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Planning of syllables in children with developmental apraxia of speech

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Abstract

The aim of the present study was to investigate whether children with developmental apraxia of speech (DAS) show a deficit in planning syllables in speech production. Six children with DAS and six normally speaking (NS) children produced high- and low-frequency of occurrence syllable utterances, in which the syllable structure was systematically manipulated in an otherwise unchanging phoneme sequence. Anticipatory coarticulation, using second formant trajectories, and durational structure were analysed. The results showed stronger coarticulation in the children with DAS when compared to the normally speaking children, but in contrast to our expectations, in neither group was a systematic effect of syllable structure on the second format trajectory found. Effects of syllable structure did emerge for durational structure in that durational adjustments were found in the segments of the second syllable. These adjustments were less systematic in children with DAS when compared to normally speaking children. Furthermore, at the prosodic level, normally speaking children showed metrical contrasts that were not realized by the children with DAS. The latter results are interpreted as evidence for a problem in the planning of syllables in speech production of children with DAS, in particular concerning prosodic aspects, which is discussed in relation to the automation of speech production.

Keywords: developmental apraxia of speech, planning, syllable, coarticulation

Introduction

In this study we investigated the use of syllables in children with developmental apraxia of speech (DAS). DAS is a speech disorder that interferes with the ability

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to produce intelligible speech due to an impairment in sequencing speech sounds, syllables and words. The speech of children with DAS is, therefore, highly unintelligible as a result of the large number of segmental errors, especially consonantal errors, (contextual) substitutions and omissions. Inconsistency of errors and groping (articulatory searching behaviour) are typical of DAS. Also, errors and distortions in vowel production have been reported (Pollock and Hall, 1991; Walton and Pollock, 1993). In addition to studies of segmental error productions, research on prosody profiles has documented inappropriate stress patterns in children with DAS (Shriberg, Aram and Kwiatkowski, 1997). It was found that children with DAS made less distinction between stressed and unstressed segments when compared to normally speaking (NS) children.

Although it is still unclear at precisely what level of speech production processing the underlying deficit that causes DAS is localized, several production models suggest that the origin can be found somewhere in the transition from a phonological code into articulo-motor output, that is, in phonetic planning, motor programming, or motor execution (e.g., Hall, Jordan and Robin, 1993; Velleman and Strand, 1994; Ozanne, 1995; Dodd, 1995; van der Merwe, 1997). Velleman and Strand (1994) suggested that children with DAS are impaired in their ability to generate and utilize frames. Thus, children with DAS 'might "have" appropriate phonological (or syntactic) elements but be unable to organize them into an appropriate cognitive hierarchy' (p. 120). They argue that although children with DAS display a large number of segmental errors, the crucial supposition is that the size of the unit underlying these errors is not the single segment itself, but the syllable in which the segment is embedded. An example of this is the often-reported inconsistency of errors produced by children with DAS (Thoonen, Maassen, Gabreëls and Schreuder, 1994).

There are several characteristics of apraxic speech that support an interpretation in which syllable context plays a predominant role in speech production. Examples are: deficits in timing and co-ordination that have been reported in voice-onset-time studies (e.g., Kent and Rosenbek, 1983; Ziegler and von Cramon, 1986a); and delayed transitions and problems in phasing the articulatory movements in apraxia of speech (e.g., Ziegler and von Cramon, 1985; Ziegler and von Cramon, 1986b; Whiteside and Varley, 1998). These types of errors are more easily described in terms of articulatory syllabic context influences, than in terms of phoneme selection and sequencing. Furthermore, recent results of Marquardt, Sussman, Snow and Jacks (2002) suggested a breakdown in the ability of children with DAS to perceive 'syllableness' and to access and compare syllable presentations with regard to position and structure.

Likewise, syllabic context plays a role in the planning and programming of speech, that is in the transition from a phonologic representation to the motor programme (Ozanne, 1995, cf. Levelt, 1989). This transition comprises the collection of spatial and temporal goals of the articulatory movements for speech sound productions, conceptualized as gestures by Browman and Goldstein (1997), from a sensorimotor memory and adapting these to the surrounding sounds. The result is a motor plan, or gestural score (Browman and Goldstein, 1997), which is subsequently translated into a motor programme by specifying the exact movements of the speech musculature, that is muscle tone, rate, direction and range of movements (van der Merwe, 1997). The present study investigated whether children with DAS show a deficit in using the syllable as a planning or programming unit.

Previously we stated that in normal speech the coherence of the spatial, temporal and scaling aspects of gestures is preserved by using syllable-sized gestural scores (Löfqvist, 1990). This means that within the syllable, a particular speech sound is dependent on the characteristics of the adjacent speech sounds, which induce coarticulation (e.g., the articulation of the [t] in 'tool' exhibits liprounding under the influence of the following, rounded vowel [u]) and durational adjustment. As a consequence of this syllabic organization it is predicted that durational adjustment and coarticulation within the syllable (intra-syllabic coarticulation) is stronger than between syllables (inter-syllabic coarticulation) (Browman and Goldstein, 1997; Levelt, Roelofs and Meyer, 1999). Evidence for deficient planning of syllables in DAS would, therefore, come from particular deviant coarticulation and durational patterns between and within syllables.

In previous research, we investigated the coarticulation patterns of children with DAS, and compared them to normally speaking children and adult women (Boers, Maassen and van der Meulen, 1998; Nijland, Maassen, van der Meulen and Bellaar, 1999; Nijland, Maassen, van der Meulen, Gabreëls, Kraaimaat and Schreuder, 2002). The results of these studies indicated that the speech of the children with DAS showed deviant coarticulation patterns as compared to the normally speaking children, with overall weaker coarticulation and less spatial (articulatory) distinction between vowels. The individual patterns of the children with DAS were characterized by idiosyncrasies, which were interpreted as indications of deviance. Besides these deviant patterns, the children with DAS, when compared to normally speaking adults and children, also displayed the highest variability in repeated utterances. From these results it was concluded that children with DAS showed a lesser degree of coarticulatory cohesion.

In the present study, coarticulatory cohesion is further investigated; in particular, coarticulation in DAS is compared to normal speech. We introduce a more rigorous experimental manipulation of the speech material in order to determine whether the deviant coarticulation patterns and durational structure reflect a disability in planning syllables. Because gestural scores are hypothesized to be organized in syllables, we predict a strong effect of syllable structure on coarticulatory cohesion and durational structure. For this reason, children produced utterances in which syllable structure was varied, while the phoneme sequence did not change. An example in English would be the phrase 'ice cream' versus 'I scream', in which the syllable boundary follows the /s/-sound in the first phrase and precedes the /s/ in the latter.[1] Notice that the sequence of phonemes is identical in both utterances.

Coarticulatory cohesion (i.e., the influence of surrounding phonemes) within and between syllables, and the durational pattern in the utterances of normally speaking children and children with DAS, is substantiated with formant and durational measurements (Ziegler and von Cramon, 1985, 1986a, b; Nittrouer, 1993; Nittrouer, Studdert-Kennedy and Neely, 1996; Lee, Potamianos and Narayanan, 1999). Because it was not known beforehand what the effect of the manipulation of syllable structure would be for normally speaking children, the speech material was constructed so that a particular coarticulation effect could occur within a syllable and across a syllable boundary. We made use of the coarticulation effect of a vowel on the preceding consonants. Under the hypothesis (that normal speech is organized in syllable-length gestural scores) it is expected that the influence of the vowel on the preceding consonant is stronger and more robust if that consonant belongs to the same syllable, than if that consonant belongs to a different one, namely the preceding syllable. Such a syllable structure effect is expected to appear both spectrally (in formant measures) and temporally (in durational measures). Thus, in the English example above, the coarticulation of the vowel [i] (in '-cream') on the [s] would be stronger in the phrase 'I scream' than in the phrase 'ice cream'. Such an effect cannot be attributed to phonemic differences because the phonemic sequence is identical in both cases; instead, it must be caused by differences in syllable structure.

Such a syllable-internal dependence of gestures made Levelt *et al.* (1999: 5) suggest that 'a speaker has access to a repository of gestural scores for the frequently used syllables of the language', i.e., the syllabary (following the suggestion of Crompton, 1982: 32, in Levelt *et al.*, 1999). The function of these stored patterns is to relieve the production process of the task of computing the motor plan for the production of a particular syllable time and again. Instead, after an acquisition period, the articulatory patterns of frequently uttered syllables are stored, and can be retrieved on demand. Thus conceived, the syllabary can be interpreted as a mechanism for automation (Varley and Whiteside, 2001; Ziegler, 2001). Syllables that do not occur in the language are not stored in the syllabary. Based on this conceptualization, a difference between intra- and inter-syllabic coarticulation is expected, particularly in high-frequency syllables, which are supposed to be stored in the syllabary. To evaluate this hypothesis further, the speech material of the present study was constructed with high-frequency syllables as well as low-frequency syllables.

Knowing the effects of syllable structure and syllable frequency for normally speaking children, the next question will be: do children with DAS produce similar or different effects? Problems in planning syllables are predicted to emerge in DAS as *deviant* coarticulatory and durational patterns dependent on syllable structure. Thus, if we find that children with DAS produce a difference between intra- and inter-syllabic coarticulation strength and durational structure, similar to the difference of normally speaking children, then we must conclude that the deficit in DAS is not particularly located in the planning of syllables. On the other hand, if children with DAS do not show a syllable structure effect like that of normally speaking children, then this finding would be interpreted as a disturbance in children with DAS with respect to the ability to plan syllables, possibly due to deficient storage and/or accessibility of the syllabary. This latter interpretation would be further supported if a smaller effect of syllable frequency were found in children with DAS when compared to normally speaking children. Thus, the question of this study whether children with DAS show a deficit in planning syllables (including the use of a syllabary) and is investigated by manipulating syllable structure as well as syllable frequency.

Method

Participants

Data were collected from six children with DAS and six normally speaking children. These individuals were randomly selected from a total number of 19 children with DAS (14 boys and 5 girls; age range: 4;11–6;10 yrs) and 19 normally speaking (NS) children (matched for sex, age and dialect). All children were native speakers of Dutch (the reason for analysing only six children with DAS and six normally speaking children is that the detailed acoustic analyses presented in this study are extremely time consuming and therefore could not be conducted on all 38 children).

The children with DAS were 'clear' cases selected from special schools for children with speech and language disorders. The selection procedure was as follows: speech-language pathologists referred 70 children with suspected DAS to the authors. These children were further evaluated on the basis of the following tasks: spontaneous speech, repetitive imitations of phonemes, words and brief phrases, repetitions of nonsense words, and a diadochokinetic task (collected by the school speech-language pathologist). The following criteria were adopted: exhibiting many phonemic errors despite a complete phoneme repertoire (as compiled in the imitation tasks), high-frequency consonant substitutions (and omissions in clusters), phoneme and syllable sequencing difficulties which emerge in repetitions and in groping behaviour, inconsistent error patterns in repetitions of words and phrases, and inability to produce complex phonemic sequences (Hall *et al*., 1993; Thoonen, Maassen, Wit, Gabreëls and Schreuder, 1996). Additional selection criteria included: (at least) average non-verbal intelligence level, no problems with hearing or with language comprehension, no organic disorders in the orofacial area, and no gross motor disturbances or dysarthria (Hall *et al*., 1993; Thoonen *et al*., 1996). These data were collected using standardized tests of hearing level and language comprehension (Bomers and Mugge, 1989; Dutch translation of the Reynell Developmental Language Scales, Reynell and Huntley, 1985). From the 70 children referred by speech pathologists, only 19 children satisfied the above criteria completely and thus were considered 'clear' cases of DAS.[2]

In order to objectify the children who were ultimately selected for the study, language and speech characteristics of these children were extracted from the administered speech tasks (see the methods of Thoonen *et al*., 1996) and are shown in table 1. The first two columns show the language production quotients at sentence (SQ) and word (WQ) level. The following columns display the language comprehension quotient and the auditory memory quotient (the average score of the normal population on these four quotients is 100; one standard deviation is 20). The columns entitled Subst and Substpl display the percentage substitutions of single, syllable initial consonants produced in an imitation task of meaningful and nonsense utterances. The percentage consonant substitutions are indicated with 'Subst'; 'Substpl' indicates the percentage substitution of place-of-articulation relative to the total number of consonant substitutions (for example, in the word /pɑk/, the first phoneme is once substituted by /m/ resulting in /mɑk/ and once by /t/ resulting in /tɑk/. The latter is a substitution of place-of-articulation, which in this case equals 50% of the total number of substitutions). The Maximum Repetition Rates (MRR), expressed in mean number of syllables per second, are given in the last two columns (monosyllabic: /papa../, /tata../, /kaka../ and tri-syllabic: /pataka../).

Speech material

The speech samples consisted of disyllabic utterances of the type '/z/-V_1-/s/-/x/-V_2-/t/', spoken within the carrier phrase 'hé … weer' (/he-…-wɪːr/) 'Hey ... again'. In these utterances, V_1 was the vowel /ə/ in the open syllable /zə/ or the vowel /ʉ/ in the closed syllable /zʉs/, and V_2 was the vowel /a/, /i/, or /o/. We varied the syllable structure (syllable boundary is indicated with the symbol #) in these disyllabic utterances, in which the syllable boundary was either located before the /sx/-cluster or between /s/ and /x/, see table 2. Furthermore, syllable frequency was manipulated by using low(zero)-frequent syllables in nonsense utterances as well as high-frequent syllables in meaningful utterances. The manipulation of meaningfulness had a major effect on syllable frequency (see table 2).[3] The low-frequent syllables were all possible Dutch syllables, in that they obeyed the phonotactic constraints of the language.

Table 1. *Individual scores on the selection tasks (meaningful and nonsense word-imitation task and a Maximum Repetition Rate task) in children with DAS and normally speaking children (NS)*

						Meaningful		Nonsense		MRR	
DAS	Age	SQ	WQ	CQ	MemQ	Subst	Substpl	Subst	Substpl	Mono-syll	Tri-syll
#1	5;0	87	86	102	96	26%	76%	47%	68%	3.53	1.93
#2	5;1	85	88	92	89	24%	56%	64%	79%	4.12	3.38
#14	5;7	75	85	83	96	15%	60%	15%	30%	4.63	3.68
#17	5;10	72	80	83	82	17%	64%	67%	70%	4.63	Unable
#20	5;11	69	89	92	75	30%	60%	48%	72%	3.31	Unable
#21	5;11	73	94	89	96	31%	85%	–	–	3.20	Unable
NS	Age	SQ	WQ	CQ	MemQ	Subst	Substpl	Subst	Substpl	Mono-syll	Tri-syll
#54	4;9	–	–	–	–	7%	0%	12%	38%	4.29	3.52
#36	5;0	–	–	–	–	0%	0%	17%	64%	4.85	3.68
#42	5;3	–	–	–		3%	0%	6%	25%	4.74	4.05
#53	5;6	–	–	–	–	8%	0%	8%	20%	4.49	5.03
#58	5;6	–	–	–	–	5%	33%	9%	33%	4.44	5.08
#49	5;11	–	–	–	–	1%	0%	13%	0%	4.97	3.06

Note: SQ = sentence production quotient; WQ = word production quotient; CQ = comprehension quotient (>80 is normal); Mem.Q = Auditory Memory Quotient; Subst = percentage substitution of singleton consonants in syllable-initial position. Substpl = percentage substitution of place relative to the number of substitutions (Subst). Mono-syll = mean number of syllables per second (Maximum Repetition Rate, MRR) of monosyllable utterances (/pa/, /ta/, /ka/). Tri-syll = MRR in a tri-syllable utterance /pataka/.

Table 2. *List of the stimuli items (with translations), together with the syllable frequency of first and second syllable (based on the Dutch database CELEX consisting of 42 million lexical wordforms)*

Syll. Struct.	Meaningful Utterance	Syll. Frequency		Nonsense Utterance	Syll. Frequency	
		First	Second		First	Second
s#x	- zus giet - (*'sister pours'*)	1413	394	- fus giek -	13	8
	- zus goot - (*'sister poured'*)	1413	427	- fus gook -	13	0
	- zus gaat - (*'sister goes'*)	1413	30 067	- fus gaak -	13	0
#sx	- ze schiet - (*'she shoots'*)	392 675	1946	- de schiek -	3 471 753	0
	- ze schoot - (*'she shot'*)	392 675	3474	- de schook -	3 471 753	0
	- ze schaat-sen - (*'they skate'*)	392 675	143	- de scha-tel -	3 471 753	11 343

Note that there is a slight articulatory difference between the vowels /ə/ and /ʉ/ (the latter can be articulated with more lip rounding than the first; International Phonetic Association, 1993). However, as will appear below, the value of the second formant frequencies of both vowels were equal.

Procedure

The child repeated the utterances that were read aloud by the experimenter (the researcher who recorded all children). Since the focus of the study is on correct production and not on correct auditory perception, the experimenter used pictures of the utterances to support the production, in order to prevent articulatory incorrect production due to incorrect auditory perception. For example, a picture of a girl, that was called 'zus' (/zʉs/) 'sister', watering the flowers, to support the utterance (within the carrier phrase): 'hé zus giet weer' ('hey sister pours again'). In case of the nonsense utterances the child was instructed with pictures showing in one condition, 's#x', a strange looking creature called 'fus' (/fʉs/) that said all kinds of funny things, like 'giek' (/xik/), 'gook' (/xok/), and 'gaak' (/xak/). In the other nonsense condition, '#sx', the pictures displayed three non-existing animal-like creatures, which were called 'schiek' (/sxik/), 'schook' (/sxok/), and 'schatel' (/sxatəl/) respectively. These 'nouns' were preceded by the definite article 'de' (/də/) ('the').[4]

The utterances were elicited in blocks, each containing the three meaningful and three nonsense utterances within one syllable structure condition ('s#x' or '#sx'). If elicitation was completely randomized, the recording procedure would have been too confusing for the children, resulting in more erroneous productions. Between two blocks a cartoon was shown to the child as distraction and the experimenter and the child talked a little while about it. Within each session all utterance-types were repeated six times randomly, so in the end each child produced 72 utterances (3 vowels $\times$ 2 syllable structure conditions $\times$ 2 syllable frequency conditions $\times$ 6 repetitions). Sometimes children (especially the children with DAS) were not able to correctly produce an utterance. In that case (judged immediately by the experimenter) a second attempt was made immediately. This second (correct) production was, then, used for the acoustic analysis. Before the actual recordings were made each utterance type was practiced in order to prevent an additional learning effect during recordings.

A unidirectional dynamic microphone mounted on a headset (Shure SM10A) and a tape-recorder (Kenwood KX54) were used to record the speech samples. The headset kept the microphone at a constant distance of 5 centimetres in front of the right corner of the subject's mouth. Recordings were made in a silent, though not soundproof, room at the schools of the children.

Acoustic analyses

The speech samples were digitized with a sample frequency of 25 kHz and the relevant sections, [V_1-/sx/-V_2] were spliced out, using the Kay Elemetrics Computerized Speech Lab (CSL) analysis system, Model 4300B. The speech samples were transcribed using a broad symbolic system (International Phonetic Alphabet), which was demonstrated to be a reliable method (Thoonen *et al.*, 1994). Only the utterances in which [V_1-/sx/-V_2] was phonemically correct were used in the acoustic analyses. The percentage omission and substitution errors of the incorrectly produced utterances will be displayed in the results section.

As a first step in the acoustic analysis, the onset and offset of each segment were marked by inspection of the oscillogram, the FFT (Fast Fourier Transformation) spectrogram, and the energy-window. In the oscillogram, the CSL-program automatically produced impulse markers in the voiced sections (V_1 and V_2) of the signal at the zero-crossings in the steep rises of the curve, corresponding with the closing of the glottis during voicing (wrongly placed impulse markers were corrected interactively). The onset and offset of the vowels were determined by using these voicing impulse markers and the information in the spectrogram (for presence of a formant structure). The offset of voicing (absence of fundamental frequency and formant structure) and the beginning of a noise structure in the spectrogram determined the end of V_1, which corresponded with the beginning of [s]. To determine the transition from [s] to [x] information of the spectrogram was used visually along with the energy-contour. The fricatives can be distinguished by their energy distribution in the spectrogram, that is the [s] contains most energy in the high frequency regions, whereas in the consonant [x] more energy is found in the lower frequency regions. As a consequence, the overall energy, displayed in the energy-contour, is higher in [s] than in [x]. With this information of the spectrogram and energy-contour, the location of the transition from [s] to [x] could be determined by hand. Figure 1

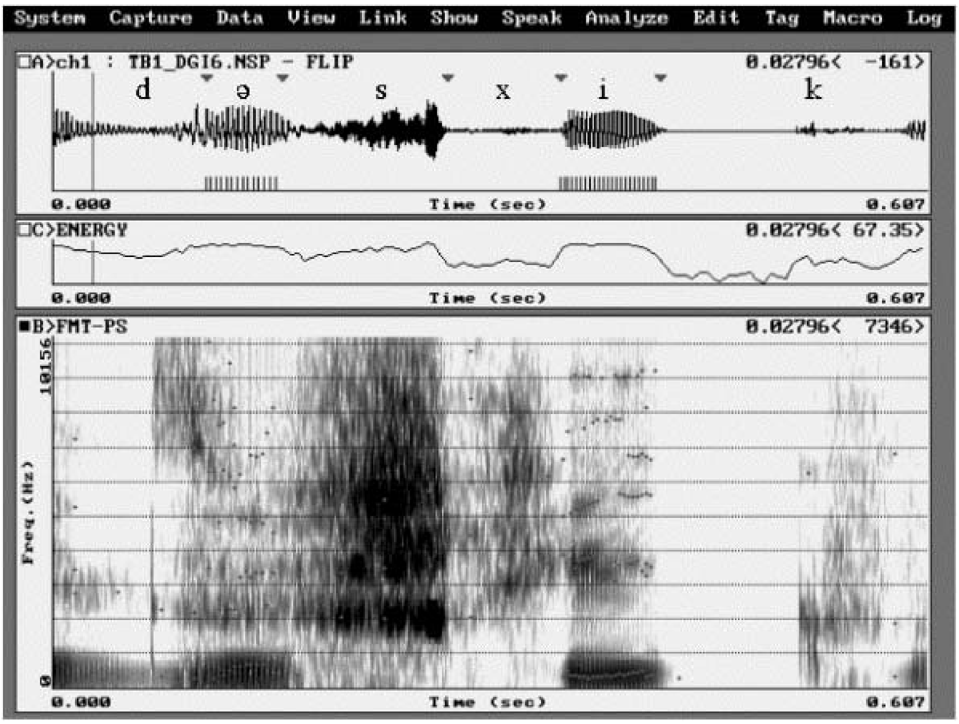

Figure 1. *Oscillogram (uppermost window) and spectrogram (lowermost window) of the utterance /he: də#sxikwɪ:r/. The little triangles in the oscillogram display the markers that were placed at segment transitions; the small black dots in the spectrogram represent the formant values.*

displays an example of an oscillogram with the on- and offset markers (see triangles), the energy contour, and the FFT-spectrogram with first and second formant traces.

Inter-observer agreement concerning the placing of these markers by two observers was tested in a subset of the data. Each observer placed markers in the utterances of three NS children and three children with DAS. The average difference between the markers set by the different observers was not larger than 7.7 ms. High correlation coefficients were found between the observers (from 0.97 to 0.99 for the different marker-placements), which indicated a significant reliability between observers, and of the method used to place the markers.

F_2 values were extracted at seven locations in the signal: at V_1 midpoint (1), at the end of V_1 (2), in the consonant [s] (3), in the consonant [x] (4), at the beginning of V_2 (5), at the end of the transition in V_2 (6) and at V_2 midpoint (7). In the voiced sections, V_1 and V_2, the formant values (with maximum bandwidth of 600 Hz) were obtained using pitch-synchronous Linear Predictive Coding (LPC) analyses (triangular analysis window; 20 components autocorrelation with pre-emphasis of 0.950), followed by a root-solving procedure (Nijland *et al.*, 2002). Additional to the F_2-measurements in the vowels, two separate LPC-analyses were performed close to the offset of the unvoiced segments [s] and [x]. For this, F_2 was calculated from a window (20 ms width) centred 20 ms before offset in the consonants [s] and [x]. Besides extracting the F_2 values from the signal, also the durations of all segments, V_1, /s/, /x/, V_2, were determined using the markers at the beginning and end of each segment.

Anatomical differences between speakers are expected to result in large inter-speaker variances in mean formant values across vowels. To correct for this variability, as a means of speaker normalization, formant *ratios* per utterance type were calculated for each child separately. For each syllable structure, the formant values (of six repetitions) of utterances with /i/ were averaged and divided by the average formant values of utterances with /o/ (i/o-ratio).[5] Subsequently, these i/o-ratios are used to determine the coarticulation effect of the vowel on preceding phonemes, as an index for distinction between the utterances: the higher the ratio, the larger the distinction. Typically, large ratios are found at vowel midpoint, where the difference between the utterances is at maximum. Smaller ratios close to unity, such as typically found in the schwa, reflect that F_2 values are equal, independent of the upcoming vowel (no coarticulation). Thus, the higher the ratio is above 1 the larger the distinction is between the utterances at that particular location.

Statistical design

In order to answer the question whether syllable structure and syllable frequency influence coarticulatory cohesion and durational pattern, analyses of variance are conducted on the i/o-ratios and the segment durations in both groups of speakers. In these analyses of variance the between subject factor is 'Group', and the within subject factors are 'Syllable structure' and 'Syllable frequency' (including all interactions).

Apart from the interaction effect of syllable structure or syllable frequency with coarticulation, also the main effects of syllable structure and of syllable frequency on the (raw) F_2 values in both groups are evaluated as well as the main effect of coarticulation of the second vowel on preceding segments. Before performing analyses of variance the condition of homogeneity of variance in the groups that are to be compared must be satisfied. This was a problem in the formant frequency data and the durational data: the repetitions in the children with DAS contained more variance as compared to the NS children (which will be discussed in the results and discussion section). Furthermore, children with DAS were not always able to correctly produce six repetitions of each utterance-type. In order to statistically correct for this problem of heterogeneity we aggregated the repeated utterances per child, which resulted in average data of each utterance type per child. On these aggregated F_2 data analyses of variance were conducted, with the factors 'Group' (between subject factor), 'Syllable structure', 'Syllable frequency', 'Vowel2' (within subject factors). Furthermore, in order to evaluate the main effect of coarticulation of the second vowel on preceding segments, a one-sample *t*-test is conducted to test whether the i/o-ratios were significantly higher than 1.

Results and discussion

The effect of the manipulation of syllable structure and syllable frequency in children with DAS when compared to NS children will be presented and discussed on (1) phonemic error frequencies, (2) coarticulation patterns in formant measures (F_2), and (3) relative segment durations. Furthermore, global differences, concerning variability, between children with DAS and NS children will be discussed at the end of this section.

Syllable structure and syllable frequency

Phonemic errors

The utterances were broadly transcribed, which showed that whereas NS children did not exhibit problems (error percentages close to 0), some children with DAS showed high error frequencies. Errors appeared particularly in the /sx/-sequence (in both 's#x' and '#sx'), even though in a different speech task, recorded during the same session, the children demonstrated that the singleton /s/ and /x/ were in the children's repertoire (Nijland *et al*., 2002). Table 3 shows for each syllable structure ('s#x' and '#sx') the percentage of correct utterances produced by the children with DAS and the percentage of phonemic errors on /s/ and /x/. The error percentage of the high-frequent and low-frequent utterances were aggregated in the table (the patterns were not different; on Wilks' Lambda based $F_{(2,43)} = 0.070$, n.s.). The column 'omission' contains the percentage 's#x'-utterances in which either /s/ or /x/ is

Table 3. *Percentages of errors in the sequence /s-x/ produced by children with DAS. The low percentage of 'other errors', like vowel errors, is not displayed in this table*

Target production	s#x			#sx		
Production	Correct	Omission	Pause	Correct	Cluster reduction	Pause
Child 1 (5;0)	25.0	41.7	33.3	5.6	83.3	11.1
Child 2 (5;1)	94.4	2.8	0	0	97.2	0
Child 14 (5;7)	97.2	0	2.8	91.6	0	5.6
Child 17 (5;10)	97.2	0	2.8	97.2	2.8	0
Child 20 (5;11)	66.7	16.7	11.1	47.2	47.2	5.6
Child 21 (5;11)	52.8	33.3	11.1	5.6	88.9	0

omitted; the column 'cluster reduction' contains the percentage '#sx'-utterances in which the cluster was reduced to either [s] or [x]. The pause is defined by the absence of energy in the signal (i.e., absence of speech), during at least 8 ms.[6]

Table 3 shows that some children exhibit a very low percentage of correct productions (children no. 1, 2, 21). Remarkable are the children that were able to produce the sounds /s/ and /x/ successively, without pause, in the condition with the syllable boundary in between the two sounds ('s#x'), yet not in the condition with the syllable boundary preceding the cluster ('#sx'). Child 2 distinctly shows this effect: 94.4% correct 's#x'-productions, but with no correct productions of '#sx'. A similar difference was found in the children 1, 20 and 21, although to a lesser extent. Thus, four out of six children with DAS showed an effect of syllable structure on phonemic /sx/ production. Apparently also in children with DAS the speech production is characterized by a syllabic organization.

Furthermore, table 3 shows that a pause between /s/ and /x/ occurred more often in the condition 's#x' than in '#sx'. Normally, production of a pause between words or syllables (in the sequence /s#x/) is possible without affecting the syllable structure of the utterance. However, if a pause is produced between /s/ and /x/ in the /#sx/-utterances, this will affect the syllable structure and consequently the meaning of the utterances, in that '#sx' changes to 's#x'. Three children with DAS (children 1, 14, 20) produced substantial percentages of pauses within the cluster [sx] (/#sx/). In contrast, none of the NS children produced pauses within the cluster. In terms of speech production processes these pauses within the cluster, contradictory to syllable structure effects above, could be interpreted as an indication of segmental rather than syllabic planning.

Formant measures

The high percentages of production errors in children 1, 2 and 21 induce a problem to further process the acoustic data of these children, because some utterance types are completely missing (e.g., the '#sx'-utterances in child 2). The average F_2-trajectories of the remaining (three) children with DAS and of the NS children are displayed in figure 2; utterances with high-frequent syllables at the left-hand side, low-frequent syllables at the right-hand side; the solid lines represent the 's#x'-utterances, the dotted lines the '#sx'-utterances.

Before discussing the interaction effect of syllable structure on coarticulation, we go through the main effect of syllable structure and the main effect of coarticulation. An effect of syllable structure is visible in figure 2 (dotted versus solid lines), especially in children with DAS. Figure 2 shows that F_2 values were higher in '#sx' than in 's#x' at mid V_1 ($F_{(1,7)} = 7.04$, $p < 0.05$), at transition onset ($F_{(1,7)} = 5.87$, $p < 0.05$), and at mid V_2, ($F_{(1,7)} = 7.32$, $p < 0.05$; the latter effect of syllable structure is stronger in children with DAS than in NS children, $F_{(1,7)} = 6.31$, $p < 0.05$). It is hard to explain why higher F_2-values are found in '#sx' versus 's#x' (and especially in children with DAS). Figure 2, furthermore, shows that, as expected, differences between the F_2-frequencies, due to differences in second vowel, are large in V_2, indicating a large differentiation of the vowels [a], [i], and [o], and smaller in the preceding segments, representing the effect of anticipatory coarticulation of the upcoming vowel V_2. As a means of speaker normalization, and as an index of coarticulation, i/o-ratios are calculated. Figure 3 shows the i/o-ratios in the successive locations of the NS children (3a) and the children with DAS (3b).

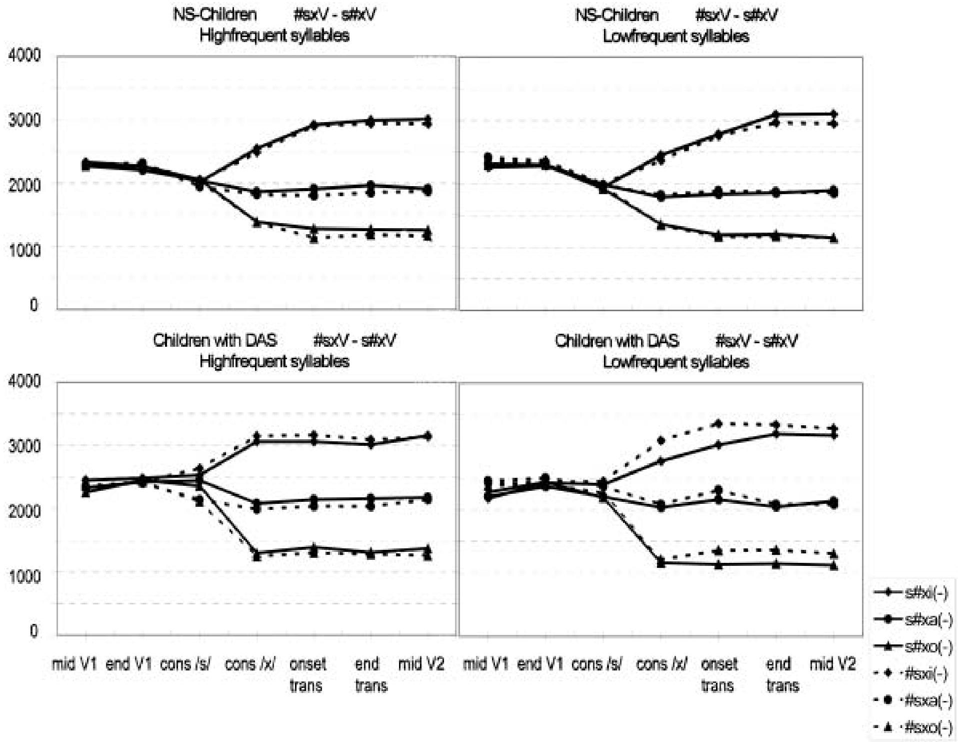

Figure 2. *F_2-trajectory of high-frequent syllable (left-hand side) and low-frequent syllable utterances (right-hand side) produced by normally speaking children (upper figures) and children with DAS (lower figures).*

The ratio-figures of both groups show a very small coarticulation effect from V_2 on V_1 (ratio is close to 1) and a larger coarticulation effect from V_2 on the [x]. Also, right at the onset of V_2, the i/o-ratio is high. In NS children (figure 3a) the coarticulation of the vowel V_2 was significant from [x] onward (i/o-ratios higher than 1: all $ts_{(22)} > 11.56$; $p < 0.001$). In children with DAS (figure 3b) ratios significantly higher than 1 were found from [s] onward (all $ts_{(11)} > 3.17$; $p < 0.01$). Moreover, the result of an analysis of variance showed higher ratios in consonant [x] in children with DAS as compared to NS children (Group: $F_{(1,7)} = 11.77$; $p < 0.025$), which indicates that intra-syllabic coarticulation was stronger in children with DAS. The i/o-ratios in the middle of V_2, which reflect the differentiation made between the vowels, did not differ between children with DAS and NS children ($F_{(1,7)} = 0.08$; n.s.).

Thus, the significant coarticulation effect from the vowel V_2 on the preceding segments is earlier (significant from [s] onward) and stronger in children with DAS as compared to NS children. This is an indication for stronger intra-syllabic coarticulation in DAS as compared to normal speech. Nittrouer *et al.* (1996) showed that during normal speech development the anticipatory coarticulation of a vowel on preceding sounds decreases with increasing age. From a gestural interpretation this means that the overlap between gestures in young children is larger than in older children and adults. According to this view, the results of the children with DAS in the present study (stronger anticipatory coarticulation and earlier in the utterance) might be interpreted as an indication for delayed development.

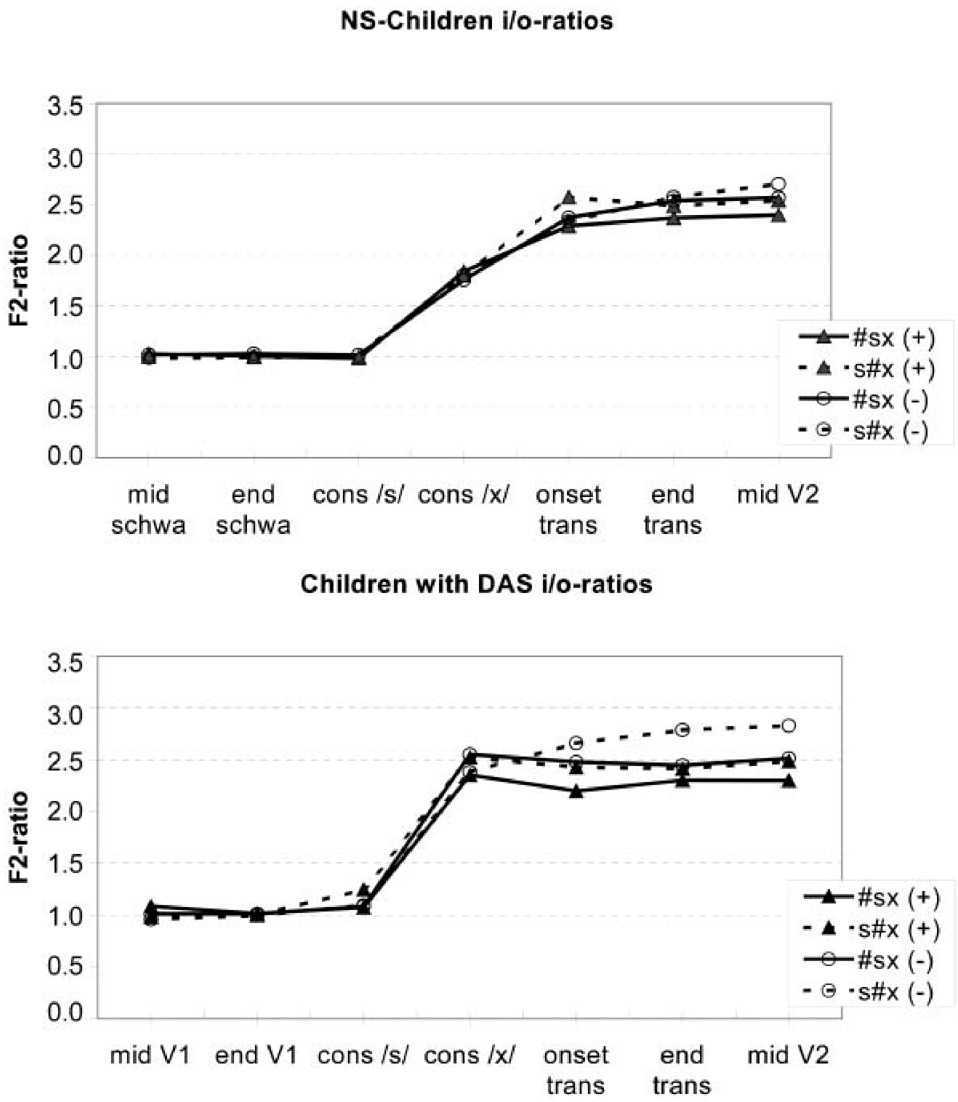

Figure 3. *i/o-ratio's in normally speaking children (upper figure Figure 3a) and children with DAS (lower figure Figure 3b) in high-frequent syllable (+) as well as low-frequent syllable (−) utterances.*

The main question in the present study is whether differences in anticipatory (intra- and inter-syllabic) coarticulation appear as a consequence of manipulating the syllable structure in NS children and, more interestingly, in children with DAS. In figure 3, such an effect is primarily expected in the consonant that changes syllable position, that is in the consonant [s]. Stronger coarticulation is expected if the /s/ belongs to the same syllable as the vowel V_2 (in '#sx'-utterances), than if it is part of the preceding syllable (in 's#x'-utterances).

The i/o-ratios (figure 3) show a significant effect of syllable structure on coarticulation at the location mid V_1 ($F_{(1,7)}=6.11$; $p<0.05$), showing that *inter*-syllabic coarticulation in '#sx' is stronger than in 's#x'. This effect emerges in both children with DAS and NS children. Otherwise, syllable structure does not affect (inter- and intra-syllabic) coarticulation at other measurement points (all $Fs_{(1,7)} < 1.09$, n.s.). In explaining the effect of syllable structure on V_1, the quality of V_1 seems to be important. Although the average second formant values of V_1 in the open syllable context (/zə/ and /də), are equal to the values in the closed syllable (/zʉs/ and /fʉs/), there seem to be other differences. The syllables differ in phonological specification of V_1 and in prosodic sense, which might influence the inter-syllabic coarticulation in two ways. First, the phonologically more specified vowel /ʉ/ possibly allows for less coarticulation than the neutral vowel /ə/. This finding corresponds to the principle of underspecification (Keating, 1988), which suggests that phonologically unmarked features remain unspecified in phonetic realizations. This enables forward and backward feature spreading of surrounding phonemes onto preceding or following underspecified phonemes. For example, since the feature 'lip rounding' is not specified (or marked) in the [s], [s] is vulnerable to anticipatory lip rounding of a following [u]. Thus, the underspecified /ə/ is easily influenced by context (the following/preceding consonant and vowel), as opposed to /ʉ/.

Second, besides the difference in phonological specification between the vowels, the syllables differ in prosodic sense as well. The significant difference in the i/o-ratios, between spondaic (as in 'CV_1s # xV_2C') and iambic utterances (as in 'CV_1 # sxV_2C') found at mid $V_{1,}$ corroborates results of other studies in which vowels in prosodically stronger positions exhibited less coarticulation than in weaker positions (de Jong, Beckman and Edwards, 1993; Cho, 1999). The closed syllables (/CV_1s#/) are stressed, whereas the open syllables (/CV_1#s/) do not have stress in these utterances. Both interpretations, phonological underspecification as well as difference in prosody processing, might account for the effect of syllable structure on the coarticulation in V_1.

To sum up, changing the syllable structure did not affect the strength and the extent of *intra*-syllabic coarticulation from the upcoming vowel V_2 in the crucial phoneme /s/, neither in NS children nor in children with DAS. In contrast, a significant effect of syllable structure on coarticulation was found on formant ratios at mid V_1 in both groups, which indicates stronger *inter*-syllabic coarticulation in '#sx' than in 's#x'.

The second question in this study was whether syllable frequency influences the coarticulatory cohesion in the utterances. Under the assumption that the articulatory gestures of frequently used syllables are stored in the syllabary and therefore will have more cohesion, we expect to find stronger coarticulation in high-frequent syllable utterances when compared to low-frequent syllables. Before discussing the interaction effect of syllable frequency on coarticulation, we briefly mention the main effect of syllable frequency on F_2 values. Figure 2 shows that manipulation of syllable frequency results in significantly higher F_2 values at consonant [s] in the high-frequent utterances as compared to low-frequent utterances ($F_{(1,7)} = 21.0$; $p < 0.005$). However, this syllable frequency effect was independent of the upcoming vowel V_2.

An interaction of syllable frequency with coarticulation is not found. Syllable frequency does not affect the strength or extent of the coarticulation (see figure 3), neither in NS children nor in children with DAS (all $Fs_{(1,7)} < 1.11$; n.s.). From the absence of a syllable frequency effect in both groups we must conclude that the existence of a syllabary, including a possible deficient syllabary in children with DAS, can not be substantiated. This could mean that either the assumption of a syllabary is false or that the effect of the syllable frequency manipulation was not strong enough in our data. Note that in the construction of the speech material only the frequency of the second syllable was strongly manipulated, especially for the syllables used in the i/o-ratios.

Durational measures

The speech of children with DAS is characterized by slow speaking rate, that is, long segment durations. Figure 4 displays the average segment durations of the different utterances types (figure 4a, NS children; figure 4b children with DAS). The results of the analysis of variance on the durations of the total group and the two groups separately (NS children and children with DAS) are displayed in table 4. Both the figures and the results of the analysis of variance clearly show that children with DAS have significantly longer total and segment durations as compared to NS children (except for V_2).

Furthermore, an effect of syllable structure emerges in the durations. This effect is different in children with DAS as compared to NS children. In NS children (figure 4a) the '#sx'-utterances are significantly shorter than 's#x'-utterances. The reason for the shorter total duration of the '#sx'-utterances is due to a shorter V_1, [x], and V_2 (shorter in '#sx' than in 's#x'). In the durations of children with DAS (figure 4b) a significant effect of syllable structure is only found in the segment duration of V_2 (shorter in '#sx' than in 's#x'), but this does not result in significantly shorter total durations.

Thus, the NS children show strong, significant effects of syllable structure on the durations of three of the four segments. Two different effects seem to be operative here: a metric and a prosodic effect. First, with regard to the duration of the consonant [x], it is found that the consonant [x] is shorter in the cluster '#sx' than in syllable-initial position in '#sx'. It is suggested that the duration of the consonant [x] is adjusted to the change in metrical structure of the second syllable. This means that in the syllable /#sxV_2/ the duration of [x] is shorter than in the syllable with /#xV_2/, because of the extra segment /s/ in /#sxV_2/. The duration of V_2 is similarly adjusted to this change in metrical structure (shorter in '#sx' than in 's#x'). Second, the duration of vowel V_1 (in the first syllable) depends on syllable structure: V_1 is shorter in /CV_1 # sxV_2C/ than in /CV_1s # xV_2C/. This effect cannot be explained by a change in metrical structure. Yet, in these utterances the first syllables differed in prosodic sense dependent on the syllable structure. That is, the closed syllable (/CV_1s#/) is stressed, whereas the open syllable (/CV_1#/) does not have stress. Thus, the significant difference in duration between spondaic (as in 'CV_1s # xV_2C') and iambic utterances (as in 'CV_1 # sxV_2C') found in V_1 for the NS children corresponds with shorter durations of vowels in prosodically weaker positions.

Although, as compared to the NS children, the children with DAS show a similar effect of syllable structure on the duration of V_2, no significant effect of syllable structure is found in [x]. Thus, in children with DAS adjustment to the change in metrical structure of the second syllable is only effectuated in V_2. An effect of syllable structure on the duration V_1, as was found in NS children, is not found in children with DAS. We argue that this difference between NS children and children with DAS is a difference in the way these two groups process prosodic aspects. NS children shorten the duration of V_1 in the prosodically weaker position. The fact that children with DAS do not show a significant effect of syllable structure in V_1 (the effect of syllable structure on the duration of V_1 even tends to go in the opposite

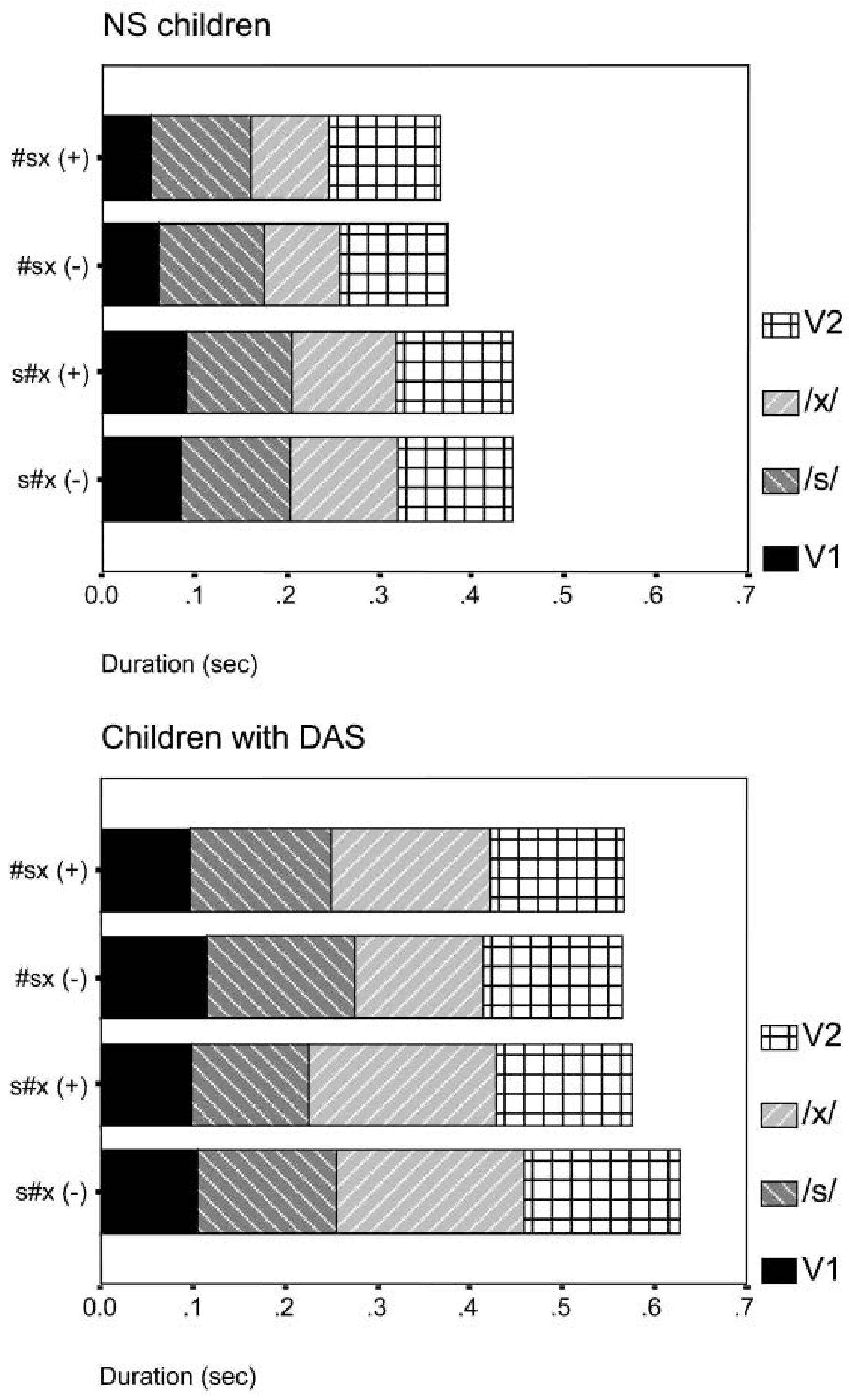

Figure 4. *Mean segment duration of normally speaking children (upper figure Figure 4a) and children with DAS (lower figure Figure 4b).*

Table 4. *F-values on segment durations across groups and of the two groups separately. Presented are F-values from the multivariate analysis of variance with main effects and interaction effects of the factors group, syllable structure (Syl.struct.), vowel2, syllable frequency (Syl.Freq.). The direction of the significant effects is displayed between square brackets*

Group	Factor	df_1,df_2	Total dur. *F*	Total dur. Sign.	V_1 *F*	V_1 Sign.	/s/ *F*	/s/ Sign.	/x/ *F*	/x/ Sign.	V_2 *F*	V_2 Sign.
Total	Group (G)	1,7	16.55**	[NS<DAS]	9.79*	[NS<DAS]	8.52**	[NS<DAS]	14.62**	[NS<DAS]	4.36	
	Syl.struct. (SS)	1,7	15.31**	[#sx<s#x]	14.45**	[#sx<s#x]	1.95		14.82**	[#sx<s#x]	13.36**	[s#x<#sx]
	Vowel2	2,14	4.96*	[/i/</a,o/]	0.68		64.22**	[/a,o/</i/]	5.16*	[/a,o/</i/]	92.15**	[/i/</a,o/]
	Syl.Freq. (SF)	1,7	2.11		4.44		4.60		0.89		4.75	
	G * V2	2,14	2.86		0.32		5.19**[2]		4.05*[2]		1.54	
	G * SF	1,7	1.21		3.58		0.98		1.08		1.74*[4]	
	G * SS	1,7	1.58		17.05**[1]		6.73**[3]		0.71		0.33	
DAS	Syl.struct. (SS)	1,2	0.95		0.28		9.74		4.13		346.44**	[#sx<s#x]
	Vowel2	2,4	0.04		0.80		19.58*	[/a,o/</i/]	2.56		26.97**	[/i/</a,o/]
	Syl.Freq. (SF)	1,2	5.10		51.19*	[high<low]	1.40		1.06		4.50	
NS	Syl.struct. (SS)	1,5	30.93**	[#sx<s#x]	45.74**	[#sx<s#x]	0.83		10.29*	[#sx<s#x]	7.35*	[#sx<s#x]
	Vowel2	2,10	18.33**	[/i/</a,o/]	0.06		57.56**	[/a,o/</i/]	0.65		66.86**	[/i/</a,o/]
	Syl.Freq. (SF)	1,5	0.10		0.06**		3.15		0.00		4.13	

Note: [1] The effect of syllable structure is stronger in NS children than in children with DAS (nos. in DAS).
[2] The effect of vowel2 is stronger in children with DAS than in NS children.
[3] The effect of syllable structure (s#x < #sx) is stronger in children with DAS than in NS children (nos. in NS).
[4] The effect of syllable frequency (highfrequent < zero frequent) is stronger in children with DAS than in NS children (nos. in NS).
$*p<0.05$; $**p<0.01$.

direction) is an indication for deviant prosodic patterns in children with DAS. This confirms the findings of Shriberg *et al.* (1997) and Velleman and Shriberg (1999), who reported inappropriate sentential stress in children with DAS. They showed that children with DAS made less distinction between stressed and unstressed segments as compared to NS children. An explanation for this could lie in difference in suprasegmental processing of the phonological phrase.

Syllable frequency does not account for differences in durational structure, except for a longer duration of V_1 in children with DAS in the low-frequent syllable utterances as compared to the high-frequent syllable utterances. As was mentioned above, syllable frequency also did not influence coarticulation as measured in the i/o-ratios. The absence of a strong effect of syllable frequency either in durational structure or in coarticulation, together with the above-mentioned comment on the manipulation of syllable frequencies, makes it hard to draw conclusions from the syllable frequency results. However, the suggestion that in children with DAS the processing of the phonological phrase is different compared to NS children continues to exist.

Besides the effect of syllable structure and syllable frequency on the durational pattern, table 4 shows that the total durations and segment durations differ significantly due to the factor Vowel2. A significant shorter duration of the vowel [i] leads to shorter total durations of the utterances with /i/, and to longer durations of the preceding segments in the /i/-utterances (except for V_1). In the separate group analyses, this effect of Vowel2 is found in the durations of the segments V_2 and [s] in both groups. However, in contrast to NS children, a shorter duration of the vowel [i] does not result in significantly shorter total durations of the utterances with /i/ in children with DAS.

Global differences: variability

Table 5 displays the variability in formant frequency values and durations measured in the two groups of speakers. The standard deviations are calculated over the average values per speaker (between speaker variability), over the repetitions within one speaker (within speaker variability), and over different utterance types. For the F_2 values, this was done at each location (from mid V_1 to mid V_2), and for the durational measures the standard deviation was calculated for each segment (V_1, [s], [x], V_2). The significance of difference in variability between the two groups is calculated with *F*-ratios on the variances (viz. the square of the standard deviation). These calculated *F*-ratios are displayed underneath the standard deviation in the table.

The standard deviation of the F_2 values show that the variability due to type of utterance increased to the end of the utterance in both groups, which is explained by the difference in utterance-types in V_2. Variability due to utterance type is not significantly different between the groups (see *F*-values). The standard deviation between speakers decrease from the beginning to the end of the utterance, although not monotonically. Again, the groups do not differ significantly on variances due to the factor Speaker, which means that the children with DAS do not differ more strongly among themselves than NS children do. In both groups the within speaker standard deviation (due to repeated productions) is highest in the middle of the utterances: in consonant [x] for the children with DAS and at the beginning of the transition in V_2 for the NS children. This within speaker variability is significantly

Table 5. *Standard deviations calculated at each location, due to utterance-type (Type), speaker or between subject variability (Speaker), and within subject variability (Within). F-ratios of between and within subject variability are calculated to show differences between speaker groups.*

			Standard Deviations of F_2 values (Hz) at the locations						
Group	Factor	df	mid V_1	end V_1	Cons /s/	Cons /x/	begin trans	end trans	mid V_2
DAS	Type	11	317.2	132.9	609.1	3091.0	3396.7	3543.4	3742.6
	Speaker	5	1223.0	1733.6	1358.6	557.8	735.2	841.6	780.7
	Within	210	220.2	186.6	274.7	305.4	284.9	247.9	219.4
NS	Type	11	313.1	242.6	176.6	2550.7	4140.5	4439.6	4713.1
	Speaker	5	1521.0	1196.6	1379.4	1201.2	1015.0	704.6	787.7
	Within	380	176.6	158.9	172.6	233.3	256.5	225.1	210.7
DAS/NS	*F*(speaker)		*1.55*	*2.10*	*1.03*	*4.64*	*1.91*	*1.43*	*1.02*
DAS/NS	*F*(within)		*1.55***	*1.38***	*2.53***	*1.71***	*1.23**	*1.21*	*1.08*

			Standard Deviation of segment durations (ms)			
Group	Factor	df	V_1	/s/	/x/	V_2
DAS	Type	11	43.6	83.5	107.3	203.2
	Speaker	5	144.1	170.8	257.1	194.3
	Within	230	26.1	43.2	53.8	33.6
NS	Type	11	102.3	56.7	97.7	201.8
	Speaker	5	114.4	114.4	135.6	176.7
	Within	420	18.8	21.0	26.2	20.6
DAS/NS	*F*(speaker)		*1.59*	*2.23*	*3.59*	*1.21*
DAS/NS	*F*(within)		*1.92**	*4.24**	*4.20**	*2.67**

Note: significance: *$p < 0.05$; **$p < 0.01$.

larger in children with DAS as compared to NS children at all locations except for the steady state of V_2 ('transition end' and 'mid V_2'). This indicates that children with DAS produce acoustically more variable repetitions than NS children.

The standard deviation of the segment durations, displayed in the second half of table 5, show a similar pattern when compared to the standard deviations of the F_2 values. However, the standard deviation between speakers show an increase to the end of the utterance (again not monotonically) instead of a decrease. The children with DAS are again more variable in the segment durations of their repeated utterances as compared to NS children. Again, the variability between speakers is not larger in children with DAS than in NS children.

To summarize, children with DAS display high variability in acoustic measures of phonemically correct utterances, which appear in the variances of repeated productions. This inconsistency in repetitions can be interpreted as evidence of immature or disturbed speech motor control (Nijland *et al*., 2002). In general we can conclude that children with DAS exhibit problems in using the syllables in the automation process of speech production. These results not only contribute to the diagnosis and understanding of DAS, but also yield guidelines for therapy. The small speech elements focused on in training programmes for children with DAS are the size of syllables in order to enhance automation (the Dutch Dyspraxia Program, Erlings-van Deurse, Freriks, Goudt-Bakker, van der Meulen and de Vries, 1993; based on the Nuffield Dyspraxia Programme, Connery, 1992). The results of the present study support this approach, however, more research is needed to evaluate the effectiveness.

In contrast to the difference in within speaker variability between children with DAS and NS children, the variance between speakers is not significantly larger in the children with DAS than in the NS children. This result was not expected. However, we have to keep in mind that between speaker differences are tested on the variances of the isolated measurement points and not on the patterns. Thus, the often-reported heterogeneity within the group of children with DAS could not be corroborated by the variability results in the present study.

Conclusion

In the present study we investigated whether the deviant coarticulation patterns (as found in previous research, Nijland *et al*., 2002) reflect an impairment in the planning of syllables in DAS. In particular, the main question was whether children with DAS as compared to NS children show deviant patterns in intra-syllabic and inter-syllabic coarticulation and durational structure as a consequence of syllable structure (and syllable frequency). If so, this would indicate a disturbance in the planning of syllables, including a deficient use and/or accessibility of the syllabary (a repository of frequently used syllables). In order to find an answer to this question, the second formant (F_2) trajectory and segment durations were measured in phonemically identical utterances with systematic differences in syllable structure ('CV_1#sxV_2' versus 'CV_1s#xV_2') and syllable frequency (highfrequent versus lowfrequent syllables).

The coarticulation patterns of both groups showed that coarticulation is stronger and more extended in children with DAS when compared to NS children. However, this effect is independent of syllable structure. We argued that this result of stronger and more extended coarticulation in children with DAS is an indication for delayed development.

An effect of syllable structure on coarticulation of V_2 on the preceding /s/ could not be substantiated, neither in NS children nor in children with DAS. Although a differential coarticulation effect due to syllable structure is found in the i/o-ratios of V_1 (the coarticulation effect of V_2 was stronger in the utterances with '#sx' than in 's#x'), no differences are found between the two groups. We argue that a difference in phonological specification of the first vowel (/ʉ/ is more specified than /ə/, and therefore less vulnerable for coarticulation) or prosody processing (in which vowels in prosodically stronger positions exhibit less coarticulation) is underlying this effect of syllable structure on V_1.

In the durational structure, more than in the coarticulatory patterns, effects of syllable structure and differences between NS children and children with DAS did emerge. In NS children the shortening of the [x] and V_2 in the '#sx'-utterances as compared to the 's#x'-utterances is interpreted as an adjustment to the metrical structure of the second syllable that contains an extra segment /s/ in the syllable /#sx V_2/ as compared to the syllable /#x V_2/. In children with DAS a similar effect is found in V_2, but not in /x/. In addition to the shorter duration of V_2 in '#sx' as compared to 's#x', the results on error percentages, which indicate that the production of [#sx] induced more difficulty than [s#x], support the hypothesis that also in children with DAS the speech production process passes through a level which is characterized by a syllabic organization. These syllabic effects in DAS were, however, not as systematic as in normal speech. Furthermore, in contrast to NS children, children with DAS show no effect of syllable structure on the duration of V_1. This finding is furthermore discussed to be a problem in prosodic processing in DAS. Models on speech production suggest that information about metrical structure and prosody are combined in what is called the 'phonetic encoding' (Levelt *et al*., 1999; Kent, 2000), 'phonetic program assembly' (Ozanne, 1995), or 'motor planning' (van der Merwe, 1997); to our opinion these are all different names to specify the same stage in which the motor plan of the syllable is generated. Thus conceived, the data of the present study revealed that children with DAS have a deficit in planning syllables.

In this study, no strong effects of syllable frequency on coarticulation and durational structure occurred in the utterances of the two groups. It is concluded that either the theoretical construct of a syllabary is false or the effect of syllable frequency manipulation were not strong enough in this study. As a last result it is found that the speech of children with DAS is much more variable than that of NS children. The higher within-subject variances are indications of a less automated process. Although studies on other speech disorders also report high variability, this finding supports the idea that children with DAS have a problem in automating speech more than normally speaking children.

In conclusion, the present study provides indications for a problem in the planning of syllables in speech production of children with DAS, in particular concerning prosodic aspects.

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Notes

1. In this example, the syllable structure is equal to the word structure, since it concerns a one-syllable word. We will use the term 'syllable structure' and 'syllable boundary, henceforth, because the influence of the syllable is important in this study.
2. Obviously, all children who were referred by the speech-language pathologists showed apraxic characteristics, however, only those who satisfied all criteria were included in the present study.
3. The term 'syllable frequency' indicates the frequency of occurrence. In this study an extreme frequency manipulation was applied from nonsense utterances with low-frequent syllables and meaningful utterances with high-frequent syllables (CELEX, Baayen, Piepenbroek and Gulikers, 1995). This does not imply that all nonsense utterances consist of low-frequent syllables.
4. It should be noted that the syllable 'de' ('the') is high frequent. However, the total utterance is nonsense.
5. Also i/a-ratios were calculated. Overall, the value of the i/a-ratios was lower than of the i/o-ratios, as expected, but their patterns were similar. The i/a-ratios are not presented in the figures.
6. In normal speech the fricatives unit seamlessly: a silence of 8 ms provides sufficient information of a pause.

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