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An ultrasonographic investigation of cleft-type compensatory articulations of voiceless velar stops

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ABSTRACT

Ultrasound imaging was used to investigate the articulation of the voiceless velar stop [k] in five speakers with compensatory articulation related to cleft palate. The perceptual evaluation of the acoustic realization and the visual assessment of the tongue movement for the target sound were made by three examiners. The analysis revealed a variety of different compensatory strategies that included glottal stops, pharyngeal stops, midpalatal stops, and glottal and velar co-productions. One patient produced isolated palatal click sounds together with a midpalatal stop. The ultrasound imaging also revealed covert articulatory movements that would have been missed in a purely perceptual analysis. The analysis of the ultrasound images points to subphonemic aspects of cleft-type compensatory articulation that are important to understand for speech therapy.

INTRODUCTION

In 1984, Code and Ball edited a book entitled *Experimental Clinical Phonetics* (in North America, published as *Instrumentation in Speech-Language Pathology*), which aimed to introduce speech-language pathologists in clinical practice to instrumental methods of speech analysis (Code & Ball, 1984). The premise of this book was that the perceptual analysis of speech disorders should be underpinned by quantitative instrumental measures. In the years since this publication, the instrumental analysis of speech errors has made great strides. Ball, Mueller and Rutter (2010) argue that our increased understanding of the motor speech process challenges the traditional division of speech errors into phonological vs. phonetic errors.

The specific compensatory speech errors of patients with cleft palate are a case in point because these errors straddle the border between phonological and phonetic errors in an interesting way. Cleft lip and palate is the most frequent congenital craniofacial anomaly and occurs in approximately 1: 650 newborns. A cleft of the palate has significant consequences for the patient's breathing, swallowing, middle ear function, and most of all, for speech (Peterson-Falzone, Hardin-Jones & Karnell, 2001; Kuehn & Moller, 2000). The soft palate is an important part of the velopharyngeal closure mechanism, which allows a speaker to differentiate nasal and oral speech sounds. Patients with an insufficient velopharyngeal closure mechanism will sound hypernasal and experience nasal air emission. Therefore, the patient will find it difficult to produce pressure consonant sounds, such as plosives and fricatives, and many patients develop active compensatory articulations (Kummer, 2008; Harding & Grunwell, 1998). These cleft-type active compensatory articulations are characterized by posterior placements in the vocal tract. Many of the compensatory sounds do not normally occur in the target language of the child (Harding & Grunwell, 1998; Trost, 1981), which is why Ball et al. (2010) argue that cleft-type compensatory articulation errors have a phonological component source with an external phonetic effect. Typical compensatory articulation errors observed in children with cleft palate are glottal and pharyngeal stops (to replace plosive sounds), pharyngeal fricatives (to replace postalveolar fricatives) and nasal fricatives (to replace alveolar fricatives). For the listener, these sounds are noticeable, distracting, and socially stigmatizing (Peterson-Falzone et al., 2001). Stengelhofen (1989) estimates that approximately 40% of patients will have a persistent, often life-long, speech disorder related to the cleft palate.

The auditory-perceptual assessment and the phonetic transcription of disordered speech can be problematic (Gooch, Hardin-Jones, Chapman et al., 2001; Kent, 1996), which is why it is desirable to supplement the perceptual assessment with instrumental measurements. A technique that has been used to describe the complexity and variability of cleft-type compensatory articulations is electropalatography (EPG; Gibbon, 2004; Howard, 2004). While EPG is an appropriate tool to describe the linguopalatal contact patterns of disordered

speakers, the speech-language pathologist can only guess which part of the tongue touched the EPG and how it got there. In this sense, EPG can only provide a negative image of tongue movement.

In the present study, we used ultrasound imaging to illustrate different cleft-type compensatory articulations for the voiceless velar plosive [k]. The study presents a subset of data from a research project that investigated the effects of different types of articulation therapy on cleft-type compensatory articulations. It was our goal to establish individual articulatory profiles in order to capture the wide variability of cleft-type compensatory articulations and to use this knowledge as a benchmark for the patients' therapy success.

METHODS

Subjects

Five patients with different types of repaired cleft palate participated in this study. Because the aetiologies and the patient demographics were quite heterogeneous, the patients are presented individually. Sandra (all names changed) was 9 years old at the time of the study. She had a bilateral cleft lip and palate. Sally was 25 years old and had an isolated cleft of the soft palate. Sabrina was 8 years old. She had a repaired unilateral cleft lip and palate. This patient had also undergone a pharyngeal flap surgery. Steve was 13 years old and had a bilateral cleft lip and palate, and Sarah 9 had a unilateral cleft lip and palate and was 20 years old. All patients and controls spoke Canadian English with the standard Southern Ontario accent that is common in Toronto. Using convenience sampling, the patients were recruited from the Hospital for Sick Children in Toronto. All research procedures were approved by the Research Ethics Boards at the Hospital for Sick Children and the University of Toronto.

Recording procedures

A General Electric Logiq Alpha 100 MP ultrasound scanner (General Electric Medical Systems, WI 53201) with a model E72 6.5 MHz transducer with a 114° microconvex array was used to record the participants' tongue movement in the midsagittal plane. The participants were seated in an office chair with their forehead against a headrest and their chin on the ultrasound transducer. The video output from the ultrasound machine was recorded to a digital video camera (ZR 45 MC, Canon Canada Inc., ON L5T 1P7) with a frame rate of 30 frames per second. The acoustic signal was recorded simultaneously. The participants spoke five repetitions each of [a'ka], [i'ki] and [u'ku] after the examiner. The isolated production task was chosen because

it allowed us to study the target sound in detail. The sound [k] was chosen as the target sound since it is readily visible in the midsagittal ultrasound image.

Data Analysis

The digital video films were downloaded to a computer and segmented. The resulting movie clips were reviewed by a team of three researchers. The researchers discussed their impressions and reconciled the auditory-perceptual and the visual information in a joint decision. This qualitative analysis of the patients' compensatory articulations was documented in a spreadsheet.

RESULTS

In the [a'ka] context, Sandra produced the [k] target as series of glottal stops [ʔ]. However, concurrent with the glottal stops, she alternated between elevation of the tongue tip and the dorsum of the tongue (Figure 1). These lingual gestures were not audible. In the [i'ki] and [u'ku] contexts, the target consonants were produced as glottal stops [ʔ] without accompanying lingual movement.

[Figure 1 about here]

Sally produced the target [k] consistently as a midpalatal plosive [c] in all vowel contexts. In the [i'ki] context, the final two repetitions of the midpalatal stop were realized with a noticeable palatal clicking sound [ɰ].

[illegible]

Steve used a consistent articulatory strategy that involved a double articulation of a glottal stop [ʔ] and a pharyngeal stop [ʕ]. He used this strategy in all vowel contexts. Figure 2 demonstrates the movement of the base of the tongue for the [ʕ].

[Figure 2 about here]

Finally, Sarah produced the target sound as a double articulation of [ʔ] and [k] in the [a'ka] and [u'ku] tasks. However, [i'ki] was produced as [i'ʔi] without any audible or visual lingual closure gesture.

DISCUSSION

The current study demonstrated that ultrasound provides useful diagnostic information for the analysis of cleft-type compensatory articulations. The patients in the current study presented with a broad range of compensatory articulations that replaced the target sound [k]. The variability of the compensatory articulations between and, in the cases of Sabrina and Sarah, within patients was remarkable.

Ultrasound has the advantage of providing a relatively complete view of the length of the tongue along the sagittal plane. While the anterior tongue tip is usually not visible (Stone, 2005), ultrasound is arguably the most convenient technique to visualize the posterior tongue and the base of tongue. This is relevant in the case of cleft-type compensatory errors because these sounds may involve pharyngeal and epiglottal sounds that cannot be displayed on the EPG. In the case of Steve, a double articulation of a glottal stop [ʔ] and a pharyngeal stop [ʕ] was noted. The ultrasound imaging allowed visualization of the movement of the base of tongue, which confirmed the perceptual assessment.

An interesting observation was the effect of the vowel context on the realization of the target sound. A number of participants varied their productions depending on the vowel that framed the target sound. In particular, the vowel [i] led to the introduction of a palatal click [ɰ] for Sally. Sabrina demonstrated variability for the [i'ki] target with a gradual change from a velar to a post-alveolar articulation. Sabrina also demonstrated an intrusion of the velar nasal [ŋ] in the [u] context. Sarah produced double articulations of [ʔ] and [k] in the [a'ka] and [u'ku] tasks, but not for [i'ki].

Children with articulation disorders without cleft palate will usually have fairly consistent distortions across different vowel contexts. However, three of the five patients in the present study seemed to have particular problems with the [i] context. High front vowels have been shown to increase perceived nasality and nasalance (Lewis, Watterson & Quint, 2000). Since this makes them more taxing on a dysfunctional velopharyngeal sphincter, patients may be more inclined to produce compensatory articulations in a high front vowel context. Such an effect was particularly pronounced for Sarah because the gradual change from the velar stop [k] to the postalveolar fricative [ʃ] was triggered by a momentary nasal emission.

Sally produced two midpalatal plosives [c] as palatal clicks [ɸ] in the [i'ki] context. Clicks have only recently been described as cleft-type compensatory misarticulations and are considered rare in occurrence (Gibbon, Lee, Yuen & Crampin, 2008). Gibbon (2004) argues that patients with cleft palate may exhibit increased tongue-palate contact, i.e., coarser lingual gestures in speech. If a patient produces a midpalatal plosive [c] with such an extensive lingual elevation, a palatal click [ɸ] may simply be a passive phenomenon that occurs during the release of the tongue from the palate.

Howard (2004) points out that instrumental procedures can reveal lingual gestures that are not audible but that may be relevant for speech therapy. The patient Sandra produced silent lingual gestures concurrent with the glottal stop [ʔ] in the context of the [a'ka] but not with [i'ki] or [u'ku]. She alternated between elevation of the tongue dorsum in a gesture that was consistent with a silent [k] and tongue blade elevation indicating a silent [t]. Even if a gesture is inaudible, it is important for speech therapy to understand what covert gestures a child is producing so that correct gestures can be rewarded and incorrect gestures can be discouraged. Ultrasound imaging of the tongue can therefore double as a tool for biofeedback in articulation therapy (Bernhardt, Gick, Bacsfalvi & Adler-Bock, 2005).

The present study was explorative and qualitative in nature. It drew on data from a small set of speakers, and its findings cannot be generalized. It will be interesting to expand our data analysis to more patients and different speech sounds in future research. However, even with only five speakers recruited through convenience sampling, we already found considerable variability between individuals. As argued by Code & Ball (1984), the instrumental analysis of speech is a useful adjunct that can help us identify the speakers' compensatory strategies. The careful analysis of the ultrasound images point to the subphonemic aspects of disordered speech production that are difficult to accommodate in current phonological theory. This underlines the importance of the effort by Ball et al. (2010) to develop the outline of a new theory of clinical phonology that is grounded in evidence from instrumental phonetic data and that can inform the diagnostic and therapeutic procedures of speech-language pathology.

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Figure 1. Ultrasound images of Sandra's tongue during the production of [a'ka]. The patient produced the target as [a' ʔa]. Note the accompanying silent elevation of the tongue dorsum (a) and the tongue blade (b).

Figure 2. Ultrasound images of Steve's tongue during the production of the target [a'ka], realized as [a' ʔ ʔa]. The tongue shape for the vowel (a) and the excursion of the base of the tongue towards the posterior pharyngeal wall are shown (b).