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An electropalatographic and perceptual investigation of /s/ productions in Cantonese children with cleft palate

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Abstract

This study had two aims. The first aim was to use electropalatography (EPG) to investigate the articulatory characteristics of /s/ produced by five Cantonese-speaking children with repaired cleft palate. The EPG stimuli were analyzed, and categorized into seven different EPG patterns. Variability among these EPG patterns was found in these aspects: a) the presence and absence of a groove, b) the location and length of the groove, and c) the extent of contact. The second aim was to investigate listeners' perceptual judgments for /s/ targets produced by these cleft palate children. A multiple-choice listening task was administered to fifteen listeners who were asked to select from seven choices after listening to each auditory stimulus. Results indicated poor intra-listener agreement and listeners had difficulties identifying the types of /s/ production. Possible reasons for this difficulty, and the clinical implications for the evaluation and treatment of cleft palate speech are discussed.

Cleft palate is a congenital deformity that occurs in utero (McWilliams, Morris, & Shelton, 1990). It occurs in the Chinese population at a rate of 1.2 per 1000 live births (Cooper, Stone, Liu, Hu, Melnick, & Marzaita, 2000). Individuals with cleft palate have been reported extensively to exhibit speech disorders, which can be classified into obligatory errors and compensatory errors (McWilliams et al., 1990). Obligatory errors, such as hypernasality, nasal emission, and weak obstruents, are misarticulations that are a direct sequel to structural defects such as velopharyngeal incompetence, oronasal fistulae and malocclusion (McWilliams et al., 1990). For instance, an individual with velopharyngeal incompetence will produce a nasalized /a/ because the nasal and the oral cavities are coupled. This speech error is inevitable because of the velopharyngeal opening. Compensatory errors, on the other hand, are viewed as learnt behaviors attempted to cope with physiological limitations, and such errors may become habitual and persist even when the structural defect is corrected (McWilliams et al., 1990). For example, one frequently reported compensatory error is the glottal stop which may be used to substitute for stop consonants. It was speculated that because the impaired velopharyngeal mechanism inhibited the build up of oral pressure for pressure consonants, the stop closure had to be produced at the glottal region because it was the only region that air-pressure build up was possible (Golding-Kushner, 1995). Other compensatory errors include pharyngeal fricative, velar fricative, pharyngeal stop, posterior nasal fricative and middorsum palatal stop (Trost, 1981).

Conventionally, perceptual analysis has been widely used in studying speech characteristics associated with cleft palate. However, perceptual analysis has been limited by its poor listener agreement and the limited information it provides on articulatory dynamics (McWilliams et al., 1990). Therefore, recently, researchers and speech-language pathologists have opted for instrumental measures, such as

spectrography, lateral radiography and electropalatography (EPG) to obtain more objective and precise information about cleft palate speech (Whitehill, Stokes, Hardcastle, & Gibbon, 1995).

EPG is an instrumental technique which provides spatial and temporal information of lingual contact with the hard palate during continuous speech (Hardcastle & Gibbon, 1997). In this system, the lingual-palatal contact patterns are registered by a tailor-made artificial palate which fits tightly against an individual's hard palate. The artificial palate contains 62 silver electrodes mounted on its surface and when any of these electrodes are in contact with the tongue, a signal is transmitted to an external processing unit which records the pattern of contact in a microprocessor. The data is then converted into a graphic presentation of the tongue-palatal contact pattern, indicating contact or no contact at each electrode on a screen display. Since EPG is able to reveal tongue-palatal contacts which are often visually inaccessible, it has become a useful tool in evaluating a variety of speech disorders including cleft palate speech (Hardcastle & Gibbon, 1997).

To identify and describe pathological speech, investigators have identified a limited number of EPG contact patterns which may serve as 'normal' templates for specific speech targets. For example, Hardcastle and Edwards (1992) examined the EPG displays of English lingual consonants produced by four normal speakers and showed that the EPG pattern for a typical /s/ was characterized by a narrow grooved configuration in the anterior region of the palate and a complete lateral seal along the margins of the palate (see Figure 1). Similar contact pattern for /s/ was also documented in an EPG study of lingual consonants produced by six normal Cantonese speakers (Kwok, 1992). Thus, if an individual exhibits a configuration that involves complete contact across the whole palate when producing /s/, this may indicate an atypical articulatory pattern and warrant intervention.

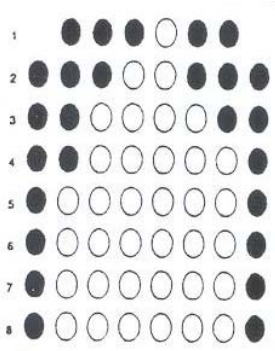


Figure 1. An EPG pattern for normal /s/ (adapted from Hardcastle & Edwards, 1992).

However, it is important to note that these 'normal' EPG patterns reported in the literature are not based on very extensive data. A wide degree of variability was evident in the production of normal population (McLeod, 2004). Roberts, McLeod, and Sita (2002, 2003), in McLeod (2004), investigated the productions of /s/ and /z/ by ten EPG researchers and the results revealed intra- and inter-subject differences in symmetry, the presence and absence of a groove, total palatal contacts and maximum contact displays. Such variability has also been reported in the speech of cleft palate speakers. In essence, Hardcastle, Morgan Barry, and Nunn (1989) studied the productions of two English-speaking cleft palate children and found variability in the location and amount of contact. Most variability involved alveolar targets. Of particular interest to this study was the fricative /s/, because it has been reported to be particularly vulnerable to disruption in both Cantonese and English. McWilliams (1953, 1958), in McWilliams et al. (1990), showed that /s/ was the most frequently and consistently misarticulated phoneme among all English speech sounds. Gibbon, Whitehill, Hardcastle, Stokes, and Nairn (1998), in a cross-language study of ten English and ten Cantonese-speaking children with cleft palate, also found that /s/ was among the four phonemes that were most susceptible to disruption. Despite the vulnerability of /s/, there have been few studies investigating /s/ productions in Cantonese cleft population in a specific and detailed manner.

Therefore this study aimed to use EPG to systematically characterize the articulatory patterns of /s/ produced by Cantonese-speaking children with cleft palate. Variability in the production of /s/ is expected. Such finding may provide clinical insights to the evaluation and remediation of speech disorders associated with cleft palate.

Part 1: An Electropalatographic Analysis of /s/

Method

The EPG and auditory data used in this study were collected by Chun and Whitehill (2003), and were analyzed with permission.

Subjects

The speakers were five Cantonese-speaking children with repaired cleft palate recruited from The University of Hong Kong Cleft Lip and Palate Centre of the Prince Philip Dental Hospital. All speakers had normal hearing abilities as determined by a pure-tone audiometric screening at 25dB HL at 500 Hz to 4000 Hz, normal intelligence, and had been identified to exhibit posterior placement of alveolar targets during a speech and language screening using the Cantonese Segmental Phonology Test (So, 1993). At the time of data collection, all the speakers had undergone traditional speech therapy for at least two years, but had residual posterior placement errors. The subject details are summarized in Table 1.

Speech Materials

Two monosyllabic word lists, constructed by Chun and Whitehill (2003), were used in this study (see Appendix A). The first word list was in /a/-consonant-vowel (/a/-C_1V_2) format and the second one in /a/-consonant-vowel-consonant (/a/-$C_1V_1C_2$) format (where C_1 = /p^h, p, t^h, t, k^h, k, f, s, ts^h, ts, l, j/; V_1 = /a, i, ɛ, ɔ, u/; and C_2 = /p, t, k/). The vowel /a/ preceding the target word was used to stabilize the tongue posture

Table 1. *Individual characteristics of the five speakers*

Subject	Age	Sex	Type of cleft
S1	6;05	F	CP only
S2	9;05	M	LCLP
S3	9;05	M	RCLP
S4	9;05	M	LCLP
S5	13;07	M	BCLP

Note. CP = Cleft palate only; LCLP = Unilateral (left) cleft lip and palate; RCLP = Unilateral (right) cleft lip and palate; BCLP = Bilateral cleft lip and palate.

(Yamashita & Michi, 1991). From these lists, seven words with initial /s/ (two attempts for each word), three in /a/-CV format and four in /a/-CVC format, were selected for analysis from each of the speakers to make up a corpus of 70 tokens.

Instrumentation

The EPG and auditory data were recorded simultaneously. The Reading EPG-3 system was used to record the articulatory data (Hardcastle, Gibbon, & Jones, 1991). The speech data was recorded in a quiet room using a TASCAM DA-30 MKII Digital (DAT) tape recorder and a Bruel & Kjaer Type 2312 MK II microphone which was maintained at a mouth-to-microphone distance of 15 cm. The subjects were asked to repeat the target words after the experimenter because the young subjects could not read fluently.

Among the 70 tokens, two data files were unavailable due to technical problems, so only 68 tokens were subjected to analysis.

Procedures

The EPG frame showing the maximum number of contacts during the frication

phase of /s/ was selected to summarize the lingual-palatal contacts for the production of /s/ in the target words (Hardcastle & Gibbon, 1997). The EPG pattern was checked with the acoustic trace to identify the frication phase. Traditional zoning scheme divided the palatogram into three regions: alveolar, palatal, and velar (Hardcastle et al., 1989). However, as the speakers in this study were all children with cleft palate and had small palates, there might not be a distinction between the palatal and velar regions. Hence, a zoning scheme which divided the palatogram into two zones – alveolar zone (row 1 and 2) and posterior zone (rows 3 to 8) was used in this study.

The lingual-palatal contacts for /s/ in the target words were then analyzed qualitatively, focusing on four features: (a) the presence of a groove, which was defined as a channel with a width of one to three uncontacted electrodes; (b) the location of groove, if present in the alveolar or posterior zone; (c) the symmetry of the groove, defined as a groove which existed in the central two columns, or involved only one of the central columns of the palate when it was three-electrodes wide; and (d) the area and extent of contact (Hardcastle et al., 1991; Hardcastle & Gibbon, 1997). A list of operational definitions was constructed to characterize all the /s/ targets produced by the five speakers (see Appendix B).

Based on the list of operational definitions, the 68 EPG frames of maximum contact were categorized independently by the experimenter and two certified speech and language pathologists who were experienced in both the speech of Cantonese-speaking children with cleft palate and with EPG. Careful analysis of the EPG patterns suggested that eight productions had been affected by technical problems. These eight tokens (8/68 = 12% of the data) were discarded. A further one token (1/68 = 1% of the data) was excluded because it did not fit into any of the categories. The inter-judge agreement for categorization of the remaining 59 tokens, calculated by

dividing the number of agreements of the three judges by the total number of tokens, expressed as a percentage, was 86% (51/59). The eight discrepancies were resolved through discussion.

Results

Seven different EPG patterns for /s/ were identified. Figure 2 shows the lingual-palatal contacts for each of the patterns and their respective frequencies of occurrence across the five speakers. The seven EPG patterns included:

A) No or minimal contact. This was an abnormal EPG pattern for /s/, which was characterized by no contacted electrodes or less than seven contacted electrodes scattered throughout the palate. Subjects 1 and 5 exhibited this pattern.

B) Lateral contact. This was another abnormal EPG pattern for /s/ with no grooved configuration. There was lateral contact, usually on the most lateral rows, on one or both sides of the palate. This pattern occurred most frequently among the seven patterns and was found in three of the subjects.

C) Stop contact. There was complete closure across the palate in one or more rows. The contact was predominantly in the alveolar zone although some also involved rows 3 to 5 of the posterior zone. Only Subject 1 exhibited this pattern.

D) Anterior alveolar groove. This pattern was characterized by a symmetric groove in the alveolar zone, and in all cases, involved the first row only. There was also a complete lateral seal on one or both sides of the margin. This pattern resembled a normal EPG pattern for /s/ and was found in Subject 4.

E) Extended alveolar groove. A symmetric groove was also noted in this pattern. The groove started in the alveolar zone and extended back into the posterior zone, forming a relatively long channel. Along this channel, some but not all rows were wider than three electrodes. Three subjects were found to demonstrate this pattern.

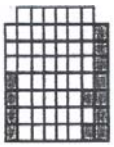
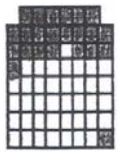
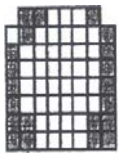
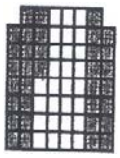
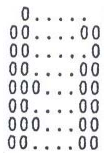
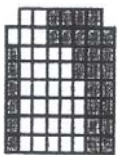
Patterns	S1	S2	S3	S4	S5	Total
A) No or minimal contact 	1	-	-	-	9	10
B) Lateral contact 	-	1	9	-	3	13
C) Stop contact 	7	-	-	-	-	7
D) Anterior alveolar groove 	-	-	-	4	-	4
E) Extended alveolar groove 	-	-	1	5	1	7
F) Posterior groove 	-	-	-	8	-	8
G) Asymmetric groove 	-	10	-	-	-	10

Figure 2. The seven EPG patterns and the frequency of occurrence in the five speakers.

F) Posterior groove. This pattern was characterized by a long symmetric groove that existed in the posterior zone (any of the rows from row 3 to 8), and was found in Subject 4 only.

G) Asymmetric groove. This pattern was similar to Pattern D (anterior alveolar groove), but the groove was asymmetric, that is, it did not involve the central two columns of the palate. Only Subject 2 showed this pattern.

Discussion

The results revealed seven different EPG patterns for /s/ produced by five Cantonese-speaking children with cleft palate. These different EPG patterns demonstrated the wide range of lingual-palatal configurations produced by cleft palate children when attempting /s/ targets. Variability among these seven EPG patterns was noted in four aspects: (a) the presence and absence of a groove, in which four of the seven EPG patterns exhibited a grooved configuration; (b) the location of the groove, with three EPG patterns showing a groove in the alveolar zone; (c) the length of the groove, varying from one-row to a continuous groove of more than four rows; and (d) the amount of contact which ranged from no/minimal contact and limited lateral contact to complete closure across the alveolar zone. Such differences illustrated a wide variability in the production of /s/ by cleft palate speakers. This finding is consistent with previous reports and provides further evidence that there is a wide degree of variability in the production of disordered populations (McLeod, 2004).

Abnormal lingual-palatal contact patterns were also found in five of the seven EPG patterns. One EPG pattern, the ‘posterior groove’ pattern, exhibited a spatial distortion that resembled the ‘palatalized misarticulation’ (PM) reported in the Japanese cleft-palate literature. Yamashita and Michi (1991) described PM as a type of misarticulation which was characterized by predominantly posterior constriction with

the posterior aspect of the tongue making contact with the posterior border of the hard palate. Since both 'posterior groove' pattern and PM involved posterior placement, this finding suggested that abnormal posterior placement is a common error pattern in both Cantonese and Japanese-speaking cleft palate children. Whitehill et al. (1995) hypothesized that those speech characteristics that were common in cleft palate speakers of different languages might be language-universal features of cleft palate speech. It was because such errors were thought to arise as a direct consequence of the structural defect and were thus expected to occur in all languages. In fact, Gibbon et al. (1998), has reported similar retracted articulation to be common misarticulations of both Cantonese and English cleft palate speech in a cross-language study of Cantonese and English-speaking children with cleft palate, suggesting that retracted articulation might be a language-universal feature of cleft palate speech. Thus, the abnormal posterior placement reported in this study which is a common error pattern in both Cantonese and Japanese cleft populations adds further support to the hypothesis that retracted articulation may be a language-universal feature of cleft palate speech.

Part 2: An Investigation on Listeners' Perceptual Judgment of /s/

As mentioned earlier, traditional evaluation of cleft palate speech was based on perceptual analysis. However, poor listener agreement was found (McWilliams et al., 1990). Two recent studies have provided evidence for this claim. For instance, in Gooch, Harding-Jones, Chapman, Trost-Cardamone, and Sussman (2001), listeners were asked to transcribe compensatory errors produced by English-speaking children with cleft palate. The results showed that inter-judge agreement for both experienced and inexperienced listeners were poor, attaining a mean of 39% and 30%, respectively.

Santelmann, Sussman, and Chapman (1999) also demonstrated that listeners were unable to identify middorsum palatal stops – a type of compensatory articulation, and inaccurately judged them as /t/ or /k/. These studies illustrated that listeners had difficulty in identifying and transcribing the speech errors associated with cleft palate. Gibbon et al. (1991) also pointed out that /s/ was problematic to transcribe. As the results of the first part of this study revealed a wide variability in the production of /s/, it is expected that listeners would find it hard to identify the error patterns of /s/ as well.

Moreover, inconsistency between EPG and perceptual findings has been documented. Whitehill et al. (1995) reported that listeners perceived /ts/ produced by Cantonese-speaking children with cleft palate as [j] even when the EPG pattern for /ts/ appeared normal. Gibbon, Hardcastle, and Dent (1995), who used perceptual and EPG analysis to study obstruent sounds in children with functional articulation disorders, also found that the EPG patterns for sounds heard as lateralized could be very different, with the place of articulation varying from alveolar, and palatal to velar regions. This indicated a discrepancy between perceptual and EPG findings, since sounds that were judged to be perceptually similar actually exhibited wide variations in their pattern of tongue-palatal contact. Most previous studies which described EPG patterns for speech were based on perceptual analysis. In other words, the investigators first transcribed the misarticulations and then identified the common EPG characteristics for sounds having this same perceptual judgment. However, little attempt has been made to look at the relationship in a reversed way, that is, to describe the perceptual judgments for stimuli showing similar EPG patterns. As the results of the first part of this study revealed seven different EPG patterns, it would be interesting to examine what perceptual judgments listeners would identify based on these specific EPG patterns.

Therefore, the purpose of the second part of this study was to investigate listeners'

perceptual judgments for /s/ targets associated with different EPG patterns and their listener agreement. Such findings might help provide a better understanding about listener's difficulties in transcribing cleft palate speech and the relationship between EPG and perceptual analysis.

Method

Subjects

The listeners were fifteen native Cantonese speakers who were fourth-year undergraduates in the Division of Speech and Hearing Sciences at the University of Hong Kong. All listeners passed a pure-tone audiometric screening at 25dB HL at 250 Hz to 8000 Hz on the day of the experiment. They had received basic training in phonetics and had experience listening to and transcribing speech of children and/or adults with speech and language disorders. However, they had little or no experience with speakers with cleft palate.

Auditory Stimuli

The auditory data of the 59 EPG stimuli analyzed in the first part of this study were used as auditory stimuli for the listening task. The DAT recordings of these 59 /s/ targets were digitized by the author using Sound Designer II with a sampling rate of 441K Hz and a resolution of 16-bits to an Apple Power Macintosh G3 computer. The speech samples were edited using Praat version 4.1.22 (Boersma & Weenink, 2004), and their volumes were adjusted to comparable intensity levels.

Procedures

Pre-test.

Nine possible substitutions of /s/ that were typical error patterns in cleft palate speech were proposed (Hardcastle & Gibbon, 1997; Stokes & Whitehill, 1996). They included 'normal' which represented typical /s/ production in Cantonese, 'alveolar stop

/t/', 'glottal stop', lateralized /s/', 'palatalized /s/', 'dental fricative', 'bilabial fricative', 'pharyngeal fricative' and '/s/ with nasal emission'. A pre-test was administered in the form of a multiple choice task to narrow down the number of choices to be included in the main study such that the task would not be too easy or difficult for the participants. The listeners were two certified speech and language pathologists who were experienced in evaluating speech of Cantonese-speaking children with cleft palate. Using a Hypercard stack running on an Apple Power Macintosh G3 computer, the auditory stimuli were randomized and played to the listeners via Sennheiser HD 25 headphones in a sound-attenuated booth individually. For each trial, one stimulus was presented and the listeners were asked to select the choice that most closely matched with what they heard. They were allowed to hear each stimulus one additional time. Two choices which neither of the listeners selected, glottal stop and alveolar stop, were excluded. All the misarticulations were perceived to be distortions of fricatives. This provided support for the notion that the manner of frication is maintained to a high degree in the Cantonese cleft population (Stokes & Whitehill, 1996).

Listening task.

The listening task was conducted in a sound-attenuated booth individually. Similar to the pre-test, a Hypercard stack was used to present the stimuli on an Apple Power Macintosh G3 computer via Sennheiser HD 25 headphones. Each token was repeated three times to measure intra-judge agreement. The speech stimuli were randomized before each listening session.

A multiple-choice task was administered. Based on the results of the pre-test, the seven choices were 'normal', 'lateralized /s/', 'palatalized /s/', 'dental fricative', 'bilabial fricative', 'pharyngeal fricative' and '/s/ with nasal emission'. The listeners were asked to select from these seven choices after listening to each stimulus. They

were allowed to hear each stimulus one additional time.

Prior to the listening task, a description of the physiological/articulatory characteristics of each error pattern included as a choice was given and explained to ensure that the listeners understood the labels (see Appendix E). The listeners were allowed to refer to the description at any time during the test. Demonstrations of each error pattern were also provided by the experimenter to each listener to establish a common understanding of the perceptual characteristics of the error types among listeners (Gooch et al., 2001). The demonstrations were repeated upon listener's request. A block of four practice trials was completed before the actual test trials to familiarize the listeners with the task.

Data Analysis

Intra-judge agreement was calculated by dividing the number of 'complete agreements' of the fifteen listeners by the total number of tokens expressed as a percentage. As each stimulus in the listening task was repeated three times, three conditions arose. The first condition was 'complete agreement' where listeners selected the same choice for all three trials. The second condition was 'partial agreement' where listeners selected the same choice in two of the three trials. 'No agreement' referred to the condition where a different choice was selected in all three trials. The number of 'complete agreements' across the fifteen listeners were then added up, and the sum was expressed as a percentage of the total number of tokens for each of the EPG patterns. For instance, Pattern A (no or minimal contact) had 10 stimuli. With 15 listeners, there were a total of 150 tokens. Out of these 150 tokens, 87 showed complete agreement, 55 showed partial agreement and 8 showed no agreement. Hence the percentage of 'complete agreement' for this pattern was 58% (87/150). The percentage of 'complete agreement' was then calculated for each of the seven EPG patterns using this method to

evaluate the intra-judge agreement.

To examine the perceptual judgments made by the listeners for stimuli associated with the seven EPG patterns, the number of times of each choice selected by the fifteen listeners was expressed as a percentage of the total number of tokens for each of the seven EPG patterns. For example, Pattern B (lateral contact) had 13 stimuli. As each stimulus was repeated three times and there were 15 listeners, there were a total of 585 tokens in this EPG pattern. Among these 585 stimuli, 298 of them were identified as normal productions, 35 of them were identified as bilabial fricative, 102 of them were identified as dental fricative, etc. The sum of each choice was then expressed as a percentage of the total number of tokens, thus giving rise to 51% (298/585) for normal productions, 6% (35/585) for bilabial fricative, and 17% (102/585) for dental fricative, respectively. The respective percentages of occurrence of the seven choices were calculated using this method for each of the seven EPG patterns.

Results

The percentages of complete agreement for the seven EPG patterns were calculated to evaluate intra-judge agreement. The results are summarized in Figure 3. The percentage of complete agreement was highest for the EPG pattern associated with stop contact (70%), followed by the 'lateral contact' pattern (61%). The EPG patterns associated with no/minimal contact and anterior alveolar groove attained about 55% of complete agreement. Intra-judge agreement was relatively poorer for the EPG patterns showing extended groove, posterior groove and asymmetric groove, which were deviations of normal /s/ lingual-palatal configurations. The lowest intra-judge agreement was found in the EPG pattern associated with extended groove (38%). In general, the intra-judgment agreement for the seven EPG patterns was low.

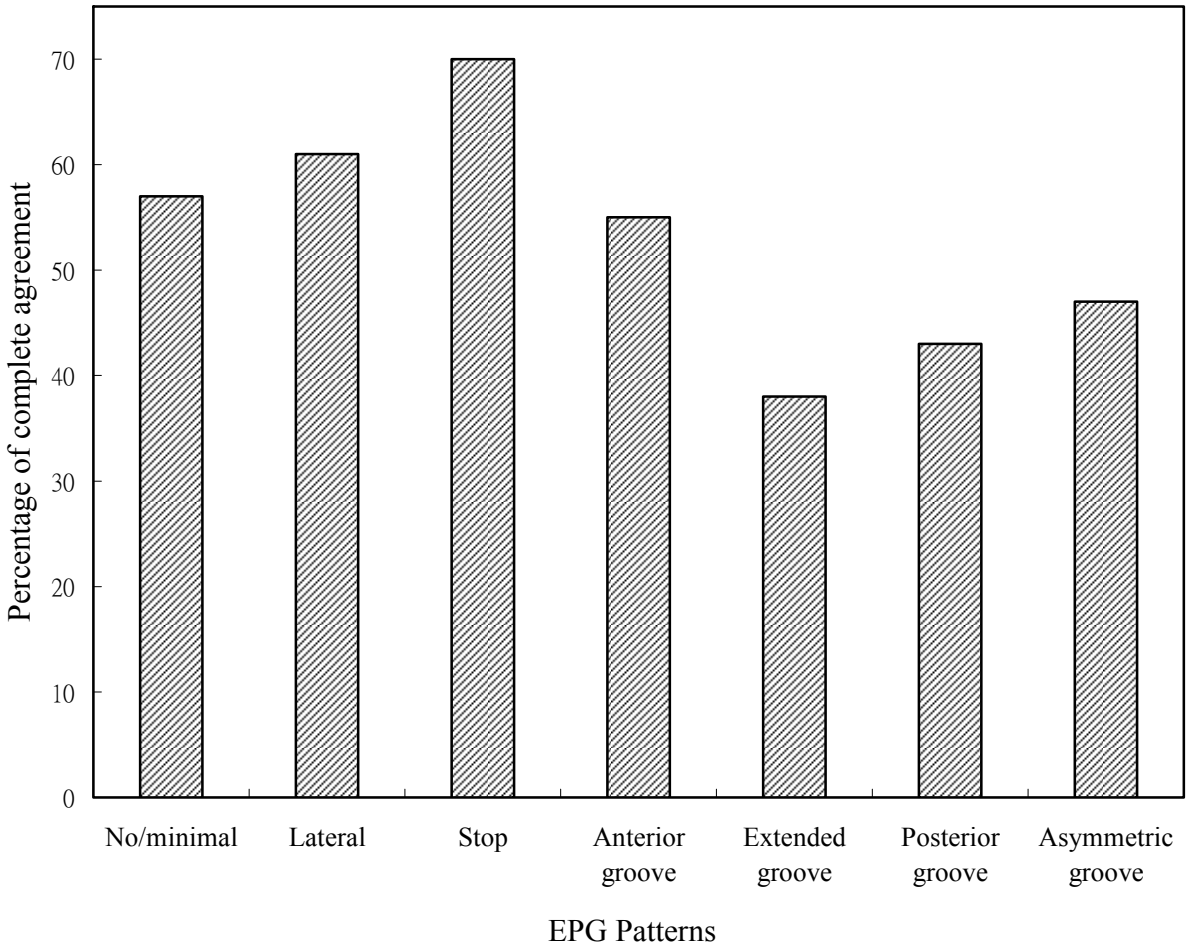


Figure 3. The percentage of complete agreement for each of the seven EPG patterns.

Figure 4 shows the respective percentages of occurrence of the seven perceptual judgments in each of the seven EPG patterns. As shown in the figure, 80% of the stimuli associated with the EPG pattern showing stop contact were identified as pharyngeal fricatives. The high percentage of occurrence of this choice and the high intra-judge agreement for this EPG pattern (as shown in Figure 3) suggested that listeners' perceptual judgments for stimuli associated with the 'stop contact' EPG pattern were consistent.

Listeners most commonly identified stimuli associated with the EPG pattern showing no/minimal contact as dental fricatives (64%). Less common choices were bilabial fricatives and pharyngeal fricatives.

For the EPG patterns which showed grooved configuration (‘anterior alveolar groove’, ‘extended groove’, ‘posterior groove’ and ‘asymmetric groove’), normal production was the most common choice for stimuli associated with these four EPG patterns. Among these four EPG patterns, listeners’ perceptual judgments for stimuli showing the EPG pattern with anterior alveolar groove were relatively more consistent as over 60% of the stimuli associated with this EPG pattern were identified as normal productions. On the contrary, for the EPG pattern exhibiting extended groove, only 45% of the stimuli were identified as normal productions, with lateralized /s/ and palatalized /s/ being the second most common choices. Intra-judge agreement was also lowest for this pattern, indicating that listeners’ perceptual judgments for this pattern were least consistent. Inconsistent perceptual judgments were also found in the EPG pattern showing posterior groove. Similarly, normal production was the most common choice with lateralized /s/ and palatalized /s/ being the second and third most common choices. In fact, lateralized and palatalized articulations of /s/ were the second and third common choices for stimuli associated with four of the seven EPG patterns.

For the EPG pattern showing lateral contact, listeners also most commonly identified stimuli associated with this EPG pattern as normal productions. This was an interesting finding since this EPG pattern did not exhibit any grooved configuration.

Discussion

The results of the second part of this study indicated that intra-listener agreement for the perceptual judgments of /s/ produced by Cantonese-speaking children with cleft palate was poor in general. Intra-judge agreement was particularly low for the EPG patterns showing extended groove, posterior groove and asymmetric groove. Perceptual judgments for stimuli associated with these two EPG patterns were also inconsistent. It is found that listeners had most difficulty in identify normal /s/ productions, lateralized

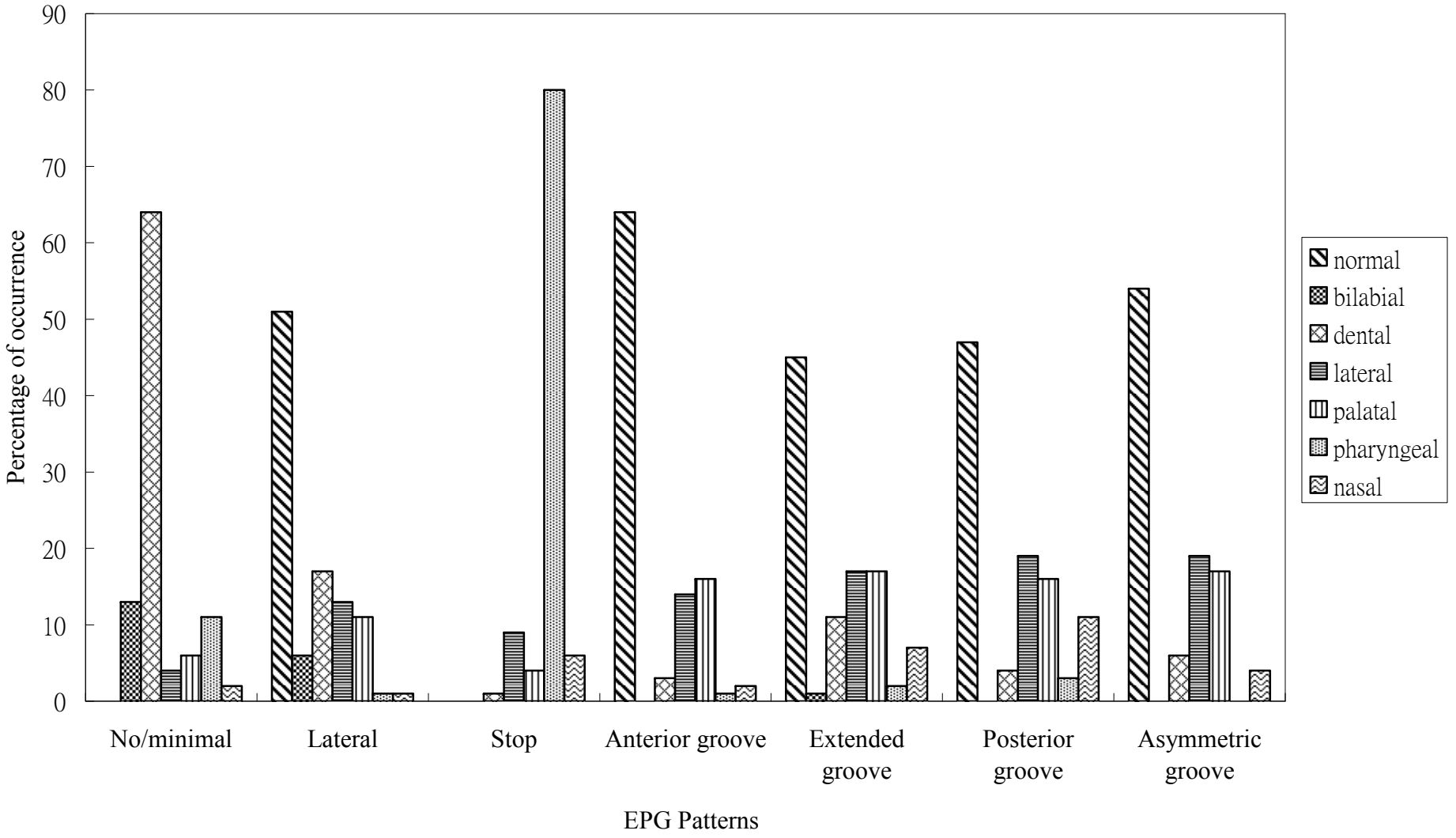


Figure 4. The respective percentages of occurrence of the seven perceptual judgments for each of the seven EPG patterns.

/s/ and palatalized /s/. These findings illustrated the difficulties listeners have when evaluating the speech of cleft palate children.

One hypothesis for listeners' difficulties in the identification of normal, lateralized and palatalized productions of /s/ is that lateralized /s/ and palatalized /s/ are not phonemic categories in Cantonese. Their acoustic cues may also overlap with the phonemic category of the fricative /s/ in Cantonese. Support for this hypothesis comes from studies by Santelmann et al. (1999) and Gooch et al. (2001). In Santelmann et al. (1999), listeners failed to identify middorsum palatal stops from /t/ and /k/ because middorsum palatal stops were not a phonemic category in English. The acoustic cues of middorsum palatal stops also overlapped with the place features of /t/ and /k/, as middorsum palatal stops are produced in the palatal region that lies between the alveolar and velar regions. This same reasoning might be applied in this study. In Cantonese, fricatives are articulated at three places – labiodental, alveolar and glottal. Since misarticulations of /s/ (lateral /s/ and palatalized /s/) are produced in regions in proximity with the alveolar region, it is likely that they may overlap with the phonemic category of /s/, thereby making it difficulty for listeners to identify the exact place of articulation. Moreover, palatalized /s/ is an allophone of /s/ in Cantonese (Bauer & Benedict, 1997). In other words, palatalized /s/ is not a phonemic category in Cantonese. Hence, this lack of phonemic distinction between /s/ and palatalized /s/ may make it difficult for listeners to identify these types of articulations uniquely.

Normal production was the most common choice for stimuli associated with five of the seven EPG patterns. Among these five EPG patterns, four of them were associated with a grooved configuration. This finding is not surprising since a grooved configuration is characteristic of normal /s/ production (Gibbon et al., 1995; Hardcastle & Edwards, 1992). However, interestingly, listeners also most commonly identified

stimuli with the EPG pattern showing lateral contact as normal production despite the absence of a groove. This finding is consistent with previous reports that there was inconsistency between EPG and perceptual data. Although perceptual analysis suggested normal /s/ production, the EPG data indicated abnormal articulatory gestures. This finding illustrated that EPG is able to reveal abnormal articulatory gestures that can not be identified based on perceptual analysis alone (Hardcastle & Edwards, 1992).

Moreover, the stop contact pattern was most commonly perceived as pharyngeal fricative. However while perceptual judgment suggested constriction at the posterior region, EPG data showed complete contact in the alveolar zone. Such perception suggested that there might be simultaneous contact at the alveolar and the pharyngeal region. This type of articulation where there was closure in two regions simultaneously was known as double articulation. Two types of double articulation have been reported in the cleft palate literature. They were labial-velar double articulation which involved simultaneous labial and complete velar closure for bilabial stops (Hardcastle & Gibbon, 1997), and alveolar-velar double constriction for velar targets (Whitehill et al., 1995). However, the alveolar-pharyngeal double articulation suggested in this study has not been reported previously. Further documentation would be required to verify its validity, for example, by using videofluroscopy or lateral radiography.

This finding also illustrated a limitation of EPG, in which EPG fails to capture contact pattern that is more anterior and posterior to the artificial palate. In addition, the information obtained from the EPG is static and does not provide any acoustic-phonetic information. Therefore it is difficult to predict what listeners would identify based on EPG pattern since speech perception involves rapidly and continuously changing acoustic-phonetic information (Philips, 1999). Besides that, EPG only records the location of contact but does not provide direct information on which part of the tongue

and how close it is to the palate (Hardcastle et al., 1991). Thus, for instance, although an EPG pattern shows contact at the posterior region, it is not known whether the tongue tip/blade/back is making the contact. Such difference may give rise to difference acoustic signals and thereby results in a difference in perception.

However, it should be cautioned that several factors might have affected the results of this study. Firstly, listeners' perceptual judgments were made from audio recordings, in which the stimuli in the listening task were presented through headphones. This may make it more difficult for listeners to identify the type of production. Stephens and Daniloff (1977) found that the articulation judgments of /s/ by six listeners made from audio recordings and live productions did not correlate well with each other. Whereas live judgments of the listeners identified that six of the speakers were consistently producing defective /s/, audio judgments showed that 25 to 75% of the productions by these six speakers were correct. In addition, the percentage of agreement for /s/ under tape recorded condition was lower (64%) than that under live speaking condition (95%). These findings indicated that audio judgments of /s/ were less likely to be reliable than were live judgments.

Another factor that might have affected the results was the lack of visual information. Some of the error types, for example, bilabial fricative and dental fricative, would be identified more easily and reliably if the listeners were able to visualize the articulatory gestures as well, for instance, during live judgment or videotapes. It has also been shown by Chun and Whitehill (2003) that visual information provided by EPG helped to improve intra- and inter-listener agreement in identifying the place of articulation in compensatory errors of cleft palate speech.

Moreover, the 'training' in the current study only involved a brief explanation of the physiological and articulatory characteristics of the error patterns and

demonstrations of each type. Gooch et al. (2001) suggested that more active training might help listeners to identify the type of errors more reliably. More active training may include asking the listeners to listen to and transcribe the speech of cleft palate speakers and then administer a post-test to ensure that the listeners can identify the errors reliably. Such active training would also help to establish a common understanding of the characteristics of the errors patterns among listeners.

General discussion

The results of this study showed that the production of /s/ targets by Cantonese-speaking children with cleft palate could be characterized into seven different EPG patterns. These different EPG patterns demonstrated the wide range of lingual-palatal configurations of /s/, which was consistent with previous reports that there was a wide degree of variability in the production of disordered populations. Listeners' perceptual judgment of /s/ productions was also investigated and poor listener agreement was found. It was hypothesized that such difficulty was due to listeners' inability to identify speech sounds that are not phonemic categories in Cantonese and that their acoustic cues overlap with existing phonemic categories in Cantonese.

The findings from this study have three clinical implications. Firstly, the variability in the production of cleft palate speakers indicated that intervention should be tailor-made for each individual. Depending on the specific error type each individual shows, the focus of treatment varies accordingly. For instance, if an individual's misarticulation of /s/ resembles the 'stop contact' pattern where no groove is present, treatment focus will first be on establishing a grooved configuration. However, if the individual exhibits a 'posterior groove' pattern, treatment focus will not be on the establishment of a groove because he already has this realization. Instead, the individual will have to decrease posterior contact and learn to produce the groove in the alveolar

region (Hardcastle et al., 1991).

Secondly, listeners encountered difficulty in identifying the type of production of /s/ by Cantonese-speaking children with cleft palate. Listener agreement on the identification of these errors was poor. Therefore systematic training and practice in listening to and identifying misarticulations made by cleft palate speakers was necessary for listeners in order for more reliable and accurate evaluation of cleft palate speech (Gooch et al., 2001).

Furthermore, although EPG is able to reveal abnormal lingual-palatal activity that could not be detected by perceptual means, for example, the absence of groove in a production which had been perceived as normal, EPG is unable to provide direct information as to which part of the tongue is in contact with the hard palate and to capture tongue movements that occurred more anterior or posterior than the artificial palate. Therefore, EPG should be used as an adjunct to perceptual analysis. A multichannel approach, which makes use of different information such as aerodynamic data, EPG data and perceptual transcription should be adopted in order to provide more accurate evaluation of cleft palate speech (Hardcastle et al., 1991).

In summary, this study provided a systematic EPG analysis of /s/ targets produced by Cantonese-speaking children with cleft palate. The seven different EPG patterns for /s/ represented a wide degree of variability in the production of cleft palate speakers. Perceptual analysis of /s/ targets also revealed poor listener agreement, illustrating the difficulties listeners encounter in identifying and transcribing the speech of cleft palate speakers. Therefore, systematic training is necessary for more accurate and reliable assessment of cleft palate speech. The variability in production also warrants intervention to be tailor-made for each individual.

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Appendix A

Table 1. Monosyllabic word lists in /a/-CV format.

1. 子	/tsi$_{35}$/	11. /ja/	/ts^{h}a$_{55}$/	21. /fi/	/fi$_{55}$/	31. 耳	/ji$_{23}$/
2. /k^{h}i/	/k^{h}i$_{55}$/	12. B	/pi$_{55}$/	22. P	/p^{h}i$_{55}$/	32. 啤	/p^{h}ɛ$_{55}$/
3. 嫁	/ka$_{33}$/	13. 爸	/pa$_{55}$/	23. 卡	/k^{h}a$_{55}$/	**33. 思**	**/si$_{55}$/**
4. 斜	/ts^{h}ɛ$_{33}$/	14. 渣	/tsa$_{55}$/	24. 騎	/k^{h}ɛ$_{21}$/	34. 啡	/fɛ$_{55}$/
5. /t^{h}e/	/t^{h}ɛ$_{55}$/	15 /ki/	/ki$_{55}$/	25. 啦	/la$_{55}$/	35. 爹	/tɛ$_{55}$/
6. 啤	/pɛ$_{55}$/	16. 呢	/lɛ$_{55}$/	26. 打	/ta$_{35}$/	36. /je/	/jɛ$_{55}$/
7. 哩	/li$_{55}$/	**17. 沙**	**/sa$_{55}$/**	27. 姐	/tsɛ$_{35}$/		
8. 寫	**/sɛ$_{35}$/**	18. 花	/fa$_{55}$/	28. 痴	/ts^{h}i$_{55}$/		
9. T	/t^{h}i$_{55}$/	19. 啲	/ti$_{55}$/	29. 他	/t^{h}a$_{55}$/		
10. 叉	/ts^{h}a$_{55}$/	20. 爬	/p^{h}a$_{21}$/	30. 嘅	/kɛ$_{33}$/		

Table 2. Monosyllabic word lists in /a/-CVC format.

1. 剔	/t^{h}ik$_{5}$/	16. 革	/kak$_{3}$/	31. 肋	/lak$_{2}$/	46. 熱	/jit$_{2}$/
2. 塔	/t^{h}ap$_{3}$/	17. 積	/tsik$_{5}$/	32. 甲	/kap$_{3}$/	47. 八	/pat$_{3}$/
3. 鉗	/k^{h}im$_{21}$/	18. 接	/tsip$_{3}$/	**33. 殺**	**/sak$_{3}$/**	48. 揭	/k^{h}it$_{3}$/
4. 激	/kik$_{5}$/	19. 霍	/fɔk$_{3}$/	34. 確	/k^{h}ɔk$_{2}$/	49. 軋	/kat$_{3}$/
5. 劇	/kɛk$_{2}$/	20. 烈	/lit$_{2}$/	35. 必	/pit$_{5}$/	**50. 攝**	**/sip$_{3}$/**
6. 托	/t^{h}ɔk$_{3}$/	21. 葉	/jip$_{2}$/	36. 鐵	/t^{h}it$_{3}$/	51. 撇	/p^{h}it$_{3}$/
7. 拍	/p^{h}ak$_{3}$/	22. 獵	/lip$_{2}$/	37. 咭	/tak$_{5}$/	52. 達	/tat$_{3}$/
8. 劫	/kip$_{3}$/	23. 撻	/t^{h}at$_{5}$/	38. 百	/pak$_{3}$/	53. 節	/tsit$_{3}$/
9. 索	**/sɔk$_{3}$/**	24. 辣	/lat$_{2}$/	39. 秩	/tit$_{2}$/		
10. 圾	**/sap$_{3}$/**	25. 答	/tap$_{3}$/	40. 立	/lap$_{2}$/		
11. 碧	/pik$_{5}$/	26. 霹	/p^{h}ik$_{5}$/	41. 妾	/ts^{h}ip$_{3}$/		
12. 的	/tik$_{5}$/	27. 法	/fat$_{3}$/	42. 益	/jik$_{5}$/		
13. 靂	/lik$_{5}$/	28. 戚	/ts^{h}ik$_{5}$/	43. 察	/ts^{h}at$_{3}$/		
14. 插	/ts^{h}ap$_{3}$/	29. 賊	/ts^{h}ak$_{2}$/	44. 帖	/thip$_{3}$/		
15. 碟	/tip$_{2}$/	30. 切	/ts^{h}it$_{3}$/	45. 傑	/kit$_{2}$/		

Note. The bolded words were selected for analysis in this study.

Appendix B

Operational definitions used in the categorization of EPG patterns.

A) Stop contact:	characterized by complete contact across the palate in one or more rows.
B) Lateral contact:	characterized by lateral contact of at least four electrodes in length on one or both margins (most lateral rows) of the palate, and an absence of a groove.
C) No or minimal contact:	characterized by no contacted electrodes or less than 7 contacted electrodes scattered throughout the palate.
D) Anterior alveolar groove:	characterized by a channel of 1 – 3 uncontacted electrodes in the 1st row of the palate only. The groove involves the central two columns of electrodes of the palate.
E) Extended alveolar groove:	characterized by a channel of 1 – 3 uncontacted electrodes wide that starts in the 1st or 2nd row and extends back into rows 3, 4, 5, 6 or 7 of the palate. Some but not all rows may be wider than 3 electrodes, and the groove involves the central two columns of the palate.
F) Posterior groove:	characterized by a channel of 1 – 3 electrodes wide in rows 3, 4, 5, 6, 7 or 8 of the palate.
G) Asymmetric groove:	characterized by a channel of 1 – 3 uncontacted electrodes wide in the 1st or 2nd row of the palate. However, the groove does not exist in the central two columns or involves only one of the central columns when it is 3-electrodes wide.

Appendix C

Description of the physiological and articulatory characteristics of the seven choices given to the subjects in the listening task.

1. Normal /s/:	It is produced with a channel formed between the upper surface of the tongue blade and the alveolar ridge, and the air stream flows out through this channel.
2. Lateral /s/:	It is produced with the tongue tip making complete contact with the hard palate, directing the air stream laterally out of both or just one side of the tongue. This diffuse pattern of air flow has a slushy quality.
3. Palatalized /s/:	It is produced with the posterior tongue dorsum and mid-dorsum elevated to make a relatively posterior, palatal contact, with air being directed over the midline of the palate.
4. Pharyngeal fricative:	It is produced with the tongue lowered and retracted towards the pharynx wall. This often involves retraction of the epiglottis and/or lateral constriction of the faucal pillars.
5. /s/ with nasal emission:	It is produced like an alveolar /s/ but with an abnormal flow of air through the nose which creates a noise during the production of the consonant /s/.
6. Dental fricative:	It is produced with the tip of the tongue articulating against the rims or backs of the upper front teeth.
7. Bilabial fricative	It is produced with a constriction made by the upper and lower lip.