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Sex differences in voice onset time: a developmental study of phonetic context effects in British English

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Received

Running title: Developmental sex differences in VOT

Abbreviated title: Developmental sex differences in VOT and phonetic context

Abstract

Voice onset time (VOT) data for the plosives /p b t d k g/ in two vowel contexts (/i ɑ/) for 5 groups of 46 boys and girls aged 5;8 to 13;2 years were investigated to examine patterns of sex differences. Results indicated that there was some evidence of females displaying longer VOT values than the males. In addition, these were found to be most marked for the data of the 13;2-year olds. Furthermore, the sex differences in the VOT values displayed phonetic context effects. For example, the greatest sex differences were observed for the voiceless plosives, and within the context of the vowel /i/.

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I. INTRODUCTION

There are relatively few studies documenting sex differences in VOT, and some report sex differences in VOT for both adults and children (Koenig, 2000; Ryalls et al., 1997; Swartz, 1992; Whiteside and Marshall, 2001). Furthermore, the general pattern suggests that women produce longer VOT values than men (e.g. Koenig, 2000; Ryalls et al, 1997; Swartz, 1992). The factors which contribute to these sex differences have not been fully established but suggestions have included aerodynamic, physiological and anatomical factors (e.g. Koenig, 2000; Swartz, 1992). It has also been suggested that sociophonetic factors could go some way in explaining sex differences in VOT in one particular accent of British English (e.g. in Sheffield, South Yorkshire) (see Whiteside and Marshall, 2001 for a discussion).

Given the evidence for emerging sex differences during preadolescence, adolescence and postadolescence in the frequency components of speech (e.g. Lee et al., 1999), it is conceivable that VOT patterns may also continue to develop during adolescence. Therefore, sex differences in spectral components that may be emerging by this time, may also be present in temporal components of speech such as VOT. There is some evidence to support the emergence of sex differences in VOT in the plosives /p b t d/ within a single vowel context (/i/) of a group of 30 preadolescent children between the ages of 6;9 and 10;7 (Whiteside and Marshall, 2001). The sex differences which emerged were characterised by the girls having longer VOT values for the voiceless plosives /p t/ compared to the boys at age 10;7. Furthermore, the net effect of these sex differences resulted in the girls' VOT patterns displaying a more marked 'voiced'/'voiceless' contrast at age 10;7 for the cognate pairs /p b/ and /t d/.

One aim of the current study was to supplement the results of the aforementioned study in a number of different ways. Firstly, new participants representing a wider age range were recruited to the study. In addition, speech data representing a richer phonetic inventory were gathered to explore sex and age differences in VOT patterns further. The VOT data of the full set of English plosives (/p b t d k g/ were examined in two peripheral vowel contexts (/i ɑ/) to gather additional data on the extent to which age and sex differences in VOT patterns may be influenced by phonetic context. Age and sex differences, and their interaction with different phonetic contexts are more well established in the frequency domain of speech parameters such as vowel formant frequencies (Traunmüller, 1988). However, there is a lack of published data on how the interaction of factors such as age, sex and phonetic context affect the development of temporal speech parameters such as VOT. By investigating the effects of sex, age and phonetic context on VOT patterns, this study aims to add to the body of published data on individual differences in VOT (e.g. Koenig, 2000, 2001; Whiteside and Marshall, 2001), and how this temporal parameter develops in children between the ages of 5;8 and 13;2 years.

II. METHODOLOGY

A. Participants

Five groups of participants from two schools in Sheffield were recruited to the study: i) mean age 5;8 years; n=6); ii) mean age 7;10 years; n=10); iii) mean age 9;10 years; n=10); iv) mean age 11;10 years; n=10); and v) mean age 13;2 years; n=10). Equal numbers of boy and girls participated in each age group. All subjects: i) spoke with a similar regional accent ii) had lived in Sheffield all their lives and within 3 to 5 miles of the school; iii) had age-appropriate intelligence levels as judged by the class teacher; iv) were monolingual speakers of English; v) had no speech, language or hearing problems; and vi) volunteered to participate in the study with parental consent.

B. Speech stimuli

All subjects produced five repetitions of each of the plosives /p b t d k g/ in a syllable initial position within the phrase frame of "Say /pi, bi, ti, di, ki, gi, pɑt, bɑt, tɑt, dɑt, kɑd, gɑd/ again". The phrases and target plosives were elicited from the children in a randomized order using a repetition task via live presentation. A repetition task was chosen in preference to either a reading task, or a picture naming task for a number of reasons. Firstly, because the study included very young children with a range of reading abilities, this would have more than likely, had an effect on the children's VOT values. Secondly, it would not have been possible to elicit correct renditions of the word "ghee" (/gi/) in a reading paradigm, as the lexical item in question is both borrowed (Hindi) and occurs infrequently in both spoken and written English. Thirdly, it was not possible to represent all the target syllables pictorially to the children.

C. Recording and analysis

The speech data were recorded in a quiet room. Data was recorded directly onto a DAT (Digital Audio Tape) recorder (Sony, model TCD-D3). Subsequently, speech samples from each subject were digitized onto a Kay Elemetrics Computerized Lab (CSL) model 4300 using a sampling rate of 16 kHz. From this digital information, sound pressure waveforms and wideband (146 Hz) FFT spectrograms were generated and displayed. A bandwidth of 146 Hz provided adequate temporal resolution to take VOT measurements which were made directly from the spectrograms by measuring the distance between the release of the plosive to the onset of voicing (marked by the first visible sign of low frequency periodic acoustic activity in the spectrograms). The point of the plosive's release was taken at the first transient burst for all samples, including those which displayed multiple bursts. In the cases where measures of VOT needed validation, sound pressure waveforms were used. In the cases where both the speech waveform and the spectrogram were referred to for validation, the VOT measurement was taken from the same data source. In the cases where VOT was unclear, e.g. plosives being released with affrication or the presence of background noise, the speech sample was discarded.

To ensure consistency in the VOT measurements, a test of inter-rater reliability was carried out. The inter-reliability measures were conducted by randomly selecting one subject from each of the 5 age groups for reanalysis by a second rater. A Pearson's product-moment correlation was used to calculate the level of inter-rater reliability. A significant correlation coefficient (*r*=0.978, p<0.0001) demonstrated a high level of inter-rater reliability.

III. RESULTS

The median, mean and standard deviation values for VOT measurements are given in Table I by plosive (/p, b, t, d, k, g/), vowel context (/i/ and /ɑ/) and sex for the five age groups (i) 5;8 years; ii) 7;10 years; iii) 9;10 years; iv) 11;10 years; and v) 13;2 years). Table I illustrates the comparability between the median and mean values. In addition, the mean values for the VOT measurements are depicted in Figure 1. The VOT values across all age groups and subjects displayed expected patterns by place of articulation, and "voiced"/"voiceless" status; "voiced" plosives displayed shorter values than their "voiceless" cognates, and bilabial plosives displayed the shortest values, and velar plosives the longest. The order of magnitude of mean VOT values by plosive for all subjects was as follows: b (18 ms) < d (25 ms) < g (38 ms) < p (60 ms) < t (81 ms) < k (82 ms). In addition, the VOT values across all subjects and age groups displayed longer values within the context of the vowel /i/ (see Fig. 2).

<PLACE TABLE I, FIGURES 1, 2 & 3 ABOUT HERE>

With respect to developmental trends, the VOT data for the 5;8 year olds displayed a tendency for longer VOT values compared to the older age groups (see Table I and Fig. 1). In addition, the data for the 5;8 year olds displayed inconsistent trends in mean and median values with respect to sex differences. For example, longer values were observed for the females for some plosive and contexts (e.g. /tɑ/, /di/, /ki/ and /kɑ/), but not for others (e.g. /dɑ/ and /gɑ/) (see Table I and Fig. 1). There were consistent trends of longer VOT values for the females in the data of some of the older age groups (e.g. the data for the 7;10-, 9;10- and 13;2-

year olds. See Table I and Fig. 1). Therefore, in order to examine the effects of sex on VOT values, Mann-Whitney U tests were carried out for four of the five age groups. Tests were not carried out for the 5;8 year-olds due to the very small number of participants in this age group. Separate tests were run for each of four age groups (7;10 to 13;2 years), and for each plosive and vowel context. Mean VOT values for each subject were used in these non-parametric tests (for each age group: n=5 for M, and n=5 for F). Results indicated the following significant sex differences (p<.05, two tailed): i) Age 7;10 years – /dɑ/ (*Z* –2.611). - here females displayed longer VOT values; ii) Age 9;10 years - /pi/ (*Z* –1.984), /pɑ/ (*Z* –2.193), /dɑ/ (*Z* –1.984) - females displayed longer VOT values for all three phonetic contexts; iii) Age 11;10 years - /bi/ (*Z* –1.984) - here males displayed longer VOT values compared to the females; and iv) Age 13;2 years - /pi/ (*Z* –2.402), /ki/ (*Z* –2.193), /kɑ/ - (*Z* –1.984) females displayed longer VOT values for all three phonetic contexts. In addition, the following data displayed trends towards significant differences (p<.1).). i) Age 7;10 years – /gi/ (*Z* –1.776). - here females displayed longer VOT values; ii) Age 9;10 years - /ti/ (*Z* –1.776) - females displayed longer VOT values; iii) Age 13;2 years - /ti/ (*Z* –1.776), /di/ (*Z* –1.776), /kɑ/ - (*Z* –1.984) females displayed longer VOT values for both phonetic contexts.

IV. DISCUSSION

The VOT data for the plosives by place of articulation, and within the two different vowel contexts replicate findings that are widely documented in the literature (e.g. Lisker and Abramson, 1964; Nearey and Rochet, 1994; Port and Rotunno, 1979; Ryalls et al., 1997). However, given the differences in the syllabic structures representing the two vowel contexts, it is difficult to ascertain the true extent of the vowel context effects on the VOT values. This requires further investigation, but controlling for all aspects of phonetic context (i.e. syllable structure, place of articulation, vowel context) could only be achieved if real and non-words were used as speech stimuli.

When the VOT data were examined for age-specific trends, it was found that the 5;8-year olds displayed a tendency for longer VOT values compared to the older age groups, a finding which corroborates earlier evidence (Kent and Forner, 1980). When the data were examined for sex differences, significant effects were found to be inconsistent, and varied with age and phonetic context. Where significant effects were found, all but one of these (age 11;10 years - /bi/) indicated that the females had significantly longer VOT values than the males. These trends corroborate the findings of an earlier developmental study (e.g. Whiteside and Marshall, 2001).

Upon closer inspection of the data it is possible to see that the 9;10- and 13;2-year olds displayed the largest number of significant sex differences across the different phonetic contexts. However, although the 9;10- and 13;2-year olds displayed the same number of significant differences across the full range of phonetic contexts, the magnitude of these sex differences appeared to be greater for the13;2-year olds (see Table I and Fig. 1). Furthermore, when the trends towards significance ($p<.1$) were examined, a greater number of trends were observed for the 13;2-year olds. These developmental trends suggest that sex differences in VOT may be developmental in nature, and that sex differences in VOT may emerge during adolescence. The more apparent lack of sex differences, and the inconsistencies in the data for the 5;8- and 11;10-year olds deserves some explanation before the developmental emergence of the sex differences in VOT is discussed. The inconsistent patterns of sex differences for the 5;8-year olds would not be totally unexpected, and could be explained in light of evidence which suggests that the anatomical and physiological variables which affect voicing and phonatory function show minimal sex differences around this age (e.g. Hirano et al., 1983; Stathopoulos and Sapienza, 1997). However, due to the very small number of subjects who participated in this age group, it would be necessary to gather additional samples in order to substantiate this suggestion. The lack of sex differences for the 11;10-year olds is more difficult to explain in developmental terms as the data for this age group appear to be out of line with those for the 7;10-, 9;10- and 13;2-year olds (see Fig. 1). A possible explanation is the contribution of individual developmental differences to the findings reported here for such a small sample. Individual developmental differences in the developmental patterns of speech are widely documented, and have been found in both temporal and spectral components of speech (e.g. Hollien et al., 1994; Smith and Kenney, 1998). However, further data would be necessary from this age group in order to determine the extent of sex differences in VOT as a function of development.

The significant sex differences and the trends for sex differences in the VOT values of the 7;10- and 9;10-year olds are not totally unexpected in light of other acoustic phonetic evidence for sex differences in pre-adolescent children (e.g. Busby and Plant, 1995). In addition, the more apparent sex differences which are present in the VOT values of the 13;2-year olds could be explained in terms of the sexual dimorphism of the larynx (e.g. Hirano et al., 1983) and the vocal tract (e.g. Fitch and Giedd, 1999) which emerge during adolescence. It is likely that during this period the female larynx will have relatively higher levels of tissue stiffness compared to the male larynx which is going through significant developmental change during this developmental phase of the human lifespan. These higher levels of tissue stiffness in the female larynx may give rise to increased levels of glottal resistance (e.g. Netsell et al., 1991; Stathopoulos and Sapienza, 1997), which could in turn be contributing to the longer VOT values observed for the 13;2-year old females compared to their male peers (Table I). The intrinsic pitch differences that have been observed for a close and elevated front vowel such as /i/ compared to a open and lowered back vowel such as /ɑ/ (see Netsell et al., 1999 for a discussion), serve to further illustrate the possible contribution of tissue stiffness to longer VOT values which are observed in the context of the vowel /i/ across all speakers (see Fig. 2); effects which may also be contributing to the larger sex differences observed for the VOT values of the voiceless plosives within this vowel context (see Table I and Fig. 1). It is also possible that sex differences in supralaryngeal dimensions, configurations and constrictions may also be contributing to the longer VOT values for the 13;2-year old females. For example, the longer VOT values for the plosives, and in particular the voiceless plosives, within the vowel context /i/ (see Table I and Fig. 1) could be explained in terms of greater levels of airway resistance which cause a delay in the onset of voicing (e.g. Higgins et al., 1998; Nearey and Rochet, 1994; Port and Rotunno, 1979). The smaller dimensions of the female supralaryngeal vocal tract and relatively smaller vocal tract constrictions which will have greater levels of airway resistance compared to their male peers, may also explain why the 13;2-year old females have longer VOT values, particularly for the voiceless plosives. Furthermore, the sex differences for the voiceless plosives which are more marked in the context of the vowel /i/ , suggests that the constrictions associated with the vowel /i/ relative to the vowel /ɑ/ may also have underlying sex differences which are contributing to an interaction between sex differences in VOT and vowel context. In addition to vowel context, the sex differences in the VOT values of the voiceless plosives of the 13;2-year olds also appeared to vary by place of articulation. Not only did the VOT values in the context of /i/ display the most marked sex differences, but these sex differences were also greatest for the plosives /p/ and /t/ within this vowel context (see Table I and Fig. 1). However, syllable structure may have also been a contributory factor. Further data are therefore required to explore these suggestions further.

In summary, vowel context and place of articulation may be among the factors which have contributed to the sex differences in the VOT values of the voiceless plosives for the 13;2-year olds in the current study. In addition, the sexual dimorphism of the larynx (e.g. Hirano et al., 1983) and the vocal tract (Fitch and Giedd, 1999) may also be contributory factors. However, the interaction between these factors, and how they impact upon age, sex and individual differences in voicing, voicing function and VOT patterns deserve further investigation.

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TABLE 1. Median, mean and standard deviation voice onset time values (in ms) for /p b t d k g/ by vowel context, sex and age group

Plosive	Vowel	Age 5;8 years		Age 7;10 years		Age 9;10 years		Age 11;10 years		Age 13;2 years	
		M	F	M	F	M	F	M	F	M	F
/p/											
Median		66.9	65.5	46.7	66.5	49.7	66.3	57.9	57.1	46.6	85.2
Mean	/i/	72.5	69.1	53.8	68.4	52.6	71.0	55.1	56.7	50.5	85.6
SD		21.3	26.0	22.1	28.0	15.0	21.8	10.4	10.9	13.3	17.6
Median		69.3	63.1	43.7	65.0	53.3	64.6	48.4	44.7	50.5	55.4
Mean	/ɑ/	71.1	70.4	47.9	63.1	52.0	65.7	48.1	47.2	51.0	58.0
SD		17.0	22.6	18.4	26.2	12.4	16.6	13.6	12.2	12.2	13.8
/b/											
Median		18.1	13.8	15.9	11.2	18.3	21.6	18.7	13.3	15.2	21.7
Mean	/i/	20.8	18.2	16.5	13.8	20.7	23.6	19.0	14.7	19.8	22.5
SD		9.2	10.5	5.4	7.0	8.7	8.1	5.4	4.2	11.0	7.5
Median		19.6	12.9	14.3	13.6	14.5	17.6	14.8	13.9	14.9	17.1
Mean	/ɑ/	21.8	17.2	15.6	14.8	16.2	18.5	15.4	14.4	15.7	18.4
SD		11.8	9.5	7.4	7.7	6.0	8.5	4.4	4.5	5.0	4.7
/t/											
Median		94.3	95.5	76.2	105.4	77.3	95.1	81.6	81.2	81.9	98.4
Mean	/i/	102.0	106.5	79.5	104.7	80.0	95.7	80.1	79.5	82.1	99.8
SD		26.4	26.2	23.6	26.9	16.6	20.4	9.7	16.3	12.3	21.5
Median	/ɑ/	79.3	114.6	60.9	73.5	67.4	74.4	68.3	63.9	69.0	74.0
Mean		87.9	109.5	63.7	76.4	67.3	75.0	69.3	65.6	67.2	77.2
SD		30.8	23.6	18.7	22.8	18.3	12.4	12.0	15.5	11.5	19.0
/d/											
Median		34.6	38.1	18.4	32.1	22.3	32.6	19.6	22.7	22.1	30.4
Mean	/i/	35.1	39.8	24.9	29.5	25.1	35.2	20.9	25.1	24.3	31.4
SD		13.6	16.7	17.7	14.2	11.5	11.6	8.9	6.9	8.0	9.0
Median		26.5	19.9	13.1	23.0	17.1	24.7	17.9	20.4	19.7	23.3
Mean	/ɑ/	28.0	21.0	14.8	22.8	19.2	28.0	18.9	21.2	20.9	25.6
SD		9.0	8.6	6.2	7.1	6.5	10.8	6.0	4.0	8.1	7.4
/k/											
Median		111.2	94.6	76.9	90.8	74.3	94.1	80.7	74.8	67.2	96.0
Mean	/i/	104.3	94.2	78.4	89.7	78.8	93.9	82.0	74.3	71.1	99.6
SD		23.4	21.4	19.7	22.1	22.0	17.0	11.8	10.3	15.7	22.0
Median		88.8	115.8	76.2	87.8	68.8	78.9	70.1	65.9	70.4	88.4
Mean	/ɑ/	96.1	106.8	74.4	87.2	70.1	80.5	72.1	66.6	71.8	90.0
SD		29.2	27.7	23.7	25.9	12.7	18.0	12.8	9.2	12.7	16.9
/g/											
Mean		44.8	42.3	36.8	49.0	42.1	45.4	32.8	31.7	36.1	39.4
SD	/i/	46.7	44.3	35.3	50.9	39.4	49.5	33.8	33.1	38.1	43.1
		15.8	14.0	14.3	17.0	11.4	13.8	8.9	6.5	11.0	12.5
Mean		41.0	22.6	36.0	31.3	38.9	40.7	25.5	29.4	33.8	34.1
SD	/ɑ/	46.7	25.4	36.8	31.0	37.8	42.1	27.5	29.7	33.9	40.6
		16.0	9.7	16.1	8.5	10.9	11.4	7.6	8.5	8.6	12.9

FIGURE CAPTIONS

FIG 1. Mean voice onset time values (in ms) for /p b t d k g/ by vowel context, sex and age group (5;8 years, 7;10 years, 9;10 years, 11;10 years and 13;2 years).

FIG. 2. Mean voice onset time values (in ms) for /p b t d k g/ for all speakers by vowel context. Error bars display +/- 1SD of the mean, and mean VOT values are also indicated.

FIG. 1.

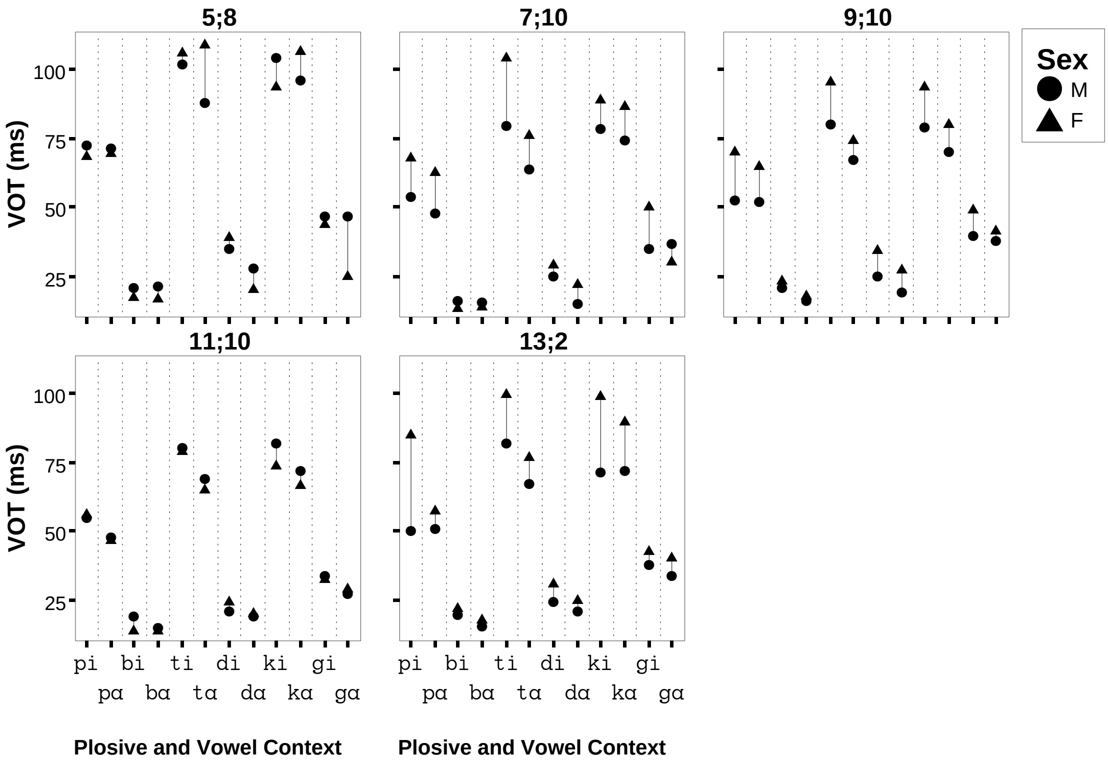
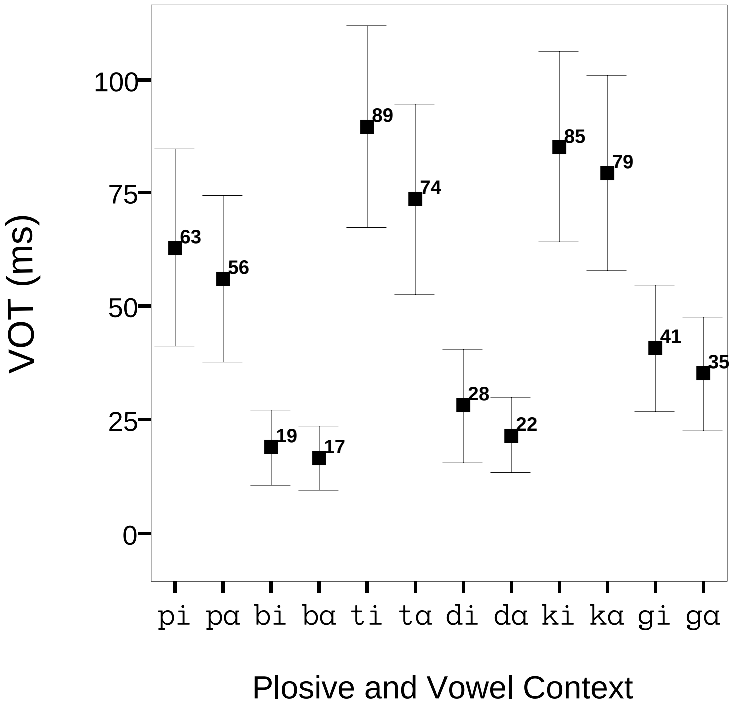

5;8
7;10
9;10
11;10
13;2
VOT (ms)
VOT (ms)
100
75
50
25
Sex
M
F
pi
pɑ
bi
bɑ
ti
tɑ
di
dɑ
ki
kɑ
gi
gɑ
Plosive and Vowel Context
Plosive and Vowel Context

FIG. 2.


VOT (ms)
100
75
50
25
0
63
56
19
17
89
74
28
22
85
79
41
35
pi pɑ bi bɑ ti tɑ di dɑ ki kɑ gi gɑ
Plosive and Vowel Context