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Segmental Aspects in the Speech of the Hearing Impaired

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This article is to summarize some of the search findings on the speech characteristics of hearing-impaired speakers. This will present information on the articulatory or segmental aspects of hearing-impaired speakers. We indicated some of the points in this article. Segmental errors, as determined by phonetic transcriptions of hearing-impaired persons' speech, can be classified by the following four categories. 1) segmentation problem 2) nasalization 3) vowel errors: neutralization, diphthongization 4) consonant errors: omission, voicing errors, substitutions.

Key word: hearing impaired segmental formant nasalization neutralization

Introduction

For many years it was believed that profoundly hearing-impaired speakers were incapable of learning to talk. Within the last decade, advances have been made in studying the speech of the hearing and analysis techniques in speech science that have increased our knowledge of normal speech production. In turn, these technological advances have been applied to the analysis of the speech of the hearing impaired.

Research on the characteristics of the speech of hearing-impaired speakers is reviewed with regard to segmental aspects. Segmental aspects are how individual speech segments are produced. This article is to summarize some of the search findings on the speech characteristics of hearing-impaired speakers. This will present information on the articulatory or segmental aspects of hearing-impaired speakers. We will consider the error patterns detailed in the descriptive literature and discuss the acoustic data for production of consonants and vowels by hearing-impaired speakers.

Segmental Aspects

Segmentation Problem

The temporal discreteness of the words phrases and sentences is not obvious. There are no visually boundaries that separate one segment from another. An important concept is that phonetic units represent the achievement of a sequence of target configurations or states of the articulatory structures.

The articulators are moving between states during most of the time in an utterance. The listener sifts the incoming acoustic information auditorily and parameterizes the contents of the message. Short pauses in the output are identified with specific phonetic features such

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as the variable voice onset time between the burst of noise and the beginning of the laryngeal tone in utterance of stop consonants. Longer pauses serve to demarcate boundaries between phrases and sentences and to identify breaks in the train of speaking (Kato et al., 1987c). Problems of segmentation are particularly important to the speaker with severely impaired hearing (Yoshino, 1985, 1987; Kato et al., 1987b).

Nasalization

Nasalization has been described as quality problem because improper velar control can give the speech a characteristic sound. In addition to affecting quality, however, poor control of the velum can also lead to articulatory problems. The velum or soft palate function as a gate between the oral and nasal cavities. It is lowered to open the passage to the nasal pharynx when a sound such as one of the nasal consonants is made, which requires that the air be emitted through the nose. Improper control of the velum has been recognized as a source of difficulty in the speech of the hearing-impaired. Erratic valving of the oral-nasal portal is evidenced by both excessive nasality in vowels and nonnasal consonats (Fletcher and Daly, 1976) and insufficient nasality on nasal consonants.

Deviant nasalization characteristics in the speech of hearing-impaired speakers can be the result of improper posture of his velopharyngeal structures (Stevens et al., 1976). The normal starting posture for speech production is a closed velopharyngeal port. For many hearing-impaired speakers, however, the velum remains lowered much of the time, with the result that many vowels are improperly nasalized. Learning velar control is difficult for a hearing-impaired child for two reasons: (1) raising and lowering the velum is not a visible gesture and is therefore not detectable by lipreading, (2) the activity of the velum produces very little proprioceptive feedback (Nickerson, 1975).

Vowel Errors

The acoustic characteristics of vowels have been studied in great detail in normal speech production, but little in speech of the hearing impaired. We will concentrate here on studies of vowel formnats. There have been several studies that have examined the acoustic characteristics of vowels produced by hearing-impaired speakers using spectrographic analysis (Angelocci et al., 1964) and study in which the speech was digitized and subjected to Linear Predictive Coding (LPC) analysis (Kato, 1987a).

The most important acoustic characteristic of vowel sounds is the frequency of the first and second formants (Peterson and Barney, 1952). However, individual vowels are not identifiable with absolute frequency values for the first and second formants, because they are dependent on the size of the speaker's vocal tract and thus must vary depending on the speaker's age and sex. The formants of children are higher than those of adults, and those of female adults are higher than those of male adults. The frequency of either the first or second formant does not depend on any single articulatory gesture, it is, in general, true that the frequency of the first formant rises as the mouth becomes more open and that the frequency of the second formant rises as the tongue is more forward and higher.

The formant frequencies, especially the second formant, provide much information needed to be distinguished among different voiced speech sounds, one might guess that the speech of the hearing-impaired would tend to show some deficiencies in this respect. Boone (1966) found that the second formant frequency tended to be lower for hearing-impaired than for hearing children, a fact which he attributed to the tongue being held too far back toward the pharyngeal wall.

Back vowels are produced correctly more

often than the front ones (Nober, 1967). This supports Boone's (1966) theory that the hearing-impaired have different resonance patterns because they tend to keep their tongues too far back and too low in their mouths. Monsen and Shaughnessy (1978) noted that the first formants of their vowels were in the same range as those of normal-hearing children, but their production of second formants was far less accurate. They suggested that since the frequency of the first formant is particularly dependent on the degree of mouth opening which is quite visible, while the frequency of the second formant is more dependent on tongue place which is less visible. For some hearing-impaired speakers, the tongue-body position is relatively immobile as far as front-back movement during speech production is concerned, with the result that there is a rather narrow range of variation of the frequency of the second formant (Monsen, 1976b; Kato, 1987a).

Vowel formants are clustered in a mid-formant frequency region (Angelocci et al., 1964), suggesting that the tongue sifts little from a neutral position in the mouth as diffrent vowels are spoken by deaf individuals. Second formant transitions from consonants to vowels are also reduced in both range and duration in utterances of deaf speakers (Monsen, 1976c).

The stability of profoundly deaf persons' vowel articulation varies, depending on the phonemic environment; this may be because the mobility of their tongues is insufficient. Katamura et al. (1987) examined the stability of vowel articulation for the final vowel in a vowel-consonant-vowel (VCV) structure. All the profoundly deaf subjects showed considerable intra- and inter-individual variability on final-vowel articulation.

Neutralization In the speech of the normal hearing, there is usually some amount of overlap in the formant frequencies of adjacent vowels. But for the hearing-impaired speakers, the amount of overlap is typically much greater, while the range of the frequencies of both the first and the second formant is less (Angelocci et al., 1964; Monsen, 1976b) Hearing-impaired speakers often neutralise vowels. According to Monsen and Shaughnessy (1978) this is mainly due to insufficient variation in the second formant. Angelocci, Kopp, and Holbrook (1964) studied spectrographs made by eighteen males reading CVC words. Fundamental frequency and formants were analyzed. Results showed that the ranges of frequency and amplitude for the first 3 vowel formants for the hearing-impaired subjects were smaller than for the normal subjects of the same age. A plot of the frequency of the first formant against the second formant showed a high degree of overlap among the vowels produced by the hearing-impaired speakers. Also, the first and second formant values for each vowel tended toward neutral vowels.

Kato (1987a) investigated dynamics of the vowel formants. A spectographic investigation was carried out on the speech of normal hearing and hearing-impaired speakers. Recordings were made of each subject. A microphone (SONY ECM290F) was placed about 0.2 meter from the subjects' mouth, and recordings were made in a quiet room. Spectral analysis of the collected data was made on the Sound spectrograph (RION SG-07). A narrow-band section was made in the steady-state portion of the vowel as near as possible to the middle of each vowel. The formant frequencies were then estimated by examination of the spectral peaks. The same speech samples were analyzed to extract such acoustic parameter as formant frequencies based on LPC analysis.

The results indicated that the transitions of hearing-impaired speakers had a restricted range and slower rate of movement than did those of the normal speakers. Furthermore, the speech of the hearing-impaired showed that the vowel formants tended to be neutralized. The consequence of the restricted range of formant frequencies in the speech of the hearing-impaired was that vowels would tend to be heard incorrectly, and in the extreme case of restricted mobility of the formants, all vowels would tend to be perceived as a neutral, indistinct schwa. The articulatory sources of restricted formant frequency movement were an insufficient and inappropriate positioning of the tongue. The vowel formants of hearing-impaired speakers tended to be flat showing little movement. The movements of the formant peaks in normal-hearing speakers showed dynamics. In the hearing impaired, the degree of the dynamics were lower than the normal speakers. Characteristics of the hearing-impaired speaker was dependent upon dynamic factors of speech. Such finding suggests articulatory stereotyping in the hearing-impaired group (Kato, 1987a).

Diphthongization Diphthong errors in the hearing-impaired have been reported to be prolongation of both phoneme parts, elimination of the second element, omission of the first element or substitution of the neutral schwa for the intended diphthong. The hearing-impaired do not move their articulators correctly in proceeding from one phoneme to the next (Angelocci, 1962; Calvert, 1962; John and Howarth, 1965; Brannon, 1966; Stevens et al., 1976). Calvert (1962) noted that in normal speech transitions were clearly visible on Sonograms, occuring rapidly and were inaudible.

Consonant Errors

Researchers have found that consonants were more often in error than vowels. Both Brannon (1966) and Markides (1970) found more consonant than vowel errors. Markides' hard-of-hearing subjects produced 9% error for vowels and 26% error for consonants, while his hearing-impaired group had 56% error for vowels and 72% error for consonants. Brannon claimed that vowels were actually produced correctly more often than consonants since vowels carried more energy, were easier to hear, and required less difficult tongue adjustments than consonants. Consonant errors has been replicated in numerous studies (Brannon, 1966; Geffner, 1980; Levitt, Smith, and Stromberg, 1976; Markides, 1970; Smith, 1975) although the actual percentage of errors in any category may vary somewhat from study to study. Consonantal errors fell into the categories of omission of word-initial or word-final consonants, voicing errors, substitution of one consonant for another.

Omissions Several researchers (Markides, 1970; McGarr and Osberger, 1978) had reported that omission of the intended consonant were a frequent error type in the speech of the hearing-impaired. Consonants with their place of articulation in the centre or back of the mouth were more frequently omitted than labial, dental or alveolar consonants. Omission of consonants may occur in the initial and/or final position of words, also reported as nonfunction of releasing or arresting consonants, respectively.

Voicing errors Failure to distinguish between voiced and voiceless consonants was a problem (Calvert, 1962; Mangan, 1961). This problem was the voicing error in which intended voiced plosives were perceived as voiceless plosives, or its reverse. Calvert (1962) measured the durations of closure and release periods of consonants and found that when a plosive was intended to be unvoiced but heard as voiced. Mangan (1961) had both exprienced and inexperienced listeners evaluate the speech production ability of 21 hearing-impaired and 9 hard-of-hearing children reading a list of familiar phonetically balanced words. A common error often mentioned was the devoicing of final voiced consonants. Nober (1967) studied 46 hard-of-hearing and hearing-impaired children. He reported that intended voiceless sounds were more often produced correctly than intended voiced sounds. Contrary to those findings, voicing errors were found to be very numerous in this hearing -impaired population. Carr (1953) reported the tendency for young hearing-impaired children to produce more voiced sounds than voiceless ones in spontaneous speech.

The phonemic distinction between the voiced and voiceless stop consonants can be measured effectively by voice onset time (Lisker and Abramson, 1964). For the voiceless consonants, the onset of voicing must be delayed (typically between 50 to 100msec) after the release of occlusion in the oral cavity, while aspiration is produced during this delay. For the voiced stops, voicing may either precede or be simultaneous with the burst and the release of occlusion. In a study of the English stop consonants produced by the hearing-impaired (Monsen, 1976a), it was shown that stop consonant errors are not random errors tending instead toward one of several systematically deviant phonological patterns (Lisker and Abramson, 1964; Wintz, Lariviere, and Herriman, 1975).

Substitutions Articulatory problems of a variety of types have been identified. Substitution of one sound for another is all articulatory difficulties encountered in the speech of hearing -impaired speakers. The important category consists of consonant substitutions. Especially voiced plosives and fricatives are often replaced by their voiceless cognate (Markides, 1970; Nober, 1967; McGarr and Osberger, 1978). Monsen (1976a, 1978) found that these confusions were mainly due to temporal distortions.

The substitution is to a phoneme with a similar place of articulation. There is general agreement that phonemes produced in the front of the mouth are more often produced correctly than are phonemes produced in the back of the mouth. This makes sense when one considers that the relative visibility of articulatory gestures should be important to hearing -impaired persons for whom there is reduced auditory information. Substitutions involving the same place of articulation have been noted in several studies. Nober (1967) analyzed correctly articulated consonants according to place of articulation and then ranked them from highest to lowest scores as follows: bilabials, 59%; labiodentals, 48%; glottals, 34%; linguadentals, 32%; lingua-alveolars, 23%; linguapalatals, 18%; and linguavelars, 12%. This general trend has been found not only for production of isolated words and sentences (Levitt, Stromberg, Smith, and Gold, 1980; Smith, 1975) but also for spontaneous speech (Carr, 1953; Geffner, 1980). A common obsevation arises from an analysis of consonant errors according to place of articulation. The type of consonant substitution is often described as one resulting from incorrect timing. These errors are described as involving an inappropriate manner of articulation.

Conclusions

In this article we have found a variety of explanations for the fact that speech of the hearing impaired is likely to be fundamentally different from that of individuals with normal hearing. In the hearing impaired these representations were likely dominated by visual sensations. This contrasts with the dominance of auditory sensations in speech of the normal hearing.

The use of modern instrumentation in the analysis of the speech of the hearing impaired is strongly encouraged. Instrumental methods are particularly good for measuring many of the segmental aspects of speech. The acoustic measurements are also useful because they can suggest how improvement may be achieved. Successful planning of communication training for the hearing-impaired required appropriate procedures to assess the individual as a person.

We were to summarize some of the points in this article. Segmental errors, as determined by phonetic transcriptions of hearing-impaired persons' speech, could be classified by the following four categories. 1) segmentation problem 2) nasalization 3) vowel errors: neutralization, diphthongization 4) consonant errors: omission, voicing errors, substitutions.

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