

# Coarticulation in fricative-vowel syllables produced by children and adults: a preliminary report

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## Introduction

‘Coarticulation’ refers to the fact that speech is produced in a highly context-dependent fashion, while at some level, invariant (phonemic) information can be extracted by listeners. Coarticulation has both language-universal and language-particular components. The universal properties stem from the fact that all humans have similar constraints on vocal tract anatomy and neuromotor processing, including the speed and agility with which the speech articulators can be moved. Most of the studies in this area have examined perseverative (or ‘carryover’) coarticulation, in which a given sound is affected by the sounds preceding it. Such effects are thought to largely reflect inertial or mechanico-elastic properties of the articulatory system. In contrast, many coarticulation properties appear language-specific, implicating higher-level cognitive and linguistic mechanisms. To examine language-particular coarticulation issues, researchers generally analyse ‘anticipatory’ coarticulation, in which a given speech sound is affected by upcoming sounds.

Much recent work on anticipatory coarticulation has focused on the nature of articulatory coordination in children. This research has led to two divergent views concerning basic tendencies that occur in development. One view holds that although young children exhibit greater variability in their articulatory gestures than adults, the extent and magnitude of coarticulation is similar in child and adult speech (e.g. Katz *et al.*, 1991). Context effects on coarticulation may be seen as an increase in the efficiency of articulatory co-ordination, and thus a sign of speech motor maturation. An alternative view holds that early speech is organized syllabically and therefore demonstrates a greater degree of coarticulation or overlap than does adult speech (e.g. Nittrouer and Whalen, 1989). On this view, maturation is indicated by a decrease in contextual influences.

Since the late 1980s there has been a flurry of research on the development of coarticulation (or gestural overlap). The majority of these studies converge on finding

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roughly equal anticipatory coarticulation of lip rounding for children and adults. However, with respect to tongue movement, findings have been mixed, with some studies suggesting children coarticulate more than adults, others showing no such differences between children and adults, and still other studies pointing to further complexities, such as coarticulation varying with the syllable type, meaningfulness, and types of context. There are many possible reasons for these disparate findings, one being that children's speech can be quite difficult to analyse acoustically. For instance, children's high fundamental frequencies make it difficult to estimate vowel formant frequencies. Also, because of the well-known many-to-one relation between articulatory gestures and the acoustic signal it can be problematic to infer speech movement patterns from acoustic data alone. For these reasons, we analysed coarticulation by measuring tongue positioning during fricative-vowel productions by children and adults. These data were compared with the results of a preliminary experiment assessing the extent to which this coarticulation could be detected by adult listeners.

### Experiment 1. Kinematic analysis

#### Method

Eight adults (four men, four women), six 7-year old children, and three 5-year old children produced the syllables /si su ʃi ju/ in the carrier phrase 'I said \_\_\_\_ again'. The fricative-vowel stimuli were collected as part of a larger database which also included /ti tu/ and /ki ku/. Only the fricative data will be discussed in this report. Tongue-tip (TT) and tongue-body (TB) movements were recorded using electromagnetic midsagittal articulography (Schoenle *et al.*, 1987), collected with a Carstens AG-100 EMA system.

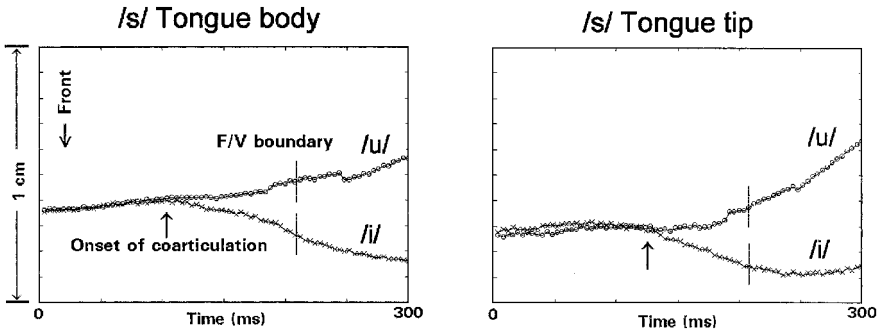
For all subjects except one 5-year old child, recordings were made of TT and TB coils. The TT coil was placed 1 cm posterior to the tongue apex and TB placements were made following a standardized template system. For adults, a reference 'maxillary plane' was established using reference coils placed on the upper incisor and nasal bridge. For child talkers it was necessary to place as few intra-oral coils as possible. Therefore, only a nasal reference was established for these talkers.

Speech samples were elicited in a randomized order following simultaneous spoken and visual examples given by the experimenter. Child talkers first completed a series of pre-test game tasks designed to increase familiarity with the EMA apparatus. Recording lasted approximately 30 min. Twelve repetitions of each stimulus were elicited.

#### Results

The kinematic data were first analysed in terms of horizontal ('x') movement over time. For instance, figure 1 shows ensemble averages for repeat productions of /si/ (crosses) and /su/ (circles) for TT and TB coils during /sV/ productions. Data for an adult talker are shown in the upper two panels, and data for a 7-year old talker in the bottom two panels. The average fricative/vowel boundaries are marked with a short vertical line. As expected, the TT and TB coils move anteriorly for syllables containing the front vowel, /i/, and posteriorly for syllables containing the back vowel, /u/. By observing the point at which the vowel-dependent trajectories diverge (arrows), it was possible to determine the onset of lingual anticipatory coarticulation

## (a) Adult talker



## (b) 7-year-old talker

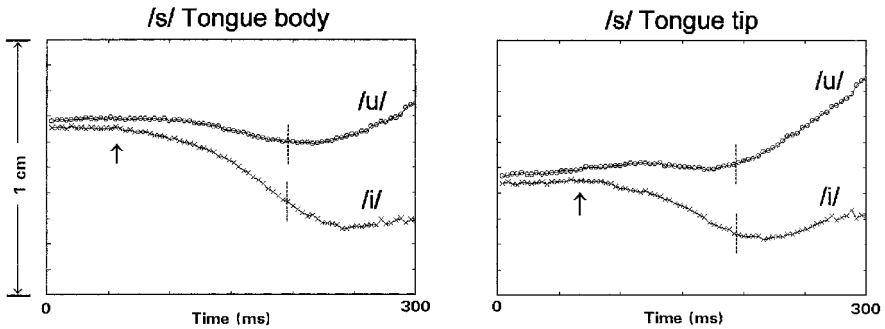


Figure 1. Ensemble averages of tongue body and tongue tip horizontal movement for repeated /sV/ productions by an adult and a 7-year old child.

during fricative production. For example, the upper left panel shows TB movement for /sV/, with vowel-dependent trajectories emerging at 105 ms (= approx. 50% of the fricative).

Visual inspection of these plots revealed fricative-specific patterns: For /sV/ syllables children's lingual positioning showed more extensive anticipatory coarticulation than that of adults. For instance, the 7-year old talker in figure 1 showed an onset of coarticulation at approximately 60 ms (= approx. 30% of the fricative). However, for /jV/ productions (not shown) children's coarticulation patterns were similar to (or less extensive than) those of adults. These patterns were confirmed in a statistical analysis of horizontal positions (ms) measured at four windows in each talker's utterance (vowel midpoint, the fricative/vowel boundary, 30 ms before vowel onset, and 100 ms before vowel onset). The data were analysed with three-way (window  $\times$  talker group  $\times$  vowel) ANOVAs conducted separately for the two fricatives (/s/ and /j/), and with *Bonferroni*-corrected planned comparisons (*t*-tests) analysing vowel differences at each window for the three talkers groups. For /sV/, significant main effects for TT and TB were noted one window earlier for children than adults, suggesting a greater temporal extent of coarticulation. In contrast, for /jV/ syllables there were no indications of earlier coarticulation in children's TT or TB data. Thus,

statistical analysis confirmed the patterns that were visually evident in the horizontal movement  $\times$  time plots.

## **Experiment 2. Perceptual experiment**

### **Method**

Listeners included ten college-aged adults recruited from the University of Texas at Dallas. Subjects reported no speech or hearing problems, and had no prior experience with speech experimentation. Listening materials were constructed from productions made by three randomly-selected talkers from each age group. For these nine talkers, two tokens of each fricative-vowel syllable (/si/, /su/, /ʃi/, /ʃu/) were randomly selected, yielding a total of 72 selected productions. Each syllable was then used to create four gated 'slices,' using a waveform editor:  $\frac{1}{2}$  Fricative,  $\frac{3}{4}$  Fricative, Full fricative, and Fricative +  $\frac{1}{2}$  vowel. These 288 stimuli were arranged in two blocks of 144 each, with stimuli in each block presented in randomized order.

Testing was conducted in a sound-treated room. Listeners were fitted with sealed earphones and instructed to listen carefully to each stimulus and identify whether it came from a /si/, /su/, /ʃi/, or /ʃu/ syllable. Responses were made using a four-button response box. Each block of 144 experimental stimuli took approx. 20 min. to complete and a five min. break was given at midpoint.

### **Preliminary results**

Analyses focused primarily on listeners' vowel identification (i.e., how well listeners scored on the vowel portion of each syllable regardless of getting the fricative correct or not). These data were analysed using four-way (talker group  $\times$  consonant  $\times$  vowel  $\times$  slice) repeated-measures ANOVA. Planned comparisons were also made between adults and children (i.e. 5- and 7-year olds taken as a group). For all analyses, data were collapsed over repetitions of the same token, tokens of the same utterance, and talkers within each age group to keep degrees of freedom from being artificially inflated. So far, the main findings have largely mirrored the kinematic data. Specifically, there was some indication that children (taken as a 'group') showed more extensive coarticulation than adults. For instance, planned comparisons showed significantly more accurate scores for children than adults at the Full fricative slice, with a trend in this direction at the  $\frac{3}{4}$  Fricative slice. However, a strict developmental trend was not observed, as scores for the 7-year old productions were frequently higher than those of the 5-year olds. Also, the perceptual data revealed some evidence of children showing earlier coarticulation than adults for /sV/, but not for /ʃV/.

### **General discussion**

The results of these experiments suggest patterns of coarticulation in children's speech are rather complex. Specifically, both kinematic and (preliminary) perceptual data reveal a greater extent of lingual coarticulation for children's /sV/ productions, but not for their /ʃV/ productions. If confirmed in future studies, such patterns may provide important clues about the way that gestural complexity affects developmental trends in speech production. For instance, if one assumes that /ʃ/ is more resistant to coarticulation than /s/ (Farnetani, 1999), then the /sV/ data may be more revealing

of a general development trend from more to less coarticulatory overlap with development. In contrast, the literature on children's developing phonology is mixed as to whether /s/ or /ʃ/ emerges first in development. Taking this criterion as a metric of gestural complexity, one might end up with the opposite conclusion. For example, if /ʃ/ emerges earlier than /s/ (e.g. Ingram *et al.*, 1980), /ʃV/ stimuli may be more gesturally 'simple' and therefore provide a clearer glimpse of children's developing coarticulation (in this case, suggesting that young children show no coarticulatory differences from adults). Experiments addressing these issues are currently underway in our laboratory.

### References

- FARNETANI, E., 1999, Coarticulation and connected speech processes. In W. J. Hardcastle and J. Laver (Eds) *The Handbook of Phonetic Sciences* (Oxford, UK: Blackstone), pp. 371–404.
- INGRAM, D., CHRISTENSEN, L., VEACH, S. and WEBSTER, B., 1980, The acquisition of word-initial fricatives and affricates in English by children between 2 and 6 years. In G. H. Yeni-Komshian, J. F. Kavanagh and C. A. Ferguson (Eds) *Child phonology: Volume 1. Production* (New York: Academic Press), pp. 169–192.
- KATZ, W., KRIPKE, C. and TALLAL, P., 1991, Anticipatory coarticulation in the speech of adults and young children: acoustic, perceptual, and video data. *Journal of Speech and Hearing Research*, **34**, 1222–1232.
- NITTROUER, S. and WHALEN, D. H., 1989, The perceptual effects of child-adult differences in fricative-vowel coarticulation. *Journal of the Acoustical Society of America*, **86**, 1266–1276.
- SCHOENLE, P., GRABE, K., WENIG, P., HOHNE, J., SCHRADER, J. and CONRAD, B., 1987, Electromagnetic articulography: use of alternating magnetic fields for tracking movement of multiple points inside and outside the vocal tract. *Brain and Language*, **31**, 26–35.