# Intervocalic Stop Voicing Revisited*

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## ABSTRACT

The purpose of this study is to revisit the property of the Korean plain stops in intervocalic position. More specifically, focusing on a word-internal, intervocalic position, this study investigates 1) how often speakers pronounce intervocalic stops as fully voiced, 2) in what amount each speaker voice the plain stops during the stop closure, 3) whether the preceding or the following vowel influences the voicing of target consonants, and 4) the fundamental frequency pattern at the vowel onset after the target consonant shows any consistent pattern, regardless of whether voicing is present during the closure. The results of this study give strong support for the phonetic account of the voicing distinction in Korean. (Jun 1995, 1996).


**Keywords: intervocalic stop voicing, rise-fall dichotomy in F0**

## 1. INTRODUCTION

It is widely assumed that voiceless plain stops are voiced between two voiced segments in Korean. This change, which I call the Plain Stop Voicing (PSV) here, is argued to be categorical modification of the target consonants in most earlier analyses based on a phonological approach (Cho 1987, 1990; Kim-Renaud 1974; Kang 1992). Cho (1990), for example, presents the following voicing rule in the segmental framework.

(1) Obstruent Voicing:

[-continuant, -aspirated, -tense] -> [+voice] / [+voice] ___ [+voice]

(Cho 1990: p.48)

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In rule (1), plain, voiceless stops are voiced between two voiced segments. To properly represent this type of categorical assimilation, use of the feature spreading has been widely assumed: features of the target segment are delinked and relinked to create a new segment type using autosegmental feature spreading.

On the other hand, work based on phonetic experiments addresses a fundamental question with respect to such categorical explanation of the plain stop voicing process, since the voicing process shows variation depending on the context. According to Jun (1995), a plain stop is more likely to be voiced in faster rate, in shorter duration, and next to a segment with a stronger voicing gesture. Further voicing is sensitive to the prosodic domains. The results of the acoustic measurements (Silva 1992; Jun 1995) show that plain stops are voiced within words, but are progressively less voiced in the edge of the bigger prosodic categories. Based on gradience of the lenis stop voicing process, Jun (1995) argues that "Lenis [plain] Stop Voicing in Korean is not a phonological rule. Rather ... a gradient process." (p. 248). The PSV, therefore, can be accounted for from a different angle in these approaches. More specifically, it does not involve the categorical modification of segments at all, and rather better explained with a gestural overlap and reduction (Browman and Goldstein 1986, 1989). The PSV is better represented by reduction in the magnitude of the glottal opening gesture responsible for voicelessness, which is caused by the gestural overlap between the plain stop's glottal opening gesture and the following (and probably the preceding) vowel's glottal closing gesture, as shown in (2).

(2) Overlapping of glottal gestures


(based on Jun 1996: p. 250)

However, note that even in these analyses arguing for a phonetic account of the PSV, they all argue that in word-internal position, plain stops are almost completely voiced, for example, 91 % in Silva (1992).

This study shows that even in word-internal structure, the voicing distinction in Korean is not categorical, and thus not congruent with the phonological analyses considering voiced stops as allophones. The results of the experiment reported here thus provide further support for the phonetic interpretation of the Korean voiced stops.

To show this, I investigate the word-internal, intervocalic plain stops. The experiments conducted in this study are divided in three parts. In the first part, this study measures the extent of voicing in two different dimensions: 'the amount of voicing', the percentage of duration which is voiced as compared to the whole closure duration, and 'the likelihood of voicing' which refers to how often a fully voiced closure appears (Smith 1997). These two dimensions are investigated, examining whether there is any speaker variation in values of these two dimensions. Similar methodology can be found in Hayes and Stivers (1996) where the amount of voicing of English /p/ in the postnasal position was examined. For five subjects, the /p/ voicing after nasals was "purely quantitative", maintaining the phonemic contrast of /p/ with /b/. Moreover, the distribution of values varied greatly: the amount of voicing ranged from 13 % up to over 60 % of the closure duration of /p/. Based on these results, the postnasal voicing in English is argued to be truly phonetic. This study also examines the possible effects of preceding or following vowels on stop voicing in the second part. If the voicing of a plain stop is influenced by preceding or following vowels, this characteristic of gradience can be support for the phonetic, not phonological nature of the PSV. In the rest of this study, the fundamental frequency pattern at the vowel onset after the target consonant is examined to see the status of the PSV. Following Kingston and Diehl (1994), the natives' perception for the phonological category is shown to be reflected in the F0 pattern of vowels following the target consonants. Thus if the PSV, in spite of many characteristics of a gradient process, shows consistency with the fundamental frequency pattern of the vowel onset, we can say that this process is allophonic, namely, phonological.

## 2. METHODS

### 2.1 Stimuli

The test words consist of VCV sequences were constructed, in which the V segments are /i/, /e/, /ɨ/, /u/, /o/, /ɔ/, or /a/, and C segment was the bilabial stop /p/, as shown in (3). The reason for the place of articulation for stops limited to a bilabial position is that this position is more clearly displayed and thus more easily discernable, as compared to other places of articulation (Silva 1992). As for the vowels, /ɛ/ was not included in the test words, following Lee (1974), and Hong (1987), where /e/ and /ɛ/ are merged at the phonetic level. Each test word was recorded in the frame sentences as in (4).

(3) test words

$V_1$/p/$V_2$

$V_1$ = i, e, ɨ, u, o, ɔ, a

$V_2$ = i, e, ɨ, u, o, ɔ, a

(4) frame sentences

ikɔ irimi _____ ta. 'The name of this is ___'

2.2 Subjects and Recording

Four male speakers, who were students or professors at Seoul National University, participated in the recording. They were native speakers of the standard Korean and had no reported history of either speaking or hearing disorders. They were all born and raised in Seoul, Korea. They were recorded in a sound-proofed booth in the Language Research Institute at Seoul National University, using a microphone (AKZ, model C414B-ULS) and a high-quality cassette recorder (Tascam, model 122MKIII). Before recording, each speaker was asked to read a few randomly chosen test sentences to familiarize themselves with the materials. Then they were asked to read each test utterance three times in random order, at a natural, comfortable speed. The test sentences were presented in lists in Korean orthography.

2.3 Analysis

The recorded data were digitized onto a CSL (Computerized Speech Lab) (model 4300) at a sampling rate of 16000 sample/second, and then stored as files to be processed by the commercial software package MULTI-SPEECH (model 3700). Waveforms, spectrograms and pitch tracks for each token were created. The total number of tokens was 587 (49 words x 4 speakers x 3 repetitions). One token from a speaker was not considered in this experiment for its bad resolution in the waveform.

The marks were placed on the waveforms as well as spectrograms. When the two displays appeared to show minor discrepancies, the mark was placed with reference to the waveform. The cues for the beginning of stop closure were the reduction of complex, periodic waves in the waveform and the attenuation of the second formant structure of the preceding vowel in the spectrogram. The beginning of stop release was captured with a sudden increase in energy in both waveform and spectrogram. The amount of voicing during stop closure was measured with periodic vibration in the waveform and a voice bar in the spectrogram during the interval of stop closure. Again if there are minor discrepancies between the displays of waveforms and spectrograms, the former was the main cue. As for the measurement of pitch patterns, voicing period marks were placed at the beginning of each vowel period, from the vowel onset to the fifth vowel period. The cue for the beginning of the vowel onset was the beginning of the second formant structure. Then the fundamental frequency values were measured at each point.

## 3. RESULTS AND DISCUSSION

3.1. Experiment one: the likelihood and the amount of voicing

Is there any significant difference in voicing among speakers? It can be examined as to the "likelihood of voicing" and the "amount of voicing". Likelihood refers to how often speakers pronounce the target consonants as fully voiced, which is equal to the number of full voiced tokens out of the whole tokens. On the other hand, the amount of voicing refers to the percentage of voicing portion during the closure duration in each token in each speaker.

First, results of the experiments for the likelihood of voicing were presented in Table 1.

Table 1. The overall percentage of tokens produced by each speaker that werefully voiced

| speaker | percentage of voicing | total number of tokens | tokens which were voiced |
|---|---|---|---|
| speaker 1 | 34% | 146 | 49 |
| speaker 2 | 74% | 147 | 109 |
| speaker 3 | 78% | 147 | 115 |
| speaker 4 | 95% | 147 | 139 |

For each utterance containing a target stop, the likelihood was calculated for each speaker by counting the number of repetitions of those utterances that were fully voiced during the whole interval of closure. Table 1 shows that only one speaker shows more than 90 % of full voicing as proposed by previous phonetic work as well as phonological analyses. Speaker 1 shows only small number of tokens which are fully voiced. Overall intervocalic plain stops are realized with a varying degree of voicing depending on speakers in this prosodic position.

Now turn to the issue of the amount of voicing. The assumption that there is no difference in voicing among speakers is tested by comparing the mean values of voicing across speakers. The mean values, standard deviation and standard errors of voicing are reported in Table 2.

Table 2. The mean phonetic values and standard errors of voicing during stop closure among various speakers (ms).

| | Speaker 1 | Speaker 2 | Speaker 3 | Speaker 4 |
|---|---|---|---|---|
| Mean | 66.93 | 87.43 | 90.79 | 93.31 |
| (Standard Deviation) | (27.26) | (22.89) | (19.06) | (7.41) |
| (Standard Error) | (2.26) | (1.89) | (1.64) | (0.61) |

Table 3. The statistical significance of the mean voicing values at each preceding vowel.

| | Speaker 2 | Speaker 3 | Speaker 4 |
|---|---|---|---|
| Speaker 1 | -8.55 (0.00) | -9.97 (0.00) | -13.09 (0.00) |
| Speaker 2 | | -1.41 (0.16) | -4.55 (0.00) |
| Speaker 3 | | | -3.14 (0.00) |

Note: i) The t-values are reported, and those in parentheses are the p-values.
ii) The t-values are based on the mean value of the speaker in the column minus that of speaker in the row.

The means are compared pair-wise using the t-test, and the t-values are reported in Table 3. The results indicate that the above assumption is rejected at 1 % significance level in all pair-wise comparisons except for that between speakers 2 and 3. It is clearly shown that speakers show quite a large amount of voicing during the whole stop closure duration, more than 65 % in each speaker. But again the speakers varied considerably as to the amount of voicing during stop closure. This is graphically represented in the following figure.

In figure 1, although all speakers produced both voiced and devoiced tokens, they varied as to how many of their tokens fell into each of the four voicing categories. Speaker 1 produced the most devoiced tokens, while speaker 4 produced most of tokens as fully voiced.[1)]

1) An anonymous reviewer points out to me that speakers' variation in the amount of voicing is the result of the speed the utterances were recorded. For example, Speaker 1 showed more devoiced tokens than speaker 4, because the reviewer suggested that speaker 1 produced tokens at faster speed than Speaker 4. However, if the amount of voicing was affected by the speed at which speakers read tokens, again it would be a strong evidence for the phonetic explanation of the stop voicing in Korean. The phonolgical contrast would not be affected by utterance speed.

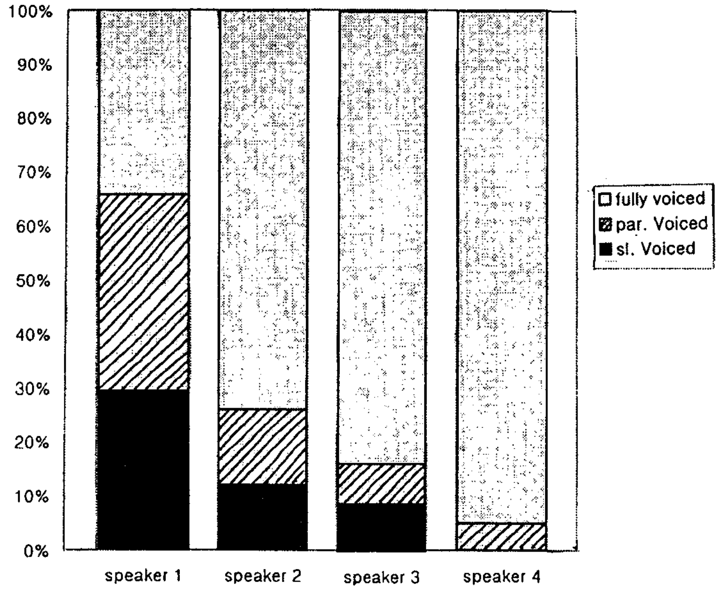


Figure 1. The overall percentage of tokens produced by each speaker that were voiceless, slightly voiced, partially voiced, and fully voiced. (fully voiced = 100 % of voicing, partially voiced = 51-99 % of voicing, slightly voiced = 1-50 % of voicing, voiceless = 0 % of voicing)

In sum, the likelihood and the amount of voicing pattern show that even in word-internal, intervocalic position, speakers do not show any consistent pattern in either of dimensions. Speakers vary considerably as to not only the number of tokens that were fully voiced, but also the amount of voicing during the stop closure. The results of the experiment reported here suggest that the PSV is not a categorical change as assumed in phonological analyses.

3.2. Experiment two: sensitivity of voicing to the preceding or the following vowels

In the previous section, it is suggested that the voicing distinction in Korean is not consistent among speakers. I turn next to the effect of adjacent segments, that is, whether the voicing of target consonants is influenced by preceding or following vowel types. Assuming the categorical nature of PSV, the voicing is expected to show any kind of consistent pattern regardless of the adjacent segments.

First, the sensitivity of the voicing to the preceding vowels was investigated. Table 4 reports the mean, standard deviation and standard errors of voicing by preceding vowels.

Table 4. The mean phonetic values of voicing during stop closure at each preceding vowel (ms)

| preceding vowels | o | a | i | u | e | ɨ | ɔ |
|---|---|---|---|---|---|---|---|
| mean<br>(s.d.)<br>(s.e.) | 89.15<br>(20.60)<br>(2.27) | 66.80<br>(33.33)<br>(3.66) | 90.76<br>(18.53)<br>(2.03) | 89.62<br>(9.35)<br>(1.03) | 88.97<br>(20.11)<br>(2.21) | 91.39<br>(16.84)<br>(1.49) | 84.65<br>(22.62)<br>(2.48) |

Table 5. The t-values of the pair-wise differences in voicing (preceding vowels)

| | a | i | u | e | ɨ | ɔ |
|---|---|---|---|---|---|---|
| o | 6.52 (0.00) | -0.47 (0.64) | -0.14 (0.89) | 0.00 (0.96) | -0.66 (0.51) | 1.31 (0.19) |
| a | | -6.97 (0.00) | -6.66 (0.00) | -6.47 (0.00) | -7.17 (0.00) | -5.21 (0.00) |
| i | | | 0.33 (0.33) | 0.52 (0.52) | -0.17 (0.17) | 1.78 (0.08) |
| u | | | | 0.21 (0.21) | -0.52 (0.52) | 1.45 (0.15) |
| e | | | | | -0.21 (0.71) | 1.26 (0.21) |
| ɨ | | | | | | 1.97 (0.05) |

Note: See note in Table 3.

Table 4 shows that the mean values range mostly around 90, except for the case when /a/ precedes. The pair-wise comparisons suggest the same. The results of t-test over the mean values of voicing are reported in Table 5. They indicate that the mean value of voicing differs at 1% significance level when /a/ precedes relative to when other vowels precede. They also differ, though at a lower significance level, between /i/ and /ɔ/, and also when /ɨ/ and /ɔ/. Each number in Table 4 shows statistical significance cancelling the assumption that there is no difference in the mean voicing values in terms of the adjacent vowels.

A similar exercise is made for the mean voicing values by the following vowels as above and the results are reported in Tables 6 and 7. The mean voicing values appear to differ significantly when either /o/ or /e/ follows, but little difference is observed when /a/, /i/, /u/ or /ɔ/ follows. Table 6 reports the mean, standard deviation and standard errors of voicing by following vowels, and Table 7 reports the results of pair-wise t-test over the mean values. The table formats are identical to those of Tables 4 and 5.

Table 6. The mean phonetic values of voicing during stop closure at each following vowel (ms)

| following vowels | o | a | i | u | e | ɨ | ɔ |
|---|---|---|---|---|---|---|---|
| mean<br>(s.d.)<br>(s.e.) | 92.26<br>(18.85).<br>(2.07) | 83.59<br>(23.86)<br>(2.63) | 84.94<br>(23.31)<br>(2.56) | 85.4<br>(23.33)<br>(2.56) | 78.05<br>(25.84)<br>(2.84) | 87.05<br>(24.93)<br>(2.74) | 89.96<br>(22.04)<br>(2.42) |

Table 7. The t-values of the pair-wise differences in voicing (following vowels)

| | a | i | u | e | ɨ | ɔ |
|---|---|---|---|---|---|---|
| o | 2.41 (0.02) | 2.04 (0.04) | 1.91 (0.06) | 3.96 (0.02) | 1.45 (0.15) | 0.64 (0.52) |
| a | | -0.37 (0.71) | -0.50 (0.61) | -1.54 (0.12) | 0.96 (0.34) | -1.77 (0.08) |
| i | | | -0.14 (0.90) | 1.92 (0.06) | -0.58 (0.56) | -1.40 (0.16) |
| u | | | | 2.05 (0.04) | -0.46 (0.65) | -1.27 (0.20) |
| e | | | | | -2.51 (0.02) | -3.32 (0.00) |
| ɨ | | | | | | -0.81 (0.42) |

Summarizing the results of experiments for the preceding and the following vowels' influence, a plain stop is more often voiced when it is preceded or followed by a certain group of vowels.[2] In other words, the PSV is influenced by a segmental context. This can be a further support for the non-categoriality of the PSV.

3.3. Experiment three: f0 change at the following vowel onset

To investigate further whether the PSV is a phonological process or a purely phonetic one, change in the onset value of fundamental frequency at the following vowel is examined. According to Silva (1994), change in f0 values during the first 10 % of the following vowel is significantly different among phonation types: the largest change in f0 occurs in the tense stops which is followed by aspirated and plain stops in

2) I don't discuss why certain vowels affect the voicing of consonants here, which is beyond the scope of this study.

this order. Following the phonological analyses, the f0 values show a consistent pattern regardless of the amount of voicing of the preceding consonants, whether the f0 values are slightly rising (Kim and Duanmu 1998) or slightly falling (Silva 1994).

To investigate the change in f0 values with voicing, it is necessary to define the following 5 types of changes. Here "f01" through "f05" represent the fundamental frequency values of the first five pitch periods of the vowel after the target consonant.

(5) Type 1 Change = f02-f01
Type 2 Change = f03-f02
Type 3 Change = f04-f03
Type 4 Change = f05-f04
Type 0 Change = f05-f01 (= Sum of Type 1 through Type 4)

As shown in Table 8, the f0 values generally decline as they change from f01 to f05, and it is notable that the Type 1 change is most significant. As a result, the Type 1 change accounts for 69 % of the total change denoted as Type 0 change.

Table 8. The mean values of changes of various types (Hz).

| | Type 0 | Type 1 | Type 2 | Type 3 | Type 4 |
|---|---|---|---|---|---|
| mean<br>(s.d.) | -14.37<br>(19,64) | -9.87<br>(18.64) | -2.40<br>(8.27) | -0.78<br>(8.95) | -1.32<br>(8.97) |

When these changes are linked to the level of voicing, the f0s are found to decrease less when voicing has a high value. To examine the result rigorously, the various types of changes are estimated as a linear function of the voicing levels using the ordinary least squares method. To put it differently, I run the following regression for each of the 5 types of the change in f0 values.

(6) Change = $\alpha + \beta *\text{voicing} + \varepsilon$, where $\varepsilon \sim N(0, \sigma)$

The results are reported in Table 9.

Table 9. The relationships among the change in f0s and voicing.

| | | Type 0 | Tyep 1 | Type 2 | Type 3 | Type 4 |
|---|---|---|---|---|---|---|
| correlation coefficient with voicing | | 0.323 | 0.310 | 0.030 | 0.004 | 0.031 |
| Regression | No Speaker Dummy[1)] | 0.270[3)] (0.033) | 0.246[3)] (0.031) | 0.010 (0.015) | 0.002 (0.016) | 0.012 (0.016) |
| | Speaker Dummy[2)] | 0.193[3)] (0.034) | 0.182[3)] (0.033) | -0.001 (0.016) | 0.015 (0.018) | -0.003 (0.018) |

Note: i) The potential differences among speakers in f0s and voicing are ignored, and the estimated equation is: each change= $\alpha$ + $\beta$ *voicing + $\varepsilon$.
ii) Any potential differences among speakers in f0s and voicing are controlled for with speaker-specific effect ( $\eta_s$ ), and the equation is: each change= $\alpha$ + $\beta$ *voicing + $\eta_s$ + $\varepsilon$, where s denotes speaker.
iii) Differs from 0 with 1% statistical significance.

The results in Table 9 indicate that most types of changes are positively associated with the level of voicing: both the correlation coefficients and most of $\beta$ estimates are positive. Given than all types of the changes are negative (See Table 8), the positive association implies that a higher value of voicing reduces the decline -- that is, the f0s decline by less when voicing takes a high value. It is notable that such positive association between the change and the level of voicing is significant only for the Type 1 change, the change from f01 to f02. The regression results indicate that, if the speaker variation is uncontrolled, a one unit increase in voicing reduces the decline from f01 to f02 by 0.246 units. Given that a similar increase in voicing reduces the decline from f01 to f05 (the overall change) by 0.270 units, the change at the first stage accounts for 91.1 % of the total changes.

It is also notable that the changing patterns of f0 values vary among speakers. The patterns are described in Figure 2, which plots the value of f01-f05 by speakers. The horizontal axis of the diagram represents speakers, each denoted by a number from 1 through 4. The vertical axis of the diagram measures the mean values of f0 values for each speaker, where each of f01-f05 is differently shaded.

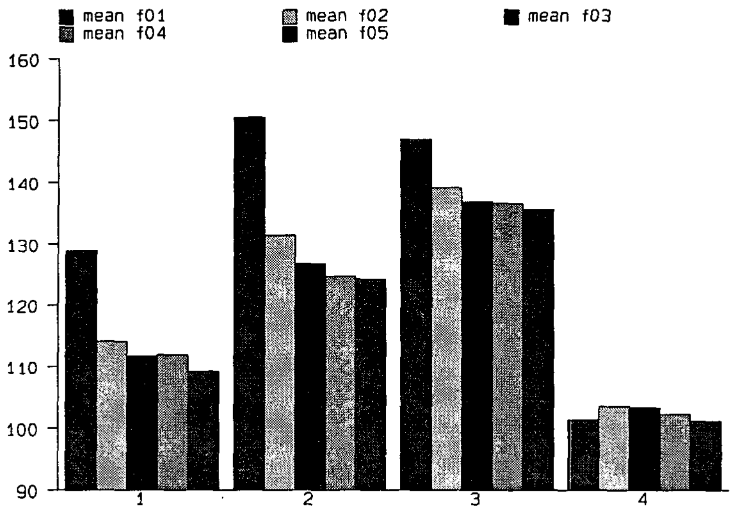


Figure 2. The mean values of f01-f05 by speakers

The results of the experiment for the f0 change show that the f0 pattern at the initial position of the following vowels varies considerably depending on speakers. As is clearly shown in figure 2, Speaker 1 through Speaker 3 show the f0 drop in the Type 1 Change, even though the degree of f0 drop in Type 1 Change is different depending on speakers. On the other hand, in Speaker 4, the f0 values increase slightly in the stage of Type 1 Change. Considering the results in figure 1 that Speaker 4 produced most of tokens as fully voiced, it seems that the high percentage of voicing is related with the f0 rise. Again the results of the experiemtns for f0 change can be a further support for the non-categorical characteristic of the PSV. The f0 change in the onset position of the following vowel is sensitive to the amount of voicing. Also the f0 change does not show any consistent pattern without any speaker variation. If the voicing distinction in Korean is phonological, namely, allophonic, the change of the onset values of fundamental frequency at the following vowel should be consistent regardless of the amount of voicing, since the plain stops are regarded as "voiced" in phonological representation. According to Kingston and Diehl (1994), the f0 perturbation pattern represents natives' perception for the phonological category. In English, for example, f0 values are lower in vowel next to initial as well as intervocalic [+voice] stops, even though initial stops are partially devoiced as in /day/ [de]. Based on this result, they argue that the f0 perturbation may be controlled by speakers, based on the phonological distinction. Thus if the voicing distinction is allophonic in Korean, the f0 change shows any kind of consistent pattern, regardless of whether voicing is present during the closure. Rather the results of the experiment conducted in this study suggest that the voicing distinction in Korean is purely non-categorical, namely, quantitative.

## 4. CONCLUSIONS

Summarizing the results of the experiments reported in this study,

1) the "likelihood of voicing": Only one speaker out of four shows fully voiced stops in word-internal, intervocalic position in more than 80 percent of tokens. All other three speakers show relatively smaller number of tokens with full voicing.

2) the "amount of voicing": The mean values of voicing during the stop closure show significant difference among speakers. One speaker shows only 67 % of the mean voicing duration, while another speaker shows up to 95 % of the mean voicing values.

3) the sensitivity of voicing to the adjacent vowels: Plain stops are more often voiced when they are preceded or followed by a certain group of vowels.

4) the f0 change: Overall, as the amount of voicing during the closure increases, the f0 values after the target consonatns are falling in the initial position of the vowel. Also speakers vary considerably as to the f0 change.

In any dimension given above, the PSV does not show any characteristic of categoriality: there is no consistent pattern to represent the distinctive feature of [+voice]. Rather, this process is shown to be quantitative and variable depending on the context. Based on these results of the acoustic experiments in this study, it would be possible to conclude that the PSV is a purely phonetic process, not allophonic as assumed in phonological analyses.

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