An EMG Study of the Tense-lax Distinction Theory

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ABSTRACT

An electromyographic device was used to investigate the relationship between a linguistic hypothesis of tense-lax distinction and muscular activity. Muscle action potentials of the orbicularis oris muscle and the depressor anguli oris muscle were obtained from four subjects using CVCVCV and CVCVC words in English and VCV and CVC words in Korean. Findings: The hypothesis that the speaker may select at least one of muscles involved in the articulation of a phoneme so that the selected muscle could be activated for tense-lax distinction, and either a timing variable or an amplitude variablethe and/or both from the selected muscle distinguish(es) /p/ from /b/ in English and /pʰ, p'/ from /p/ in Korean, with the English /p/ and the Korean /pʰ, p'/ being tense, and the Korean unaspirated /p/ and the English /b/ lax, has been verified, except for the case with subject 2 in stressed syllables in English. (2) Thus, the linguistic hypothesis of tense-lax distinction was strongly supported by the muscular activities during the Korean bilabial stops, with /pʰ/ and /p'/ being tense and /p/ lax. (3) Considering the intermuscle compensation and the interspeaker variabilities in the choice of a muscle or muscles, in English the usability of the feature 'tensity' appeared to be positive rather than negative although further investigations with more subjects remain to take on the muscles associated with the onset/offset of the labial closure, including the respiratory muscles related with the aspiration. The phoneme-sensitive EMG manifestations of stress and possible reasons for the interspeaker variabilities are discussed.

1. Introduction

In English Phonetics and Phonology, it has been strongly claimed that the difference between the two sets of consonants can be carried by the presence or the absence of the vocal fold vibration throughout the oral closure phase. However, in an experimental study with British English intervocalic lax (i. e. phonologically voiced) stops (Kim, 1989), it was found that the amount of variability in the voice cessation time as the percentage of the duration of oral closure was ± 31 (where the voice cessation time indicates the voiced

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interval from the onset of oral closure to the offset of the vocal fold vibration during the oral closure phase). Moreover, the feature [voice] varies due to factors, such as speaker, position, etc. (e. g. in word-initial position, Lisker and Abramson, 1964; in word-final position, Flege and Brown, 1982). In isolated word-initial position, three of the four American speakers produced most of the phonologically voiced stops with no voicing or substantial period of devoicing (Lisker and Abramson, 1964), and in utterance-final words, post stressed /b/ was partially devoiced by half the American speakers (Flege and Brown, 1982). Thus, as pointed out by Kim (1989), the usability of the feature [voice] for voiced-voiceless distinction appeared to be negative both in production (Kim, 1989, 1987) and in perception (Lisker, 1957; Port, 1979), and the linguistic hypothesis of tense-lax distinction appears to be one of the basic problems to be solved.

However, a review of the previous EMG studies, associated with labial closure gestures, reveals that there have been contradictory or highly variable EMG findings in English: (1) the EMG activities from the orbicularis oris muscle are essentially the same for /p/ and /b/ (e.g. for CVCV/VCVC utterances, Harris, et al., 1965; for CVC utterances, Tatham and Morton, 1968; for CV/VC/VCV utterances, Lubker and Parris, 1970; for VCV utterances, Sussman, et al., 1973; for CVC/VCV utterances, Tatham, et al., 1985). More specifically, it has been shown by Harris, et al. (1965) that for some speakers /p/ produced slightly more EMG activity in the orbicularis oris muscle than /b/, but the differences were so small and the interspeaker variability so large that the statistical significance could not be demonstrated; (2) In word-final position of the isolated /CVC/ words, the peak EMG amplitude in the orbicularis oris muscle for /p/ (mean 350 μV) was significantly greater than for /b/ (mean 220 μV) but not in word-initial position (Fromkin, 1966); (3) However, it was not pointed out by these authors that in unstressed syllables there was a clear tendency to a higher EMG activity in the orbicularis oris muscle for /p/ than /b/, particularly in /VCV/ and /VC/ utterances although the difference is not always stable (Lubker and Parris, 1970, Table I and II); (4) In /VCV/ words embedded in the carrier phrase: "That's a ___ a month." /p/ and /b/ were significantly differentiated by the peak EMG amplitudes from the depressor anguli oris muscle but not either by the orbicularis oris muscle or by the quadratus labii superior muscle, and the mean peak EMG amplitude in /p/ was significantly greater (42%) than in /b/ (Sussman, et al., 1973); (5) There was an intermuscle compensation that one of two subjects did not use his jaw to any great extent during the speech inventory, even for open vowels, and he showed an inverse relationship between jaw elevation for the medial stop consonant and contraction of mentalis to elevate the lower lip for the same consonant (Sussman, et al., 1973).

Probably, much of the conflict in the previous research is due to the variability in the data and it seems that such variability is considered to be an inherent characteristic of the data, and finally such consideration has driven investigators to give up any further research into the phonetic clew for the tense-lax opposition. However, considering the data from the depressor anguli oris muscle, the intermuscle compensation and the tendency to a greater EMG activity in the orbicularis oris muscle for /p/ than for /b/ in unstressed syllables (Lubker and Parris, 1970; Fromkin, 1966), it seems that there are some rooms for a further investigation into the phonetic evidence for tense-lax distinction. In the previous EMG studies, the EMG data obtained from the orbicularis oris muscle were formulated into a single histogram or a Table, and on the basis of the overall average data (i. e. across subjects and the stress placement), it was strongly argued that "the difference between the bilabial stops can be accounted for on the basis of the behaviour of the glottis" (Harris, et. al., 1965; for similar claims, see Lubker and Parris, 1970; Fromkin, 1966). As a result, the possible effects of stress and intermuscle compensation on the EMG activities have been relatively neglected. Take for example, the isolated monosyllable /CVC/ word, used in an EMG study (Fromkin, 1966), is considered to have been produced with stress on it, and in the /C1VC2/ context, the effect of stress on the muscular activities may be linked more closely to C1V- than -VC2 (MacNeilage and Declerk, 1967; Tatham and Morton, 1968). If this is the case, the isolated /CVC/ words used by Fromkin (1966) appeare to be improper for her claim that "if muscular gestures for /p/ and /b/ are either identical or if there is no consistent relationship, a feature other than the tense-lax feature must distinguish these two phonemes, e. g., the action of the glottis" (p. 170). In the study, she failed to consider the effects of stress on the EMG activities. In C2 (i. e. in unstressed position) of the isolated /C1VC2/ context, the greater EMG amplitude for /p/ than /b/ may have had something to do with the effects of stress on the EMG activities in the orbicularis oris muscle. If so, Fromkin's EMG data (1966) are likely to be in favor of the tendency to a higher EMG activity in the orbicularis oris muscle for /p/ than /b/ in unstressed syllables. On the basis of this, one can assume that in unstressed syllables there will be a higher EMG activity in the orbicularis oris muscle for /p/ than /b/ in English. This hypothesis has been verified in an EMG study (Kim, 1995). He found (1) that in English the effects of stress on the peak EMG amplitude were phoneme-sensitive; in isolated /CVCV/ utterances the peak EMG amplitude in the orbicularis oris superior muscle for /b/ was significantly greater (overall average 37%) in stressed syllables than in unstressed syllables, but this difference did not occur in /p/ and (2) that the effects of the manner of articulation on the EMG activities were stress-sensitive; in unstressed syllables the peak EMG amplitude was greater (overall average 32%) in /p/ than in /b/, but in stressed syllables the peak EMG was essentially the same for /p/ and /b/.

Most of the previous studies (i. e. Harris, et al., 1965; Tatham and Morton, 1968; Lubker and Parris, 1970; Tatham, et al., 1985) have paid their attentions generally to the single muscle, that is, the orbicularis oris muscle. However, considering the facts that the onset/offset of labial closure are an output of the delicate synchronization of many muscle activities (i. e., the orbicularis oris muscle, the depressor anguli oris muscle, the quadratus labii superior muscle, the mentalis muscle, etc.) and that the speakers may have different accents, different habits of speech and different pathological problems, it seems reasonable to presume that the speaker may not necessarily choose and activate the orbicularis oris muscle for the tense-lax distinction. Some speakers may choose and activate a muscle or muscles other than the orbicularis oris muscle, e. g. the depressor anguli oris muscle (Sussman, et al., 1973), and others may choose another muscle. The choice of a muscle or muscles to articulate a phoneme may be dependent upon the accents, habits of speech, and the pathological reasons, which may result in the intermuscle compensation. If so, it seems natural to suppose that there may be interspeaker variabilities in choosing a muscle or muscles for the tense-lax distinction. As a result, the overall data, obtained across subjects, may be inconsistent rather than consistent. Considering this, one may hypothesize that the speaker may select at least one of the muscles, involved in the articulation of a phoneme, so that the selected muscle could be activated for the tense-lax distinction, with /p/ being tense and /b/ lax.

Although English has shown inconsistent EMG data, Korean has produced clear EMG clew for the tense-lax opposition. In an EMG study with two Korean speakers (Kim, 1995), it was found that two variables, i. e. the peak EMG amplitude and the duration of muscle action from the orbicularis oris muscle, were valid measures for the tense-lax distinction in Korean, with /p/ being lax and /p', pʰ/ being tense (where /p/ indicates phonologically an unaspirated lax stop, /p'/ an unaspirated tense stop and /pʰ/ an aspirated tense stop). In isolated /VCV/ words where the V was /ɑ/ and the C bilabial stops, overall (i. e. across all subjects and tokens) the two variables discriminated between /p/ and /p'/ and between /p/ and /p'/ at the 0.001 level of confidence or better when the significance was tested by related t tests.

In this study, attentions will be confined to the EMG activities from the orbicularis oris muscle and the depressor anguli oris muscle during the bilabial stops in English and Korean since the two muscles have shown some positive EMG data for the tense-lax distinction in the previous studies (Lubker and Parris, 1970; Fromkin, 1966; Sussman, et. al., 1970; Kim, 1995), and the feature tensity has been defined as the amount of muscle action (or energy) used in articulating a phoneme. According to this conception, the tense stop should be characterized either by a longer EMG activity or by a greater peak EMG gesture and/or by both, compared with its lax counterpart. The articulatory correlates of the feature tensity are time and/or amplitude.

The hypothesis tested was as follows:

Hypothesis 1: The speaker may select at least one of muscles involved in articulating a phoneme so that the selected muscle could be activated for tense-lax distinction, and either a timing variable and/or an amplitude variable from the selected muscle distinguish(es) /p/ from /b/ in English and /p^h, p'/ from /p/ in Korean, with the English /p/ and the Korean /p^h, p'/ being tense, and the Korean unaspirated /p/ and the English /b/ being lax.

This hypothesis was based on the conception of the feature 'tensity' and the intermuscle compensation which may result from speaker variabilities in accents, habits of speech and pathological reasons. The statistical analysis was carried out by related t tests using Statworks on Macintosh P. C. (Quadra 650), and the experiment was undertaken in the department of Rehabilitation, Pusan National University Hospital. Although the linguistic hypothesis of the tense-lax distinction has not yet clearly been verified, the term 'tensity' is commonly used for stop consonants in the existing literature (e. g. Gimson, 1981; Roach, 1984; Giegerich, 1992; O'Conner, 1988). This study will also use the terms 'tense' and 'lax'. Roach (1984) stated that "it is probably true that **p, t, k** are produced with more force (though nobody has really proved it - force of articulation is very difficult to define and measure)."

2. Method

2. 1. Subjects

Four (two Americans and two Koreans) of five subjects were used in this study. An American English speaker was rejected because it was impossible to syllabicate his EMG signals. He spoke with unusual strength throughout trial runs, thus giving unsatisfactory recordings. One of the Korean subjects (i. e. the author) had a near Seoul accent, that is, the standard Korean, and the other had a Pusan accent. The American subjects had a near mid-western American accent. All of the subjects had no reported speaking problems.

2. 2. Speech items

The two types of speech items in each language were constructed as seen in Table I (where the Korean /p'/ indicates an unaspirated tense stop, /pʰ/ an aspirated tense stop, and /p/ an unaspirated lax stop):

Table I. Speech items used.

English items			Korean items		
1. /bəbəbʌ́/	2. /bʌ́bəbə/	3. /pəbəbʌ́/	1. /ʌ́pə/	2. /ʌ́p'ə/	3. /ʌ́phə/
4. /bəbəpʌ́/	5. /bʌ́bəpə/	6. /pʌ́bəbə/	4. /pʌl/ (punishment)	5. /phʌl/ (a mud of flat)	
7. ballóon	8. pallóon		6. /p'ʌl/ (in relation of)		

In the English natural word-like items, "balloon" and "palloon," the /b/s and /p/s were produced in unstressed syllables, and the /CVCVCV/ words were pronounced with stress either on the first syllable or on the third syllable in order to determine the effects of stress on the EMG data. Thus, stress was one of the controlled experimental conditions. In unstressed syllables the vowel was a schwa and in stressed syllables it was /ʌ/. The English items were embedded in the carrier phrase: "That's a ______ a month." The carrier phrase was duplicated from Sussman, et. al. (1973) since one of aims of this study was to see whether or not the findings, associated with the depressor anguli oris muscle, hold true. On the other hand, the Korean items with /VCV/ and /CVC/ structures were produced in isolation in order to create similar conditions to the previous studies (Kim, 1995; Kim, 1965). The stimulus materials were not designed to provide cross-language comparison but to see whether or not the findings in the previous studies hold true for both languages.

2. 3. Procedures

For subject training, preparations prior to the test session, the method used by Tatham (1985) was duplicated. Before they read the items, for more than thirty minutes the speakers were trained to correctly produced the vowels in the items and at the same time to produce the items with the same or a similar strength throughout the experiments. At a trial session the English speakers showed difficulties in disrimination of the schwa vowel [ə] from the vowel [ʌ]. They had a tendency to pronounce the vowels with a similar strength. It is felt that natural word-like speech items would increase validity although subject performance was felt to be satisfactory. It took about fifty minutes for one subject to read eight times each of the speech items which were in random order in a list.

2. 4. Electrode Placement

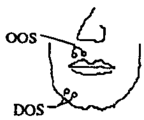
The Orbicularis Oris Superior muscle (OOS)

The electrode placement for OOS was at the vermilion border as seen in Figure 1. The nonspeech tests for OOS consisted of having the subject compress the upper lip against the upperincisors, depress the upper lip, whistle, and perform a kissing gesture. If the activity bursts from the obtained EMG signal corresponded to these active upper lip gestures, we would be satisfied with our placement.

The Depressor Anguli Oris muscle (DOS)

The electrode placement for DOS was approximately one-fourth inch lateral to the lateral margin of the vermilion border and approximately three-eights inch below the level of apposition of the lips. The nonspeech gestures used for DOS verification consisted of depressing the angle of the lips. If maximal EMG activity was obtained during these gestures, we would be satisfied with our placement.

Figure 1. Simplified diagram showing electrode placement for the orbicularis oris (superior) muscle (OOS) and the depressor anduli muscle (DOS).



2. 5. Instrumentation

To examine the activities from the orbicularis oris muscle and the depressor anguli oris muscle, using an electro-myograph (Counter Point MK2, DATEC CO.) and an audio microphone, surface electrode electromyography was used. The electrodes were of silver-cupped type on the small plates, approximately 1 cm in diameter. They were filled with an electrode jelly and affixed with tape to a slightly abraded skin surface as seen in Figure 1., and the subjects were grounded. The display sensitivity was set at 100 ms/D and 200 μV/D, and the range of frequency was 20 to 10 KHz. The EMG signals were first monitored by watching the display on the screen to make sure that the noise remained negligible. The microphone was used for reference lines for the onset of oral closure and release during the bilabial stop consonants. The amplified raw EMG signals both from the obicularis oris muscle and from depressor anguli oris muscle were recorded on channel two and three, respectively, and an audio signal from a microphone was recorded on channel one. The peak EMG amplitude and the duration of muscle action in the orbicularis oris muscle and the depressor anguli oris muscle were obtained from surface electrodes as each of the subjects produced the speech items.

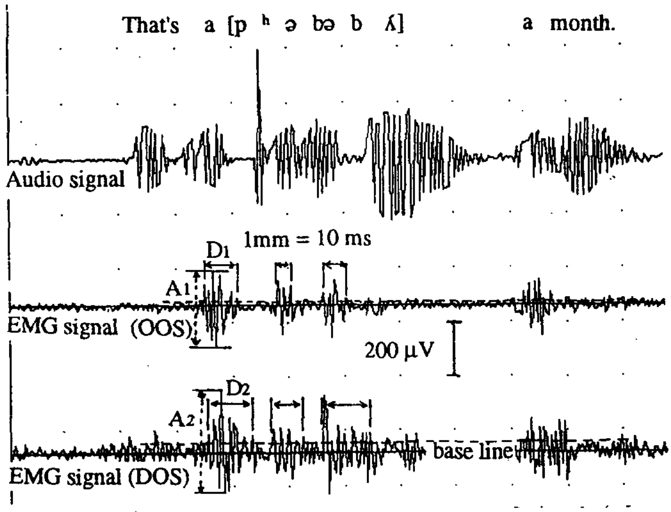
2. 6. Measurements

The following measurements were made from the raw EMG signals in the orbicularis oris muscle and the depressor anguli oris muscle:

(a) The peak amplitude of EMG signals corresponding to the stop consonants.

(b) The duration of these signals.

Figure 2. The print-outs of audio signals and raw EMG signals (where OOS indicates the orbicularis oris muscle and DOS the depress anguli oris muscle).



The durational measurements (i. e. distance Ds on the raw EMG signals) were taken manually from the point where the tracing rose significantly above the noise level (i. e. the dot lines in the raw EMG signals) to where it fell again below this level (see Figure 2). Half of distance A was considered to be corresponding to the peak EMG amplitude for the stop consonants. Because of the experimental situation, the measurements were made from the raw EMG signals. But I was satisfied with the data obtained since the difference between the raw data and the rectified data was negligible when the same speaker (i. e. the author) produced the same speech items although they are not comparable directly due to the differences in time and devices.

3. Results and discussion

The peak EMG amplitude in the orbicularis oris muscle (OOS)

In English, as seen in Table II, the difference between /p/ and /b/ in the peak EMG amplitude from the OOS was generally insignificant, regardless of subjects, stress placement, and position (i. e. word-initial/final position). However, Figures 3 and 4 show that in average (across tokens), there was a general tendency to a higher peak EMG amplitude in the OOS for /p/ than /b/, regardless of subjects, except for the single case with subject 2 in the word-final stressed syllable where the reverse was true, but the difference was so small and the amount of variability (i. e. standard deviation) was so large that the statistical significance could not be presented. This is similar to the claims found in the previous studies (e. g. Lubker and Parris, 1970; Harris, et al., 1965; Sussman, et al., 1973) but different from the tendency to a significantly higher peak EMG amplitude from the OOS during /p/ than /b/ in unstressed syllables (Fomkin, 1966; Kim, 1995). For the speakers served, the peak EMG amplitude in the OOS was an invalid variable for the tense-lax distinction.

Table II. T-test in EMG gestures during the English /b/ and /p/ (where S* indicates that the probability (p) is 1 per cent or greater and S indicates 5 per cent, n=8).

	Peak EMG amplitude				Duration of muscle action			
	Orb. oris muscle		Dep. ang. or.		Orb. oris muscle		Dep. ang. or.	
/b/ vs. /p/	Sig.	t	Sig.	t	Sig.	t	Sig.	t
Subject 1								
CVCVC'V	NS	1.397	S*	3.520	NS	0.487	NS	6.065
C'VCVCV	NS	0.801	S*	7.543	S*	4.128	S	2.263
C'VCVCV	NS	1.990	S*	9.616	NS	0.230	S*	5.527
CVCVC'V	S	2.966	S*	10.851	S*	1.265	NS	0.560
-alloon	S	2.669	S*	6.120	S*	5.550	S*	3.924
Subject 2								
CVCVC'V	NS	1.886	S*	3.092	S*	3.031	NS	0.826
C'VCVCV	NS	1.271	NS	0.780	NS	1.018	NS	1.249
C'VCVCV	NS	0.657	S	2.101	S*	5.106	S*	4.771
CVCVC'V	NS	0.618	NS	1.523	NS	0.892	NS	1.090
-alloon	NS	1.523	S	2.925	S	2.101	S	2.190

In Korean, on the other hand, as shown in Table III, the peak EMG amplitude in the

OOS was significantly greater in /p', pʰ/ than in /p/, regardless of subjects and position (i. e. intervocalic/word-initial). Overall (i. e. across subjects and tokens), the peak EMG amplitude in the OOS discriminated /p/ from /p', pʰ/, regardless of position, and was at the 0.001 level of confidence or better when the significance was tested by related t test. The amount of the EMG gestures from the OOS was generally in the following order: the unaspirated tense stop /p'/ > the aspirated tense stop /pʰ/ > the unaspirated lax /p/ (see Figures 7 and 8), but the difference between the two sets of tense stops was generally insignificant. This coincided with the previous study (Kim, 1995) with two Korean subjects and isolated VCV words. Thus, the peak EMG amplitude in the OOS was a valid measure for the tense-lax distinction in Korean.

Table Ⅲ. T-test in EMG gestures during Korean bilabial stops (where S* indicates that the probability (p) is 1 per cent or better and S indicates 5 per cent, n=8)

	Peak EMG amplitude				Duration of muscle action			
	Orb. oris muscle		Dep. ang. or.		Orb. oris muscle		Dep. ang. or.	
VCV(S1)	Sig.	t	Sig.	t	Sig.	t	Sig.	t
p : p'	S*	8.268	S*	4.975	S*	11.961	S*	8.526
p : pʰ	S*	4.557	NS	1.341	S	2.870	S*	5.659
p' :pʰ	S*	3.469	S*	4.318	S*	5.243	NS	0.493
CVC(S1)								
p : p'	S*	5.627	S*	3.460	S*	3.987	S*	5.143
p : pʰ	S*	4.326	S*	4.235	S*	4.723	S*	3.494
p' : pʰ	NS	0.362	NS	1.013	NS	1.517	S*	3.426
VCV(S2)								
p : p'	S*	8.268	S*	13.507	S*	8.214	S*	5.192
p : pʰ	S*	6.850	S*	3.693	S*	7.417	S*	5.811
p' : pʰ	S*	3.529	S*	4.445	S	2.624	NS	1.139
CVC(S2)								
p : p'	S*	5.274	S*	5.829	S*	4.286	S*	3.794
p : pʰ	S*	4.864	S*	5.303	S*	5.502	S*	4.995
p' :pʰ	N*	0.346	S	2.290	NS	0.087	NS	1.069

The peak EMG amplitude from the depressor anguli oris muscle (DOS)

In English, as shown in Table II, subject-independent EMG performance was observed. For subject 1, the peak EMG amplitude from the DOS was significantly greater during the production of /p/ than during /b/, irrespective of stress placement, position (i. e. word-initial/final) and word-structures (CVCVCV/ CVCVC), and there was no overlap in the EMG data between the two sets of bilabial stops (see Figure 3). This was similar to the previous study (Sussman, et al., 1973). On the other hand, the Table presents that subject 2 performed a stress-sensitive manifestation of the EMG activity in the DOS where in unstressed syllables the peak EMG amplitude in the DOS was significantly higher for /p/ than /b/, but in stressed syllables the statistical significance could not be demonstrated, although across eight tokens, there was a tendency to a higher muscular gesture in average for /p/ than /b/ (see Figure 4). Thus, subject 2 showed the significant effects of stress on the peak EMG amplitude, and this coincided with the existing findings associated with the peak EMG amplitude in the OOS (Kim, 1995; for similar results, see also Fromkin, 1966; Lubker and Parris, 1973) although they are not directly comparable due to the differences in speech items, devices, etc. Considering the intermuscle compensation, resulted from the variabilities in accents, habits of speech and pathological reasons, subject 2 might have activated a muscle or muscles other than the OOS and DOS for the tense-lax opposition in stressed syllables.

Figure 3. The mean peak EMG amplitudes from the orbicularis oris muscle (PemgO) and the depressor anguli oris muscle (PemgD) in μV during the AmEng /b/s and /p/s spoken by a female speaker (S1) (the C in the #Cv-indicates the word-initial unstressed stops, the C's in the #Cv- the word-initial stressed stops, the C in the -Cv# the word-final unstressed stops in the words 'balloon' and 'palloon', vertical lines = standard deviations, n = 8).

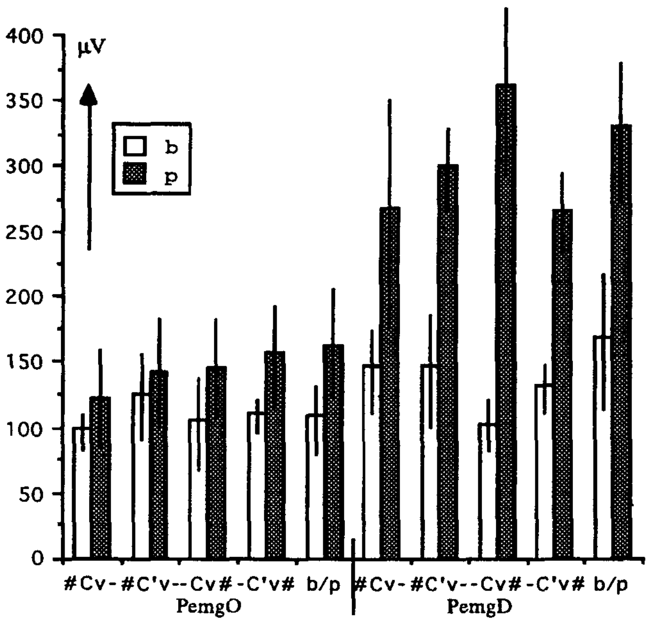
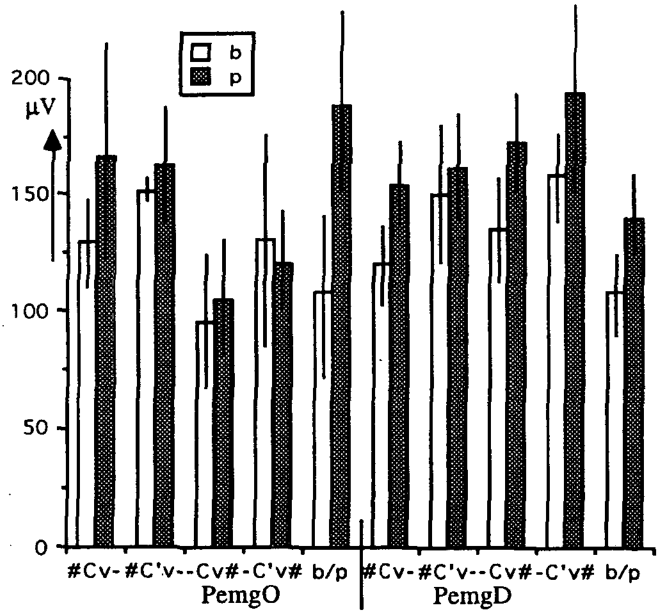


Figure 4. The mean peak EMG amplitudes from the orbicularis oris muscle (PemgO) and the depressor anguli oris muscle (PemgD) in μV during the AmEng /b/s and /p/s spoken by a female speaker (S2) (the C in the #Cv-indicates the word-initial unstressed stops, the C's in the #Cv- the word-initial stressed stops, the C in the -Cv# the word-final unstressed stops in the words 'balloon' and 'palloon', vertical lines = standard deviations, n = 8).



On the other hand, as seen in Table III, in Korean the depressor anguli oris muscle showed a highly significantly greater peak EMG amplitude in /p', pʰ/ than in /p/, regardless of subjects, position and word-structures, except for the single case with subject 1 during the intervocalic stops. Across subjects and tokens also, the statistical significance for the tense-lax opposition was at the level of 0.001 or better, regardless of position (intervocalic/word-initial), with the single exception of subject 1 in intervocalic stops. As presented in the Table, subject 1 demonstrated that in intervocalic position the difference between /pʰ/ and /p/ in the peak EMG amplitude in the DOS was insignificant although the mean EMG gestures from the DOS were higher for /pʰ/ than /p/ (see Figure 7). Therefore, it is safe to claim that the peak EMG amplitude from the OOS was a valid measure for the tense-lax distinction. The peak EMG amplitude in the DOS during the articulation of the Korean bilabial stops was generally in the following order: /p'/ > /pʰ/ > /p/ as well as for the case with the OOS.

The duration of EMG activity in the OOS and DOS

In English, as noted in Table II, overall (i. e. across subjects, position, and stress placemen), the difference between the two sets of stops was inconsistent in the duration of EMG activity in the OOS and the DOS. Therefore, the timing variables in both muscles were invalid measures. In all inconsistent /p/ - /b/ opposition, however, subject 2 presented the only exception in unstressed syllables. In the unstressed syllables, the speaker produced a systematic tendency to a significantly longer durational EMG activities in the DOS during the production of /p/ than during /b/, but this was not seen in the OOS. The unstressed syllable-related EMG activities from the DOS was agreeable to the case with the OOS (Kim, 1955; Fromkin, 1966).

Figure 5. The mean duration of EMG activities in the orbiularis oris muscle and the depressor anguli oris muscle in ms during the AmEng /b/s and /p/s spoken by a female speaker (S1) (the C in the #Cv- indicates the word-initial unstressed stops, the C's in the #Cv- the word-initial stressed stops, the C in the -Cv# the word-final unstressed stops, the C' in the -Cv# the word-final stressed stops, and b/p the stops in 'balloon' and 'palloon', vertical lines = standard deviations, n = 8).

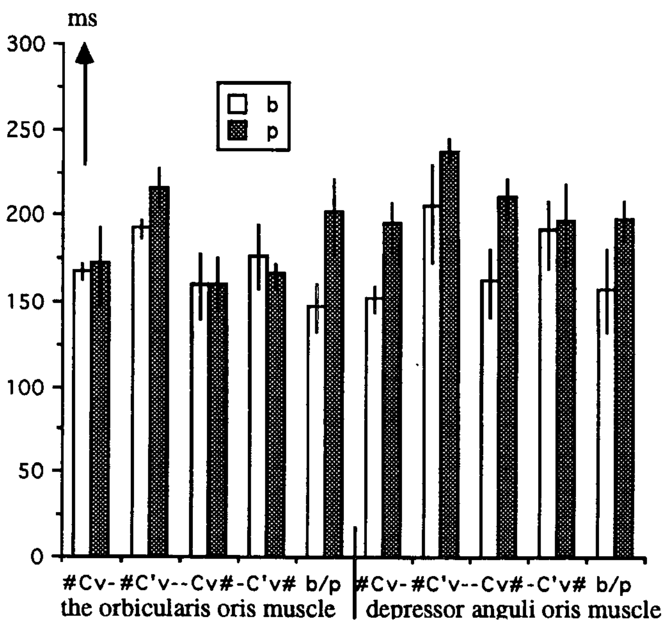
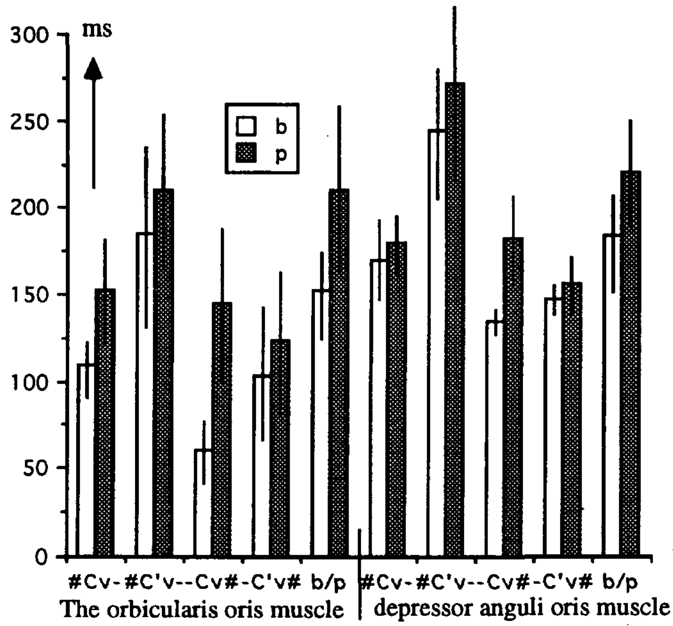


Figure 6. The mean duration of EMG activities in the orbiularis oris muscle and the depressor anguli oris muscle in ms during the AmEng /b/s and /p/s spoken by a female speaker (S2) (the C in the #Cv- indicates the word-initial unstressed stops, the C's in the #Cv- the word-initial stressed stops, the C in the -Cv# the word-final unstressed stops, the C' in the -Cv# the word-final stressed stops, and b/p the stops in 'balloon' and 'palloon', vertical lines = standard deviations, n = 8).



Although English has not provided us with a clear durational EMG clew in both muscles for the tense-lax distinction, Korean showed a clear durational EMG activity in the two muscles for the tense-lax distinction. As seen in Table III and Figures 7 and 8, each subject performed a significantly longer duration of muscle action in /p', pʰ/ than /p/, regardless of position. Across subjects and tokens also, the timing variables from the two muscles distinguished /p/ from /p'/ and /pʰ/ at the 0.001 level of confidence or better, regardless of position. The durational EMG variable for the Korean stops was generally in the order: /p'/ > /pʰ/ > /p/ (see Figures 7 and 8), but the difference between the first two stops was generally insignificant.

Figure 7. The mean duration of peak EMG amplitudes in μV and the muscle action intervals in ms duration in the three types of Korean bilabial stops spoken by subject 1 (the C in the vCv-O indicates the intervocalic unstressed stops, the O the orbicularis oris muscle, the D the depressor anguli oris muscle, the C in the Cvl-O the word-initial stressed stops, the vertical lines = standard deviation, and n = 8).

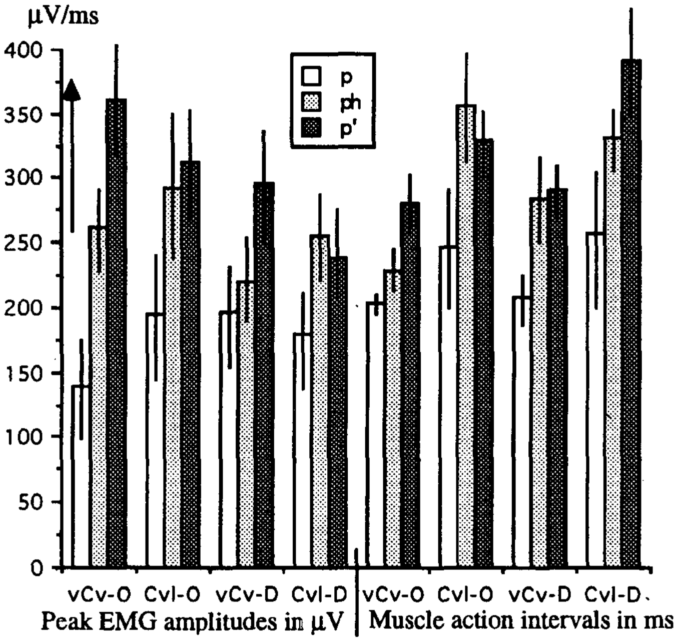
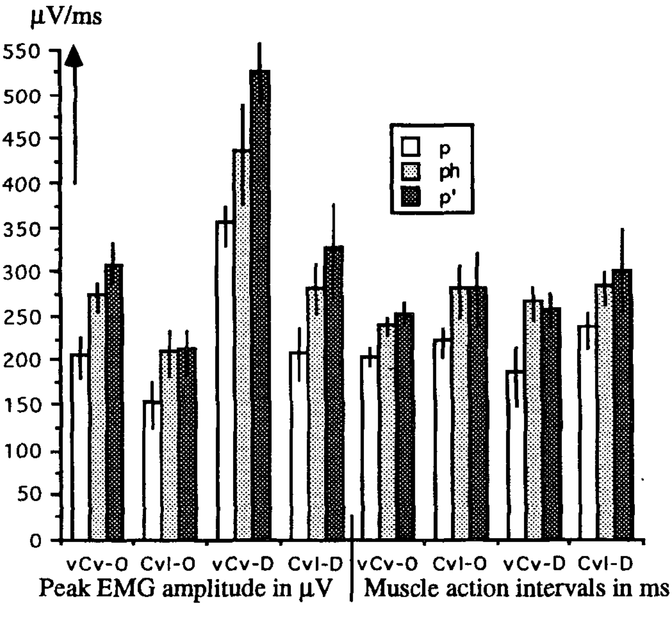


Figure 8. The mean duration of peak EMG amplitudes in μV and the muscle action intevals in ms duration in the three types of Korean bilabial stops spoken by subject 2 (the C in the vCv-O indicates the intervocalic unstressed stops, the O the orbicularis oris muscle, the D the depressor anguli oris muscle, the C in the Cvl-O the word-initial stressed stops, the vertical lines = standard deviation, and n = 8).



So far, we have seen four EMG variables from the two muscles in terms of the variable-based observation as most cases in the existing literature, and it was found that across subjects and tokens Korean presented three satisfactory measures for the tense-lax opposition; (1) the peak EMG amplitude in the DOS, (2) the duration of EMG activity from the OOS, and (3) the duration of EMG activity from the DOS. In English, however, there was a subject-independent muscular performance. For subject 1, the peak EMG amplitude from the DOS was a valid measure for the tense-lax distinction which was coincided with the previous study (Sussman, et al., 1973). Subject 2, however, demonstrated a stress-sensitive manifestation of the peak EMG amplitude in the DOS. In unstressed syllables, the peak EMG amplitude in the DOS was a valid measure, but this was not the case in stressed syllables.

However, from the view point of hypothesis 1 that the speaker may select at least one of muscles involved in the articulation of a phoneme so that the selected muscle could be activated for the tense-lax distinction, and a timing variable or an amplitude variable and/or both from the selected muscle distinguish(es) /p/ from /b/ in English and /pʰ, p'/ from /p/ in Korean, with the English /p/ and the Korean /pʰ, p'/ being tense, and the Korean unaspirated /p/ and the English /b/ lax, the interpretation of the data obtained would be somewhat different from that in terms of the variable-based observation. In a sense of the variable-based observation, in English one of the four variables, i. e., the peak EMG amplitude in the DOS, was a valid measure for the tense-lax opposition, except in the case with subject 2 in stressed syllables, whereas in terms of hypothesis 1, at least two of the four variables distinguished significantly between /b/ and /p/, except for the case with subject 2 in stressed syllables, and at most the four variables worked fully for the /b/ - /p/ opposition in the words 'balloon' and 'palloon' (see subject 1 in Table II). Subject 2 performed a systematic stress-sensitive EMG activity. In stressed syllables, none of the four variables was a valid measure for the tense-lax opposition while in unstressed syllables at least two variables were used for /b/ - /p/ opposition, regardless of position. The stressed syllable-related insignificant /b/ - /p/ distinction was due mainly to the phoneme-sensitive EMG manifestation of stress, which in turn created an insignificant difference in the EMG activities between the two sets of stressed stops. As seen in Figure 4, subject 2 showed that the stops in stressed syllables were accompanied by an increase by 16 % or more in the mean values for the EMG activities during /b/, regardless of variables, as compared with the amount of the EMG increase during /p/. These findings coincided with the previous study (Kim, 1995). Thus, as pointed out by Kim (1995), the effects of stress on the EMG activities were phoneme-sensitive, but in an opposite direction to the case with aspiration. A review of the existing literature presents that VOT in /p, t, k/ was significantly greater in stressed syllables than in unstressed syllables while this difference was negligible in /b, d, g/ (for BrEng intervocalic stops, see Kim, 1987; for AmEng word-initial stops, see Lisker and Abramson, 1967). Stressed syllables in English are produced with a stronger burst of initiatory energy - a more powerful contraction of the chest muscles - than of unstressed syllables (e. g. Giegerich, 1992; Roach, 1984). Aspiration is an output of combination of two factors; (1) the timing of vocal fold adduction in relation to stop release and (2) airflow out of the lungs generated by the respiratory muscle activities. However there is a claim that aspiration (i. e. VOT) depends on the timing of vocal fold adduction in relation to stop release. As pointed out by Kim (1987), VOT is acoustically totally silent. Thus, on the basis of the phoneme-sensitive EMG manifestations of stress, the stress-related aspiration, and the intermuscle compensation resulted from variabilities in accents, habits of speech and pathological reasons, one could presume that in stressed syllables subject 2 might have activated a muscle or muscles other than the OOS and DOS for the tense-lax distinction. Accordingly, the usability of the feature 'tensity' appeared to be positive in English rather than negative although further investigations with more subjects remain to take on the muscles associated with the onset/offset of the labial closure, including the respiratory muscles related with the aspiration.

In Korean, as seen in Table III, in general all of the four variables worked very significantly for the tene-lax distinction, except for the single case with subject 1 where onlt three variables worked. In all tense-lax opposition, for the subject the single variable, i. e., the peak EMG amplitude from the DOS, was an invalid measure to discriminate /p/ from /p^h/ in the /VCV/ word. Thus, the hypothesis that the speaker may select at least one of muscles involved in the articulation of a phoneme so that the selected muscle could be activated for the tense-lax distinction, and either a timing variable or an amplitude variable and/or both from the selected muscle distinguish(es) /p/ from /b/ in English and /p^h, p'/ from /p/ in Korean, with the English /p/ and the Korean /p^h, p'/ being tense, and the Korean unaspirated /p/ and the English /b/ lax, has been verified, except for the case with subject 2 in the stressed syllable in English. In Korean, thus, the feature 'tensity' clearly distinguishes between /p^h, p'/ and /p/. However, as pointed out by Kim (1995), we need 'aspiration' and 'tensity' simultaneously so that the speaker can distinguish three types of stops. This means that neither aspiration nor tensity is the primary feature, and is the same for both. The argument contrasts with the existing literature: (1) the voicing lag, i. e. aspiration, must be the primary opposing feature among the three series of the Korean stops (Lisker and Abramson, 1964) while (2) tensity is the primary feature that occupies the higher node in the phonological hierarchy of stops, and the voice onset timing the secondary (Kim, 1965).

In summary,

(1) The hypothesis that the speaker may select at least one of the muscles involved in the articulation of a phoneme so that the selected muscle could be activated for tense-lax distinction, and either a timing variable or an amplitude variable and/or both from the selected muscle distinguish(es) /p/ from /b/ in English and /pʰ, p'/ from /p/ in Korean, with the English /p/ and the Korean /pʰ, p'/ being tense, and the Korean unaspirated /p/ and the English /b/ lax, has been verified, except for the case with subject 2 in stressed syllables in English. (2) In Korean, the linguistic hypothesis of tense-lax distinction was strongly supported by the muscular activities during the Korean bilabial stops, with /pʰ/ and /p'/ being tense and /p/ lax, and the amount of EMG activities for the Korean stops was generally in the following order: /p'/ > /pʰ/ > /p/, but the difference between the two sets of tense stops was generally insignificant. (3) The usability of the feature 'tensity' appeared to be positive in English rather than negative although further investigations with more subjects remain to take on the muscles associated with the onset/offset of the labial closure, including the respiratory muscles related with the aspiration. (4) In English, there was a subject-independent muscular performance. For subject 1, at least two of the four variables distinguished significantly between /b/ and /p/, and at most the four variables worked fully for the /b/ - /p/ opposition in the words 'balloon' and 'palloon' Subject 2 performed a systematic stress-sensitive EMG activities. In stressed syllables, none of the four variables was a valid measure for the tense-lax opposition when in unstressed syllables at least two variables were used for /b/ - /p/ opposition, regardless of position. The stressed syllable-related insignificant /b/ - /p/ distinction was due mainly to the phoneme-sensitive EMG manifestation of stress, which in turn created an insignificant difference in the EMG activities between the two sets of stressed stops.

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