Stop-consonant production by dysarthric speakers:
Use of models to interpret acoustic data

Kelly L. Poort

Department of Electrical Engineering and Computer Science, Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

Abstract: Acoustic measurements have been made on stop consonants produced by several normal and dysarthric speakers. Various aspects of production following release of the oral closure were quantified through the use of acoustic measures such as spectra and durations of noise bursts and aspiration noise, as well as shifts in frequencies of spectral prominences. Through comparison of these measurements from the normal and dysarthric speech, and based upon models of stop-consonant production, inferences were drawn regarding articulator placement, rate of articulator release, tongue-body movements, and vocal-fold state. The dysarthric speakers deviated from normals particularly with respect to alveolar constriction location, rate of release, and tongue-body movement into the following vowel.

INTRODUCTION

This study investigates how speakers with dysarthria produce stop consonants in ways that are different from speakers with no known speech or hearing difficulties. The production differences between normal and dysarthric speakers are assessed through the use of a combination of acoustic analysis, perceptual analysis and models of normal stop-consonant production. The acoustic analysis, while quantitative wherever possible, is occasionally supplemented by qualitative analysis. This ongoing study is aimed at finding a set of acoustic measurements that characterize deviant stop production for dysarthric speakers possessing varying degrees of intelligibility. The set of acoustic measurements taken from dysarthric speakers is compared to the range of variation in the same set of acoustic measurements taken from normal speakers. With the aid of the models, the aspects of stop production performed incorrectly can then be determined for each of the dysarthric speakers.

MODELING

The production of an intervocalic stop consonant can be considered to consist of four consecutive phases (based on physiologic events): the onset of closure, when one articulator is approaching the other; the closure, when the articulators are held together, completely obstructing the airflow and creating a pressure buildup behind the constriction; the offset of closure, initiated by the rapid release of the articulator that formed the constriction; and the movement of the articulators (particularly the tongue body) toward configurations appropriate for the following vowel. The velopharyngeal port remains closed throughout intervocalic stop production. Depending upon the voicing characteristics of the particular stop consonant, various adjustments in the glottal opening, vocal-fold stiffness, and vocal-tract wall stiffness accompany the actions of the lips, tongue blade and/or tongue body. Theoretical models exist to describe events occurring during stop-consonant production. A low-frequency model accounts for vocal-tract pressures and airflows generated by the relatively slow-moving articulators (1-4). High-frequency models account for the sound source generation, the filtering of the vocal tract and the resultant acoustics produced (5-6).

MEASUREMENTS AND RESULTS

A database containing utterances from dysarthric and normal speakers has previously been recorded by H. P. Chang and H. Chen at M.I.T. This database consists of recordings of the Kent et al. 70-word list (7) for eight normal (4 M, 4 F) and eight dysarthric (4 M, 4 F) speakers. Eleven repetitions of the 70-word list were recorded by the dysarthric speakers and five repetitions of the list were recorded by the normal speakers. The word intelligibility of the dysarthric speakers varies from 23 – 98% (8). From the 70-word list, this study focuses on the aspects of stop production following release of the oral closure in the initial stop of the 13 words containing initial stops and the three words containing initial stop clusters.
Acoustic analysis of these stops examined aspects of production such as the duration and spectra of frication noise bursts and aspiration noise, and shifts in frequencies of spectral prominences. Many of the model parameters can be derived from these types of acoustic measurements. Through comparison of these acoustic measures from the normal and dysarthric speech, and based upon the stop production models, inferences can be drawn regarding articulator placement (by examining burst spectra), rate of articulator release (from burst duration), tongue-body movements (from formant transitions), and vocal-fold state (from low-frequency spectra). The dysarthric speakers deviated from normal speakers particularly with respect to alveolar constriction location, rate of release, and tongue-body movement into the following vowel.

As an example, articulator placement for alveolar stop production is considered in further detail. For this type of stop, the constriction is formed by placement of the tongue tip against the alveolar ridge. The shape of the vocal tract anterior to the constriction can be modeled as a tube, closed at the end near the constriction and open at the lips. During the time period immediately following release, when the constriction is still quite narrow, noise is generated at the constriction. This noise source excites the resonances of the front cavity. The lowest front-cavity resonance is equal to $c/4L$, where $c = 354 \text{ m/s}$ and $L = \text{length of the front cavity}$. The spectra shown in Figures 1 and 2 were calculated by averaging across spectra spaced 1 ms apart for the first 5 ms following the release of /d/ in dug. The lowest front-cavity resonance in the burst spectrum for the normal speaker (Figure 1) is 4300 Hz, yielding a front cavity length of 2.1 cm. For the normal speakers in this study, the range of lowest front-cavity resonances is approximately 3500-5500 Hz, corresponding to front cavity lengths of 1.5-2.5 cm. The lowest front-cavity resonance in the burst spectrum for the dysarthric speaker (Figure 2) is 2800 Hz, yielding a front cavity length of 3.2 cm. For three of the eight dysarthric speakers, the range of lowest front-cavity resonances is shifted downward to 1500-2800 Hz, corresponding to front cavity lengths of 3.2-5.9 cm. These long front-cavity lengths indicate that the articulator placement more closely resembles that of a velar stop, either through placement of the tongue tip further back on the palate or via formation of the constriction with the tongue body rather than the tongue tip.

![FIGURE 1. Averaged burst spectrum of /d/ in dug for one normal speaker.](image1)

![FIGURE 2. Averaged burst spectrum of /d/ in dug for one dysarthric speaker.](image2)

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REFERENCES

1. Rothenberg, M., Biblotheca Phonetica No. 6 (1968).

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