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An Ultrasound Study of Lingual Coarticulation in Children and Adults

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Abstract

There have been a number of studies which compared coarticulatory patterns in children and adults, but these studies have produced conflicting results, particularly with respect to anticipatory lingual coarticulation. This study used articulatory measures derived from ultrasound imaging, in order to establish any differences between child and adult coarticulatory patterns, and to quantify the degree of variability in children's and adults' productions.

The participants were four adults and four normally developing children aged 6 to 9 years, all speakers of Standard Scottish English. The data were the syllables /fi/, /fu/ and /fa/, in the carrier phrase "It's a ... Pam" (ten repetitions). Synchronised ultrasound and acoustic data were recorded using the Queen Margaret University ultrasound system. Extent of consonantal coarticulation and within-speaker variation in child and adult productions were compared according to a new ultrasound-based measure of coarticulation.

A significantly greater amount of anticipatory lingual coarticulation was found in children than in adults. Much within-group variability was observed, in both age groups. Within-speaker variability was significantly greater in children than in adults. These results are in agreement with some previous studies. Possible reasons are discussed for some of the contradictions in the literature on child and adult coarticulation.

1. Introduction

This study used ultrasound imaging in order to establish how children's patterns of lingual coarticulation differ from adults', how these observed coarticulatory patterns may be explained and what is the nature and the degree of variability found in children and adults.

One of the gaps in our knowledge about developmental paths taken by children to adult-like motor control of speech concerns the development of coarticulation, the articulatory overlapping of adjacent sounds. Previously published studies which compared coarticulatory patterns in children and adults have produced conflicting results, with some reporting that children exhibit less coarticulation than adults (e.g., [4]), others a similar amount (e.g., [9]), and yet others more (e.g., [5, 7]).

A greater within-speaker variability in articulatory patterns exhibited by children than by adults (e.g., [5]) may have contributed to the equivocal results. Another factor may be that most previous studies relied heavily on acoustic analysis, which provides only indirect evidence of articulatory movements, and is particularly problematic in child speech, because of the high fundamental frequency and consequent difficulties with formant tracking ([1]). Possibly as a result of the relative unavailability of suitable articulatory instrumental techniques, developmental studies of coarticulation comparing adults' and children's productions using articulatory data are very few. One example is an EMA study reported in [2]. An advantage of ultrasound over EMA is that it is non-invasive, and it registers the movement of the whole midsagittal section of the tongue, including the tongue root.

The research questions in this study were:

- Do children demonstrate a significant difference from adults in coarticulatory patterns, and what is the direction of any difference?
- Is within-speaker variability in coarticulation significantly greater in children than in adults?

2. Method

The participants, all native speakers of Standard Scottish English, were four normally developing children aged 6 to 9 years (C1 male aged 8;4, C2 female aged 6;10, C3 male aged 6;4, C4 male aged 8;6), and four adults. The data were the syllables /ʃi/, /ʃu/ and /ʃa/, in the carrier phrase “It’s a ... Pam”. The target syllables were spelt as “she”, “shoe” and “shah”, respectively; the sentences were shown to the participants on the computer screen, accompanied by images corresponding to the target words. Every target was repeated ten times. Synchronised ultrasound and acoustic data were collected using the Queen Margaret University ultrasound system ([13]).

A new methodology for analysing ultrasound data (see [14]) was used. Ultrasound frames at two time points, the middle of the consonant and the middle of the vowel, were identified in each of the different CV sequences, based on the acoustic data. At each time point, a cubic spline was automatically (with subsequent manual correction) fitted to the tongue surface contour. Each spline was defined in terms of xy coordinates, and these coordinates were used for comparing tongue curves.

Tongue curve comparison was based on nearest neighbour distance calculations (e.g., [8]). Magnitude of Coarticulation (MC) for the consonant in each of the three pairs of vowel environments was calculated, separately for each subject, using the formula:

$$MC_C = \frac{V1 - V2}{(C_{V1} - V1) + (C_{V2} - V2)}$$

In the formula, C is the target consonant; V1 and V2 are two vowel phonemes providing the alternative conditioning environments; C_{V1} is C in the environment of V1; C_{V2} is C in the environment of V2. This measure of coarticulation expresses the ratio of the distance between the vowel contours (which is proportionate to the possible degree of consonantal adaptation offered by the two vowel contexts) and the sum of the consonant-vowel distances in each vowel

environment (which is in inverse proportion to the degree of consonantal adaptation to the vowel contexts). The greater the MC value, the stronger is the coarticulatory effect produced on a given consonant by the two vowels.

For each speaker, for the consonant in each pair of vowel contexts, MC values and Coefficients of Variation across ten tokens were obtained. MC values and Coefficients of Variation (CVs) were compared across age group and vowel pair.

In order to establish whether any across-group differences could be due to measurement error, a reliability test was conducted, using a subset of the data. The tongue shapes for /ʃ/ and /a/ in the syllable /ʃa/ in one child speaker (Child 2) and one adult speaker (Adult 1) were subjected to a repeat spline-fitting procedure. With only the original ultrasound image displayed, the same routine was followed as described above. The distance was then measured between the set of curves for /ʃ/ from the first spline-fitting and the set of curves for /ʃ/ from the second spline-fitting, separately for the child speaker (i) and for the adult speaker (ii). The distance was also measured between the set of curves for /ʃ/ from the child speaker and the set of curves for /ʃ/ from the adult speaker, from the first spline-fitting only (iii). An ANOVA was conducted, the dependent variable having three levels: (i), (ii) and (iii). If the across-speaker distance was significantly greater than both within-speaker across-test distances, then it could be concluded that the measurement error had no effect on the experimental results. The calculations for /a/ were exactly the same as those described for /ʃ/.

3. Results

Table 1 presents MC values for every vowel pair and mean CVs across vowel pairs, for each subject. The Univariate ANOVA showed a significant main effect of age group on MC ($F = 110.51$; $df = 1$; $p < 0.001$). On average, MC was greater in children (mean MC of 1.00 in children versus mean MC of 0.80 in adults). Note also a difference in MC across vowel pairs ($F = 1061.35$; $df = 2$; $p < 0.001$), with the pair /i/-/u/ affecting the consonant the least, and the pair /a/-/i/ producing, on average, the greatest effect.

Table 1. MC values and CV values. Standard deviations for MC values are in brackets.

	MC, a/i	MC, a/u	MC, i/u	CV
Child 1	1.40 (0.21)	1.36 (0.26)	0.39 (0.15)	23.91
Child 2	1.30 (0.27)	0.81 (0.27)	0.93 (0.14)	23.54
Child 3	1.05 (0.10)	1.11 (0.11)	0.69 (0.24)	17.96
Child 4	0.75 (0.12)	0.71 (0.18)	0.55 (0.15)	22.65
Adult 1	0.97 (0.07)	0.91 (0.09)	0.50 (0.07)	10.46
Adult 2	1.02 (0.07)	1.18 (0.11)	0.24 (0.05)	12.75
Adult 3	1.09 (0.06)	0.94 (0.11)	0.38 (0.05)	8.82
Adult 4	1.00 (0.10)	0.84 (0.10)	0.73 (0.12)	12.85

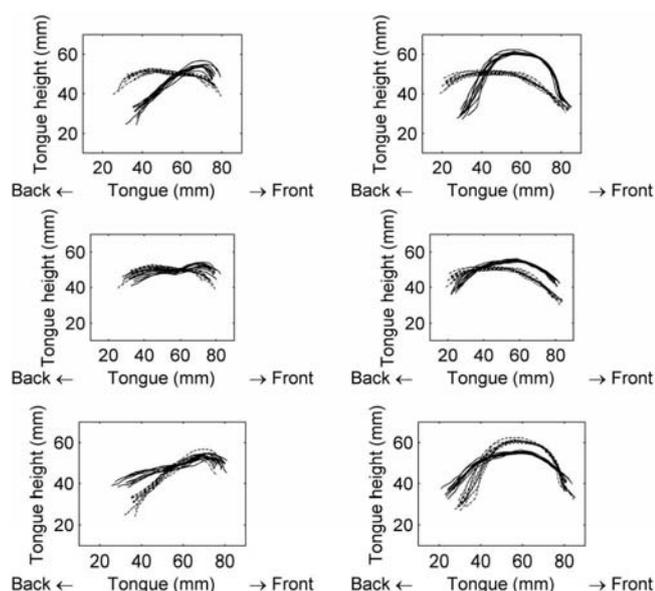


Figure 1. Tongue contours for /ʃa/ and /ʃi/ in Child 2 (left) and Adult 1 (right). Row 1: /i/ from /ʃi/ (solid) and /a/ from /ʃa/ (dashed). Row 2: /ʃ/ (solid) and /a/ (dashed) from /ʃa/. Row 3: /ʃ/ (solid) and /i/ (dashed) from /ʃi/. Lines for 10 repetitions are presented.

Figure 1 presents tongue curves for /ʃi/ and /ʃa/ in Child 2 and in Adult 1. The figure shows relatively

small distances between the consonant and the vowel in Child 2, compared to Adult 1; this difference has contributed to the greater MC in this child than in this adult.

An independent *t*-test demonstrated a significant difference in the CV between adults and children ($t = 3.38$; $df = 22$; $p < 0.01$). Table 1 illustrates greater values of the CV in children.

In the reliability test, the across-speaker distance was significantly greater than both within-speaker across-test distances ($F = 566.31$; $df = 2$; $p < 0.001$, for /ʃi/; $F = 428.42$; $df = 2$; $p < 0.001$, for /a/); thus, the measurement error did not affect the results.

4. Discussion

In this study, children showed a significantly greater amount of anticipatory lingual coarticulation than adults. This finding is in agreement with the results of previous studies that have reported greater coarticulation in children than in adults (e.g., [6, 10, 7]). These studies used very similar data to those that we used, the principal difference being the analysis technique.

Only three child MC values were greater than all adult values, and only two adult MC values were smaller than all child values. This finding about overlap in child and adult MC values agrees with previously published reports on within-group variability in children and adults (e.g., [9]; [11]; [5]).

Significantly greater CVs in children than in adults show that adults and children differ in the degree of within-speaker variability in coarticulatory patterns, children being more variable than adults. These results agree with existing literature (e.g., [5]).

Our results contradict the findings of some earlier studies partly because very different processes have been called “coarticulation” in the literature. For example, anticipatory nasalisation in /ini/ sequences (observed more often with increasing age) was analysed in [12]; degree of F2 transition during the vowel in the word “box” (a continuous F2 rise in adults versus a steady-state F2 in four-year-old children) in [4]; degree of undershoot of the vowel /u/ in “we saw you hit the cat” (greater in adults than in children) in [4]. These findings have been taken to support the claim that adults coarticulate more than children. All these studies have analysed coarticulatory effects on vowels, induced by adjacent consonants or by the position in the sentence. The

methodology proposed in this paper could be used in order to compare vocalic coarticulation in children and adults, to investigate the suggestion that consonants and vowels in young children may differ in their susceptibility to coarticulation.

Three studies ([9, 6, 3]) analysed coarticulatory effects produced by the vowels /i/ and /u/ on coronal consonants, by measuring the concentration of energy during the consonant in anticipation of the vowel F2. Our findings can be compared with the results of these acoustic analyses, because it has been claimed that F2 anticipation represents lingual coarticulatory effects, as opposed to lip rounding ([6], p. 122). Two studies, [9] and [3], found no significant differences in coarticulation between children and adults; [6] showed greater coarticulation in children. Slight methodological differences between these works could have contributed to the conflicting results. In our work, a significant difference between children and adults on this vowel pair was obtained ($p < 0.001$ in a t -test, after a Bonferroni adjustment for three tests, one for each vowel pair). It might be that our articulatory measure is more sensitive than acoustic measures; we intend to undertake acoustic analysis of our data which would help in establishing whether this is the case.

In our study, within-speaker variability of coarticulation reflected the child-adult difference better than the amount of coarticulation did. Examination of the productions of each speaker individually is currently being conducted using more CV sequences and a larger number of speakers.

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