'coronal' as opposed to 'dorsal' placement for /tʃ/.

The results of the current study show that placement during the occlusion of the affricate was relatively stable, and showed no evidence of moving backwards or forwards.

This finding is in contrast to the observation by Bernhardt, et al. (2005) that normal speakers move their tongues backwards from alveolar to post alveolar during the occlusion phase of affricates. This movement would have appeared as a relatively steeply downward sloping trend line, which was not observed for the speakers in this study. Although it is necessary to be cautious about generalising these findings from a small number of subjects, the clinical implications of these findings are that there is no reason to encourage an individual with a speech disorder to attempt to move the tongue backwards during the occlusion phase of affricates.

The duration measurement results showed that the occlusion duration for /t/ and /tʃ/ ranged from approximately 60-100 ms and that the occlusion phase for /tʃ/ was longer than for /t/ in most speakers. These findings are consistent with previous studies, such as Umeda (1977) which give occlusion durations for /t/ to be around 77 ms. Crystal and House (1982) found that the voiceless stop was about two thirds of the duration of the voiceless affricate. Some caution is needed in interpreting this finding, however, because these measurements included the fricative component and not just the occlusion phase.

In terms of the amount of contact, the results of this study show that for most speakers /tʃ/ involved more tongue palate contact than /t/. One possible explanation is that the higher contact relates to high intra oral pressure requirements for oral stops, fricatives and affricates (Subtelny, Worth & Sakuda, 1966). However, looking at the details of these measurements, Subtelny, et al. (1966) found that mean pressures in cm H_20 (averaged for males and females) were similar for /t/ and /tʃ/ (6.8 and 7.1 respectively). A more likely explanation is that the active articulator involved in affricate production is the tongue blade whereas for the stop it is the apex. The tongue blade involves a greater tongue surface area than the tongue tip and so is therefore likely to involve more contact against the palate than when the apical portion of the tongue is the active articulator.

This study has highlighted the need for further research to investigate the effect of different palate sizes and shapes on EPG patterns. Anatomical differences in hard palate dimensions differ between speakers and these dimensions also change rapidly during the childhood years. The effects of these differences and lifespan changes on EPG patterns remain largely unexplored. Furthermore, there are no EPG data from speakers with abnormal palatal size and shape (e.g. associated with a repaired cleft palate) or an abnormal relationship between the maxilla and mandible (e.g. due to a malocclusion), but who nevertheless manage to achieve normal speech. These data would provide a more refined basis for distinguishing between normal and abnormal EPG patterns, which would prove useful when using EPG for diagnosis and therapy.

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Appendix 1. The composite palates show tongue-to-palate contact at the maximum contact point for each speaker for /tʃ/ and /t/ averaged for all vowel environments.