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ABSTRACT

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AN INSTRUMENTAL ANALYSIS OF THE VOICING CONTRAST IN WORD-INITIAL STOPS IN THE SPEECH OF FOUR-YEAR-OLD ENGLISH-SPEAKING CHILDREN

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ABSTRACT. This paper reports on an investigation of the voice-onset-time (VOT) characteristics of word-initial stops produced by four four-year-old children. Instrumental analysis of the children's spontaneous speech showed that they had distinct distributions for voiced and voiceless stops at all three places of articulation and that there was very little overlap between voiced and voiceless cognates. Comparison of words uttered in isolation with words uttered in a sentence context revealed that these children had shorter VOT values in running speech. Reanalysis of data from younger children showed evidence of such modification according to context at age 1;9. However, even at age four the data were not completely adult-like: compared with adults, the four-year-olds had longer mean VOT values, there was a greater range of values and there was less modification according to sentence context. The four-year-olds' data were interpreted as further evidence for the position that in producing voiceless stops in terms of mean VOT values children first overshoot adult values and then only gradually draw them back towards adult values.

1.0 Introduction

In this paper we report data on the voice onset time (VOT) characteristics of word-initial stops in the speech of four-year-old American English-speaking children and compare them with similar data from two-year-olds and adults.[1] We use VOT here as a phonetic measure to trace the acquisition of the voicing contrast in English stops.

While several phonetic parameters underlie the control of voicing, VOT has so far proved to be the most reliable acoustic measure. In accordance with Lisker & Abramson 1964 and subsequent literature, VOT is defined as the time interval between the burst of a stop and the onset of glottal pulsing. Its physiological basis can probably be found

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in temporal control of the larynx in relation to supraglottal activity (Lisker & Abramson 1971). English has a voicing contrast at three places of articulation. With the voiced stops /b,d,g/ the onset of glottal pulsing is usually at or shortly after the burst (the "short lag" range), although some speakers tend to produce devoiced stops with glottal pulsing prior to the burst (the voicing "lead" range, denoted by negative VOT values). The voiceless stops /p,t,k/ are produced with a longer time interval between the burst and glottal pulsing (the "long lag" range). VOT also varies by place of articulation alveolar stops having longer VOT values than labial stops, and velars having longer values than alveolars.

Lisker & Abramson (1964) give figures for adult speakers of American English. Utterances of /b,d,g/ with lead are analysed separately from those in the short lag range. For words spoken in isolation they give means of 1ms., 5ms. and 21ms. for short lag /b,d,g/ respectively and -101ms., -102ms. and -88ms. for /b,d,g/ with lead values. The means for the voiceless series /p,t,k/ are 58ms., 70ms. and 80ms. respectively. In Lisker & Abramson's isolation data there is no overlap in the range of values for voiced and voiceless stops at any of the three places of articulation. When the words are spoken in sentences, the VOT distinction is reduced: the VOT values for voiceless stops are considerably shorter than when spoken in isolation and the ranges for voiced and voiceless cognates overlap.

In our longitudinal study of two-year-old English-speaking children we found evidence for three stages in the acquisition of the voicing contrast. In the first stage the children do not produce any distinction in their speech in terms of VOT in stops which are phonemically voiced and voiceless in the adult form: most tokens for both sets of stops fall in the range 0-30ms. and there are no differences in the mean values for voiced and voiceless phonemes. In the second stage the distribution for voiced and voiceless phonemes at any one place of articulation are highly overlapping; most tokens for both stops are still in the short lag range but the means for the voiceless stops are significantly longer than the means for the voiced stops. This is the first stage at which there is evidence of a distinction between the stops in the children's productions. We have hypothesised that under normal listening conditions adults are not aware of this first attempt at a distinction. In the third stage the children at first overshoot the adult values, producing voiceless stops that are considerably longer than their adult counterparts, and they then gradually draw them back towards the adult values.

The study of four-year-olds presented here provides a data point two years later when children have acquired productive control of most of the phonological oppositions of English but are still refining phonetic detail. The questions to be asked of these data are 1) what evidence can be found for developmental changes between age two and four that indicate qualitative differences in speech production at the two ages and 2) to what extent have the four-year-olds mastered the phonetic details of the adult VOT system?

In order to compare our data with the two-year-old data and with adult data, we carried out two analyses. We first analysed a sample of spontaneous speech to get our overall view of the VOT characteristics of the four-year-olds' stops.

However, it is difficult to compare this directly with adult data; a sample of spoken speech contains a web of interwoven variables which comes under the general rubric of "speech context" and which affect VOT considerably in adult speech. They include stress, speech rate, syntactic category, phonetic environment, sentence context and utterance length (Lisker & Abramson 1967; Disimoni 1974; Klatt 1975). Given the vagaries of child speech, it is difficult to categorise tokens in terms of many of these variables. However, some such breakdown is necessary for a direct comparison with adult data. Sentence context (i.e. at the simplest level the distinction between whether a token is uttered in isolation or in a sentence) is one variable which can be reliably assigned, and its effects on VOT in adult speech have been documented (Lisker & Abramson 1967). Further, of the variables mentioned above it appears to be the one which affects VOT values the most.

Our second analysis therefore looked at tokens which had been uttered in isolation and compared them with tokens in sentences. The breakdown of the data into these two categories gives a more precise comparison with adult data and provides another way of looking at the extent to which the four-year-olds' data are adult-like. It is also important for our comparison with the younger children: since the proportion of isolated tokens changed over time during the longitudinal study, spontaneous speech of the younger children could not be compared directly to the spontaneous speech of the older children.

2.0 Method

The subjects for this study were four children, two girls and two boys, who will be referred to as Karen, Hilary, Dan and John. Karen and Hilary were first-born and Dan and John second-born. They were all middle class monolingual speakers of American English who had been exposed to no other languages in the home and whose English was developing normally. Their ages ranged from 3;10.19 to 4;2.9 when they were first recorded

The children were recorded in a high quality sound-isolated room at the Stanford Speech Research Laboratory. Each child was recorded for half an hour on two occasions within a period of two weeks. Recording was carried out on a Revox A77 tape recorder with a Sony Electret microphone which was attached to a soft cloth vest which the child wore. The recording room was decorated as a playroom. The child sat with an experimenter and talked while playing with toys and looking at books. An observer sat in the control room taking notes on the sessions and operating the tape recorder.

The tapes of the samples of spontaneous speech obtained from these sessions were transcribed using a Revox A77 tape recorder and Superex St-pro B-V headphones. Words beginning with a singleton stop were transcribed phonetically and also categorised in terms of the sentence context in which they were uttered. They were first divided into two categories on the basis of whether or not the words were uttered in isolation. The non-isolated tokens will be referred to as the sentence data (although they in fact include a few instances of counting numbers and listing objects which are not true sentence frames). The sentence tokens were broken down into four further categories: sentence initial, sentence final, embedded in a sentence and embedded in a list.

From the tapes of each child we instrumentally analysed the first fifteen word-initial tokens of each of the six stop consonants of English. (Further tokens were later analysed for the comparison of contexts.) The VOT of the word-initial stops was measured using a Kay Sonograph 7029 ADC linked to a Tektronix Oscilloscope 564 by means of a locally designed and constructed triggering system. Further details of the procedures which were common to all our studies can be found in Huntington et al 1978. Frequency distributions were calculated for the data for each stop for each child; means, standard deviations and ranges were calculated and the differences between the means for voiced and voiceless cognates were compared using one-tailed t-tests. In the later analysis of the voiceless stops by context were also compared using one-tailed t-tests.

3.0 Resu

The overall results for the first fifteen tokens of each of the six stops are given in Table One. Production distributions are given separately for each of the four children; since their results were broadly similar to each other, their combined results are also given.

The data in this analysis represent a sample of the spontaneous speech of these children. All four children had distinct distributions for voiced and voiceless stops at all three places of articulation. There was a small amount of overlap in the ranges for voiced and voiceless tokens; individually, three of the children showed this at all three places of articulation, while the fourth, Karen, exhibited no overlap. In the combined results the interplace relationship found in adults was followed, the alveolar stops being longer than the labials, and the velars being longer than the alveolars, although none of the individual children followed this pattern in all respects. There were five instances of adult-like lead values and a further three tokens where there was slight lead, 0 to -10ms., which should probably be classified with short lag rather than with lead. (Such "short lead" does not occur in adults.) Six of the eight lead tokens were for /b/.

The second analysis was in terms of the speech context in which the words were uttered. Dealing with each of the voiceless stops /p,t,k/, for each child we compared "isolated" tokens and "sentence" tokens, instrumentally analysing additional words from the recordings where necessary. We aimed to obtain fifteen tokens in each category for each child; this was possible with the sentence data but there were not fifteen isolated tokens for each stop in the recordings.

The results of this analysis are given in Table Two. Although there is considerable variability in the individual children's results, the general pattern is that, as expected, the sentence tokens have shorter VOT values than do the isolated. In the combined comparisons the means for the sentence data are shorter than those for the isolated data at all three places of articulation, although none of the differences between the means are statistically significant. In adults the actual pos-

Child		KAREN	HILARY	DAN	JOHN	COMBINED
Age		4;2.9	4;0.15	3;10.19	4;0.28	
/b/	MEAN	3.80	7.47	4.07	-1.53	3.45
	N	15	15	15	15	60
	SD	4.97	5.96	47.61	33.27	28.73
	RANGE	-4/15	0/18	-117/54	-90/21	-117/54
/p/	MEAN	76.60	82.00	76.27	63.40	74.57
	N	15	15	15	15	60
	SD	32.71	43.33	36.67	32.25	36.23
	RANGE	41/143	3/174	25/162	21/106	3/174
/d/	MEAN	11.80	14.07	22.47	20.33	17.17
	N	15	15	15	15	60
	SD	8.85	11.20	12.49	13.[illegible]9	12.11
	RANGE	-5/31	0/41	6/50	3/4[illegible]	-5/50
/t/	MEAN	87.13	64.47	74.93	88.67	78.80
	N	15	15	15	15	60
	SD	56.99	49.22	32.11	31.70	43.90
	RANGE	34/236	4/163	22/132	41/150	4/236
/g/	MEAN	10.73	20.13	31.40	17.73	20.00
	N	15	15	15	15	60
	SD	6.92	8.89	13.27	37.77	21.60
	RANGE	0/23	0/39	15/58	-113/45	-113/58
/k/	MEAN	82.80	87.87	90.40	82.40	85.87
	N	15	15	15	15	60
	SD	24.69	53.60	49.37	21.74	39.10
	RANGE	48/125	27/204	40/224	35/126	27/224

Table 1. English four-year-olds: mean VOT values in milliseconds, number of tokens, standard deviations and range for each stop. (All differences in mean values between voiced and voiceless cognates are significant at $p < .001$.)

		KAREN	HILARY	DAN	JOHN	COMBINED
/p/	ISOLATED	68.00 (6)	107.55 (11)	81.77 (13)	62.75 (8)	83.05 (38)
	SENTENCE	71.00 (15)	78.00 (15)	65.47 (15)	61.87 (15)	69.08 (60)
	EMBEDDED	68.09 (11)	63.20 (5)	56.36*(11)	67.64 (11)	63.92*(38)
/t/	ISOLATED	100.00 (2)	77.00 (6)	80.43 (7)	79.30 (10)	80.72 (25)
	SENTENCE	78.73 (15)	50.80 (15)	64.60 (15)	81.93 (15)	69.02 (60)
	EMBEDDED	57.82*(11)	36.50*(10)	67.80 (10)	66.56 (10)	54.40*(41)
/k/	ISOLATED	86.43 (7)	138.67 (6)	75.20 (10)	90.80 (10)	90.97 (33)
	SENTENCE	80.53 (15)	96.60 (15)	85.80 (15)	76.00 (15)	87.47 (60)
	EMBEDDED	73.10 (10)	60.30*(10)	83.50 (10)	75.40 (10)	73.08*(40)

Table 2. English four-year-olds: mean VOT values in milliseconds and number of tokens for voiceless stops, broken down by speech contexts.

* significant difference between means for isolated and embedded tokens ($p < .05$).

ition of a word in a sentence can affect the VOT (e.g. prepausal lengthening in sentence final position, Klatt, 1975). To make a finer analysis, although with less data, we therefore dealt solely with tokens embedded in a sentence (i.e. excluding those in initial position, in final position and in lists) and compared these with the isolated tokens.

These data are given in Table Two. In general, the means for the embedded tokens were lower than the overall sentence figures. When compared with the isolated tokens the means for the embedded tokens were significantly lower at all three places of articulation. This was also true for some of the individual children's results.

4.0 Comparison with adults

The four-year-olds data is similar to that reported for adults. (We have used Lisker & Abramson's 1964 data for comparison. The various studies of adult speech give slightly different values; inspection of these other studies (e.g. Klatt, 1975, Moslin, 1978), however, shows Lisker & Abramson's original values to be representative.) In both adults and four-year-olds there were clear VOT distinctions between voiced and voiceless tokens at each place of articulation. The means for velar stops were longer than those for alveolars, which in turn were longer than those for labials. Overall in the sentence data there was some overlap between voiced and voiceless distributions at each place of articulation. However, the four-year-olds data were not completely adult-like: the mean values were longer than those for adults, they did not reduce as much in different sentence contexts, and they exhibited a greater range.

Lisker & Abramson 1967 have VOT data for isolated tokens and for sentence tokens which can be compared with the four-year-old data here. These are given in Table Three. Across all three places of articulation the children's mean values are consistently longer than the adults. This is true both for isolated tokens and for sentence tokens. The ratio of the sentence to the isolated means (S/I) shows the amount that VOT values are modified in the two contexts. These ratios for adults and four-year-olds at each place of articulation are also given in Table Three. We can see from the table that when the tokens are in sentences VOT values are reduced far more by the adults than by the children.

The children also exhibited a greater range of VOT values than the adults in Lisker & Abramson's study. With far more tokens the adult isolated values for /p,t,k/ ranged over 100ms., 75ms. and 85ms., repectively, while the children's isolated values for the same stops ranged over 228ms., 98ms. and 262ms., respectively. There is one difference between the two studies in the manner of data collection which could possibly account for this variation. The adults were reading sentences and presumably aiming for consistency (see Lisker & Abramson 1967, p18), whereas the child data were taken from naturalistic speech which probably included a greater range of expressiveness and hence variability. As noted before,

		FOUR-YEAR OLDS	ADULTS
/p/	ISOLATED	83.05	58.00
	SENTENCE	69.08	33.00
	RATIO S/I	.83	.57
/t/	ISOLATED	80.72	70.00
	SENTENCE	69.02	38.00
	RATIO S/I	.86	.54
/k/	ISOLATED	90.97	80.00
	SENTENCE	87.47	48.00
	RATIO S/I	.96	.60

Table 3. English four-year-olds: mean VOT values in milliseconds for isolated and sentence data compared with adult data from Lisker and Abramson 1964, p.394; 1967, p.10.

there were very few instances of adult-like voicing lead in the four-year-olds' data. This suggests that four-year-olds use prevoiced stops (i.e. with lead VOT values) less often than adults; however, we cannot be certain from the results of just four children, since not all adults use lead.

The picture that emerges from the comparison of these children with adults is that the four-year-old children have consistently longer VOT values for voiceless stops, that they do modify their VOT values in the two different contexts, but that they do not modify them to as great an extent as adults do. They also appear to exhibit more variability then adults.

5.0 Comparison with two-year-olds

It is difficult to compare these data on four-year-olds with the results of our longitudinal study of two-year-olds. Each of the four younger children was at a different stage of acquisition at the end of the study. One child did not have a clear contrast between voiced and voiceless phonemes and was still producing most tokens of both voiced and voiceless phonemes with short lag voicing. The other three had overshot adult values for voiceless tokens; one child was certainly beginning to draw her VOT values back toward adult values, and another, although exhibiting greater variability, appeared to be close to adult values by the last session.

Looking at the overall data, not broken down by sentence context, if we compare the four-year-olds' data with the data from the last sessions of the three two-year-olds who had a clear voicing contrast (Macken & Barton 1977), there were no obvious differences in mean VOT values, nor in variability expressed in terms of either standard deviation or ranges. There was, however, less inter-subject variaiton in the four-year-olds.

Since the four-year-olds modified their VOT values in different sentence contexts, we re-examined the two-year-old data to look for similar effects. The two-year-olds spoke less than the four-year-olds, so there is less data and less certainty with the comparison, but it is possible to compare the isolated and the sentence tokens on the last sessions of the three two-year-olds who had a clear voicing contrast (ages 2;0.10 to 2;1.17). The means for the overall data and the breakdown into isolated and sentence tokens are given in Table Four. (Because of the differences between the children we have not combined the data here.) In all of the eight comparisons between isolated and sentence data, the means are lower for the sentence data. It is clear from these figures that these two-year-old children were also modifying their VOT values in the different contexts. Thus, like the four-year-olds, their speech was sensitive to the context in which it was uttered. Since the data are spread thinly throughout several categories, we are hesitant to give a precise figure, but the data certainly suggest that the two-year-old children modified their speech in the different contexts to a similar extent as the four-year-olds.

Given that the two-year-old children modified their speech according to context on their last sessions, there are two reasons for wanting to look back through the earlier sessions of the longitudinal study. Firstly, we want to be sure that this systematic influence does not affect our earlier claims of the children overshooting the adult VOT values and then gradually drawing their values back. It appears that although the proportion of isolated tokens changed over time this did not affect our findings. To take the example of one of the two-year-olds, Tom, in the five samples of his language that we analysed between the ages 1;6.24 and 2;1.17, the percentage of isolated tokens in the samples went down consistently from 100% to 9%. If we had solely analysed isolated utterances throughout, the mean VOT values would have been longer towards the end of the study. Nevertheless, both isolated and embedded tokens followed the same pattern of increasing and then decreasing.

The second reason for looking back at the earlier sessions of these children is to find out if they had always been sensitive to context, even when they first produced words in sentences. For all three children modification took place earlier than these last sessions. We traced evidence of modification back to ages 1;11.8, 1;9.2 and 1;9.15 in Tom, Tessa and Jane respectively. Earlier than this, the situation is less clear-cut as there were fewer tokens in sentences.

	CHILD	TOM	TESSA	JANE
	AGE	2;1.17	2;0.10	2;1.16
/p/	OVERALL	32.33(15)	93.40(15)	71.39(13)
	ISOLATED	82.50(2)	97.63(11)	72.28(7)
	SENTENCE	24.61(13)	83.25(4)	70.33(6)
/t/	OVERALL	61.93(14)	100.20(15)	109.23(13)
	ISOLATED	98.50(2)	117.83(6)	176.00(2)
	SENTENCE	55.91(12)	88.44(9)	97.09(11)
/k/	OVERALL	91.60(15)	125.93(15)	124.62(13)
	ISOLATED	- (0)	145.29(7)	127.14(7)
	SENTENCE	91.60(15)	109.7[illegible](8)	121.66(6)

Table 4. English two-year-olds' mean VOT values in milliseconds and number of tokens for voiceless stops, overall and broken down by speech contexts.

We would need more data to evaluate whether the children modified their speech according to context in this manner when they first produced two word sentences.

6.0 Comparison with other studies

Two other studies of English-speaking children conflict with each other in the mean VOT values they report for children around this age. Zlatin & Koenigsknecht 1976 report data for two-year-old children (ages 2;6 to 3;0) and six-year-olds; for both age groups tokens were spoken in isolation and means for /p,t/ were approximately 70ms and the mean for /k/ approximately 80ms. Gilbert 1977, studying apical stops from the spontaneous speech of children aged 2;7 to 3;3, gives an overall mean of 140ms. for /t/. Our means for isolated tokens agree with Zlatin & Koenigsknecht's although our values are approximately 10ms. longer than theirs. (One difference between the two studies is that Zlatin & Koenigsknecht's values for each place of articulation were obtained from repetitions of only one or two words.) The means reported by Gilbert are much longer than either of these two studies; the differences we have found between different contexts are not great enough to account for such long VOT values; nor are there obvious differences in methodology to account for them. Since Gilbert's mean value covers six children, it is unlikely that the difference can be attributed to individual variation. We can offer no way of reconciling the different figures.

Our results with English-speaking children are comparable to our findings on four-year-old Cantonese-speaking children (Clumeck et al 1979). Like English, Cantonese has a VOT distinction between short lag and long lag and four-year-old Cantonese speakers had a clear voicing distinction in terms of VOT. However, both the English and the Cantonese results are very different from our findings with speakers of Spanish (Macken and Barton 1979). At four years the Spanish speakers we studied did not have a clear voicing distinction in terms of VOT. There are two important differences between English and Spanish in their voicing contrasts. Firstly, in terms of VOT, the voicing distinction in Spanish is a contrast between lead and short lag. Secondly, the voiced phonemes have commonly occuring allophones which affect word-initial stops. The influence of these two factors on the acquisition of the voicing contrast in Spanish is discussed in detail in Macken & Barton 1979.

In general our English results agree with those of other investigators (Kewley-Port & Preston 1974; Zlatin & Koenigsknecht 1976) that once a clear voicing contrast is acquired there appears to be little change between then and four years. However, the interpretation Zlatin & Koenigsknecht put on their data is that acquisition of the voicing contrast can be characterised as a consistent movement towards adult values; this does not fit in with the overall pattern observed in our studies. There was not a gradual extension of the VOT values of voiceless stops but rather the children first overshot the adult values and then only gradually drew them back towards the adult ones. Even at age four, our subjects produced voiceless stops with VOT values that were longer than their adult counterparts.

There have been relatively few instrumental studies of other phonetic parameters once children have acquired most of their phonology. Nevertheless, studies of duration of consonant clusters (Gilbert & Purves 1977; Menyuk & Klatt 1975; Hawkins 1978) and other segments (DiSimoni 1974; Smith 1978) have also found children's productions at this age to have greater duration than adults. It has been proposed that in terms of duration children's productions do not become adult-like until age seven (Gilbert & Purves 1977) or older (DiSimoni 1974). Our data support the postition that once children have acquired productive control of the phonological oppositions of their language they continue to refine phonetic details for several years. Our analysis of younger children's data nevertheless demonstrates that at least as early as 1;9 there is evidence of children modifying duration according to the speech context in which a word is uttered.

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