THE VOICED-VOICELESS DISTINCTION IN FOUR-YEAR-OLD CHILDREN

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1. INTRODUCTION

1.1. Phonological development

Learning to speak is a more complex task than just discovering the articulatory movements required for the production of speech segments. Most children learn to recognize and produce the sounds of their language community quite early and grow gradually towards the complex patterns of adult phonology. In general, phonological theories present extensive descriptions about sound structures in many languages and studies on phonological development are going to be related more and more to the adult phonological characteristics. Data of child language offer a certain accessibility to sound structures and the acquisition process in the child can often be recognized as a basis for related empirical studies, such as phonetics. The technical description of speech sounds at a segmental level can provide detailed information about:

- the developing language system in terms of phonemic distinctions
- the developing articulatory skills and knowledge about speech production

Current theories of phonological development can be divided into four major classes:

- Biological determinism: the adherents take genetics as a starting point to explain the phonological acquisition and think there is an innate biological system which grows towards the adult system (Stampe, 1969).
- Behavioral determinism: behaviorists are not concerned with the order in which sounds appear and they just consider it to be a part of the general process of learning (Skinner, 1957).
- Prosodic theory: the child's perception plays a crucial role and it is the auditory salience of speech sounds which causes the earlier or later acquisition of sounds. The children will grow from grosser distinctions to finer distinctions in both perception and production. However, only individual and no 'universal' predictions are made (Waterson, 1971).
- Structuralist theories: speech sounds are acquired in an orderly and predictable sequence regardless of the language spoken. There are structural laws that underlie the acquisition process (Jakobson, 1941; Chomsky & Halle, 1968; Ferguson, 1977)

The best known and most influential theory is certainly the structuralist approach. Many researchers report that Jakobson's predictive statements about the acquisition of speech sounds are in correspondence with their own observations. His predictions are based upon the principle of acquiring speech sounds growing from maximum contrast production towards minimum feature contrasts. In this study we find some evidence regarding the 'structuralist' approach as well as the 'prosodic' approach. For more detailed information we refer to Ferguson & Garnica (1975). Here we only want to give an outline of a generally agreed order of sound acquisition largely based on the structuralist approach:

- Vowels: the optimal vowel is /a/ and the vowel mastery first grows from a vertical opposition [high/low] towards a horizontal opposition [+back/-back] and [+round/-round].
- Consonants: the labial consonants /p,m/, opposed maximally to the most open sound /a/, are the first to be acquired and they develop further towards plosives differing in place. In the next stage fricatives and affricates are mastered (Fig. 1).

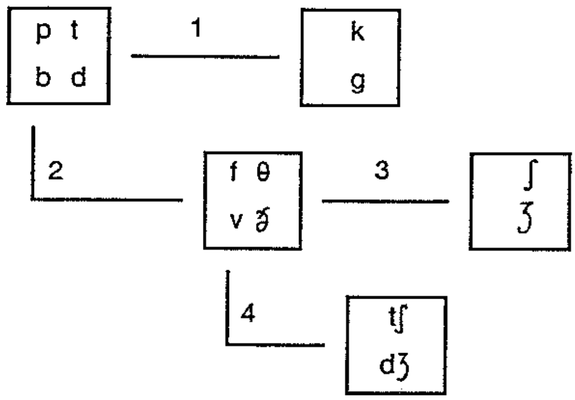

Fig. 1 Order of acquisition of consonants according to Jakobson. (Adapted from Blache, 1978, p.83).

One of the criticisms against Jakobson is the fact that he did not account for the babbling stage; in his opinion sound development only starts with meaningful words. Ferguson (1977) and Koopmans-van Beinum & Van der Stelt (1986) clearly state that babbling plays a role in the acquisition of the first sounds. Moreover, studies show for example that infants hardly babble voiceless fricatives and rather prefer voiced plosives, the latter being the group of consonants acquired early by children.
Snow (1963) present a plausible rank ordering of speech sound acquisition. Plosives and fricatives are mastered in a different order and within the set of stops the voiced-voiceless distinction is observed by the age of 4 in initial, intervocalic, and final position.
Phonologists agree about the fact that /b/ is acquired before /p/, /d/ before /t/; the whole group of stops, their voicing distinction included, is acquired before the group of fricatives. The consistency of results from many studies indicates that features which seem to have absolute or categorical characteristics, such as [nasality] and [voice], are easier to identify and produce than features just having relative characteristics, such as [continuant] and [place].

1.2. Motor control

In the present paper we examine more closely the acquisition of the voiced-voiceless distinction within consonants concentrating on the acoustic-phonetic structure. A lot of acoustic and perceptual research has been done on adult data and many acoustic parameters are involved in describing the distinction between voiced and voiceless consonants. In the time domain we can distinguish several parameters, such as duration of the consonant, duration of the preceding vowel, duration of the noise burst in plosives, presence or absence of vocal vibration during the consonantal closure, and spectral extensiveness of the vowel formant transitions (Slis, 1985).

From a developmental point of view the contrast of the voiced-voiceless distinction will be acquired when two criteria are met:

1. The child must be able to produce the relevant acoustic characteristics of the voiced and voiceless sounds being perceptually distinctive.
2. And the child must be able to produce the speech sounds in a way that corresponds to the language specific characteristics.

Certainly, the child's productive ability concerning the voiced/voiceless contrast does not depend only on phonological knowledge but for a great part on perceptual discrimination and dynamic control of the articulators. The child's speech mechanism is not fully developed , not until the age of 9 (DiSimoni, 1974) and the refined coordination in speech gestures as phasing and coarticulation will only develop after 3 or 4 years of age. Generally, research on children's temporal control in speech production reveals several developmental aspects (Hawkins, 1984):

- a slower and more variable performance
- some stereotyped behavior (no differentiation in different phonetic contexts)
- a gradual refinement towards adult norms
- overgeneralization of recently acquired rules
- sudden periods of rapid change

1.3. Research

Most of the phonetic research upon developmental data in this area has been done concerning four-year-old American English and Spanish children. The voiced-voiceless contrast in initial postion has been studied by VOT measurements in English and Spanish (Macken & Barton, 1979, 1980). Also the phonological vowel lengthening before final voiced consonant in English has been examined by durational measurements (Raphaël et al.,1980). Segmental durations of English 4 year old children have been studied in initial, intervocalic and final position (Smith, 1978). Finally, the influence of voiced and voiceless consonants on preceding vowel duration and the influence of vowels on following consonant durations have been a topic of research (DiSimoni, 1974a, 1974b).
In general, different stages of temporal development can be discerned in the aspects of the voiced-voiceless distinction:

- Voiced consonants are learned first by young children.
- The VOT contrast and the closure duration contrast is established. However, with respect to adult data, 4-year-old children show an overshoot in the durational parameters of the voiceless consonants.
- The disproportionate contrast will gradually be reduced towards adult norms.
- The extensive vowel lengthening before final voiced consonants (in English) is already mastered by the age of 4.
- Children show a large intra- and inter-subject variability.

Several researchers (Smith, 1978; Macken & Barton; 1979; Kent, 1981) conclude that the longer durations indicate that young children "must learn to shorten rather than to lengthen articulatory units in order to produce phonological length distinctions" (Smith, 1978) and that the exact refined segmental production develops with age.

1.4. Hypotheses

In this study we concentrate on a group of 4-year-old children; it constitutes a part of a larger developmental study of children up to 12 years old. At the age of 4 the child's phonological knowledge is considerable and he/she grows towards a more refined motor control on his/her articulators. Children master the voiced-voiceless distinction (at least the distinction within plosives) for 80% (Menyuk, 1971) and in our opnion the distinction between phoneme mastery and phonetic process cannot be separated completely. For a detailed explanation of the articulatory effort and the laryngeal mechanism in the production of voiced and voiceless consonants we refer to Slis (1985) and Van den Berg (1958). In Dutch little acoustic-phonetic research has been done on children's speech utterances and the consonantal distinction mentioned above has only been observed in adult data. And, within the developmental voicing phenomenon a broad crosslinguistic comparison still has to be established.

The closure and opening gesture of the voiceless consonant demands a complex articulatory coordination in VCV sequences. It will be longer than the voiced consonant and the vowel preceding the voiceless consonant is rather short because of an anticipatory effort; the vowel preceding the voiced consonant is lengthened. Much research has been done on this phenomenon and several explanations are given accounting for the vowel lengthening (Belasco, 1953; Chen, 1970; Klünder et al., 1989). In general, a temporal compensation in VC [-voice] and VC [+voice] can be observed.

The starting point of our study (based on a pilot experiment) is the claim that children use a certain strategy of maximalization of the contrast in the voiced-voiceless distinction. The exact acoustic-phonetic features of the contrast, length being one of the most important in child language, have to be learned by exposure to linguistic environment and by maturation of motor control. Besides the consonants contrasting in [voice], the velar consonant /k/ will be examined having no functional voiced opponent in Dutch, as well as the consonant /m/ being one of the consonants children learn first.

Secondly, Dutch has a clear phonological distinction in vowel length (Booij, 1981). How do children handle this contrast in their speech production and is the vowel already influenced by the following voiced or voiceless consonants. Considering the fact that children's speech can be described as an 'articulatory' model rather than a 'timing' model as in adults (Kent, 1981), we would expect a preponderance of segmental length distinctions in vowels as well as in consonants and a minimum of coarticulatory and compensatory effects between consonant and preceding vowel in the (C)*VC*V sequence.

2. METHOD

2.1. Subjects

The subjects for this study are 6 four-year-old children, 3 boys and 3 girls, all inhabitants of Nijmegen, a city in the south-east of The Netherlands. One of the reasons to select our subjects in this area is that people in the north-west of the country almost all devoice the voiced fricatives. The selected children are all monolingual speakers of Dutch and have been exposed to no other language at home. None of them showed any hearing loss or speech pathology. In Table I we give the ages of the children at the time of the recording and the number of utterances available for analysis. The age range is from 4 years 2 months to 4 years 8 months and all parents belong to the same social-economic status.

Table I. Ages of subjects at the recording. M/F refers resp. to 'male' and 'female'. N=number of words analysed.

Subject	M/F	age	N
1	F	4;5	100
2	F	4;7	99
3	F	4;5	98
4	M	4;2	91
5	M	4;6	100
6	M	4;8	98

2.2. Corpus

Our purpose is to collect the same set of words from each child and to control for the voiced and voiceless consonants in *intervocalic* position as well as for the vowel *preceding* this consonant. A corpus of 52 meaningful words has been developed (e.g. 'petten' vs. 'bedden', 'kabel' vs. 'stapel'). All the items are two-syllabic words and the first syllable is always stressed. In developing the corpus we have been faced with several restrictions:

- The vocabulary of four-year-old children is rather limited concerning word pairs that can be matched for intervocalic voiced and voiceless consonants.
- We had to make a selection of words that are either mono-morphemic (e.g. 'stapel') or bi-morphemic (e.g.'stappen'). The latter group consists of plural nouns or verb infinitive both containing the suffix '-en', and this could be a grammatical factor that influences the closure gesture.

e.g.

singular	plural	verb
'stap' [stap] (step)	'stappen' [stapən]	'slapen [sla:pən] (to sleep)
'kip' [kIp] (chicken)	'kippen [kIpən]	'kopen' [ko:pən] (to buy)

- It was impossible to select an equal number of words matching for types of consonants and vowels. However, we tried to select the best set of words that are known by young children.

In Table II the construction of the corpus is reflected concerning the intervocalic consonant and the preceding vowel. We choose for the voice-distinctive consonants /t,d/, /p,b/, /f,v/, /s,z/, for the consonant /k/ having no functional voiced counterpart in Dutch and for the consonant /m/, being one of the first consonants acquired by young children. The vowels /i/ and /u/ are included in the category of short vowels because they really behave like short vowels in the children's data (mean duration of [i] =117.60 ms., mean duration of [u]=125.23 ms.) Besides, it will not be astonishing that the number of plosives exceeds the number of fricatives in children's vocabulary.

Table II. Construction of the corpus concerning the sequence VC (V=long) and VCC (V=short) in *CV(C)CV* words. The numbers indicate the number of words containing the specified VC sequence; V=vowel, C=consonant.

	C [-voice]	(15)	'petten'
	C [+voice]	(4)	'bedden'
short vowel (28) ----	/k/	(4)	'takken'
	/m/	(3)	'kammen'
	C [-voice]	(11)	'stapel'
	C [+voice]	(9)	'kabel'
long vowel (24) ----	/k/	(5)	'koken'
	/m/	(4)	'zomer'

2.3. Procedure

In this research of the voiced-voiceless distinction in young children's speech development we have chosen for a procedure of word elicitation. Studying the acoustic-phonetic sound structure of children's utterances we think that a spontaneous word elicitation procedure will be better than an imitation task of meaningful words or nonsense words (Smith, 1978; DiSimoni, 1974). It will also be a more controlled study compared to those who use spontaneous words differing in stress.

All the words we have selected were represented by pictures on separate cards. If the picture did not really represent the word itself, there was some close relationship to it that would give rise to an appropriate elicitation. We have explained the procedure to one of the parents (in all cases the mother) and told her that it was not allowed to let the child imitate. All the words that had to be elicitated were indicated beneath the picture. Before the recording the mother and the child regarded the pictures together for two reasons:

- Mother and child would get used to the task, to the pictures and to the words the mother had to elicitate.
- Some words unknown to the child could be explained and the child would remember the word during the definitive recording session.

This procedure would account for a more or less spontaneous speech production without straightforward imitation. All the children were recorded twice using the same set of words and the same elicitation procedure; mother and child were sitting both at a table in front of the microphone. The experimenter tended the taperecorder and gave, if necessary, supplementary instructions.

The recordings were made with a taperecorder Tandberg and a Sennheiser MD21HN microphone at the children's home. At the end, we obtained 12 recordings (6 children x 2 replications) and theoretically 624 utterances (52 x 12). However, only 586 words remained for further analysis:

- 12 words were not recorded due to a lack of knowledge of the children
- 26 words had to be rejected because of external factors, such as noise, or mother and child talking at the same time.

2.4. Measurements

All the utterances of the children were transcribed phonetically and the waveforms were stored digitally on a microVAX II computer, using a 20 kHz sample frequency and a 9.6 kHz low-pass filter. The durational measurements of vowels and consonants were made using a speech editing waveform system; during the

measurements both auditory and visual information were available.
The following measures have been derived from the oscillographic waveform:
a) duration of the vowel preceding the intervocalic consonant
b) duration of voicing during the voiced intervocalic consonant
c) duration of the closure for the intervocalic consonant
d) duration of the frication noise in voiced and voiceless intervocalic consonants
e) the burst duration for the voiced and voiceless consonant
f) the total consonant duration = closure duration + burst duration
g) the total word duration

Segmenting and measuring durations are considerably more difficult than simply noting that various signal components are there. A great part of the difficulty depends on the phonetic context of the utterance in question. Unvoiced plosives and fricatives will hardly give rise to ambiguous segmentation whereas voiced plosives and liquids always complicate the task.
The segmentation has been done by hand and we have used several criteria:

Vowel preceding the intervocalic consonant:
- The beginning of the vowel has been marked at the first regular vocalic period. The boundary between vowel and plosive or fricative is rather obvious. When the initial consonant consists of one of the liquids a change in formant structure and amplitude has been taken as the segmentation point. Also the auditory information helps in segmenting at the right place.
- End of the vowel has been marked at the last vocalic period when followed by a voiceless plosive. When followed by a voiced plosive or liquid, again the change in formant structure and amplitude as well as vocal fold vibration has revealed to be a good anchor point. The slow speaking rate of children often presents a clear cut in this VC sequence (Fig. 2).

Intervocalic consonant:
- The end of the vowel constitutes the begin of the closure duration or the frication noise.
- In voiceless plosives the silent interval has been taken up to the burst, in fricatives the total frictation noise has been segmented which corresponds mostly with the beginning of the vowel. Even segmenting the burst is not always easy to do. The release of the consonant /k/ often shows a double burst and releases of dental plosives tend to be rather long, almost frication noise; we have always taken the first clear burst as the start of the release, whether followed by a second burst or not. The end has been taken at the end of the aperiodic noise.
- The end of the closure in voiced plosives has been taken at the end of the burst. If no burst was present, which has been often the case in the children's data, the transition in periodicity of voicing has been taken as the end of the closure (Fig.2).

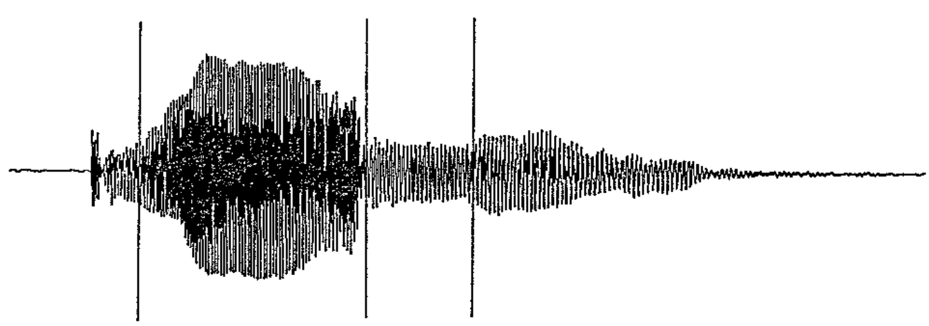

Fig.2 Oscillographic waveform and segmentation criteria of the word [krɑbən]

RESULTS

3.1. Voicing

The elicited set of words of all children are classified into 3 categories. These correspond to 'correct' realization (I), 'incorrect' realization (II) and, what we call, 'interrupted' realization (III) of the intervocalic consonant. In fact, every time we talk about 'consonant' in this section we mean the 'intervocalic consonant'. Words are classified into the second category ('incorrect') when children use:

- voice during the consonantal closure while a voiceless consonant is required ([t] -> [d])
- no voice during the consonantal closure while a voiced consonant is required ([d] -> [t])

A consonants has been classified into the third category ('interruptive'), when some criteria are met:

- In voiced plosives, voice does not continue but is followed by a silent interval > 25 ms (+burst). For adults a 10 - 20 ms silent period is normal.
  The burst in voiced plosives exceeds 20 ms in duration.
- In voiced fricatives, voice is interrupted by voiceless friction after which voice can continue again.
- The (voiced) friction is followed by a silent interval of > 25 ms.

In our data, only voiced consonants had to be categorized into this category. The results are indicated in Table III and Fig.3a and Fig.3b.

Table III. Correct (I), incorrect (II) and interrupted (III) realizations of the intervocalic consonant. Results are given for children pooled. Boys (M) and girls (F) are separated for the summation of the categories I and III ('correct' and 'interrupted'). The column '% correct' represents the percentages of realizations in categories I + III together.

	I	II	III	M	F	% correct
Voiced						
Plosive	99	5	14	60	53	95.8
Fricative	24	21	6	17	13	58.8
/m/	64	0	0	34	30	100
Voiceless						
Plosive	192	3	0	97	95	98.5
Fricative	52	1	0	26	26	98.1
/k/	105	0	0	54	51	100
Total	686	30	20	288	268	

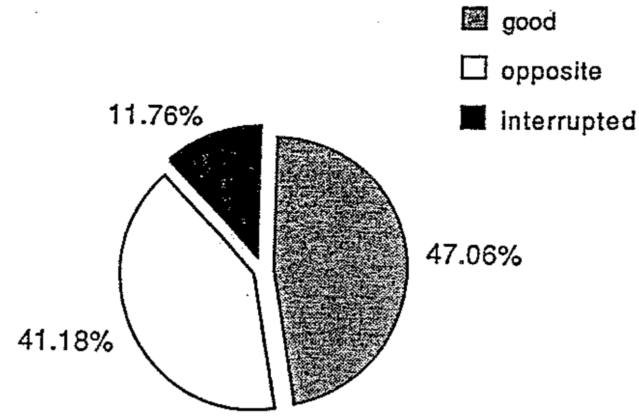

Fig. 3a. Distribution of voiced plosives according to the categories I,II,III.

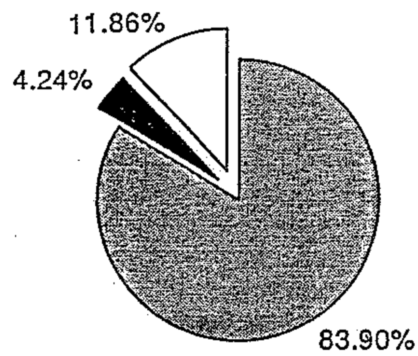

Fig. 3b. Distribution of the voiced fricatives according to the categories I,II,III.

The data in Table III correspond well with data concerning sound acquisition: plosives (including the consonant /k/) are mastered fairly well by children four to five years old; fricatives on the contrary are produced correctly for about 50%. However, it is surprising to see that children use correctly the voicing mechanisme within fricatives because even in adult data the use of voiced fricatives is rather unpredictable and adults tend to devoice them. So, the difficult combinatory mechanism of voicing and frication is not unknown to young children. At this age boys and girls do not show any differences in performance.
In Fig.3a an 3b we can see that the majority of consonants are produced correctly and we will examine more closely the corresponding phonetic aspects of temporal structure. In further statistical analyses, however, we do not make the distinction between the first and third category and consider them all to be exact productions of voiced and voiceless consonants.

3.2. Temporal control

The durational measurements of the consonants and the preceding vowels of the six subjects show some interesting effects. Concerning the statistical analyses, in terms of a repeated measurement design, we first examined the two replications of the 6 subjects in separate analyses of variance (MANOVA). This because children possibly do not behave the same in a replication task. The results of MANOVA concerning the first and second replication did not show any differences at all and we decided to take together for further analysis the data from both measurements. However, the data from the plosives /p,b,t,d/, fricatives /f,v,s,z/, the consonant /k/ and the consonant /m/ are kept apart in four separate groups.

In table IV and Fig.4 the averages of total consonant duration (closure duration + burst) of voiced vs. voiceless plosives, voiced vs. voiceless fricatives and of the consonants /k/ and /m/ are indicated. Also the average closure duration and burst duration concerned are indicated. Multivariate analyses of variance show several effects:

Within the plosives, there is a significant difference in total duration of the pooled voiceless consonants /p,t/ vs. the pooled voiced consonants /b,d/; (F(1,15)=56.57; p<.001). In Table IV we can see that the difference in closure duration is considerable. The difference in duration of the voiceless fricatives /f,s/ vs. the voiced fricatives /v,z/ is also significant; (F(1,15)=35.88; p<.001). Temporal behavior of the consonant /m/, one of the first consonants acquired, is very stable and almost adult-like. Also the voiceless consonant /k/ behaves differently from the labial and dental plosives; the variance due to place of articulation will be analysed and discussed later (par. 3.4).

Table IV. Mean total consonant duration (TD), closure duration (CD) and burst duration (BD) in ms. N=number of tokens; sd=standard deviation of total consonant duration.

Voiced	TD	sd	CD	BD	N
Plosive	72.79	30.28	61.05	11.66	113
Fricative	89.69	68.70	-	-	30
/m/	91.26	23.92	-	-	64
Voiceless	**TD**	**sd**	**CD**	**BD**	**N**
Plosive	149.19	60.17	123.81	25.33	191
Fricative	146.10	49.10	-	-	53
/k/	94.06	20.93	72.78	21.64	105

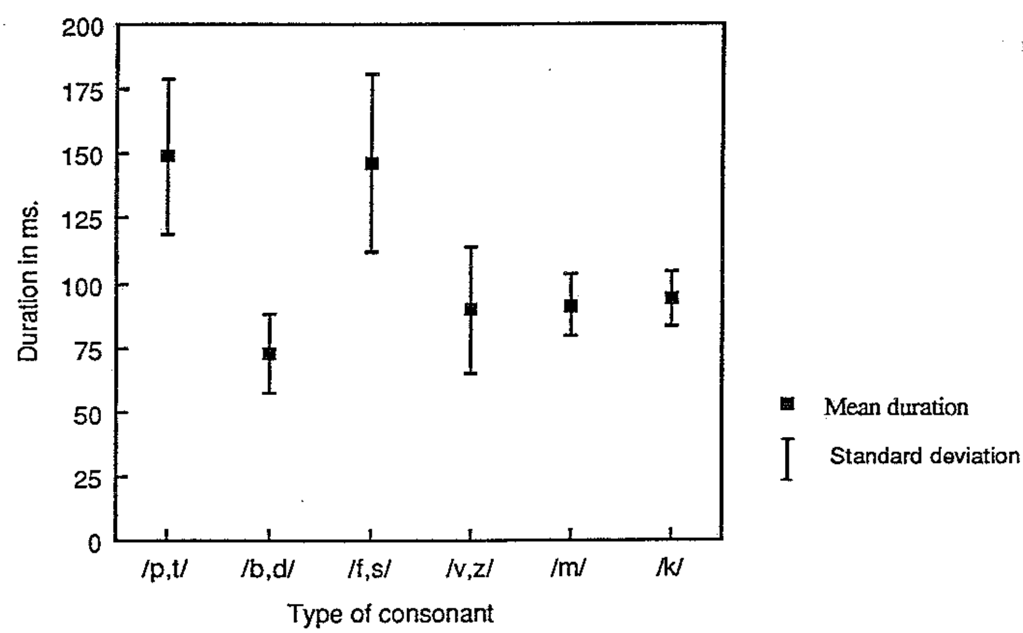

Fig. 4 Total consonant duration of intervocalic consonant in 4-year-old children. Standard deviations are given for the six types of consonants mentioned in Table IV.

For children having a slower speaking rate than adults the voiced consonants are rather short although the voiceless consonants are always lengthened considerably. In adults a mean difference of just 30 ms has been found (Slis, 1985); the children show a length difference between voiced and voiceless plosives of almost a factor 2.
Although there is a great variability between subjects, *all* children show the tendency of a short voiced consonant in contrast with a lengthened voiceless consonant. In addition, the large standard deviations of the voiceless plosives /p,t/ and the fricatives /f,s/ correspond to findings of Smith (1978) and probably show the difficulty of the laryngeal adjustment rules; a voiceless consonant demands an interruption of voice and a restart again which demands a good coordination of articulatory timing. The intervocalic voiced consonants just reflect a type of assimilation in the environment of two voiced sounds. Besides, there is no evidence that the voiced fricatives which are produced completely without vocal pulsing, that is [v] realized as [f] and [z] realized as[s], behave differently from the voiceless fricatives; the mean duration of the voiced fricatives [-voice] is 144.28 ms, the mean duration of the voiceless fricatives being 142.92 ms.

Because our material contains mono-morphemic and bi-morphemic words, we examined whether a difference between the closure durations of the voiceless consonants was present, due to the morphological construction of the word. However, no significant differences have been observed (Table V).

Table V. Average closure duration of voiceless plosives and fricatives in ms. in words containing one morpheme or two morphemes. 'Plos' refers to 'plosives', 'Fric' refers to fricatives. Duration in ms.

	1 morph.	2 morph.
Plos [-voice]	113.86	122.21
Fric [-voice]	150.87	140.13

Furtheron, no difference in the average consonantal duration beyond 8 ms can be found whether the consonants, i.e. plosives, fricatives, /k/ as well as /m/, are preceded by a short or a long vowel. In adult speech a coarticulatory effect can be seen (Slis, 1972):
- A long vowel, always marking an open syllable in two-syllabic words, causes the following consonant to be short. The consonantal gestures seem to belong all to the next syllable. Besides, the vowel reflects a large standard deviation.
- A short vowel causes the following consonant to be long. The opening and closing gesture of the consonant is considered to belong to different syllables (the ambisyllabic effect)

The children's utterances do not show this coarticulatory effect due to syllabic weight and the more detailed phonetic differentiation does not play a role yet. Their productive data can be represented as:

3.3. Vowel duration

Next to the contrast in consonantal duration we have examined the Dutch vowel length contrast and the influence of voiced and voiceless consonants upon the preceding vowel duration. Again we have separated the words containing the four types of consonants; plosives, fricatives, /k/ and /m/. The results of the vowel duration measurements are indicated in Table VI :

Table VI. Vowel duration in ms preceding voiced and voiceless consonants, (plosives + fricatives pooled), /k/ and /m/. Below the mean durations of short and long vowel duration are indicated, independent of consonantal environment; also adult mean durations of the same vowels are indincated. They are calculated from isolated words (Koopmans-van Beinum, 1980); ( )=standard deviation; N=number of tokens in children; subjects are pooled. Ratio=duration of long vowel divided by duration of short vowel.

	C [+voice]	C [-voice]	/k/	/m/
Short	142.16	148.32	146.99	138.10
N=	79	135	47	32
Long	232.36	232.21	233.21	206.91
N=	64	112	58	32

	4-year-old	Adult
Short N=293	145.33 (44.19)	116.00
Long N=266	229.42 (60.50)	200.45
Ratio	1 : 1.6	1 : 1.7

A significant difference between short and long vowels is present. We tested the durational difference in the short-long opposition in vowels preceding plosives ($F(1.15)=191.95$; $p<.001$) and before fricatives ($F(1,15)=132.73$; $p<.001$). It is clear that the short-long opposition is identical in all consonantal environments. Certainly, the children's vowel durations are longer than the adult ones but from the data it can be stated that the relative length difference is almost comparable. Apparently, 4-year-old children have acquired the phonological contrast in vowel duration more accurately than the consonantal durations.

However, the well known vowel lengthening or shortening effect in function of the following voiced or voiceless consonant can *not* be detected in the children's data. Whereas in Dutch adults show a difference of 30 to 40 ms (Slis, 1985), the corresponding effect can not be deduced from our developmental study (Table V). The difference between vowel duration in the voiced vs. voiceless context does not exceed the 10 ms neither before plosives nor before fricatives ; short vowels and long vowels do not behave differently.

The temporal organization of the children's articulatory and coarticulatory gestures in the voiced-voiceless distinction can be illustrated in a schematic representation (Fig.5a, 5b, 5c).

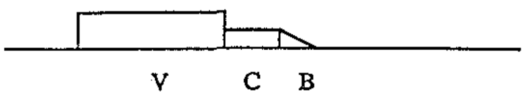

Fig.5a Sequence short vowel (V) voiced closure (C) and burst (B)

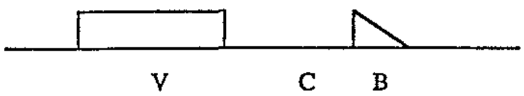

Fig.5b Sequence short vowel (V) voiceless closure (C) and burst (B)

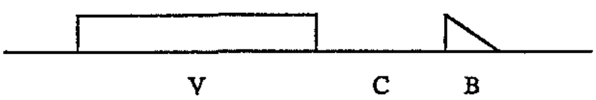

Fig.5c Sequence long vowel (V) voiceless closure (C) and burst (B)

As can be seen the difference in total consonant duration (mainly closure duration) between voiced and voiceless consonants is considerable and no coarticulatory effect is present concerning preceding vowel shortening or lengthening (Fig.5a vs. Fig. 5b).
Secondly, irrespective of the vowel (long vs. short) there is no difference in the temporal build-up of the following consonant (Fig.5b vs. Fig.5c).

3.4. Place of articulation

In par. 3.1. we reported the differences between the voiceless plosives /p/, /t/ and /k/. The consonant /p/ can be defined as [labial], the consonant /t/ as [dental] or [dental/alveolar] and the consonant /k/ as [velar]. They all reflect the build-up of a closure phase followed by a release. We measured the closure duration, burst duration and total duration (closure + burst) according to the same criteria (see par. 2.4.). An ANOVA procedure indicates a significant difference between the three consonants in 'total consonant duration' ($F(1,5)=68.04$; $p<.001$) and closure duration ($F(1,5)=53.36$; $p<.001$). No significant difference has been found for burst duration (Table VII).

Table VII. Total consonant duration (TD), closure duration (CD) and burst duration (BD) in ms for the voiceless plosives /p/, /t/, /k/ reflecting difference in place of articulation. N=number of tokens; subjects are pooled; ( )=standard deviation.

	TD	CD	BD	N
/p/	139.27	123.51.	16.79	126
	(59.81)	(60.11)	(12.31)	
/t/	143.69	106.36	33.36	96
	(61.72)	(23.81)	(20.87)	
/k/	94.06	72.78	21.64	105
	(23.91)	(62.63)	(10.06)	

A post-hoc comparison analysis (Scheffé's multiple comparison procedure) has been performed. According to Scheffé, the level of significance has been taken at p=.10. In Table VIII we give the crosstabulations and indicate the significant differences in durational measurements for 'total consonant duration', 'closure duration' and 'burst duration'.

Table VIII. Crosstabulations of significant differences (*) between the consonants /p/, /t/ and /k/ for total consonant duration (TD), closure duration (CD) and burst duration (BD). Level of significance p =.10 (Scheffé).

TD				CD				BD			
	/p/	/t/	/k/		/p/	/t/	/k/		/p/	/t/	/k/
/p/	-	-	*	/p/	-	-	*	/p/	-	*	-
/t/	-	-	*	/t/	*	-	*	/t/	-	-	-
/k/	-	-	-	/k/	-	-	-	/k/	-	*	-

Concerning total consonant duration the back consonant /k/ differs considerably from both front consonants /p/ and /t/ . The comparisons of closure duration reflect the sáme differences between back consonant vs. front consonants but also a significant difference is obtained between the front consonants /p/ and /t/. When we consider the burst duration there is a significant difference between 'dental' burst and 'labial' burst and also between the 'dental' burst and the 'velar' burst.
In short, the post-hoc procedure indicates that the temporal build-up of the velar consonant can not be compaired simply with the temporal build-up of the front consonants; it is the closure duration of /k/ which is shorter and more stable than those of /p/ and /t/. When we look at the burst durations we can see that the burst of the dental consonant /t/ exceeds those of /p/ and /k/, while in adults the burst of /k/ tends to be the longest.
Apparently, in correspondance with the vocal tract physiology of young children (Lieberman et al.,1972) the articulation back in the mouth when the mass of the tongue is involved, demands less activity, time, and less refinement than the articulation in front of the mouth with the tip of the tongue or the lips. From our data it is clear that the backward, vertical movement of the tongue during the consonant /k/ is the easiest articulation in VCV sequences.

4. CONCLUDING REMARKS

We will try to draw some conclusions from the results presented above and to formulate the specific interests of speech developmental aspects as far as possible. We think the conclusions can be rather straight and clear. The data reveal that the temporal characteristics of adult speech concerning the voiced-voiceless distinction is only partially present in the data of young children and can be discussed as follows:
For the material investigated it is evident that the four-year-old children are able to produce the voiced/voiceless distinction in plosives without any problem, the distinction in fricatives however certainly cause some problems. In most cases the voiced consonants are substituted by voiceless consonants. While at the phonemic

level a preference for voiceless consonants is present, at a more detailed phonetic level we can see a preference for voiced consonants in terms of durational characteristics. The temporal build-up of voiced and voiceless consonants show that children do not control yet "the time allowable for each unit" and that they tend to maximalize the opposition; the voiceless consonants show an overshoot and the voiced consonants are rather short and stable for young children having a slower and more variable performance than adults. In agreement with Ferguson (1977) we can state that the consonants children use during their babbling period (especially voiced consonants and the consonant /m/ where voice can be continuated) are phonetically more stable and more adult-like.In addition, concerning consonants having different places of articulation (such as /p/, /t/, /k/) the durational characteristics indicate that young children have a preference for 'ease of articulation'.

Regarding the voiced-voiceless distinction in intervocalic position, the 4-year-old children in our study seem to differentiate the durational characteristics that are most obvious; a clear distiction between voiced and voiceless consonants is present as well as an adult-like length distinction between long and short vowels. However, they do not manifest any interactive effect of coarticulation between V and C. There are two, probably interfering, explanations to give:

- Young children still depend on a syllabic *CV* - *CV* articulation
- In intervocalic position it demands a good articulatory coordination to produce a voiceless consonant with an appropriate timing in voice break, pressure build-up and restart of voice.

In accordance with DiSimoni (1974) we can conclude that the more segmental-oriented mechanism has to grow towards a more timing-oriented mechanism with a more refined motor control. In further research we will concentrate on 2 more groups of children, 6-years-olds and 12-years-olds, to examine in a developmental point of view these aspects of the voiced-voiceless distinction.

REFERENCES

Berg, J. W. van den (1958). "Myoelastic-aerodynamic theory of voice production", J. Speech Hear. Res., 1, pp. 227.

Blache, S. E. (1978). The acquisition of distinctive features. Baltimore: University Press.

Booij, G. E. (1981). Generatieve fonologie van het Nederlands. Utrecht/Antwerpen: Uitg. Het Spectrum.

Chen, M. (1970). "Vowel length variation as a function of the voicing of the consonant environment", Phonetica, 22, pp. 129-159.

Chomsky, N. & Halle, M. (1968). The sound pattern of English. New York: Harper.

DiSimoni, F. G. (1974). "Evidence for a theory of speech production based on observations of the speech of children", J. Acoust. Soc. Am., 56, 6, pp. 1919-1921.

DiSimoni, F. G. (1974a). "Influence of vowel environment on duration of consonants in the speech of three-, six- and nine-year-old children", J. Acoust. Soc. Am., 55, 2, pp. 360-361.

DiSimoni, F. G. (1974b). "Influence of consonant environment on duration of vowels in the speech of three-, six- and nine-year-old children", J. Acoust. Soc. Am., 55, 2, pp. 362-363.

Ferguson, C. A. & Garnica, O. K. (1975). "Theories of phonological development". In E. H. Lenneberg & E. Lenneberg (Eds.), Foundations of language development (Vol.I) New york: Academic Press, pp. 153-180.

Ferguson, C. A. (1977). "New directions in phonological theory: Language acquisition and universals research". In R.W. Cole (Ed.), Current issues in linguistic theory. Bloomington, Ind.: Indiana University Press, pp. 247-299.

Hawkins, S. (1984). "On the development of motor control in speech: Evidence from studies of temporal coordination". In J. N. Lass (Ed.), Speech & Language; Advances in basic research and practice, Vol.11, Academic Press Inc., pp. 317-375.

Jakobson, R. (1941). Kindersprache, Aphasia and und allgemeine Lautgesetze. Uppsala, [Translated by A. R. Keiler, Child language, aphasia and phonological universals, The Hague: Mouton, 1968].

Kent, R. D. (1981). "Articulatory-acoustic perspectives on speech development". In Stark (Ed.), Language behavior in infancy and early childhood, Elsevier North Holland, Inc., pp. 105-126.

Kirk, R. E. (1982). Experimental Design. Procedures for the behavioral Sciences (second edition). Belmont, Calif.: Brooks/Cole Publishing Company.

Koopmans-van beinum, F.J. (1980). Vowel contrast reduction. An acoustic and perceptual study of Dutch vowels in various speech conditions. Doctoral thesis, University of Amsterdam, The Netherlands.

Koopmans-van Beinum, F. J. & Van der Stelt, J. M. (1986). "Early stages in the development of speech movements". In B. Lindblom & R. Zetterstrom (Eds.), Precursors of early speech. Wenner Gren Int. Symp. Series, Basingstoke, Hampshire, England: Macmillan Press, pp. 37-50.

Klünder K. R., Diehl, R. L. and Wright, B. A. (1989). "Vowel-length differences before voiced and voiceless consonants: an auditory explanation", J. of Phon., 16, pp.153-169.

Lieberman, P., Crelin, E. S. and Klatt, D.M. (1972). 'Phonetic ability and related anatomy of the new born and adult human, neanderthaler man and chimpanzee', American Anthropologist, 74, pp. 287-307.

Macken, M. A. & Barton, D. (1979). "The acquisition of the voicing contrast in Spanish: a phonetic and phonological study of word-initial stop consonants", J. Child Lang. 7, pp. 433-458.

Menyuk, P. (1971). The acquisition and development of language. Cambr. Mass., Univ. Press.

Raphaël, L. J., Dorman, M. F. and Geffner, D. (1980)."Voicing-conditioned durational differences in vowels and consonants in the speech of three- and four-year old children", J.of Phon., 8, pp. 335-341.

Scheffé, H.A. (1959). The Analysis of Variance, New York: Wiley, 1959

Skinner, B. F. (1957). Verbal behavior. New York: Appleton.

Slis, I.H. (1985). The voiced-voiceless distinction and assimilation of voice in Dutch. Doctoral thesis, University of Nijmegen, The Netherlands.

Smith, B. L. (1978)."Temporal aspects of English speech production: A developmental perspective", J. of Phon., 6, pp. 37-68.

Snow, C. (1963). "A detailed analysis of the articulation responses of normal first grade children", J. Speech Hear. Res., 6, pp. 277-290.

Stampe, D. (1969). "The acquisition of phonetic representation". Paper presented at the 5th regional meeting of the Chicago Linguistic Society, pp. 443-454.

Waterson, N. (1971). "Child Phonology: A prosodic view", J. of Linguistics, 7, pp. 197-211.