FORMANT LOCUS EQUATIONS AND COARTICULATION IN DYSPRAXIC SPEECH

C.Chinnery, G. J. Docherty and D. Walshaw
Department of Speech, University of Newcastle upon Tyne .

ABSTRACT

Calculations of formant locus equations in the production of CV sequences were used to investigate the hypothesis that syllables produced by dyspraxic speakers could be characterised as being less coarticulated than those produced by normal speakers. The results give indications that some dyspraxic subjects can be described as having less coarticulatory cohesion between a consonant and a following vowel.

INTRODUCTION

Speech dyspraxia is an impairment in the volitional control and coordination of the muscles used in speech production. Speakers with dyspraxic speech typically have great difficulty in articulating words, even though they know exactly what they want to say. Their speech is characteristically dysfluent, marked by struggle behaviour and many false starts. It has been hypothesised that one of the central problems faced by dyspraxic speakers is precisely in the area of coarticulation. The evidence for this, however, is rather limited and is inconsistent. Ziegler & von Cramon [1, 2] report the case of a single apraxic speaker whose speech was marked by a delay in onset of anticipatory coarticulatory gestures resulting in a 'loss of segmental cohesion'. Itoh et al [3] note the presence of anticipatory coarticulation in their single apraxic subject, but note some deviations between their speaker and the pattern found for normal speakers. On the other hand, Katz [4] found no differences in coarticulatory patterns across normal speakers and those with posterior and anterior aphasia (with the anterior group being considered to be equivalent to those labelled in other studies as dyspraxic).

This paper reports a study which has investigated the hypothesis that dyspraxic speech is 'less-coarticulated' than normal speech; i.e. that speech sounds in dyspraxic speech production are produced in more discrete fashion than is found in normal speakers.

In order to measure the degree of coarticulation present in dyspraxic speech, formant locus equations have been employed. The application of locus equations to measurements of F2 was first described by Lindblom [5]. In calculating the equation, a straight line regression function is fitted to a scatter plot of F2 measured at vowel onset (F2ONSET) on the y-axis and F2 measured at the vowel midpoint (F2MID) on the x-axis. The relationship between these two quantities can be captured by the following equation,

$$F2ONSET = k * F2MID + c$$

where k is a coefficient relating to the slope of the regression line, and c is the estimated y-intercept. Sussman [6] has reported the existence of strongly linear relationships between F2ONSET and F2MID across different manners of consonant articulation. Different slopes and y-intercepts are found to correspond to different places of consonant articulation. For /g/ in English it is necessary to calculate three equations corresponding to cases with a following front, back unrounded, and back rounded vowels [6].

It has been noted [7] that locus equations can also be used as an index of CV coarticulation. A flat slope would indicate that F2 onset varies little as a function of different vowel environments suggesting relatively low articulatory cohesion between the C and the following V. Steeper slopes indicate that F2ONSET is increasingly coming under the influence of the F2MID value, indicating greater coarticulatory cohesion. In the context of the present study of dyspraxic speech, two questions arise: do dyspraxic speakers show linear relations between F2ONSET and F2MID similar to those found in normal speakers, and if so, do the slopes indicate any less articulatory cohesion than is present in normal speakers?

METHOD

Subjects

Two groups of subjects were recruited for the study; 5 dyspraxic speakers (D1 - D5) diagnosed as having verbal dyspraxia of speech, and 4 normal control speakers (N1 - N4). All subjects were native speakers of English from the North-East of England. Criteria for dyspraxic subject selection were: (a) they should be native speakers of English; (b) they should be diagnosed as having verbal dyspraxia by the speech & language therapist responsible for their case; (c) subjects should have reasonable comprehension abilities (sufficient to understand the elicitation task described below) (d) subjects should be able to read aloud real and nonsense words, or to repeat words without the aid of a visual cue. All subjects had suffered a stroke resulting in non-fluent aphasia and verbal dyspraxia to varying degrees of severity. Four normal control subjects were recruited broadly matched for age and sex with the dyspraxic subjects.

Materials

Subjects were asked to read a list of real and nonsense words with the structure C-V-/t/ formed by all possible combinations of /b,d,g/ and /i, ɪ, ɛ, a, ʌ, ɒ, ɔ, ʊ, u/ Each set of nine words was repeated six times by each subject giving a maximum of 162 single word utterances per subject. The CVC words were presented to both sets of subjects orthographically stencilled onto cards. The presentation of the cards was randomised. No data has been obtained relating to subject D3's production of words with an initial /g/, since this subject systematically produced these words with an initial /d/ (these tokens have not formed part of the analysis presented below).

Recordings and Measurements

Recordings were made in a recording studio or in a quiet room at the patient's home using a SONY Pro-Walkman D6 tape-recorder. The recordings were subsequently digitised at a sampling rate of 10Khz and analysed using a KAY Elemetrics Computer Speech Lab.

In line with [6, 8], formant measurement were carried out using two procedures (i) manual positioning of a cursor in a wide-band spectrographic representation; (b) LPC analysis of the same data, using the CSL's 'LPC formant history' routine. The average value of the two formant measurements for each vowel was taken and used in the subsequent statistical analysis.

For each word, two F2 formant measurement points were taken. (i) the value of F2 at the first identifiable glottal pulse following the release burst of the initial stop, as indicated by the first vertical striation (F2ONSET); (ii) the value of F2 at the mid-point of the vowel (the half-way point between the first and final vertical striations for the vowel (F2MID). Following [6, 8] the criteria listed were below were used to identify the measurement point for F2MID; (a) if the formant resonance was relatively 'steady state' a mid-point value of the steady-state portion was taken; (b) if the F2 resonance was diagonally rising or falling, a visually-determined mid-point was chosen; (c) if the pattern was either 'U-shaped' a measurement was taken at the point at which the curve changed direction (i.e. at the maximum or minimum frequency respectively).

RESULTS

Table 1 shows the principal locus equation parameters calculated for /b/, /d/, /g/ with a following front unrounded vowel and /g/ with a following back rounded vowel, for each of the speakers investigated. In almost every case (exceptions are discussed below) there is a strongly significant linear relationship between F2ONSET and F2MID ($p < .001$). We now consider, in turn the results from the normal and dyspraxic speakers.

Control Speakers

For normal speakers, significantly steeper slopes are found for /b/ than for /d/. For /g/, the results are less stable, but, on the whole, /g/ in the context of a back rounded vowel produces a steeper slope than /g/ in the context of a front unrounded vowel. Consistently lower y-intercepts are found for /b/ than for /d/, whilst with /g/ there is a difference depending on the following vowel environment with a lower y-intercept being found when a back rounded vowel follows. These results are entirely in line with those previously reported for normal speakers of English [6, 8]. The

Table 1. Parameters (slope, y-intercept) and R-squared) for the formant locus equations for dyspraxic (D1 - D5) and normal control subjects (N1 - N4).

Subj	Slope (s.d)	Y-int (s.d.)	R-sq
/b/			
D1	0.607 (0.046)	485 (72)	77.2%
D2	0.891 (0.047)	98 (72)	90.7%
D3	0.924 (0.041)	52 (72)	92.4%
D4	0.612 (0.026)	680 (45)	91.8%
D5	0.849 (0.028)	214 (38)	95.6%
N1	0.682 (0.031)	394 (48)	90.8%
N2	0.634 (0.043)	519 (78)	82.2%
N3	0.745 (0.032)	358 (50)	92.0%
N4	0.761 (0.042)	210 (56)	87.4%
/d/			
D1	0.188 (0.079)	1688(130)	10.5%
D2	0.508 (0.058)	976 (91)	73.7%
D3	0.569 (0.049)	1088(100)	76.9%
D4	0.309 (0.034)	1620 (65)	66.7%
D5	0.345 (0.043)	1317 (66)	61.3%
N1	0.323 (0.034)	1183 (53)	63.0%
N2	0.313 (0.036)	1432 (67)	63.2%
N3	0.367 (0.035)	1216 (57)	69.3%
N4	0.498 (0.034)	827 (47)	81.4%
/g/ before front Vs			
D1	-0.086 (0.137)	2329(291)	0.0%
D2	0.577 (0.079)	1045(147)	75.6%
D3	+-+-+ no data available +-+-+		
D4	0.411 (0.072)	1623(169)	60.3%
D5	0.521 (0.058)	1127(106)	84.4%
N1	0.200 (0.099)	1727(191)	11.8%
N2	0.480 (0.137)	1293(311)	34.9%
N3	0.373 (0.066)	1406(131)	57.5%
N4	0.511 (0.145)	966(239)	34.2%
/g/ before back rounded Vs			
D1	1.640 (0.309)	-539 (72)	69.4%
D2	0.615 (0.058)	593 (330)	22.3%
D3	+-+-+ no data available +-+-+		
D4	1.130 (0.131)	262 (160)	72.3%
D5	0.650 (0.190)	776 (212)	31.7%
N1	1.138 (0.134)	286 (154)	72.6%
N2	0.884 (0.034)	509 (185)	59.6%
N3	0.313 (0.138)	404 (147)	72.1%
N4	0.802 (0.092)	531 (104)	72.6%

steeper slope for /b/ indicates a higher degree of articulatory cohesion between /b/ and a following vowel than between /d/ and a following vowel, as might be expected given the functional independence of the bilabial and dorsal articulatory systems. The only exception to the general picture just described is with Subject N1's results for /g/ in the context of a following front vowel. The linear relationship between F2ONSET and F2MID is only borderline significant ($p = 0.056$), and the low R-squared figure suggests that only a very low percentage of variation in F2 onset can be predicted by the linear relationship with F2 midpoint.

Dyspraxic speakers

With the dyspraxic speakers, too, the general finding is that there is a strong linear relationship between F2 onset and F2 midpoint. Like the normal speakers, they show steeper slopes for /b/ than for /d/. The slopes for /g/ show considerable variability but two speakers (D1 and D4) have slopes for /g/ before back rounded vowels which are significantly steeper than for /g/ before front unrounded vowels (although see further comments on D1 below). For subjects D2 and D5 the differences in slope for /g/ as a function of vowel environment are less evident. Overall, there is no evidence that the dyspraxic speakers' slopes are any flatter than those found for normal speakers, suggesting that all speakers are showing comparable degrees of coarticulatory cohesion. The y-intercept estimates for /b/ are lower than for /d/, whilst for /g/, differences in y-intercept are found as a function of the following vowel environment. This general pattern of a linear relationship between F2ONSET and F2MID is not found uniformly across the dyspraxic group however. The clearest departure from this general trend is found in Subject D1's /g/ productions in the context of a front unrounded vowel where no linear relationship whatsoever can be found between F2ONSET and F2MID. Other subjects show instances where, whilst there is a linear relationship, its strength is considerably less than typically found for the normal speakers; for example, /d/ for speaker D1, or /g/ in the context of back rounded vowels for speakers D2 and D5.

DISCUSSION

The results show that locus equations for the normal speakers investigated conform to those previously reported in the literature showing a significant linear relationship between the onset of F2 at vowel onset and the value of F2 at the vowel midpoint, with differences in slope and y-intercept being found as a function of the identity of the pre-vocalic consonant. For the dyspraxic speakers, similar significant linear relationships are found.

However, some dyspraxic speakers occasionally show significant deviation from this normal pattern indicating, in those cases, less coarticulatory cohesion between the consonant and the following vowel. The results therefore suggest that for at least some dyspraxic speakers (such as subject D1), dyspraxia can be partially manifested in abnormal patterns of consonant-vowel cohesion as reflected in formant locus equations. We must also conclude that this impaired cohesion need not be found across every syllable produced by that speaker since subject D1's /b/ locus equation parameters are entirely within normal limits. It is noteworthy that the same speaker shows a considerably less reliable (though still significant) linear relationship between F2ONSET and F2MID in the /d/ syllables. It seems that difficulties for this speaker arise when trying to coordinate consonant and vowel articulations which involve lingual articulations and particularly when they involve the same part of the tongue dorsum (as in /g/ followed by a back rounded vowel).

This small study is the first attempt to use formant locus equations to investigate articulatory cohesion in apraxia of speech. The fact that some differences have been observed between the dyspraxic and normal samples and also within the dyspraxic group suggests the need for a follow-up study with a larger number of subjects, and looking at a broader range of pre-vocalic consonants. It would be particularly interesting to investigate whether formant locus equations permit a sub-categorisation of dyspraxic speakers by virtue of the degree of articulatory coherence which they show, and whether any such sub-categorisation corresponds to any other aspects of the subjects' speech and/or oro-motor performance.

ACKNOWLEDGEMENTS

The first author would like to acknowledge support from the University of Newcastle upon Tyne Research Committee.

REFERENCES

[1] Ziegler, W. & von Cramon, D. (1985) Anticipatory coarticulation in a patient with apraxia of speech. *Brain & Language*, 26,117-130.

[2] Ziegler, W. & von Cramon, D. (1986) Disturbed coarticulation in apraxia of speech: acoustic evidence. *Brain & Language*, 29,34-47.

[3] Itoh, M., Sasanuma, S., & Ushijima, T. (1979) Velar movement during speech in a speaker with apraxia of speech. *Brain & Language*, 7, 227-240.

[4] Katz, W. (1988) Anticipatory coarticulation in aphasia: Some methodological considerations. *Brain & Language*, 35, 340-368.

[5] Lindblom, B. (1963) Spectrographic study of vowel reduction. *Journal of the Acoustical Society of America*, 35, 1773-1781.

[6] Sussman, H. et al (1991) An investigation of locus equations as a source of relational invariance for stop place categorisation. *Journal of the Acoustical Society of America*, 90, 1309-1325.

[7] Krull, D. (1989) Second formant locus patterns and consonant-vowel coarticulation in spontaneous speech. *Phonetic Experimental Research, Institute of Linguistics, University of Stockholm (PERILUS)*, 10: 87-108.

[8] Sussman, H. (1994) The phonological reality of locus equations across manner class distinctions: Preliminary observations. *Phonetica*, 51, 119-131.