DYSARTHRIC SPEECH IN CEREBRAL PALSY. A HORNET'S NEST OF ACOUSTIC AND ELECTROMYOGRAPHIC DATA

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ABSTRACT - Speech waveforms were recorded simultaneously with electromyographic (EMG) signals from fourteen articulator muscles in cerebral palsied and normal subjects during a test sentence of continuous speech. This experiment has led to two parallel investigations of cerebral palsied and normal speech, using acoustic features for one study, and EMG activity of the articulator muscles for the other. Abnormal features found to be characteristic of cerebral palsied speech are reported here for both investigations, and related to articulatory dysfunction in dysarthria of cerebral palsy.

INTRODUCTION

Dysarthria in cerebral palsy is a speech defect which results from abnormal control of muscles associated with the speech mechanism. The condition of cerebral palsy embraces a collective set of disorders of the body's motor functions - non-progressive disorders which have been caused by damage to the central nervous system either before, during or shortly after birth. The motor disorders associated with cerebral palsy can affect the function of muscles associated with the speech mechanism just as they affect limb muscles. The production of speech involves the interrelationship of respiratory, laryngeal, pharyngeal, velar and articulatory musculature, and any of these areas may be affected in cerebral palsy.

The study presented in this paper has concentrated specifically on articulatory muscle function and the associated acoustic signal during continuous speech. To this end, acoustic waveforms and simultaneous EMG signals from up to fourteen articulatory muscles were recorded from both normal and cerebral palsied subjects to enable a comparative analysis of muscle function and acoustic characteristics of the groups to be made. The eventual aim of the study is to discover if a relationship can be found between acoustic characteristics (such as formant trajectories) of the speech waveform and the corresponding EMG activity of the muscles, thus creating the possibility of a dynamic articulatory-acoustic map.

To date, the EMG and acoustic data have been analyzed independently, in both cases making a comparison of the normal and cerebral palsied data. Preliminary comparisons of the two sets of results appear to show consistency of interpretation in at least two of the abnormalities found in the acoustic and EMG signals of the cerebral palsied speakers.

EXPERIMENTAL METHOD

Subjects

The subjects used in the study were seven young adult cerebral palsied subjects, aged 19-34 years, and six young adult normal subjects, aged 20-30 years. Neurological examination of the cerebral palsied subjects revealed a range of types of cerebral palsy, with five subjects being predominantly athetoid, and two predominantly spastic. All had dysarthric speech which was either of very limited intelligibility or unintelligible, and this lack of intelligibility was assessed as being caused primarily by dysfunction of the articulatory muscles.

Procedure

EMG signals from 14 articulator muscles were simultaneously recorded, along with the acoustic signal, onto a 14-channel FM tape recorder with a specially adapted audio channel. The EMG signals were detected via bipolar hooked-wire electrodes which were inserted into 14 muscles of the lips, tongue and jaw. Details of the muscles sampled, the method of insertion, verification of the electrode position, and calibration of the EMG signal for maximal contraction are described by O'Dwyer et al.(1981).

A variety of speech samples were recorded from each subject, including single words, short phrases, and a test sentence. Fifty repetitions of the sentence "Do all the old rogues abjure weird ladies?" were recorded. This sentence was composed to mimic conversational speech and to elicit large ranges of articulator movements (van Doorn, 1982), in order to emphasize any abnormalities of speech in the cerebral palsied subjects.

Acoustic signal processing

The recorded speech waveform from the test sentence was low-pass filtered at 5 kHz, digitized at a rate of 10 kHz, and stored on computer disc files for each subject. This digitized signal was used primarily to establish time trajectories of the first three formants during the test sentence, and secondarily to derive manually the fundamental frequency contours, intensity contours, speech rates, and syllable durations. The formant trajectories were derived from the sequence of short-time linear prediction spectra (Markel and Gray, 1976). Details of the particular features of the linear prediction analysis for this study are given in van Doorn (1982). Briefly, the digitized signal was pre-emphasized with a difference filter, divided into 10 ms rectangular frames, and analyzed using the autocorrelation method of linear prediction with a 12-pole filter. The filter coefficients were then used to calculate the spectral envelope of the short-time spectrum for each 10 ms frame of the speech data, and the first three formants were found from these spectral envelopes by using a peak picking technique.

Using this processed acoustic data, a comparison of normal and cerebral palsied speech was made, predominantly on the basis of the formant trajectories for the first three formants, and to a lesser extent using the fundamental frequency and intensity contours, speech rates and syllable durations. The comparison of the trajectories for the first three formants was made with particular reference to their transitional features associated with articulatory movements during continuous speech. The features examined were (1) formant patterns during transitions, (2) durations of the transitions, (3) frequency range of the transitions, and (4) maximum rate of change of formant frequencies during transitions.

EMG signal processing

The recorded EMG signals were full-wave rectified and smoothed using a filter system which produced an optimal compromise between smoothing the rectified signal and reproducing any rapid changes in muscle activity. Details of the filters used can be found in Neilson and O'Dwyer(1981);(1984). The smoothed rectified EMG signals were digitized at a rate of 100 Hz

and stored on computer files for comparison between normal and cerebral palsied speakers of the following features:
(1) reproducibility of EMG activity during each syllable of the test sentence
(2) bandwidths of the EMG signals.

RESULTS

The differences found between the acoustic features of normal and cerebral palsied speech can be summarized as follows:
In cerebral palsy the fundamental frequency contours and the intensity contours showed inappropriate exaggerated fluctuations, the speech rates were reduced, and the syllable durations were prolonged. The transitions in the formant trajectories were found to contain some anomalous features in cerebral palsy, viz. (1) inappropiate transition patterns, (2) reduced frequency excursions during transitions, (3) increased transition durations, and (4) decreased maximum rates of frequency change during transitions. These anomalous features can be seen on inspection of Figure 1, which also demonstrates the reduced speech rate and prolonged syllable durations.

An important observation made during the investigation of the formant trajectories was that the abnormal features of the trajectories for any one cerebral palsied subject appeared to be reproducible across the repetitions of the test sentence. This observation is borne out in Figure 1. This apparent reproducibility of the formant trajectories has not yet been investigated on a rigorous statistical basis. The EMG signal patterns recorded simultaneously with the speech signal, however, have been analyzed statistically to establish a measure of their reproducibility (Neilson and O'Dwyer, 1984). This analysis revealed that the reproducibility of the EMG signals over 20 repetitions of the test sentence was statistically similar for the normal and cerebral palsied speakers. Such reproducibility is illustrated for a cerebral palsied subject in Figure 2. It is expected that the proposed study of the reproducibility of the formant trajectories during cerebral palsied speech will reveal similar results.

Analysis of the reproducible patterns of EMG activity revealed gross abnormalities in the cerebral palsied subjects (O'Dwyer and Neilson, 1986). For example, large magnitudes of muscle activity, evident in Figure 2, were significantly greater than normal. Moreover, the temporospatial patterns of muscle activity in the cerebral palsied subjects differed significantly from normal. Furthermore, while they showed no limitation in velocity of muscle activation, the cerebral palsied subjects had a significantly reduced frequency bandwidth in their EMG signals.

DISCUSSION

The acoustic features of cerebral palsied speech investigated in this study were chosen because there is some evidence (see van Doorn, 1982; 1983 for details) that each feature is related in a complex way to the physiological mechanisms associated with speech production. Hence, abnormalities in the acoustic features would reflect certain abnormalities in the speech mechanism and the findings from this study have been interpreted in terms of possible underlying physiological function.

The inappropriate fluctuations in the fundamental frequency and intensity contours of cerebral palsied speech could be interpreted as an indication of lack of control of laryngeal and/or respiratory musculature.

With regard to the formant trajectories, the duration of the transitions in these trajectories would appear to be a reflection of the time taken for the articulators to move from one position to another. On this basis, the longer transition times found in cerebral palsied speech could be linked to slow articulatory movements during continuous speech. The frequency range of the formant transitions can be interpreted in terms of the range of tongue movement (in both inferior-superior and anterior-posterior dimensions). Thus, it would be possible to relate the reduced frequency range of the formant transitions found in cerebral palsied speech to a reduced range of tongue movement, particularly in the anterior-posterior direction. The maximum rate of formant frequency change during a transition appears to be a complex indication of the relative velocity of articulator movements. Thus, the reduced rate of formant frequency change found in cerebral palsied speech would appear to indicate a reduced rate of articulator movements. Consistent with this interpretation is the reduced bandwidth of EMG activity in the cerebral palsied subjects, which indicates that the bandwidth of their articulator movements almost certainly is also reduced.

The pattern of the formants in the formant trajectories appears to be an indicator of the interrelated movements of the articulators from one position to the next. Hence, the abnormal formant patterns found in cerebral palsied speech could be considered as manifestations of incorrect articulatory movements and placements. This is consistent with the abnormal temporospatial patterns of their EMG activity. The reproducibility of the abnormal formant trajectories and EMG patterns implies that these signals are under voluntary control despite transient disruptions by involuntary activity (see Figure 2). This finding contradicts traditional views of dysarthria in cerebral palsy which postulate such factors as involuntary movements and primitive reflexes as primary causes of the movement disability. The reproducible patterns of the acoustic and EMG signals support the proposal (see Neilson and O'Dwyer, 1981; 1984 for details) that, consequent to disruption of brain mechanisms subserving motor learning, cerebral palsied subjects are unable to formulate appropriate voluntary motor commands to muscles.

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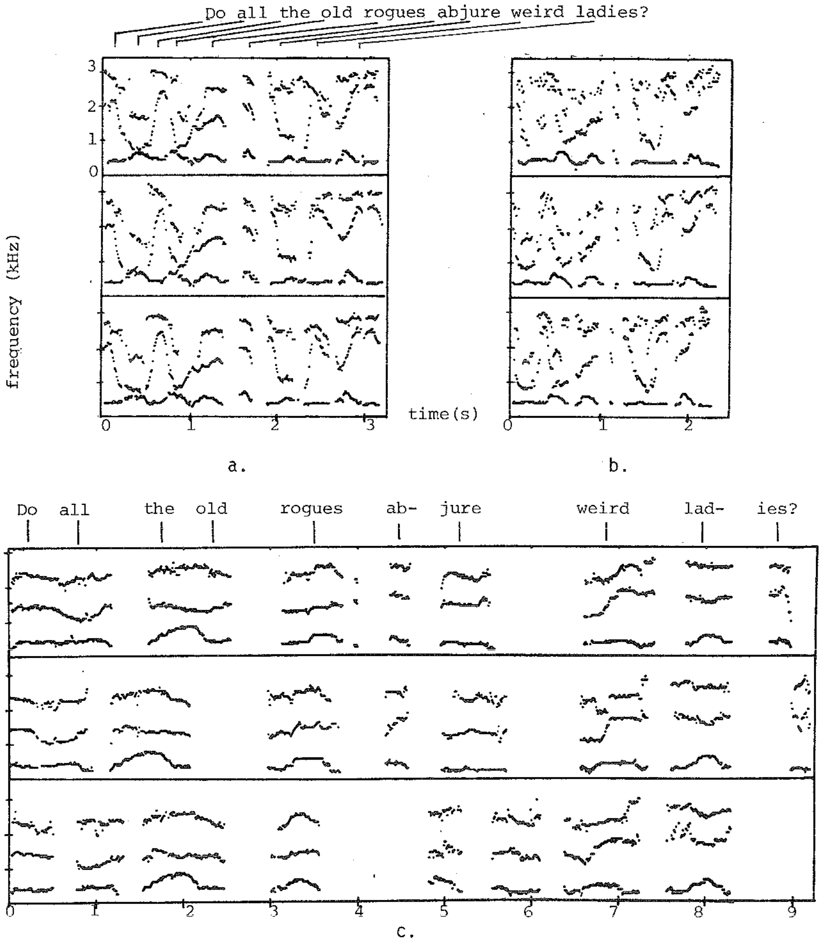

Figure 1. Digitized formant trajectories of the first three formants for the test sentence 'Do all the old rogues abjure weird ladies?' for two normal subjects(a,b) and one cerebral palsied subject (c). Three repetitions of the sentence are included for each subject.

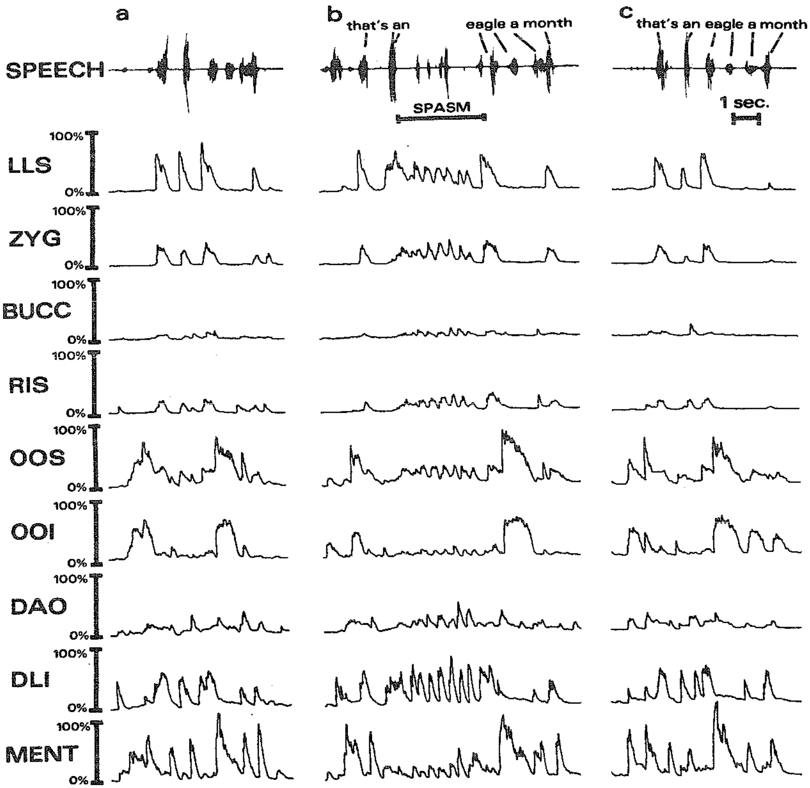

Figure 2. Smoothed EMG signals from nine lip muscles in a cerebral palsied subject during three repetitions of the phrase "that's an eagle a month". The EMG patterns associated with each syllable in the phrase are similar for each repetition. In (b) a spasm occurs in all lip muscles which halts speech output between "an" and "eagle". Following the spasm, speech continues with the same EMG pattern for "eagle" as in (a) and (c). Vertical calibration bars indicate 0% to 100% of maximal voluntary contraction for each muscle. For description of muscles, see O'Dwyer et al. (1981).