Perceptual cues for Korean tense and lax consonants

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The present study investigates the perceptual cues for tense and lax consonants in Korean. The results indicate that closure duration is a primary cue to the perception of tense and lax stops in intervocalic position, but not in word-initial position. In this position, VOT was found to be an important cue to the perception of these two categories. Contrary to expectations, burst amplitude does not play a role. These phonetic findings support the geminate analysis of tense consonants proposed by Han (1992), where intervocalic tense consonants occupy two timing slots and word-initial ones have only one.

1. Introduction

Most current work assumes that Korean has a three-way phonation contrast for stops and affricates, and a two-way phonation contrast for fricatives: *lax* or *plain* consonants are produced with slight aspiration; *aspirated* consonants are strongly aspirated; and *tense* or *reinforced* consonants are unaspirated and have some kind of tension involved in their articulation (e.g., Kim-Renaud 1974; Ahn 1985; Sohn 1987; Cho 1990). All obstruents are voiceless, but in intervocalic position, lax consonants may become voiced. Minimal triplets for stop consonants are presented in (1).

(1)　　　lax　　　　　　pul 'fire'　　　　tal 'moon'
　　　　　aspirated　　　p^{h}ul 'grass'　　t^{h}al 'mask'
　　　　　tense　　　　　p'ul 'horn'　　　　t'al 'daughter'

The purpose of this paper is to investigate the perceptual cues for tense and lax consonants in Korean. In this study, I test the perceptual role of three factors - Voice Onset Time (VOT), closure duration, and burst amplitude in tense and lax consonants, with respect to two prosodic positions (intervocalic and word-initial).

Consider first the factor of VOT. Production studies by Lisker and Abramson (1964), Kim (1965), and Han and Weitzman (1970) show that Korean tense and lax consonants are clearly distinguished from aspirated consonants in terms of VOT, since both tense and lax consonants have shorter VOTs than aspirated consonants. However, tense and lax consonants have overlapping VOT values, which is clearly shown in Table 1.

	/p'/	/p/	/pʰ/	/t'/	/t/	/tʰ/	/k'/	/k/	/kʰ/
mean	7	18	91	11	25	94	19	47	126
range	0:15	10:35	65:115	0:25	15:40	75:105	0:35	30:65	85:200
number	15	30	21	16	24	12	16	34	12

Table 1. VOT values (ms) of Korean stops in initial position. (Lisker and Abramson 1964: p 397)

These data suggest that the tense and lax stop categories of Korean are not distinguished by VOT alone.

Han and Weitzman (1970) and Abramson and Lisker (1971) conducted a series of speech perception experiments to see to what extent VOT might provide sufficient perceptual cues for distinguishing tense from lax consonants. Han and Weitzman (1970) investigated the acoustic features correlated with the three-way phonation type in Korean in the following two dimensions: timing of voice onset and quality of voice onset (fundamental frequency and intensity). An aspirated stop was taken, and the portion between the stop release and voice onset was cut back in 20 ms steps until this time interval was completely removed. Then, portions of voicing were cut back in 10 ms steps, for a total of 30 ms. The created tokens were presented to native Korean subjects. The result showed that, as VOT was cut back, subjects' judgments switched from aspirated to lax stops. However, even when stimuli with VOT values for tense stops were presented, subjects identified those as lax stops. Only stimuli with lead VOT were identified as tense stops. When the subjects identified stimuli as tense stops, the waveforms of manipulated tokens showed that the intensity build-up after voice onset was relatively rapid like that for tense stops. Thus Han and Weitzman (1970) conclude that VOT cannot distinguish tense from lax stops; instead, they argue that the intensity build-up can be a cue to differentiate these two phonation types.

Abramson and Lisker (1971) also investigated the perceptual efficacy of VOT for Korean initial stops. First they showed that the VOT values of tense and lax alveolar stops overlap somewhat in the measurements for two native speakers. They then prepared two synthetic VOT continua for perception tests. One ranged from a voicing lead of 150 ms to a voicing lag of 150 ms. The other continuum excluded all voicing lead variants. In the response curves for the latter range, three out of five subjects responded as expected and showed a partition of tense, lax, and aspirated in that order. This revealed that VOT was a straightforward cue. But the other two subjects showed only two phonation type

responses, namely, lax and aspirated. Responses to the larger continuum showed that in three out of five cases, subjects heard the voicing lead as tense stops, while the rest of the continuum was divided between lax and aspirated stops. This study implies that even though VOT contributes to distinguish the three phonation types in Korean, there must be other characteristics in addition to VOT.

Overall, the results of the studies on VOT reveal that there must be additional characteristics to differentiate the tense and lax categories.

Consider now the second factor of closure duration. Han (1992) and Silva (1992) showed that the difference in duration between intervocalic tense and lax consonants is much larger than that between tense and lax consonants in word-initial position. Measurements by Han (1992) for two male speakers, for example, are presented in Table 2.

	position			
	intervocalic		word-initial	
phonation	lax	tense	lax	tense
mean	54	145	53	83
number	24	24	22	24

Table 2. Closure duration (ms) of bilabial and alveolar stops in Korean (Han 1992: p 216).

First, the duration of tense consonants in intervocalic position is significantly longer than in initial position: the intervocalic tense consonants are almost twice as long as those in initial position. Second, the duration of tense and lax consonants in initial position is also different, but the difference is not so great as in the above case. Finally, in intervocalic position, tense consonants are almost three times longer than lax consonants. Thus, closure duration is an important factor to distinguish tense consonants from lax consonants in intervocalic position, but less so in word-initial position.

These phonetic findings have important implications for a phonologically adequate analysis of Korean tense consonants. Although most current work assumes that Korean has a three-way phonation type contrast in stops, Han (1992) proposes a geminate analysis for the tense consonants. I argue that Korean tense consonants are geminates of the lax consonants and that the feature of tension is the result of the phonetic implementation of geminates. Moreover, I argue that geminates show timing differences according to prosodic position, namely, intervocalic vs. word-initial: geminates in intervocalic position keep their timing slots during the derivation, while geminates in word-initial position lose one timing

slot in terms of Stray Erasure (Steriade 1982), due to the fact that in Korean only one timing slot is allowed in onset as well as coda position. For this reason, Korean allows the following three types of phonation for tense and lax consonants:

(2)   a. C   b. C   c. C   C
                | \   /
            [+tension]   [+tension]

If I simply represent the feature of "tension" as [+tension], the structure in (2a) is for word-initial tense consonants; that of (2b) is for lax consonants in word-initial as well as intervocalic positions; and the structure of (2c) represents intervocalic tense consonants. Thus so-called tense consonants can be distinguished from lax consonants through timing differences in intervocalic position, but not in word-initial position. As a result, the only factor which differentiates word-initial tense and lax consonants is "tension".

The third factor tested here is burst amplitude. According to Han (1992), closure duration is not sufficient to differentiate the two stop categories in word-initial position. Then the only factor for differentiation is the feature of "tension". This is clearly shown in the schematization of the two structures in (2a) and (2b). Here I test one possible candidate for "tension", burst amplitude. Pike (1943), Jaeger (1983), and many others claim that a greater force of articulation, which is assumed to be one of the crucial properties of tense segments, would necessarily be accompanied by a greater intensity, while Debrock (1977) argues that the intensity of consonants is not the property of "tension". I test these claims in the following perception experiments.

In sum, four perception experiments will be presented. Following a production study (Experiment 1), Experiments 2 and 3 investigate whether closure duration is an important perceptual cue for tense and lax consonants in intervocalic and in word-initial position, respectively. Experiments 4 and 5 test two factors, VOT and burst amplitude respectively, as perceptual cues in word-initial tense and lax consonants.

2. Experiment 1

In order to prepare materials for the perception experiments, a production test was first conducted. I measured the closure duration, VOT and burst amplitude of tense and lax bilabial stops in each prosodic position (intervocalic and word-initial).

2.1 Stimuli

Target segments and frame sentences are presented in (3) and (4).

(3) test words

	intervocalic		word-initial	
lax	opa	'overcoat'	pa	'see' (colloquial)
tense	op'a	'brother'	p'a	'mash'

(4) frame sentences

intervocalic: Chungsook _____ kayo

'Chungsook (a girl's name) 's ___ is......'

'As far as Chungsook's __ is concerned,'

word-initial: Sakwa _____ cuseyo

'Please ___ the apple.'

In this study, the phonation type contexts are limited to a single place of articulation, that is, bilabial position. The findings are, however, assumed to hold for alveolar and velar consonants as well.

2.2 Subjects and recording

For intervocalic tokens, one female native speaker of Korean, a graduate student in the Linguistics department at Cornell University, participated in the recording. The speaker was born and raised in Korea, and spent 2 years in the U.S. She read the randomized sentences containing the test words 9 times at a normal speaking rate. The materials were recorded in a sound-proof booth, using a cardioid microphone (Electrovoice, model RE20) and a high-quality cassette recorder (Marantz, model PMD 222).

For word-initial tokens, one male native speaker of Korean was recorded[1]. This speaker was also born and raised in Korea and came to the U.S. 7 years ago. Six repetitions of the test words were recorded in the same manner as described above. Neither speaker had a known history of either speech or hearing disorders.

2.3 Procedure

The test sentences were digitized on a Sun 3/160 computer at a sampling rate of 11025 Hz. Waveforms and spectrograms for each token were displayed using the commercial

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[1] This is the same speaker as one of the speakers in Han (1992).

software package *waves+* . The closure duration, VOT, and amplitude of each stop consonant token were then measured in each position. The beginning of stop closure was marked in terms of decrease in amplitude of the second formant of the preceding vowel in the spectrograms. The cue for the beginning of the release (end of closure) was a weak burst-spike in the waveforms and a vertical line in the spectrograms. Two tokens of /opa/ did not clearly show the beginning and end of closure and were therefore excluded from the measurements. The duration between the release point and the onset of voicing was measured for the VOT. Finally, RMS amplitude values for the burst, burst plus following aspiration, and the three vowel periods showing maximum amplitude were measured.

2.4 Results and Discussion
2.4.1 Closure duration

As shown in Table 3, the difference in duration between tense and lax consonants in intervocalic position is larger than in word-initial position. Even though in word-initial position tense consonants are significantly longer than lax consonants [p= .0001 by two-way ANOVA], this is assumed to be a phonetic difference. In contrast, in intervocalic position, these duration differences are so large that they are argued to be phonologically determined, not phonetically. These results are similar to those in Han (1992). Thus, the present corpus, although small, is adequate for the modeling of stimuli to be used in the perception experiments.

	intervocalic		word-initial	
	tense	lax	tense	lax
mean	126	45	85	60
range	121-133	35-50	76-97	58-65
number of tokens	9	7	6	6

Table 3. Closure duration (ms) of tense and lax bilabial stops.

2.4.2 VOT

The results in Table 4 show that tense consonants have relatively shorter VOTs as compared to lax consonants. One thing to note is that the VOT values of lax consonants are quite large when we compare these values with those in previous studies such as Lisker and Abramson (1964) and Han and Weitzman (1970). I will get back to this issue in Section 5.4.

	tense	lax
mean	8	48
range	7-11	28-69
number of tokens	6	6

Table 4. VOT values (ms) of word-initial tense and lax bilabial stops:

2.4.3 Burst amplitude

Tense consonants have large values of amplitude in all three measurement points, burst, VOT, and three pitches of vowels showing maximum amplitude. Since absolute RMS amplitude values cannot be directly compared because of potential variations in speakers' intensity levels, both measures were normalized in terms of the ratio of Noise/Vowel RMS amplitude values. It is interesting that lax consonants have larger RMS amplitude values than tense consonants, since the vowels following tense consonants have much larger amplitude values than those following lax consonants. Thus, if we take the ratio of Noise/Vowel in RMS amplitude values, tense consonants have smaller ratios. This result is not limited to the present study. The waveforms of a bilabial stop in Han and Weitzman (1970) also show larger amplitude in the vowels of tense consonants as compared to those of lax ones.

	tense			lax		
	burst	VOT	Vowel	burst	VOT	Vowel
mean	59	58	77	56	55	68
range	56-64	54-59	76-78	49-62	51-59	65-72
number of tokens		6			6	

Table 5. RMS amplitude (dB) of burst, VOT and vowel in word-initial tense and lax bilabial stops.

3. Experiment 2

In this first perception experiment, the closure duration of tense and lax bilabial stops in intervocalic position is manipulated to see if it plays a role in the perception of the two phonation types. The goal of this experiment is to test the perceptual importance of findings by Han (1992) and Silva (1992) who showed that intervocalically tense consonants are significantly longer than lax consonants. The implication of this finding is that in intervocalic position, as closure duration increases, subjects will perceive an increasing number of stimuli as tense, as compared to lax.

3.1 Stimuli

The method in constructing the stimuli was similar to that used by Hankamer, Lahiri and Koreman (1989). Using *waves+*, two sets of stimuli were created with closure duration varying incrementally between that of lax consonants and that of tense consonants. One continuum was made by lengthening an original lax segment. The other continuum was made by shortening an original tense segment. The original closure durations of the test tokens used for creating the stimuli were 43 ms for the lax consonant and 127 ms for the tense consonant. Thus, both were quite close to the average value of closure duration. To create the test stimuli, I took equal intervals of 10 ms between the minimum closure duration of lax stops and the maximum closure duration of tense stops. The silent interval corresponding to the closure of the original tense and original lax consonants was replaced, using a waveform editor, by silence intervals of 35, 45, 55, 65, 75, 85, 95, 105, 115, 125 and 135 ms. In sum, two continua with 11 members each were created, one based on an original tense consonant, the other on an original lax consonant.

3.2 Subjects

20 subjects participated in the perception test. 10 subjects were presented with the continuum created from the original tense consonant. The other subjects listened to the continuum created from the original lax consonant. They were all graduate students or post-docs at Cornell University, except for one subject, who was an instructor of an introductory course in Korean. Subjects were all native speakers of Korean and had no known history of hearing disorders.

3.3 Procedure

Each subject was tested individually in the phonetics laboratory at Cornell University. Subjects were seated in front of a response box containing two response buttons labeled *opa* and *op'a* in Korean orthography. They were instructed to decide whether the sound they heard via headphones (Sony MDR-7506) was *opa* or *op'a*, and to press the appropriate response button. Only one hand was used for response, and the responses were recorded by a PC with Bliss software (Mertus 1989) which controlled this experiment. Before the perception test began, I read prepared instructions to each subject, and ran a set of practice trials. At the end of the test, I debriefed each subject. The results from two subjects were not included in the analyses; one subject pressed only one button throughout the experiment, the other subject said that she could not figure out the difference between the stimuli in the continuum at all.

For the analysis of the identification data, the data were represented in terms of percent identification label as a function of stimulus number. More specifically, the data were expressed by % /p'/ response. Crossover points for each individual subject were determined by first transforming the % /p'/ responses of each subject to z-scores, and then doing a linear regression on the normalized values for the points that mark the shift between two unambiguous identification labels. The crossover point for each subject was determined by solving the regression equation for x, where y=50%.

3.4 Results

Figure 1 shows the mean percentage tense consonant responses at different closure durations. The line connected with diamonds represents responses to stimuli created from an original lax consonant /p/; the line connected with squares represents responses to stimuli created from an original tense consonant /p'/.
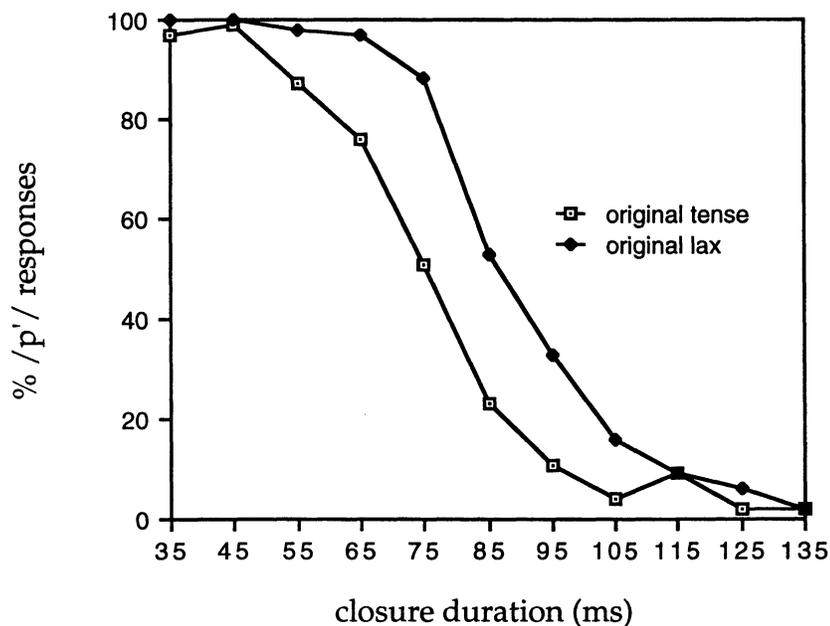
Figure 1. Mean percentage /p'/ responses at different closure durations for continua created from tense and lax stops.

Korean native subjects responded to the manipulated stimuli as expected. The curves in Figure 1 show that subjects perceived the stimuli categorically, with short closure durations giving rise to lax percepts and long closures giving rise to tense percepts.

While both continua yielded systematic results, the response curves are not identical. Responses to stimuli created from an original tense consonant cross over from lax to tense earlier than responses to stimuli created from an original lax consonant. The mean boundary values for original tense and original lax consonants were 82.9 and 103.7, respectively. A comparison of the twenty individual crossover points for the two groups showed a statistically significant difference in the location of the category boundary ([t (18) = -4.61, p = .000] by an independent two-tailed t-test). There seem to be additional characteristics other than the closure duration in the perception of these two categories.

3.5 Discussion

The results of this perception experiment show that closure duration is a primary cue to distinguish tense from lax consonants in intervocalic position. These results are consistent with the acoustic measurements by Han (1992) and Silva (1992). However, even though closure duration is a highly significant perceptual cue in distinguishing between tense and lax consonants, it does not appear to be the only cue. Otherwise, we would expect the two response curves to be identical. When the closure duration is ambiguous, secondary cues appear to contribute to the listener's perception. We might think of VOT as a secondary cue for the perception of these two consonants, since many researchers assume that lax stops are voiced in intervocalic position. For example, Abramson and Lisker (1970) state that lax consonants "assimilate to preceding voicing in medial position, and VOT separates all three categories" (Abramson and Lisker 1971: p 179). Thus, according to this study, in intervocalic position VOT is a primary perceptual cue for tense vs. lax stops, in that tense stops have positive VOT, while lax stops have negative VOT. However, the waveforms and spectrograms for intervocalic lax stops in the present study show that while one lax token out of the six was actually voiced, one of them was partly voiced, and the rest of them were voiceless. Figure 2 clearly reveals that Korean native speakers are not consistent with respect to voicing the lax stops. The word /opa/ was pronounced differently by the same speaker, as a voiced stop [oba] (top) and as a voiceless stop [opa] (middle), which is compared with the waveform of an intervocalic tense stop [op'a] (bottom), where no voicing occurs. Thus the assumption that the intervocalic lax stops become voiced allophonically is not consistently realized. These acoustic findings suggest that intervocalic voicing cannot be an important cue. Future research is needed to investigate the secondary cues in this position.
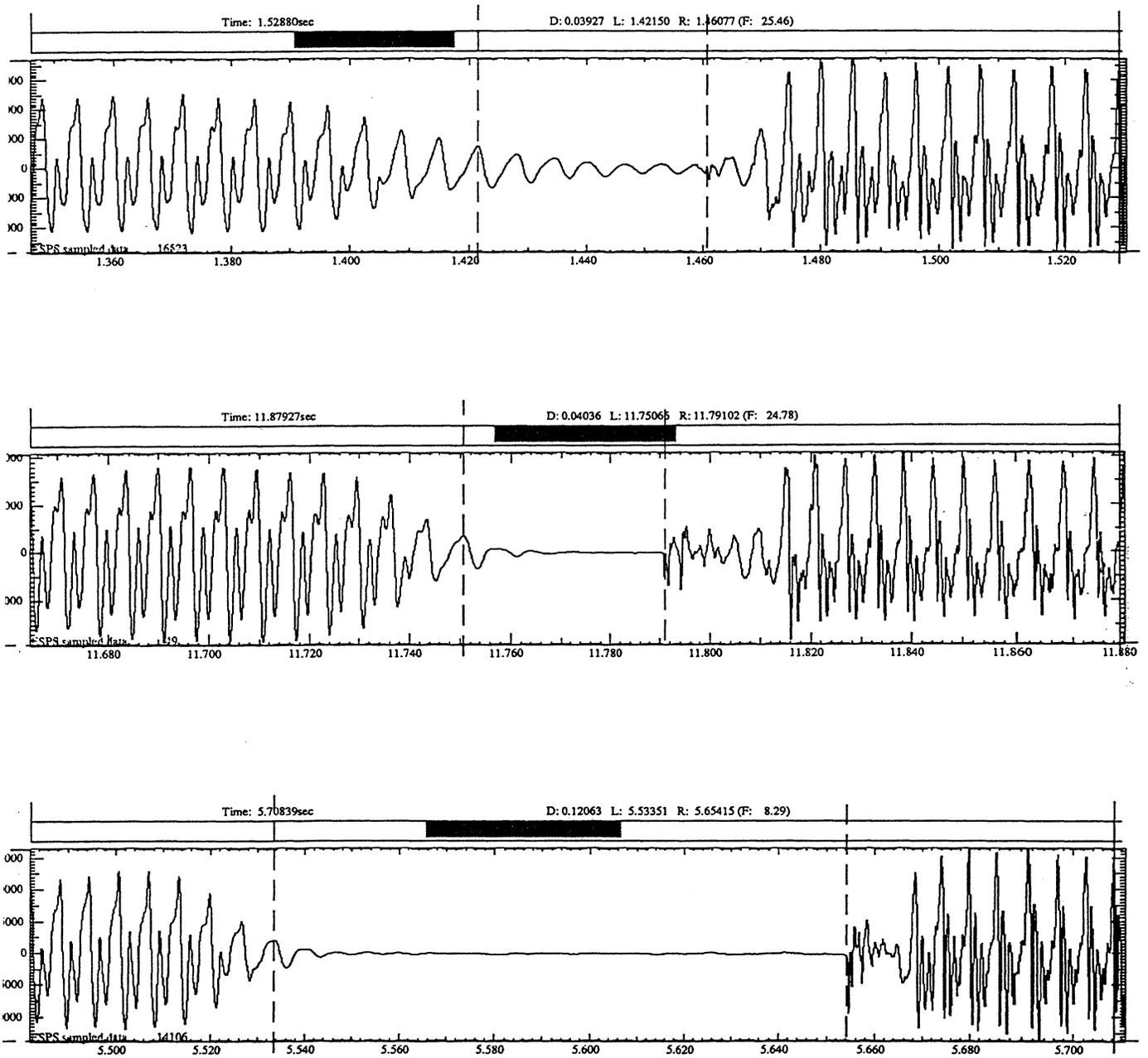
Figure 2. Sample waveforms for the /opa/ where /p/ is pronounced as voiced (top) and voiceless (middle) as compared to those for the /op'a/ (bottom).

4. Experiment 3

Given the result that closure duration is a primary cue to differentiate tense and lax consonants in intervocalic position, the following experiment investigates, using the same methodology, whether closure duration also plays a role in distinguishing these two stop categories in word-initial position. The results of production studies by Han (1992) and Silva (1992) suggest that closure duration may not distinguish these two stop categories in word-initial position, since the length difference between them is smaller than in intervocalic position.

4.1 Stimuli

Stimuli were created using the same methodology as in Experiment 2. Silent intervals corresponding to the closure duration were 55, 65, 75, 85, 95, and 105 ms. The closure durations of the test tokens used for creating the stimuli were 51 ms for the lax consonant and 74 ms for the tense consonant.

4.2 Subjects and Procedure

Ten subjects participated in the experiment. The presentation order of the two continua was counterbalanced. Five of the subjects first listened to the continuum made from an original tense consonant followed by that made from an original lax consonant. The other five first listened to the continuum made from an original lax consonant and then to that from an original tense consonant. Subjects were asked to identify stimuli as either *pa* or *p'a*. All other procedures were the same as in Experiment 2.

4.3 Results

Figure 3 shows that subjects did not perceive the stimuli categorically and that the two curves, one from an original tense consonant, and the other from an original lax consonant, were very different.
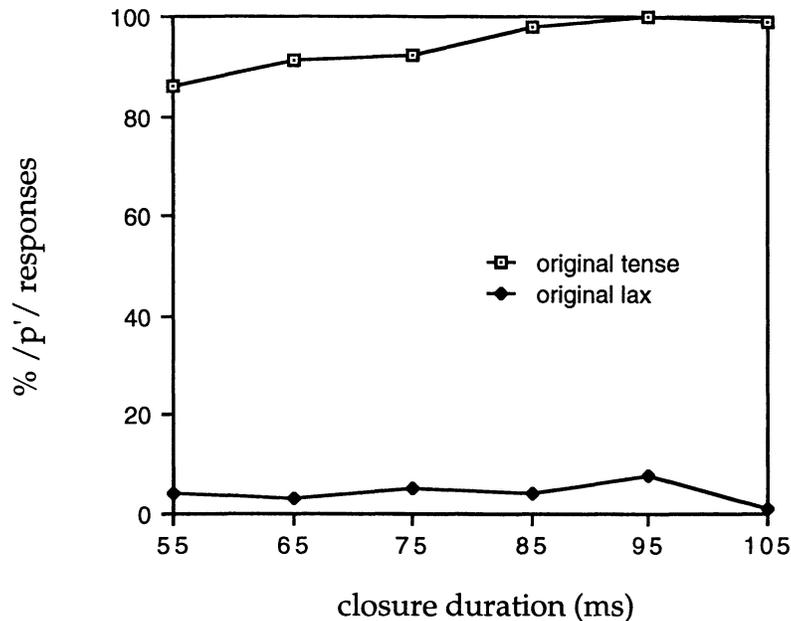
Figure 3. Mean percentage /p'/ responses at different closure durations for continua created from tense and lax stops.

4.4 Discussion

These results show that closure duration is not a factor in distinguishing tense from lax consonants in word-initial position. Regardless of manipulated closure duration, stimuli made from an original tense consonant were perceived as tense, while stimuli created from an original lax consonant were perceived as lax. Thus, closure duration can clearly not override other cues: no matter what we do with closure duration, perception remains the same. This is in good agreement with the results of acoustic measurements by Han (1992) and Silva (1992). It also supports the phonological argument by Han (1992) that in word-initial position, tense and lax consonants both have only one timing slot, and that they are structurally indistinguishable. Then a question arises here: what is the primary perceptual cue for word-initial tense and lax consonants? In the next two experiments, I will test two candidates, VOT and burst amplitude.

5. Experiment 4

Given the result that closure duration does not play a role in the perception of tense and lax consonants in word-initial position, the primary perceptual cue for these two phonation

types in this position is investigated in the present experiment. In this experiment, I examine whether VOT contributes to the perception of tense and lax stops, even though previous studies (Han and Weitzman 1970, Abramson and Lisker 1971) suggest that VOT does not play a role in the perception of the two phonation types.

5.1 Stimuli

A test continuum was created from computer-edited versions of natural speech. The methodology for creating these stimuli was similar to that used by Miller and Dexter (1987) and Burton, Baum, and Blumstein (1989).

One token each of *p'a* and *pa* was used to create a single *p'a-pa* series. The VOT value of the original *p'a* was 9 ms, while that of the original *pa* was 53 ms. The test continuum was created by replacing increasingly longer segments of the initial portion of *p'a* with segments of equal duration taken from the initial portion of *pa*. The first stimulus is the original *p'a* token. For the second stimulus, the 12 ms of burst plus following aspiration of *p'a* was replaced by 12 ms of the initial noise part of *pa*. For the third stimulus, the noise part and the first pitch period of *p'a* were replaced by those of *pa*. For the fourth stimulus, the noise part and the first 2 pitch periods were replaced, and so on, until, for the 7th stimulus, the first 56.4 ms were replaced, which approximately corresponded to the original VOT value of *pa*. The overall duration of each CV token was the same. To determine the appropriate step-size, cursors were placed at zero crossings of the vowel waveforms. The duration of noise (burst + aspiration) and vowel and step size of the continuum are presented in Table 6.

stimulus	VOT	vowel	step size
1	9	120	
2	12	117	
3	20.9	108.1	8.9
4	29.7	99.3	8.8
5	38.6	90.4	8.9
6	47.4	81.6	8.8
7	56.4	72.6	9

Table 6. Duration of VOT, vowel, and step size (ms) for the test continuum members.

Stimuli were then transferred to a PC with Bliss software.

5.2 Subjects and Procedure

9 Korean subjects participated in this experiment. They had no reported history of hearing impairment. The procedure was the same as in Experiment 2. Practice trials were presented and then each continuum member was presented 10 times in a random order for a total of 70 stimuli. Subjects were asked to indicate what they heard by pressing one of the two buttons labeled *p'a* or *pa* .

5.3 Results

Figure 4 displays the mean identification function for the continuum *p'a-pa*, across subjects. The percentage of /p/ responses is plotted as a function of VOT. The first stimulus represents the VOT value for the original /p'a/ token. As the figure shows, /p/ responses increase as VOT values increase.
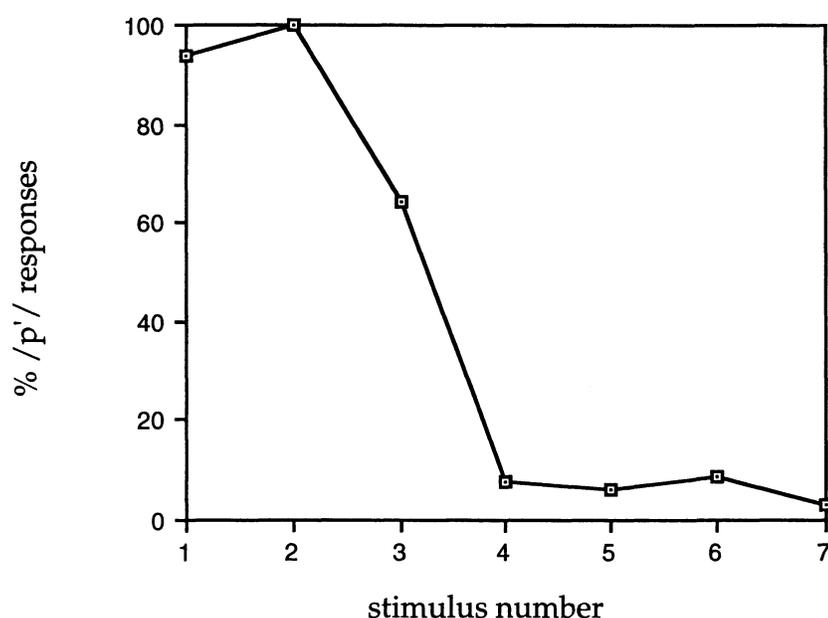
Figure 4. Mean percentage /p'/ responses at different VOT values. The first stimulus represents the VOT value for the original tense consonant.

5.4 Discussion

The results of the present experiment show that VOT is an important factor for the perception of tense and lax consonants in word-initial position. This is contrary to the claims of perceptual studies by Han and Weitzman (1970) and Abramson and Lisker (1971), in which VOT was argued to be insufficient to differentiate tense consonants from

lax consonants in word-initial position.

It is of interest that the VOT values measured in the present study are much greater than those measured in earlier works. The mean VOT value for the bilabial stops in initial position is 18 ms in previous analyses, while in my corpus, it averaged 48 ms. In addition, lax consonants in the present study have VOT values ranging from 28 ms to 69 ms. The tendency for the larger value for VOT and its wide range is also found in other recent phonetic studies, such as Silva (1991, 1992) and Lee (1994). Although Silva (1992) did not explicitly mention that VOT is sufficient to distinguish between lax and tense consonants, he pointed out the fact that his VOT values are noticeably greater than those gathered in previous works, as shown in Table 7.

	p	t	k	mean
C.-W. Kim (1965)	23	38	45	35
Lisker and Abramson (1964)	18	25	47	30
Han and Weitzman (1970)	23	28	52	35
Silva (1991)	60	51	71	61

Table 7. Mean VOT values (ms) for lax stops in initial position. (based on Silva 1992: 37)

Lee's (1994) measurements also have noticeably greater VOT values than those in previous studies. As she shows in her Figure 6, the VOT values of the bilabial and alveolar stops are greater than 40 ms, while the VOT values for velar stops are above 90 ms. Based on these results, Lee argues that "VOT and the accompanying aspiration is one of the most salient acoustic properties in distinguishing the three stop categories of Korean. Though it has been reported in Kim (1965) that the VOT range of unaspirated consonants [tense consonants] and slightly aspirated consonants [lax consonants] might show overlap, all differences are statistically significant on the 1 % level in my data" (Lee 1994: p 3). It is unclear what accounts for these discrepancies. As Silva (1992) points out, there might be differences in the way the VOT was measured. Or the value of VOT has increased in Korean native speakers. The earlier acoustic studies were conducted some 25 to 30 years ago. The younger generation recorded in the more recent studies may produce lax stops with larger VOTs.

The discrepancies between the present perception study and previous ones such as Han and Weitzman (1970) and Abramson and Lisker (1971) might be due to differences in methodology. In the present study, the test stimuli were created by replacing the silent

interval corresponding to the VOT of original tense and original lax consonants. In contrast, previous studies systematically cut back the aspiration portion of one token of an aspirated consonant. This methodology is less desirable since it may introduce spectral discontinuities between the manipulated aspiration portion and vowel onset. It is not clear at this point if this methodology affects the perception of stimuli, but it seems that the methodology used in the present study contributes to the result of categorical perception of the VOT continuum.

6. Experiment 5

In this experiment, I examine if burst amplitude is a cue to distinguish tense from lax consonants in word-initial position. As shown in Experiment 3, closure duration does not contribute to the perception of these two phonation types in this position, and thus the only factor for differentiation is the feature of "tension", which is interpreted as burst amplitude in Pike (1943), and Jaeger (1983).

6.1 Stimuli

Stimuli for the burst amplitude continuum were created based on the stimuli of the VOT continuum, used in Experiment 4. The RMS amplitude value of the noise portion (burst + aspiration) was first measured for all the tokens of each phonation type *p'a* and *pa*. Also, the RMS amplitude value of 3 pitch periods of the vowel which showed maximum amplitude were measured for each category. Since absolute RMS amplitude values cannot be compared, both measures were normalized in terms of the ratio of Noise/Vowel RMS amplitude values. RMS amplitude was on average 0.75 for tense consonants, and 0.81 for lax consonants. For the continuum created for Experiment 4, the RMS amplitude value of the vowel was 75.5 dB. Thus to get the RMS amplitude value of tense consonants with this continuum, the amplitude of the noise portion of the 7 stimuli made in Experiment 4 was scaled down to 56.6 dB (.75 x 75.5). A second continuum was created by scaling up the amplitude of the noise portion of the 7 stimuli which was made for the VOT continuum to 61.2 dB (.81 x 75.5). Thus two continua were created, which are the same in terms of VOT, but one had the appropriate amplitude for tense consonants in the noise portion and the other for lax consonants.

6.2 Subjects and Procedure

Eighteen Korean subjects participated in the experiment. Nine subjects were presented with stimuli with the amplitude for lax consonants, and 9 other subjects were presented

with stimuli with the amplitude for tense consonants. All other procedures were the same as in Experiment 4.

6.3 Results

Figure 5 displays the mean percentage /p'/ responses at different VOT values for each amplitude manipulation. For ease of comparison, responses to the VOT continuum for Experiment 4 are again displayed. The line connected with squares with a dot inside is the curve indicating the /p/ responses to the VOT continuum from Experiment 4. The line connected with diamonds is the curve for /p/ responses to stimuli with the amplitude for lax consonants. The line connected with bold squares indicates /p/ responses to stimuli with the amplitude for tense consonants. The first stimulus number represents the VOT value for original tense consonants. All three response curves are not statistically different (F<1 by one-way ANOVA).
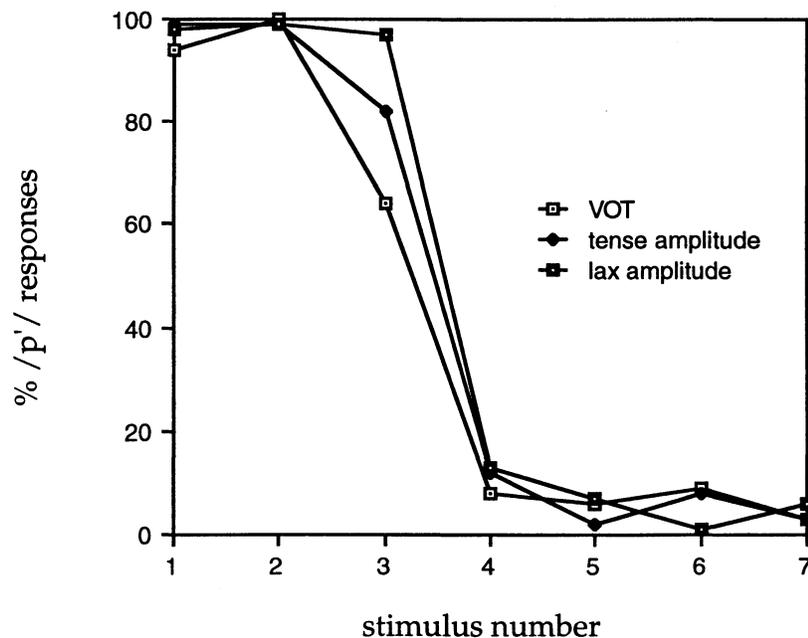

Figure 5. Mean percentage /p'/ responses at different VOT values for each amplitude manipulation.

6.4 Discussion

The results of the present experiment show that burst amplitude does not contribute to the perception of lax and tense consonants in word-initial position. That is, there is no

difference in the perception of a VOT continuum with the amplitude characteristics of a lax stop as compared to that of the same VOT continuum with the amplitude characteristics of a tense stop. Thus summarizing the results of Experiment 4 and Experiment 5, VOT, but not burst amplitude, is a primary cue to distinguish tense from lax consonants. I expected earlier that the feature of tension would be represented as burst amplitude, following Pike and others, but it appeared that there was no relationship between burst amplitude of stops and the "tension" - force of articulation - of the consonants. This might result from the large value of vowel amplitude following tense stops as compared to lax stops. As shown in Table 5, lax consonants have larger RMS amplitude values than tense consonants, since the vowels following tense consonants have much larger amplitude values than those following lax consonants. Thus even though tense consonants have larger burst amplitudes, tense consonants have smaller amplitudes after we take the ratio of Noise/Vowel. The role of vowel amplitude as a cue to the tense/lax distinction will be investigated in future research. In sum, VOT appears to be a primary perceptual cue for word-initial tense vs. lax consonants, whether VOT is the acoustic representation of "tension" or not.

7. Conclusion

In the present series of perception experiments, the perceptual cues for distinguishing tense and lax consonants in Korean were investigated. It was observed that closure duration is a primary cue to differentiate tense and lax consonants in intervocalic position, but not in word-initial position. Given the result that closure duration is not a cue for the perception of word-initial tense and lax stops, VOT and burst amplitude were investigated as perceptual cues for these two categories in this position. It was shown that VOT appears to be a perceptual cue for these two categories in word-initial position, while burst amplitude does not seem to play a role.

These phonetic findings have important implications for a phonologically adequate analysis of the Korean tense consonants. As discussed earlier, Han (1992) argues that tense consonants are geminates of the lax segments, and that the feature of tension is the result of the phonetic implementation of geminates, with a loss of the length contrast initially. The results of the perception experiments support this phonological analysis. In intervocalic position, closure duration -- the phonetic realization of phonological timing -- is one of the salient cues in the perception of the two consonant categories, lax vs. tense. However, in word-initial position, closure duration is not contrastive[2].

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[2] Here we might think of VOT as the phonetic realization of phonological timing. As Lisker (1974) points out, the acoustic measures corresponding to length in consonants (and vowels) have not been explicit.

At this point it is difficult to say if the feature of tension at the segmental tier is realized as VOT . There might be other phonetic characteristics corresponding to the feature of tension, and VOT might be one of the derived properties. To fully explore this issue, we plan to investigate more candidates for the phonetic properties of "tension".

8. References

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Lahiri and Hankamer (1988), however, rather clearly show that the acoustic cue distinguishing geminate from non-geminate stop consonants is the duration of stop closure.

For the Korean case, VOT values, in contrast to closure duration, do not seem to be matched to timing slots as does the closure duration, since there is no phonological evidence that the segments with longer VOT, lax and aspirated, behave like geminates, whereas those with shorter VOT, tense consonants, behave like non-geminates.

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