Intervocalic coarticulation across syllables in children with Childhood Apraxia of Speech

Patrizia Bonaventura, Barbara Lewis, Lisa Freebairn and Sara Clopton

Department of Communication Sciences
Case Western Reserve University

CASE COLLEGE OF ARTS AND SCIENCES

American Speech-Language-Hearing Association

RESEARCH SHOWCASE CASE WESTERN RESERVE UNIVERSITY

INTRODUCTION

The present study aims at investigating characteristics of speech production in Childhood Apraxia of Speech (CAS), that can indicate progress in internal structuring of motor patterns within syllables, and in structuring of syllable sequencing. Difficulties with timing and sequencing of phonetic units, as well as difficulties in combining smaller units (including units of movement) into larger wholes and decreased ability to accommodate to context, with resulting problems in coarticulation, rate and complexity of productions (Velleman, 2003) are common symptoms across the apraxias.

In particular, two production abilities have been observed, as typical of the motor programming process (Klapp, 2002), i.e. ability to structure internal components of "units of movements", or syllables (INT), and ability to sequence correctly syllables in the utterance (SEQ). The hypothesis was here tested that during acquisition of speech production, either development of INT, or of SEQ, or both, would incur in disruption due to CAS (Robin, 2004). Two stages of speech development were observed, in order to test whether disruption due to CAS affects either one or both the INT and SEQ processes, and when the disruption appears and/if it recovers.

Acoustically-based studies on coarticulation have provided contradictory evidence about the degree of intersegmental coordination, by using different measurements, i.e. F2 measurements and locus equations (Nijland, Maassen, van der Meulen, Gabreels, Kraaimaat, &Schreuder, 2003; Sussman, Marquardt, & Doyle, 2000). Also, studies of coarticulation in adult apraxia have provided contradictory results, some reporting delayed or deficient coarticulation (Ziegler and von Cramon 1985; 1986 a, b; Tuller and Story 1987; Southwood et al. 1997) and others including normal pattern (Katz, 1987, 1988). Therefore, a more detailed observation of specific aspects of gestural coordination in production would be necessary in order to disambiguate this information.

In order to observe specific degrees of intergestural coordination during speech acquisition in CAS, a longitudinal perspective has been adopted, and the observations in the present study focused on productions by three children diagnosed with Childhood Apraxia of Speech and three age-matching normals, recorded at two time points, during childhood (4-7 years), pre-school/school age period (8-11 years). The data analyzed were mono- and multisyllabic words, obtained by elicitation in a Goldman-Fristoe test, and multisyllabic words and non-words, elicited during the same recording session. Two acoustic analyses were performed, in order to estimate the degree of internal syllable structuring, as measured within the vocalic nucleus on the basis of F1/F2 ratio; also, the child's skills in coordination of vocalic gestures in sequencing syllable was measured by plotting F1-F2 trajectories across syllables in multisyllabic words and nonsense words. The effects were compared in speech and non speech samples, in order to verify whether same mistakes in gestural coordination would occur both in words and non-words or whether the misarticulations would be restricted to articulation of speech sounds**.**

GOAL OF THE STUDY

The goal of the present study is to observe the development of the internal structuring of vocalic nuclei (to be considered as part of the INT process), and also the emergence of the coordination between vocalic gestures across syllables (as deriving form the SEQ process).
The goal of the observation is to verify whether disruption occurs specifically in the formation of the syllabic structure (in particular of the nucleus), or in the coordination between syllables in sequencing, or in both processes. Also, development of the INT and SEQ skills was observed at two time points, in order to identify time markers characteristics of CAS. Finally, coordination of tongue body gestures was compared in words and non-words, in order to verify whether some of the errors are typical of acquisition of speech production.

	CAS children	Age in years	Normal children	Age in years
T1	GK	3.83	DV	4
T1	MB	3.41	HS	4
T1	DS	7.11	ES	8.25
T2	GK	5.50	SB	5.58
T2	MB	7.67	BW	7.08
T2	DS	7.83	DV	8.83

Table 1 *CAS and normal subjects*

METHOD

Subjects and speech samples

Speech samples from six children (3 diagnosed with CAS and 3 age-matching normals) were observed at two time points, childhood (3-7) and pre-school/school age period (8-11 years). The audio material was kindly provided by Prof. Lewis. The children recruited from the previous study (Lewis et al. 2004) were diagnosed with CAS based on multiple criteria (Shriberg, Arama and Kwiatkowski, 1997a, 1997b, Stackhouse, 1972, Hall et al. 1993; Ozanne, 1995): children were first diagnosed as suspected CAS by the child's speech-language pathologist, then they were tested for motor programming deficits, based on demonstration of at least four generally recognized characteristics of CAS (e.g. difficulties in sequencing phonemes and syllables, consonant deletion, inconsistency in articulation with unusual errors; Hall et al, 1973; Velleman and Strand, 1994). Low diadochokinetic rates (Total Function Score at least 2SD below the norm with respect to the mean for age proposed in the Oral and Speech Motor Control Protocol (Robbins and Klee, 1987) determined eligibility. Presence of nondevelopmental processes, as determined on the basis of the Khan-Lewis Phonological Processes analysis (KLPA; Khan-Lewis, 1986) also was a criterion for selection. Finally, the diagnosis for CAS required presence of sequencing errors in the Oral and Speech Motor Control Protocol (Robbins and Klee, 1987) and in the Multisyllabic Word Repetition and Nonsense Word Repetition tasks (Catts, 1986). Also, receptive language abilities were assessed by the Test of Language Development-Primary: 2nd Edition (TOLD P-2; Newcomer and Hammill, 1988).
The normal group consists in normal siblings of the children with disorders, recruited within the genetic study (Lewis et al., 2004). Normal children were administered the same assessment battery as the CAS and the SSD children. These subjects were selected to match the CAS children by age within a 6-12 months range.

Analyses

The present study is based on a unique speech corpus including productions by children with childhood apraxia of speech, recorded at different time periods: childhood (3-7ys) and preschool/school age period (8-11ys); the corpus includes also productions by age-matching children in normal development. This corpus is unique, as it provides a developmental perspective on childhood apraxia of speech, allowing at the same time, a comparison with normal speech. On the other hand, the word lists recorded for the study were designed to match two different goals at the same time: to provide an accurate assessment of CAS (therefore including articulation tests, like Goldman-Fristoe, and different multisyllabic words lists), and to provide data for phonological analysis, indicating the stage of development of the child (TOLD language test, conversational speech samples).
The present study intended to observe the speech corpus from a phonetic point of view: given the variety of lists administered at different time periods, and the different recording conditions, it was not possible to obtain from the speech corpus a uniform and systematic representative sample for every vowel production. Vowels have been measured, as produced in the different words available, under different stress conditions; also, not in every repetition the sample was clear enough to obtain measurable spectrograms. Therefore, only audio signals that were suitable for a spectrographic analysis have been selected for measurement. The limited number of analyzable data and the individual age-matching of the children did not allow to obtain generalizable data to compare by statistical analysis. Despite these methodological limitations, the study provides a unique perspective on development of intrasyllabic structuring of vocalic nuclei, and of intersylalbic vocalic gestural coordination.

F2/F1 ratio analysis

The original tapes were digitized at a sampling rate of 22kHz. The Praat package was used for display, playback and acoustic measurements. Wideband spectrograms were created using a black on white spectrographic display with a frequency range of 0-5kHz and a 3.5-second window.
First and second formant measurements were obtained from three sources: a) from cursor frequency readouts (via mouse positioning), on the wideband spectrogram display; b) linear predictive coding (LPC) spectra; c) automatic formant tracking Praat algorithm (see Figg. 1 and 2).
F1 and F2 measurements and F2/F1 ratio values were calculated for the vowels [E I O AE], for all children at different time stages (see Tables 2 and 3).

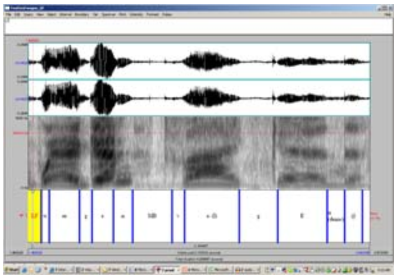

Fig. 1 *Spectrogram for word 'wagon': LF (SPL) pronunciation and MB (CAS, 3;41ys) repetition*

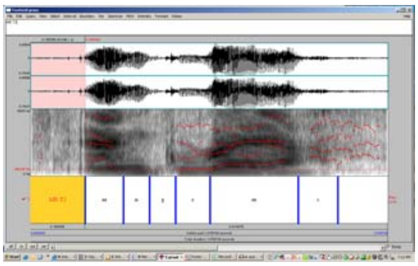

Fig. 2 *Spectrogram for phrase 'and grass': MB (CAS, 7.67ys) pronunciation*

RESULTS

Children F2/F1 ratio data have been compared within time periods and between CAS and normal age-matching pairs; the results are reported in Tables 1 and 2, showing, at T1, similar patterns within CAS children for vowels [E] and [I]; [E] and [O] patterns are similar between CAS and normal children, whereas F2/F1 ratio values generally differ between CAS and normal children for [I] and [ae]. At T2 there is more intersubject variability among the CAS children, and also a greater difference between CAS and normal patterns.
Similar tendencies are found in the F2/F1 plots for vowels by CAS vs. normal children at T1 (Fig. 3) and at T2 (Fig. 4).

T1	CAS1-GK	normal1-DV	CAS2-MB	normal2-HS	CAS3-DS	normal3-ES
E	3.6	3.5	3.4	2.5	3.5	3.8
I	4.8	3.2	4.5	3.8	4.6	4.3
O	2.4	2.4	2	2	1.8	1.8
ae	2.8	2.2	2.6	3.6	2.3	2.8

T2	CAS1-GK	normal1-SB	CAS2-MB	normal2-BW	CAS3-DS	normal3-DV
E	2.7	3	2.7	2.6	3.6	3.2
I	4.6	5.2	3.6	3.6	3.1	4
O	2.1	1.7	1.6	2.2	1.8	2.3
ae	3.4	2.8	2.7	2.4	3	3.8

Tables 2 and 3. *Average F2/F1 ratios for CAS vs. age-matching normal children at two time points, childhood (3-7ys) and preschool-school age period (8-11ys)*

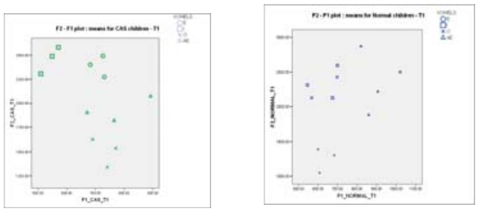

Fig. 3 *Vowel space in CAS vs. normal children at T1 (3-7ys)*

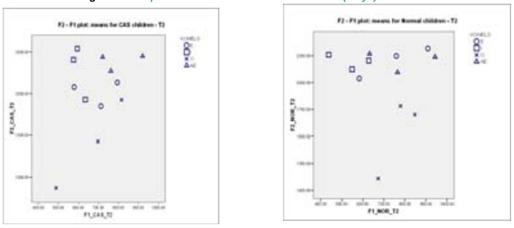

Fig. 4 *Vowel space for CAS vs. normal children at T2 (8-11ys)*

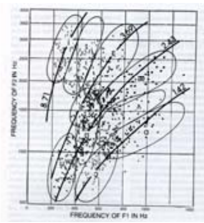

Fig. 5 *F1-F2 plot for American vowels produced by76 speakers (33 men, 28 women and 15 children) (from Peterson and Barney, 1952)*

A comparison between vowel spaces at T1, based on F2/F1 plots (Figg. 3 and 4), reveals a trend in CAS children, who show consistent patterns, similar to target normal spaces (as compared with the reference formant chart for American vowels in Fig. 5, from Peterson and Barney, 1952), for all vowels. On the contrary, normal children, at the same age, show an overlapping space for vowels [E I AE] and a more consistent and accurate production of [O], with respect to target normal spaces and to CAS.
At T2, however, for CAS children, the [E I AE] spaces show complete overlapping with no apparent concentration, indicating an indistinct use of the three different tongue configurations, to achieve the target [E I AE] vowels. The T2 formant space for normal children, on the other hand, shows a rearrangement in the sense of separation of vowels [E I AE] towards the target pattern.

Intersyllabic coarticulation

F2 trajectories in VCV sequences of the form [schwa-s-I], [u-s-I] and [al-sI] in 3 words and non-words as pronounced by a CAS child at T2 (DS) and by its age-matching normal (DV), have been measured at 6 points: a) schwa midpoint b) schwa end, c) in the fricative portion of the signal 30 msec before vowel onset, d) vowel transition onset e) vowel transition end, and f) vowel midpoint. The measurement was intended to provide a tentative evaluation of the degree of coordination of tongue body movements for production of adjacent nuclei across syllables (Öhman, 1966; Boers, Maassen and van der Meulen, 1997).
F2 trajectories have been calculated based on means of two points from the different repetitions (all data available) of the 3 words and non words by the CAS and normal child, at the two different time points (Fig. 6).
A great variability in schwa production, due to influence of the upcoming vowel, is shown in these preliminary data both by the normal child and by the CAS child, so confirming a trend of contradictory evidence obtained from previous acoustic studies: in fact, studies of coarticulation in adult apraxia have reported both delayed or deficient coarticulation (Ziegler and von Cramon 1985; 1986 a, b; Tuller and Story 1987; Southwood et al. 1997) and normal patterns (Katz, 1987, 1988).
Also, a great effect of [u] and [al] on the upcoming [I] has been found in the F2 trajectories for words pronunciations.

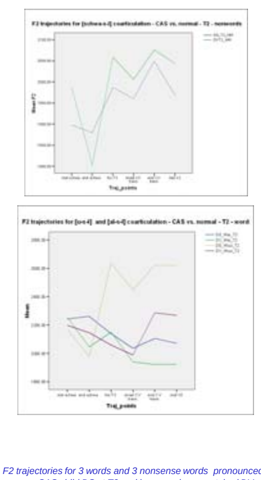

Fig. 6 *F2 trajectories for 3 words and 3 nonsense words pronounced by CAS child DS at T2 and by normal age-matched DV*

CONCLUSIONS

The preliminary results from this study indicate that intrasyllabic vocalic gestures structuring may emerge in CAS children at childhood (3-7ys of age) following a normal development pattern, but that, at the following age stage, maybe in connection with acquisition of more complex intergestural coordination patterns, involving different vowels and consonants, the vocalic tongue movements do not appear to be clearly distinct and to overlap. In normal children, an opposite pattern was observed, with a generic front vowel space emerging at childhood, that separates towards more specialized articulatory target areas for front and more central phones later, at the preschool/school age period.
At the level of intervocalic coordination across syllables, the limited preliminary observations on a CAS 7ys old child and his age-matched normal, provided an indication of presence of large intervocalic coarticulatory effects, both in CAS and in normal children at age 7-8ys.
These results contradict previous evidence obtained from children with CAS at 5ys of age (Boers et al., 1988), showing more reduced coarticulation between syllable nuclei at that age, in CAS than normal.
The present results seem to support the hypothesis that both INT and SEQ processes are disrupted in CAS. However, the results might also reflect the non-controlled phonotactic environment for the vowels observed in our study, or intersubject variability.
A more systematic analysis of different vowels in controlled phonotactic and stress contexts, would be necessary to clarify whether the patterns described in the present study can be generalized. Also, kinematic studies on CAS would contribute to provide decisive evidence about gestures coordination within and across syllable nuclei.

REFERENCES

•Boers, B., Maasen, B. and van der Meulen, E. (1998) "Phonological encoding processes in Children with Developmental Apraxia of Speech", in: Deger, W. and Ziegler, D. 'Clinical Phonetics and Linguistics', pp. 131-138.
•Lewis, B. A., Freebairn, L. A., Hansen, A. J., Iyengar, S. K., & Taylor, H. G. (2004). School-age follow-up of children with childhood apraxia of speech. Language, Speech, and Hearing Services in the Schools, 35, 122–140.
•Öhman, S.E.G. (1967b) "Numerical model of coarticulation", JASA, 41, 310-20.
•Shriberg, L. D., Aram, D. M., & Kwiatkowski, J. (1997a). Developmental apraxia of speech: I. Descriptive and theoretical perspectives. Journal of Speech, Language, and Hearing Research, 40, 273–285.
•Shriberg, L. D., Aram, D. M., & Kwiatkowski, J. (1997b). Developmental apraxia of speech: II. Toward a diagnostic marker. Journal of Speech, Language, and Hearing Research, 40, 286–312.
•Shriberg, L. D., Aram, D. M., & Kwiatkowski, J. (1997c). Developmental apraxia of speech: III. A subtype marked by inappropriate stress. Journal of Speech, Language, and Hearing Research, 40, 313–337