An Electropalatographic Investigation of Middorsum Palatal Stops in an Adult With Repaired Cleft Palate

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Objective: **Middorsum palatal stops are compensatory articulations that occur relatively frequently in cleft palate speech. This study used electropalatographic (EPG) and acoustic data to investigate /t/ and /k/ targets produced as middorsum palatal stops ([c]) by an adult with an articulation disorder associated with a repaired cleft palate.**

Results: **Two novel observations were made from the instrumental data. First, although /t/ and /k/ targets were judged by phonetically trained listeners as homophonous (i.e., both produced as [c]), the EPG data revealed that the place of articulation for the [c] produced for /t/ was more anterior than the place of articulation for the [c] produced for /k/. Second, production of palatal stops involved lateral release followed by a variable period of lateral friction. Measurements made from the instrumental data quantified the temporal extent of lateral friction during the aspiration period.**

Conclusions: **These observations merit further systematic investigation in cleft palate speech, and the procedures reported in this study are considered appropriate for such future research.**

KEY WORDS: *articulation disorder, cleft palate, electropalatography, middorsum palatal stop*

One common type of abnormal articulation in cleft palate speech is retracted or ‘‘backed’’ tongue placement. Backing particularly affects sibilants, alveolar stops, and to a lesser extent velar stops (Morley, 1970; Fletcher, 1978; McWilliams et al., 1990). Trost (1981) described a particular type of abnormal articulation referred to as middorsum palatal stops ([c, ɟ]), which are substitutions used to replace /t/, /d/, /k/, and /g/. Middorsum palatal stops are made in the approximate place of the glide /j/ with midpalatal lingual contact produced with the tongue dorsum raised and the tongue tip down. Trost states that ‘‘perceptually, the phoneme boundaries between /t/ and /k/ or between /d/ and /g/ are lost’’ (p. 196). Although in middorsum palatal stops /t/ and /d/ targets are retracted from alveolar to palatal placement, /k/ and /g/ targets show the opposite trend as they are fronted from velar to palatal placement.

The articulatory characteristics of middorsum palatal stops have been described frequently using perceptually based transcription (McWilliams et al., 1990; Albery, 1991; Chapman and Hardin, 1992). Although widely used, there are well-recognized problems associated with relying on transcription data alone for investigating disordered speech (Hardcastle et al., 1987; Kent, 1996). First, there is the problem of the unreliability of transcribed data. Santelmann et al. (1999) reviewed studies of the reliability of transcribed data from cleft palate speech and concluded that there are inherent difficulties involved, particularly when the speech contains compensatory articulations such as middorsum palatal stops.

An even greater limitation is that at best the activity of transcription affords an indirect representation of the actions of the articulators, with the result that articulatory information must be inferred by the transcriber from an accumulation of complex cues contained in the acoustic signal. It has been shown that inferences about articulation based on transcription data can be misleading. Gibbon (1999) found that lingual stops that are abnormally articulated by children with functional articulation disorders are often recorded as ‘‘accurate’’ or ‘‘correct’’ productions in transcription.

Electropalatography (EPG) is an instrumental technique that has proved useful in providing objective articulatory data from speakers with cleft palate (e.g., Michi et al., 1986; Gibbon and Hardcastle, 1989; Hardcastle et al., 1989; Yamashita and Michi, 1991; Yamashita et al., 1992; Whitehill et al., 1996). EPG records details of the location and timing of tongue contacts with the hard palate during speech (Hardcastle et al., 1991a; Hardcastle and Gibbon, 1997). Characteristic patterns are pro-

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duced by normal speakers for sounds such as /t/, /d/, /n/, /k/, /ɡ/, /s/, /z/, /l/, /ʃ/ (as in *sh*oe), /tʃ/ (as in *ch*op), /dʒ/ (as in *j*ob), /j/ (as in *y*ou), and /ŋ/ (as in so*ng*). EPG also records abnormal placement for these target sounds, making it a valuable technique for investigating errors in cleft palate speech.

EPG has been used to investigate abnormal tongue-palate contact patterns associated with retracted articulations in relatively large numbers of Japanese speakers with cleft palate. Yamashita et al. (1992) investigated EPG patterns in 53 Japanese-speaking individuals with cleft palate, aged 4 to 20 years. One of the most frequently occurring EPG patterns in Japanese speakers with cleft palate has been labeled ''palatal misarticulation'' or PM (Okasaki et al., 1980; Michi et al., 1986; Yamashita et al., 1992). PM is defined as tongue-palate contact involving the tongue dorsum and middorsum elevated to make contact with the posterior hard palate and involves EPG patterns that have contact either across the whole surface of the palate or confined to the most posterior region of the palate. PM is considered to include Trost's middorsum palatal stop (Yamashita and Michi, 1991; Yamashita et al., 1992).

PM has been reported to affect Japanese dental and alveolar targets /s/, /ts/, /dz/, /ʒ/, /tʃ/, /t/, /d/, and /ɾ/; it is one of the most commonly occurring errors in Japanese cleft palate speech. Yamashita et al. (1992) found that approximately three-quarters of the 53 speakers they investigated showed evidence of PM. In addition to the relatively large numbers of Japanese speakers investigated with EPG, abnormally retracted tongue palate contact patterns have been reported in smaller numbers of English cleft speakers (Gibbon and Hardcastle, 1989; Hardcastle et al., 1989) and Cantonese cleft speakers (Whitehill et al., 1995; Whitehill et al., 1996).

However, it is not reported in the Japanese, English, or Cantonese EPG studies whether the speakers with cleft palate produced the classic middorsum palatal stop that Trost (1981) described, in which palatal substitutions occur for /t/, /d/, and /k/, /g/ targets resulting in a loss of the alveolar-velar contrast. For example, although the studies report palatal articulations for alveolar targets, none systematically compared contact patterns for alveolar targets with patterns for velar targets in individual speakers. This omission makes it difficult to know whether place of articulation of the palatal [c] used for /t/ is always precisely the same as placement of [c] used for /k/ targets, as Trost (1981) suggests.

The aim of this study was to use EPG and acoustic data to investigate place of articulation for /t/ and /k/ targets in an English-speaking adult with a repaired cleft palate. Perceptually based speech analysis revealed that alveolar and velar targets were produced as middorsum palatal stops. The study used EPG to establish whether place of articulation for /t/ targets was different from placement for /k/ targets, despite the two phoneme categories being perceptually homophonous. Perceptual analysis revealed a secondary feature of lateral release during production of /t/ and /k/ targets, with a variable amount of lateral friction occurring during the aspiration period. The study used a combination of EPG and acoustic data

	Row		
000000	1	Alveolar	Anterior (tongue tip/blade)
000..000	2		
0.....00	3	Post-alveolar	
0......0	4		
0......0	5		Posterior (tongue dorsum)
0......0	6	Palatal	
0......0	7		
0......0	8	Velar	

FIGURE 1 A single electropalatographic frame showing row numbers and the regions of the palate.

to measure the temporal extent of lateral friction that occurred during aspiration of /t/ and /k/.

METHOD

Instrumentation

The Reading EPG3 system (Millgrant Wells Ltd., Rugby, England) was used (Hardcastle et al., 1991a; Hardcastle and Gibbon, 1997), with the EPG sampled at 100 Hz simultaneously with the acoustic signal at 10,000 Hz. An essential component of EPG is an artificial palate, which is custom made to fit against a speaker's hard palate. The artificial palate contains 62 electrodes, placed in eight horizontal rows according to well-defined anatomical landmarks (Hardcastle and Gibbon, 1997). The electrodes are arranged so that the spacing between the back four rows is twice that of the front four rows. EPG data are displayed as sequences of two-dimensional representations referred to as palatograms or EPG frames. Figure 1 shows a single EPG frame, which is divided into regions (alveolar, postalveolar, palatal, and velar) that correspond in an approximate way to phonetically relevant regions of the hard palate.

Subjects

The subjects were three English-speaking adults, one male subject (D, aged 36 years) with an articulation disorder associated with a repaired cleft palate and two female control subjects (C1, aged 43 years, and C2, aged 29 years). D and C2 both spoke with a Scottish (Glasgow) accent, C1 spoke with a southern British standard accent. Case history details for D are in Appendix 1. The control subjects had no present or past speech, language, or hearing difficulties, and they had normal occlusion. Artificial palates were constructed for the three subjects (Fig. 2). D wore an upper denture, so his EPG palate consisted of a duplicate denture with the 62 electrodes embedded in it.

Speech Analysis

Two speech-language pathologists who were trained in the use of the International Phonetic Alphabet and experienced in the transcription of cleft palate speech, transcribed a sample

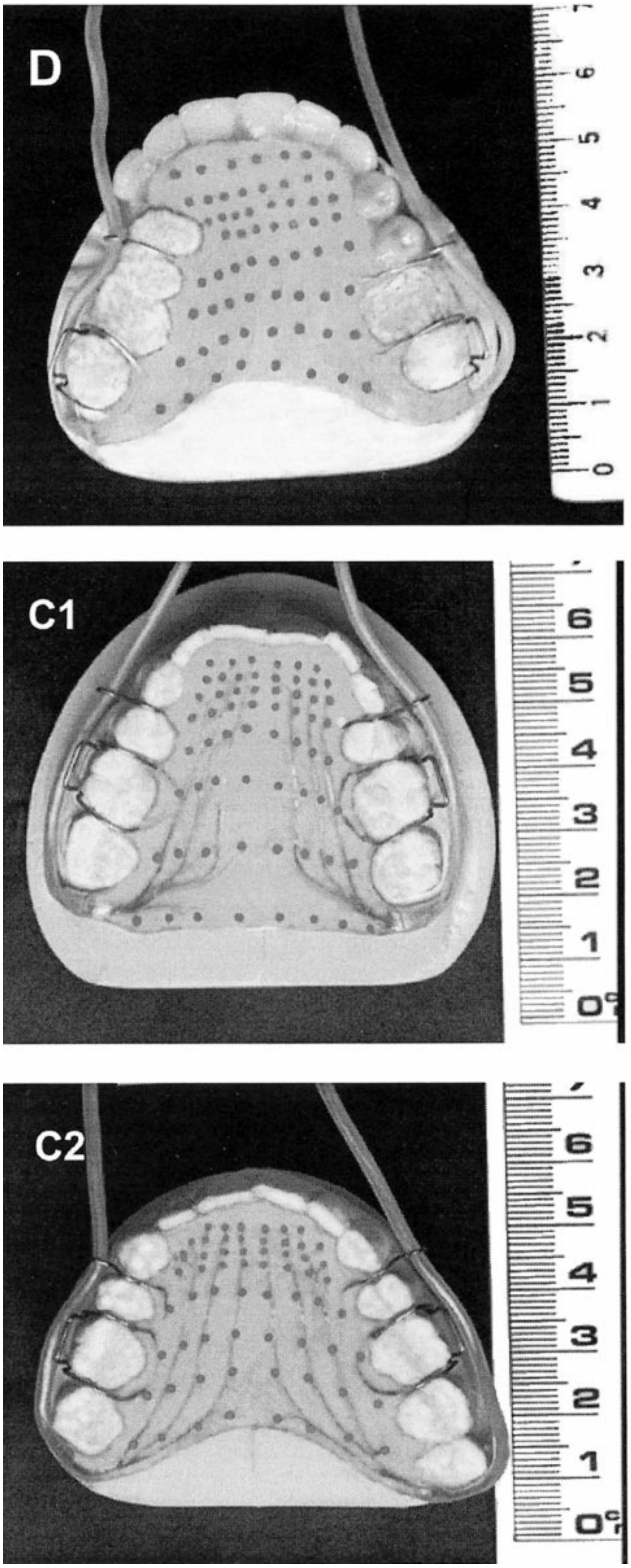

FIGURE 2 Photographs of artificial palates placed on top of plaster impressions for D (subject with a repaired cleft palate and speech disorder) and C1 and C2 (controls).

of D's speech at the time of the EPG recording. The speech sample contained naturalistic conversation, reading aloud a word list, and a prose passage. The perceptually based analysis showed that /t/, /d/, /k/, and /g/ targets were produced as palatal plosives ([c, ɟ]). A secondary characteristic was that these targets had lateral release and variable periods of lateral friction during the aspiration period. Nasals were also palatal (/n/, /ŋ/ → [ɲ]), and sibilant targets were judged as lateral fricatives (/s/, /ʃ/ → [ɬ]; /z/, /ʒ/ → [ɮ]). Affricates were retracted and lateralized, and /r/ and /l/ were produced as velar approximants. Speech intelligibility was rated as moderately impaired in conversational speech.

EPG and Acoustic Recording

Simultaneous EPG and acoustic data were recorded as the subjects read aloud a word list (Gibbon et al., 1993). Because D wore a denture, he adapted readily to the presence of the artificial palate in his mouth and was able to speak naturally and comfortably with the palate in place. The control subjects were both experienced EPG users and were accustomed to speaking with the artificial palate in place. As a result, the subjects acclimatized readily to the presence of the palate in the mouth for the EPG recording. Twenty-four words (12 containing target /t/ and 12 containing /k/) per subject were analyzed. The targets were in word-initial position and the subjects were instructed to say the words at a natural, conversational rate.

Annotation Points

EPG and acoustic data were displayed using the EPG3 software. Annotation points were identified on the recorded data using criteria reported in previous studies (Gibbon et al., 1993a, 1993b). The annotations contained spatial information (contacted electrodes) and timing information, which were exported from the EPG3 software and imported into a commercial software package for analysis purposes. Three annotation points were identified from the EPG records (1 through 3 below) and two from the acoustic waveform (4 through 5 below) using the following criteria:

1. Approach to closure—the first EPG frame showing complete midsagittal contact across the palate.
2. Maximum constriction—the frame with the highest number of contacted electrodes during the constriction phase.
3. Articulatory release—the final frame that shows complete midsagittal contact across the palate.
4. Stop burst—the point on the waveform trace that shows a burst following the acoustic stop closure.
5. Onset of voicing—the point at which modal voice is initiated for the following vowel.

Annotation points 1 through 5 were marked for all subjects' /t/ targets. Annotation points 1 through 5 were marked for D's and C1's /k/ productions. C2's EPG patterns for /k/ did not always show complete closure, so only maximum constriction (annotation 2) was marked for these targets. Figure 3 illustrates the five annotation points during C2's production of /ə ′tul/ in the phrase *a toolshed*. The EPG frames occur at 10-millisecond intervals. Annotations 1 through 5 are marked above the acoustic waveform and on the EPG printout. The control subject's EPG pattern for /t/ at maximum constriction (frame 183) has a characteristic horseshoe shape, which is typical of normal EPG patterns for alveolar stops such as /t/, /d/, and /n/ (Dagenais et al., 1994; Hardcastle and Gibbon, 1997).

In Figure 3, articulatory release (annotation 3) is closely timed with the stop burst (annotation 4). Articulatory release is followed by air flowing from the oral cavity with a central airstream. The sudden release of air from the mouth results in an abrupt burst seen on the acoustic waveform (annotation 4). The delay in initiation of voicing (annotation 5) results in the aspiration period. The aspiration period is measured from the stop burst (annotation 4) to the onset of voicing for the following vowel (annotation 5).

Spatial Measurements

Center of gravity (COG)

A COG index was used to determine whether D used a different place of articulation for /t/ and /k/ targets. The COG 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 COG value represents a forward (i.e., anterior) place of articulation, whereas a low COG value reflects a posterior place of articulation. The COG index has been used to measure place of articulation on the hard palate in a number of previous studies (e.g., Gibbon et al., 1993b; Wakumoto et al., 1996; Gibbon et al., 1999). For further description of the COG measure, see Baken and Orlikoff (2000), Gibbon and Nicolaidis (1999), and Hardcastle et al. (1991b). The COG formula is in Appendix 2.

Timing Measurements

Articulatory release index (ARI)

The ARI was devised for this study in order to capture the abnormal timing of articulatory release in D's speech relative to the stop burst. Unlike the control subjects, D maintained complete articulatory closure for varying periods after the acoustic stop burst for /t/ and /k/. This type of release was interpreted as involving lateral release. In this type of articulation, oral closure is maintained centrally but air is released laterally. Normal speakers can have lateral release of /t/ in words such as *bottle*, in which a lateral follows a stop (Ball, 1993). However, D had lateral release in all realizations of lingual stops, regardless of context.

The index is an adaptation of similar indices used to investigate timing relationships between articulators (Hardcastle et al., 1991a; Gibbon et al., 1993b; Gibbon and Nicolaidis, 1999). The ARI formula is in Appendix 3. An ARI of 100 indicates that the stop burst (annotation 4) and articulatory release (annotation 3) occur simultaneously, as would be expected in normal speakers. If articulatory release occurs after the acoustic stop burst, the ARI is <100, and if release is before the acoustic stop burst, the ARI is >100. Stop burst (annotation 4) and articulatory release (annotation 3) occur close together in time in the control subject's production of /t/ in Figure 3, and this close timing relationship is reflected in an ARI value close to 100 (97 in this example).

Results

Spatial Measurements

Center of gravity (COG)

Inspection of skewness and kurtosis statistics indicated that COG values were normally distributed and conformed to assumptions of homogeneity of variance (Box's M = 12.6, $F_{6,\ 27141} = 1.9$, $p = .074$). The COG data were analyzed using a 3*2 mixed model analysis of variance (ANOVA), although it is not intended to use this analysis to generalize from these results to the cleft opulation as a whole. There was one variable distinguishing targets (/t/, /k/) and another distinguishing subjects (D, C1, and C2), with 12 observations per group. The ANOVA revealed significant main effects for target ($F_{1,33} = 1617.6$, $p < .001$) and subject ($F_{2,33} = 13.4$, $p < .001$) and a significant interaction between the two factors ($F_{2,33} = 189.3$, $p < .001$).

D's COG values for /t/ (Table 1) were found to be significantly lower than the control subjects' ($p < .001$), indicating that D produced /t/ at a more posterior (i.e., retracted) place of articulation than the control subjects. D's COG values for /k/ (Table 1) show the opposite trend, with /k/ targets showing significantly higher COG values ($p < .001$) than the controls'. This result indicates that D had a more anterior (i.e., fronted) place of articulation for /k/ than the controls.

Moreover, the simple main effect of target indicates that the differences in COG values for /t/ and /k/ are significant for all subjects ($p < .05$). The finding that the control subjects produced different places of articulation for /t/ and /k/ was expected because these speakers had alveolar placement for /t/ and velar placement for /k/. However, it was noteworthy that D's COG values showed a significantly different place of articulation for /t/ targets, compared with /k/ targets, because the perceptual analysis indicated that /t/ and /k/ were judged as homophonous [c].

Figure 4 shows composite EPG frames for /t/ and /k/ targets at approach to closure (annotation 1), maximum constriction (annotation 2), and articulatory release (annotation 3) for D, C1, and C2. Two observations can be made from this figure. The first observation concerns the different places of articulation produced by D for /t/ and /k/ targets. Figure 4 shows that for /t/ targets, complete constriction extends from rows 3 to 8, with some side contact in row 2. However, constriction

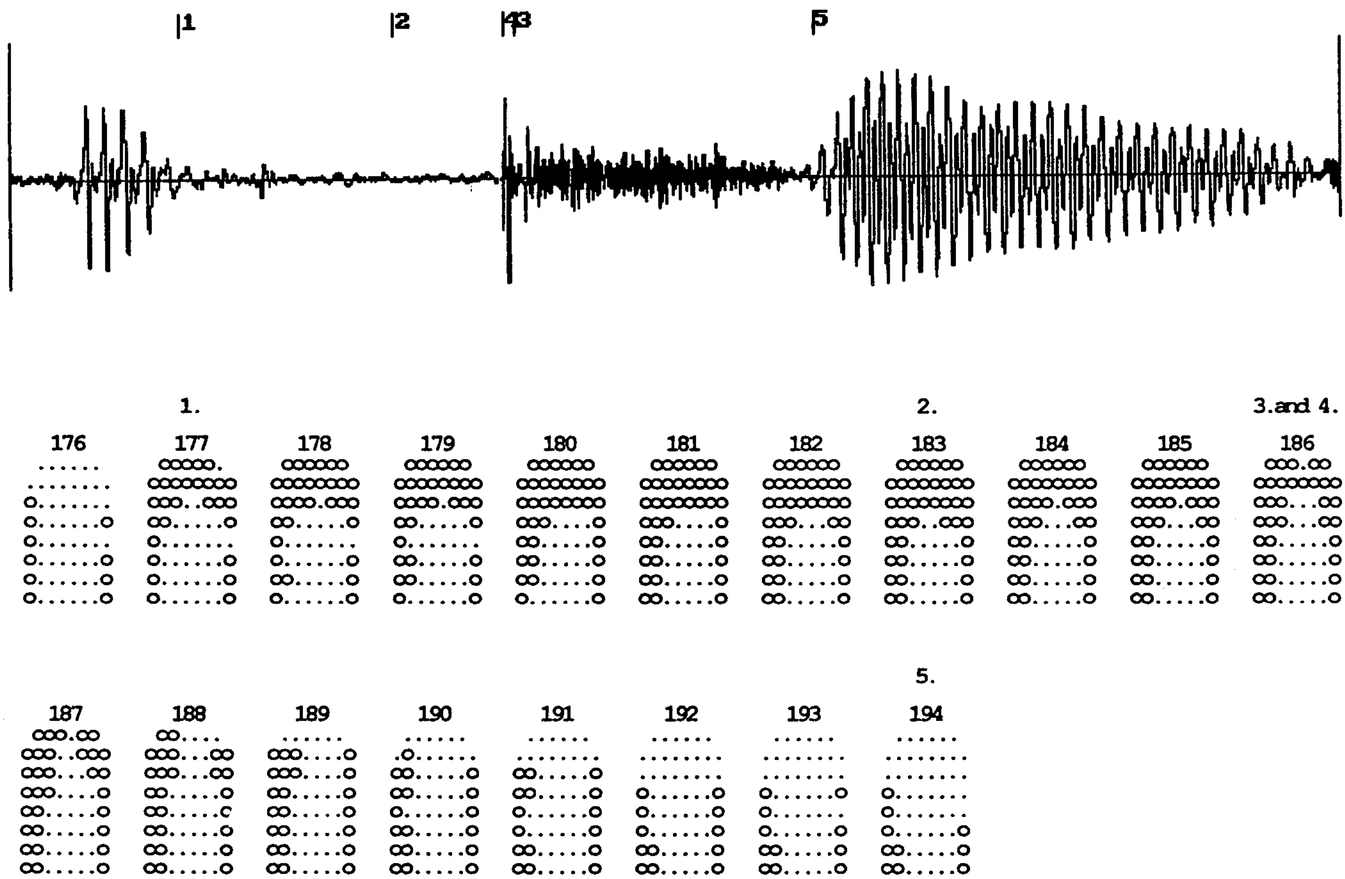

FIGURE 3 **Illustration of simultaneous acoustic and electropalatographic data recorded from a control speaker. The acoustic signal shows /ə tul/ extracted from the phrase *a toolshed.* The electropalatographic patterns below the waveform are for the /t/ gesture only. Annotation points 1 through 5 are marked above the acoustic waveform and on the relevant electropalatographic frames. The articulatory release index value for this example is 97, reflecting almost simultaneous occurrence of stop burst (annotation 4) with articulatory release (annotation 3).**

is confined to rows 5 to 8 with some additional lateral contact for /k/ targets. Thus, place of articulation for /t/ extends into the postalveolar region, whereas place of articulation for /k/ is confined to the palatal and velar regions.

A more anterior placement for /t/, compared with /k/, is more striking at approach to closure (Fig. 4). During this phase of stop production, complete contact across the palate for /t/ targets is in row 5 (palatal), compared with row 8 (velar) for /k/. In contrast to maximum constriction and approach to closure, placement at articulatory release for /t/ and /k/ involves complete contact across the palate in the palatal region (row 5).

The control speakers' EPG patterns for /t/ and /k/ are consistent with findings reported in previous studies for larger groups of adult speakers for these targets (e.g., Hardcastle and Roach, 1977; Gibbon et al., 1993b; Dagenais et al., 1994). Figure 4 also shows clear differences between D's EPG patterns and those of the controls. D's EPG patterns differ from the controls' patterns at all phases of /t/ and /k/ production. For example, EPG patterns produced by C1 and C2 for /t/ show a typical horseshoe shape—quite unlike D's patterns for /t/, which involve contact across the whole of the palate except in the most anterior rows. D's productions of /k/ also involve extensive tongue-palate contact across the palate in the posterior regions. Once again, the high amount of contact in the palatal region produced by D for /k/ is unlike the patterns produced by the controls for /k/, in which complete contact across the palate is confined to the velar region.

TABLE 1 **Center of Gravity Values for /t/ and /k/**

Subjects	*/t/, mean (SD)*	*/k/, mean (SD)*
D	3.2 (0.33)	2.36 (0.3)
C1	4.94 (0.13)	1.39 (0.36)
C2	4.86 (0.25)	1.28 (0.22)

* D = subject with an articulation disorder; C1 and C2 = control subjects; SD = standard deviation.

Timing Measurements

ARI

The results of the ARI (Table 2) show that the controls had average ARI values close to 100. D in contrast had a lower average value, indicating that articulatory release occurred after the stop burst, on average approximately one-third of the way through the aspiration period. The ARI values indicated

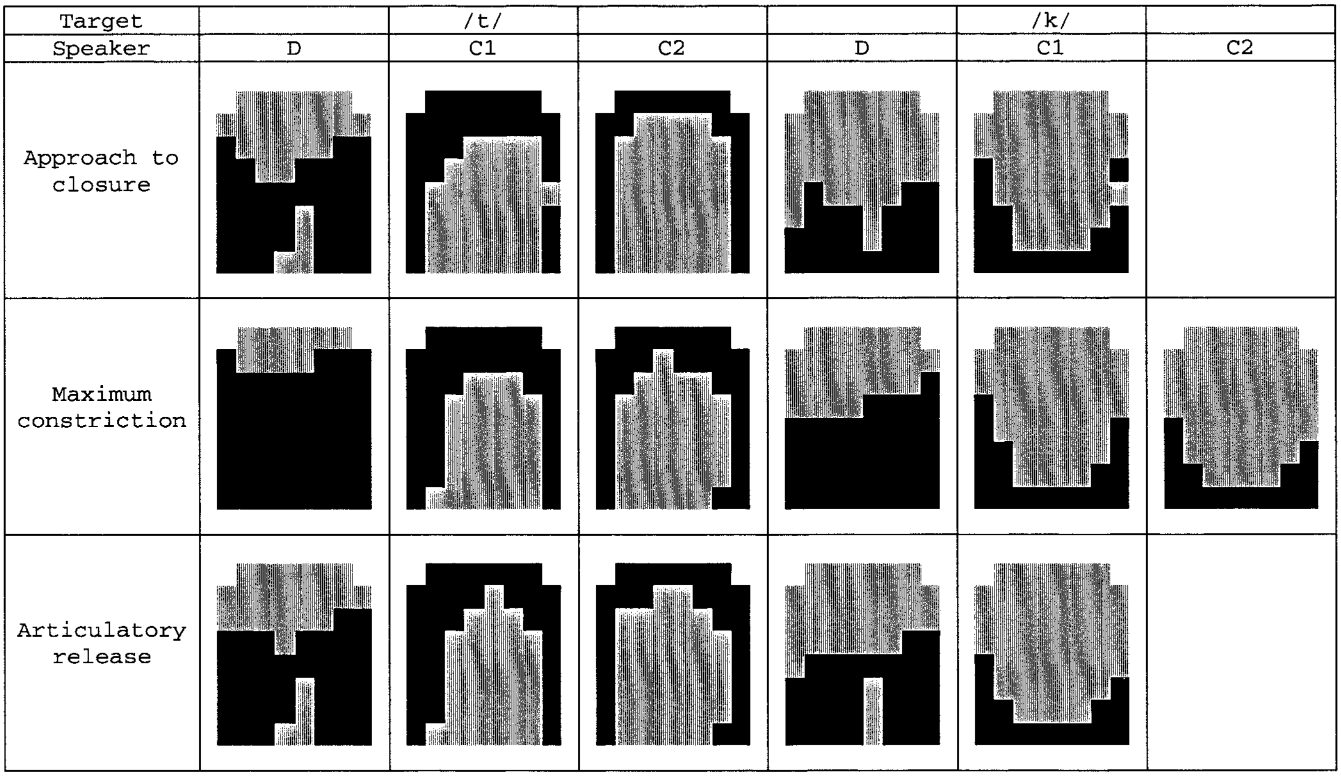

FIGURE 4 Composite electropalatographic palatograms for /t/ and /k/ at the approach to closure, maximum constriction, and articulatory release for the three speakers. Tongue-palate contact occurring > 50% over 12 tokens is displayed as black squares, contact occurring < 50% as gray squares.

substantial negative skewness, so the Kruskal-Wallis *H* test was used to determine differences in ARI values between subjects, with 12 observations per group. The results were $\chi^2_2 = 16.4$, $p < .001$. Mann-Whitney *U* tests were used for pair-wise comparisons of the test results. D showed significantly different ARI values from C1 ($U = 12$, $p < .001$) and C2 ($U = 13$, $p < .001$). However, no significant difference in ARI values was found for C1 and C2 ($U = 55$, $p = .326$).

D's abnormal articulatory release of palatal stops is illustrated in Figure 5 in which articulatory release (annotation 3) occurs approximately one-quarter of the way through the aspiration period. The delay in release of articulatory constriction relative to the stop burst is reflected in the low ARI value of 76. D's articulatory release occurs after the acoustic stop burst, in contrast to the control subject's production in Figure 3 in which articulatory release and stop burst occur almost simultaneously. During the data analysis, we found that a silent closure phase on the acoustic trace followed by a weak stop burst was typical of D's productions of /t/ and /k/ targets. Figure 5 illustrates the closure phase (the period between annotation 1 and annotation 4) and D's weak stop burst (annotation 3).

TABLE 2 Mean Articulatory Release Index Values*

Subjects	*ARI, Mean (SD)*
D	66.83 (19.08)
C1	96.91 (3.77)
C2	95.85 (4.48)

* D = subject with an articulation disorder; C1 and C2 = control subjects; ARI = articulatory release index; SD = standard deviation.

Discussion

D produced classic middorsum palatal stops in the sense that listeners could not distinguish between alveolar and velar targets, with the result that the phoneme boundary was lost (Trost, 1981). However, D did not articulate alveolar targets in exactly the same way as velar targets, as might be assumed from a transcription-based analysis of his speech. Analysis of the COG values showed that D had a significantly more anterior place of articulation for the palatal stop produced for /t/, compared with the palatal stop produced for /k/. The place distinction for /t/ and /k/ was evident at approach to closure and maximum constriction but not at articulatory release.

Covert Contrasts

Subtle articulatory differences between target phonemes, such as produced by D for /t/ and /k/, have been referred to as covert contrasts. The term *covert contrast* was first used by Hewlett (1988) to describe instrumentally measurable differences among target phonemes that are neutralized in listeners' perceptions. The existence of covert contrasts has been reported for children with functional phonological disorders (for recent reviews, see Edwards et al., 1997, and Gibbon and

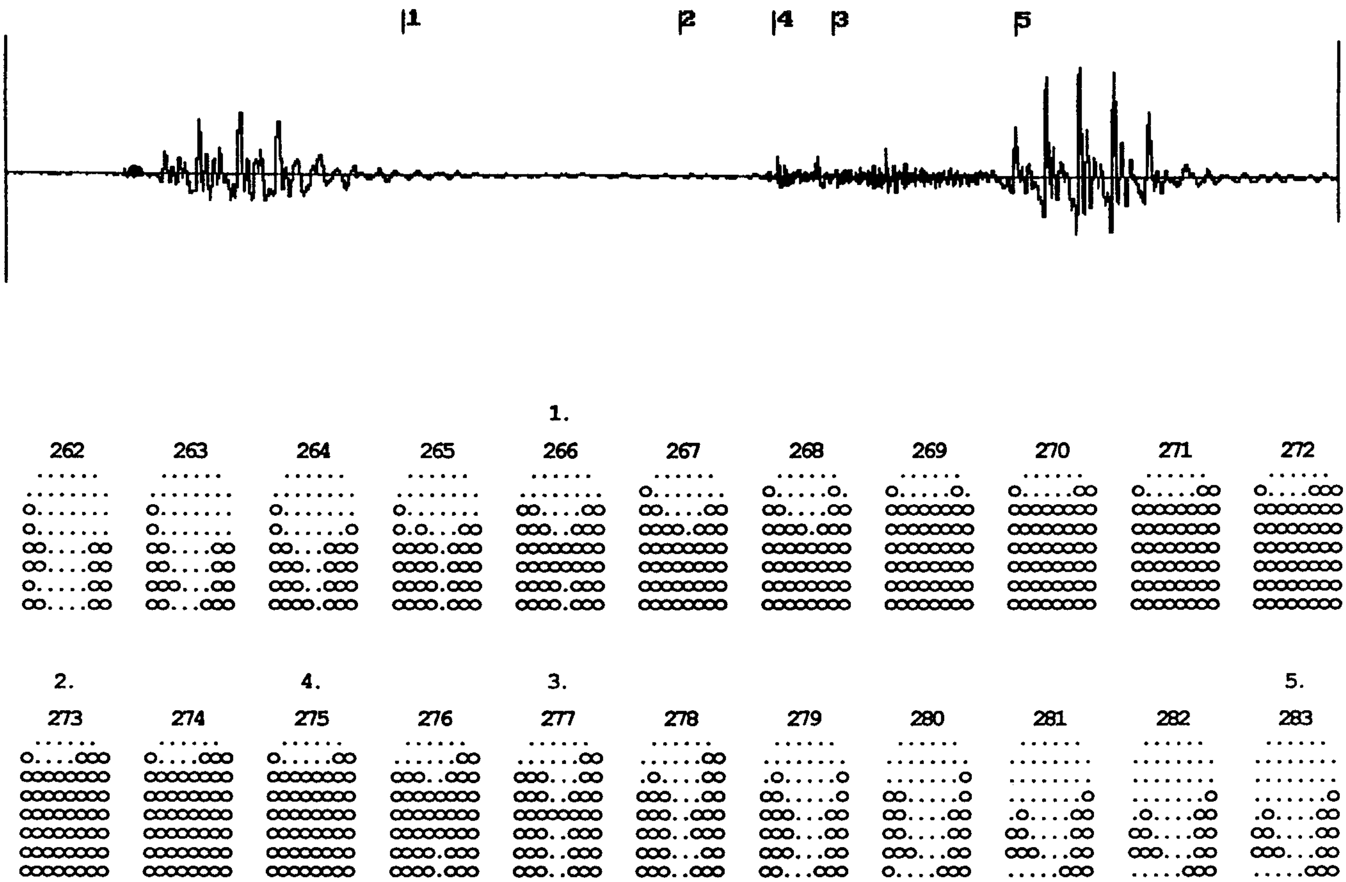

FIGURE 5 **Simultaneous acoustic and electropalatographic data recorded from D. The acoustic signal shows the target /ə ˈtul/ [ə ˈc¹ul] extracted from the phrase *a toolshed.* The electropalatographic patterns below the waveform are for the /t/ target gesture only. Annotation points 1 through 5 are marked above the acoustic waveform and on the relevant electropalatographic frames. The low articulatory release index value in this example (76) reflects the delay in articulatory release relative to stop burst.**

Scobbie, 1997), but to our knowledge covert contrasts have not been reported in cleft palate speech.

Covert contrasts are important because production of a phonetic distinction between phonemic categories is considered relevant to diagnosis. Evidence of an articulatory distinction between phonemic categories is often used to differentiate between speech errors that are phonetic in origin and those that have a phonological basis (McWilliams et al., 1990; Grunwell, 1993; Sell et al., 1994). With reference to cleft palate speech, Sell et al.'s (1994) view is that an articulatory distinction between phoneme classes indicates that there is ''an appreciation of the need to signal a phonological contrast, i.e., the speech difficulty is phonetic in nature'' (p. 8). Differentiating between phonetic and phonological speech errors has therapeutic as well as diagnostic implications. Phonetic errors are viewed as requiring motor-oriented therapy, whereas phonological errors require an approach focusing on linguistic conceptualization and organization (Bernthal and Bankson, 1988; Klein, 1996; Sell et al., 1994).

The EPG data showed that D was making an articulatory distinction between /t/ and /k/. Furthermore, observation of D's EPG patterns for /s/ and /ʃ/ targets, which were heard as homophonous lateral fricatives [ɬ], revealed another case of covert contrast. The EPG data showed that the EPG patterns for /ʃ/ targets had consistently less lateral contact on one side of the palate than /s/ targets. The existence of covert realization of /t/-/k/ and /s/-/ʃ/ contrasts is interpreted as evidence that the majority of D's abnormal articulations were phonetic in origin. However, D's palatal stops and lateral fricatives could be considered speech errors with phonological consequences for listeners since the alveolar-velar (e.g., /t/-/k/) and alveolar-postalveolar (e.g., /s/-/ʃ/) contrasts were neutralized in listeners' perceptions. This interpretation of EPG data illustrates how instrumental data can assist in the diagnostic process and demonstrates that distinguishing phonetic from phonologic speech errors is not always possible on the basis of perceptually based data alone.

Listener Perceptions

There are a number of possible explanations for the finding that listeners failed to detect the articulatory distinction that D produced for /t/ and /k/ targets. It may be that the articulatory distinction was so subtle that it could not have been detected easily by the human ear. On the other hand, it may be that palatal sounds are problematic perceptually for English listeners. Santelmann et al. (1999) suggest that ‘‘the middorsum palatal stop may be especially difficult for English speakers because it overlaps with two phonemic categories [i.e., alveolar and velar]’’ (p. 234). Finally, a factor that could have contributed to listeners' difficulty in detecting the place distinction for /t/ and /k/ in D's speech was the phonetic detail of articulatory release. The different placements for /t/ and /k/ targets at approach to closure and at maximum constriction were not observed at articulatory release, which had placement in the palatal region for both targets. The similar location of articulatory release in the palatal region for /t/ and /k/ targets would have contributed to perceptual cues that led listeners to judge these targets as homophonous palatal stops.

Lateral Release

Lateralization is a feature of cleft palate speech that has been noted to affect sibilant targets mainly. In a review of 263 individuals with cleft palate, Greene (1960) found that 19% had lateral articulation of /s/ and /z/. A less studied characteristic of cleft palate speech is lateral release in which it occurs as a secondary articulatory feature of lingual stops such as /t/ and /k/. Albery (1991) noted that abnormal lateral release can affect alveolar and velar stops in cleft palate speakers. However, lateral release has received little attention in the cleft palate literature. This lack of research is surprising because lateral release affects the cues that listeners use to identify place of articulation, with the result that abnormal lateral release would be predicted to have an adverse effect on speech intelligibility.

The finding that D had complete tongue palate contact occurring simultaneously with lateral release is in agreement with the findings from the Japanese literature on ‘‘lateral misarticulation’’ (LM). Yamashita et al., Suzuki, Michi and Ueno (1981) defined LM as involving the tongue dorsum making complete contact across the palate (i.e., there is no evidence of tongue grooving) and lateral release of air (i.e., air directed out of the occluded dental arch posterior to the molar teeth). Yamashita et al. (1992) found that the majority of speakers who produced lateral fricatives did so with complete contact across the whole of the palate.

The ARI made it possible to quantify details of the timing of articulatory release relative to the stop burst during production of /t/ and /k/ targets. The ARI showed that for D, unlike the control subjects, articulatory release of the tongue constriction for /t/ and /k/ targets was not closely timed with the acoustic stop burst. On average, the first third of the aspiration period for D's /t/ and /k/ involved lateral escape of air, while the remaining period of aspiration involved a central airstream. Although on average one-third of the aspiration period involved lateral friction, the timing of articulatory release for /t/ and /k/ was variable, with ARI values ranging from 39 to 99. The finding that the timing of articulatory release was variable supports other studies (e.g., Wada et al., 1970) that have reported increased variability in articulatory release in cleft speakers with articulation disorders.

Perceptual judgments indicated that D's middorsum palatal stops involved lateral release and variable amounts of lateral friction during the aspiration period. There is no way of knowing from EPG and acoustic data alone where precisely in the vocal tract the air was escaping during the period between the acoustic stop burst and articulatory release in D's speech. The presence of complete central articulatory closure indicates that the air was not escaping centrally. Further, a simple procedure—the ‘‘cold mirror test’’ (Yamashita and Michi, 1991)—was used to reduce the possibility that air was escaping through the nose during /t/ and /k/ productions. Because most of the hard palate region was occluded during /t/ and /k/, it is most likely that the air was escaping laterally in the retromolar region.

D's low and variable ARI values were in contrast to the control subjects' ARI values, which were close to 100. There are two possible methodological reasons the controls did not achieve ARI values of exactly 100, even in cases in which articulatory release occurred simultaneously with stop burst. First, the Reading EPG3 samples articulatory data at 100 Hz and the acoustic signal at 10,000 Hz. The effect of the different sampling rates is that there is an inherent error factor of $\pm$ 5 milliseconds in the ARI calculation. Second, EPG may not detect the exact time of articulatory release in which release occurs at a more anterior location than the first row of EPG electrodes (i.e., for /t/) or at a more posterior position than the back row of EPG electrodes (i.e., for /k/). Thus, the precise time of articulatory release may have occurred later than indicated from the EPG trace for the control subjects' productions. Nevertheless, even given the procedural limitations outlined, the control subjects still achieved ARI values near 100.

Inferring Tongue Behavior From EPG

D's articulations of /t/ and /k/ targets involved extensive tongue-palate contact across the whole of the hard palate area, with the exception of the most anterior region. Although EPG does not record which part of the tongue is contacting the palate, it is possible to make inferences about this. For example, in cases in which EPG contact occurs in the anterior zone (i.e., the first four rows that constitute the alveolar and postalveolar regions), it is inferred that the tongue tip/blade is the active articulator. In cases in which contact is in the posterior zone (i.e., the back four rows that are the palatal and velar regions), it is inferred that the front portion of the tongue dorsum, sometimes referred to as the anterodorsum, is the active articulator (Hardcastle and Gibbon, 1997; Gibbon, 1999; see Fig. 1).

The EPG data suggest that D was using the anterodorsum to make contact with the palate during productions of /t/ and /k/. Overuse of the tongue dorsum supports previous studies that have shown a tendency for cleft speakers to articulate with the back, rather than the tip, of the tongue (e.g., Morley, 1970; Lawrence and Philips, 1975; Yamashita et al., 1992). The EPG data from D's productions support Trost's (1981) original description of middorsum palatal stops, which she states are produced with ‘‘midpalatal lingual contact with tongue tip down’’

(p. 196). A relevant point in relation to Trost's quote is that the authors observed the tongue tip-down position when watching D's face while he was speaking.

Comparing EPG Patterns From Cleft and Control Speakers

D's EPG patterns for /t/ and /k/ were different from normal patterns for these targets (Hardcastle and Roach, 1977; Gibbon et al., 1993b; Dagenais et al., 1994). However, direct comparisons between EPG patterns produced by speakers with abnormal palatal arches and speakers with normal palatal arches need to be made with caution. For example, D's hard palate was flatter and more irregular in shape than the controls' (Fig. 2). The placement of electrodes on the artificial palates according to anatomical landmarks assists in making comparisons between EPG patterns produced by different speakers (Hardcastle et al., 1991a). For instance, in all speakers, the most posterior row of electrodes is placed on the junction of the hard and soft palates, and the lateral electrodes are on the gingival border. Placing electrodes according to anatomy-based criteria means that, although physical distance between electrodes may vary from speaker to speaker, it is possible to compare EPG patterns from different speakers in terms of their contact in the various phonetic regions of the hard palate (i.e., alveolar, postalveolar, palatal, and velar).

Conclusion

This study reports two novel features of middorsum palatal stops, namely covert contrast and lateral release. We have argued that it is important to identify these features for research and clinical purposes, and we have demonstrated that quantifying these features is possible using the instrumental procedures described. It is clear that further research is needed. One issue to be addressed is whether these features are widespread in the middorsum palatal stops produced by speakers with cleft palate. A group of individuals who produce middorsum palatal stops needs to be investigated before this question can be answered. The methodology and indices developed and described in this study are considered appropriate for such future research into middorsum palatal stops.

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APPENDIX 1 Case Details for D*

Age (y)	*Medical*	*Speech Pathology/Educational/Vocational*
0–5	• Left unilateral cleft lip and palate. • Lip repair at 3 months. • Palate repair at 18 months. • Episodes of conductive hearing loss.	• No regular speech therapy during the preschool years.
5–18	• Episodes of hearing loss continue during the school years. • Class III malocclusion. • Further surgery offered at 16 years, but parents refused to take this up.	• Weekly speech therapy from 5 to 12 years. • D viewed speech therapy as beneficial, but difficulties with production of /t/, /d/, /s/, /z/, /ʃ/, and /tʃ/ persisted. • Left school at 18 years.
18–32	• No medical intervention received.	• No speech therapy received.
33–36	• Self-referral at 33 years. • Poor oral hygiene at 33 years, partial upper denture fitted. • Videofluoroscopy and endoscopy at 33 years showed good sphincteric pattern of closure with no pharyngoplasty. • Le Fort I osteotomy involving maxillary advancement, fistula closure, and alveolar bone grafting performed at 34 years. • Outcome of surgery successful for bone grafting and fistula closure, but a class III malocclusion remained. • Ear infections 6 months after surgery, with 30–50 dB bilateral loss, but a year after surgery showed normal hearing levels.	• Worked full-time in a bank. • The main feature of D's speech was the use of middorsum palatal stops for /t/, /d/, /k/, and /ɡ/ and lateralization of sibilant targets. • A speech pathologist reported D's speech to be unchanged following surgery. • Speech intelligibility following surgery remained moderately affected. • Speech therapy for 6 months following surgery had no impact on articulation disorder. • Referred for EPG recording at 36 years.

* Medical and speech pathology notes only available from age 33 years onward. Information sources before this were D's general practitioner and self-report.

APPENDIX 2 The Center of Gravity (COG)

The COG follows:

$$\left[\frac{(0.5 \times R8) + (1.5 \times R7) + (2.5 \times R6) + (3.5 \times R5) + (4.5 \times R4) + (5.5 \times R3) + (6.5 \times R2) + (7.5 \times R1)}{(R8 + R7 + R6 + R5 + R4 + R3 + R2 + R1)}\right],$$

where R is the number of contacted electrodes in horizontal rows of the EPG palatogram.

APPENDIX 3 The Articulatory Release Index (ARI) Formula

$$\frac{\text{Stop burst (annotation 4)} - \text{onset of voicing (annotation 5)}}{\text{Articulatory release (annotation 3)} - \text{onset of voicing (annotation 5)}} \times 100.$$