Stress Effects on Korean Vowels with Reference to Rhythm

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<Contents>

<Abstract>

Stress Effects on Korean Vowels with Reference to Rhythm

Ilsung Yun

Stress effects upon Korean vowels were investigated with reference to rhythm. We measured three acoustic correlates (Duration: VOT, Vowel Duration; F0; Intensity) of stress from the seven pairs of stressed vs. unstressed Korean vowels /i, ε(e), a, o, u, ɨ, ə/. The results of the experiment revealed that stress gave only inconsistent and weak effects on duration, which supports that Korean is not a stress-timed language as far as strong stress effects on duration are still considered crucial in stress-timing. On the other hand, Korean stressed vowels were most characterized with higher F0 and next with stronger intensity. But speakers generally showed tactics to reversely use F0 and intensity in stressing an utterance rather than proportionately strengthening both of the two acoustic correlates of stress. There was found great inter-speaker variability especially in the variations of duration.

* Keywords: Korean vowels, Stress, Rhythm, Duration, F0, Intensity, Stress-timing.

1. Introduction

Moving things generally have their own typical rhythm. The Earth rotates about 365 times in every year, the human heart beats regularly, the pendulum in a clock periodically swings back and forth, etc. Likewise, it has widely been accepted that languages are spoken in their own inherent rhythm and especially since Abercrombie [1] divided all the languages into two types: stress-timed and syllable-timed, rhythm has been one of the major subjects among linguists and phoneticians. In spite of much research, however, they failed in finding the physical evidence enough to prove isochrony between stresses or syllables [20][24][5], etc. and instead some authors like Lehiste [20] suggested that isochrony be perceptually understood. But the entity of rhythm itself has not been denied, and as indicated by the remark of Roach [25](p.138): ".... the large-scale, objective study of suprasegmental aspects of real speech is difficult to carry out, and much research remains to be done," more systematic and scientific research to disclose rhythm in each language is expected to be carried out.

The existing studies classify Korean as (1) syllable-timed language [21], (2) stress-timed language [14][15] or (3) word-timed language [17][10]. This confusing situation suggests that it is high time that systematic research threw light on Korean rhythm. But the aim of this essay is confined to supplying some basic data to judge whether or not Korean is a stress-timed language, and this paper shows the comparison of stressed and unstressed Korean vowels with regard to rhythm.

There are four acoustic correlates of stress: fundamental frequency, intensity, duration and vowel quality among which, it is normally said that fundamental frequency is the strongest cue for the presence of stress and the next one is duration, although this hierarchy can vary between languages [8][9][2][19][3]. The variance especially in the duration of a vowel according to the presence or absence of stress, in turn, can be a clue to find out rhythm. Delattre [6] (p. 196) writes, "syllabic stress affects syllabic duration for every position or type of syllable, but this conditioning is relatively strong in English, weak in Spanish, and medium in German." However, it is well known that the increment of syllabic duration is mainly restricted to the vowel [11][12][23]. With regard to shortening of unstressed syllables in English, Klatt [12] claims that the durational difference between an unstressed unreduced vowel and stressed vowel is largest in a phrase-final syllable at the rate of about 0.65:1. Such large durational difference due to stress is thought to be a cause of an impression that English is a stress-timed language. Therefore, it is meaningful to investigate the difference of vowel duration according to the presence or absence of stress in Korean as well, the result of which will be used as small evidence to judge at least whether Korean is stress-timed or not. In addition to duration, this study collected pitch (F0) and intensity from the target vowels for the purpose of identifying some other features that stress induces in Korean vowels.

2. Methods

Four speakers of Seoul Korean aged from twenties to forties (two males: Speakers 1, 2 and two females: Speakers 3, 4) served as subjects in the experiment. They showed no speaking and hearing problems. The materials for experiment were nonsense words with two syllables, each of which comprised the phonologically voiceless tense aspirated Korean stop /ph/ and one of seven Korean vowels: /i, ɛ, a, o, u, ɨ, ə/ (e.g., phiphi). Seoul Korean reportedly has eight monophthongs: /i, ɛ, e, a, o, u, ɨ, ə/ [16]. But the vowel /e/ was excluded in this experiment, because nowadays most Koreans hardly discriminate the two front vowels /e, ɛ/ both in production and perception [22]. In order to avoid word-final lengthening effect, each speech item was carried in a frame: "nan .... da" where "nan" is a phrase consisting of "na" (the first person) and "n" (the shortening form of a subjective morpheme "nin"), and "da" is a verb ending. And the frame means "I am ...." A list containing the speech items as in <Table 1> was given to the speakers, and they were asked to alternately stress the two syllables (e.g., phiphi, phiphi), with maintaining the naturalness as Korean. Before recording they had brief practices, for Koreans are not used to giving clear stress on words as in English and furthermore the stimuli were nonsense words. The list was produced twelve or thirteen times, out of which only ten tokens were chosen for each speaker and item, excluding tokens pronounced relatively wrong. The total number of tokens finally obtained was 560 (14 items (stressed/unstressed) x 10 repetitions x 4 subjects). All the utterances were made at normal rate and directly recorded into a computer through a microphone in the recording room of the Speech Laboratory of the Hankuk University of Foreign Studies. The software for speech analysis used in the experiment was Praat.

<Table 1> Speech items (bold syllables are stressed.)

phiphi	phɛphɛ	phapha	phopho	phuphu	phɨphɨ	phəphə
phiphi	phɛphɛ	phapha	phopho	phuphu	phɨphɨ	phəphə

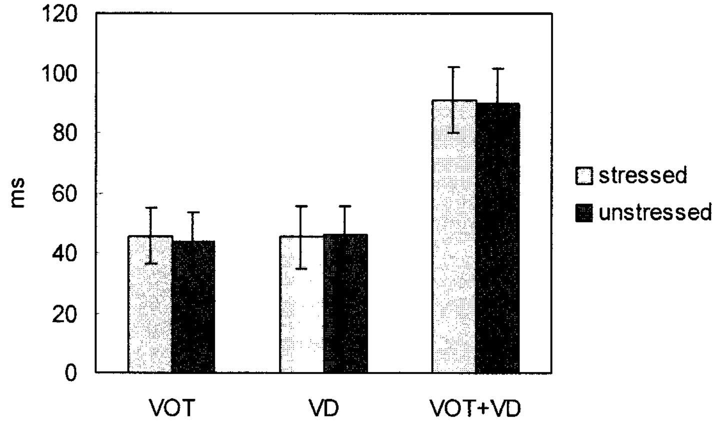
In the experiment, vowel duration (VD) of the first syllables of speech items was measured out of waveforms on channel 1 and spectrograms on channel 2. That is, the target of measurement was the interval from the onset of regular pulse of vowels to the offset which indicates the onset of the following stop consonant /ph/. The second and third formants of the target vowels were referred to decide their beginning and end. Secondly the aspiration (voice onset time: VOT) preceding the target vowels was measured. It was first because the correlation between VOT and the following VD seemed worth examining. In addition VOT could vary depending on the presence and absence of stress. For instance, English stops show longer VOT while Dutch ones manifest shorter VOT when they are stressed [4]. On the other hand, the average Fundamental Frequency (F0) and intensity values were automatically calculated across the intervals of the target vowels. Paired t-tests were performed for each group of data (i.e., duration, F0, intensity) to identify whether or not stress caused significant differences in vowels. Three- or two-way Analyses of Variance (ANOVAs) with Speaker, Vowel and Stress as factors were done to investigate stress effects on duration, F0 and intensity. Regressions were also run to examine correlations among the acoustic measures and stress.

3. Results and discussion

3.1. Pooled results and discussion

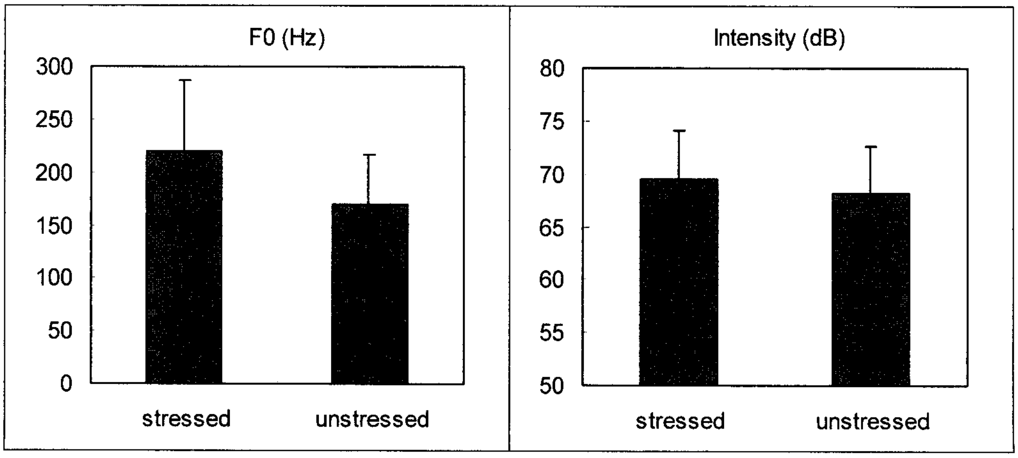
<Figure 1> shows mean values of stressed and unstressed vowel duration (VD), VOT and their sums (VOT+VD) respectively across all speakers and items. Overall it is likely that stress gives remarkable changes neither to VD nor to VOT. First, stress did not lengthen vowels, and the mean duration (45.25 ms) of stressed vowels was even shorter than that (45.9 ms) of unstressed ones, even if the difference was very small (-0.657 ms). A paired t-test confirmed that stressed/unstressed vowels were not different in duration (see <Table 2>). By contrast, stress resulted in a bit longer VOT and the difference (2.075 ms) proved significant ($p = 0.001$) by a paired t-test. On the other hand, VOT and VD showed significant negative correlations irrespective of stress: the Pearson's correlation coefficient was -0.414 ($p = 0.000$) between stressed VOT and VD, and it was -0.239 ($p = 0.000$) between unstressed VOT and VD. Therefore, the two mean values (VOT and VD) were summed up. The total duration of VD and VOT was also longer (1.418 ms) when stressed, but the significance was

weak (p = 0.012). Here, it should be reminded that we hardly tell the durational differences of only about 2 ms and the stress effect on VOT or VD+VOT will be perceptually negligible in spite of the statistical significance.



<Figure 1> Mean values of stressed vs. unstressed vowel duration (VD), VOT and VOT+VD with standard error bars (four speakers, seven Korean vowels, n = 280)

While duration remained little changed, F0 noticeably varied according to the presence or absence of stress and the variance was very highly significant. Finally stress induced only a small difference in intensity but the difference was also very significant probably due to the small Standard Deviation (see <Figure 2> and <Table 2>).



<Figure 2> Mean F0 and intensity of stressed and unstressed vowels with standard error bars (four speakers, seven Korean vowels, n = 280)

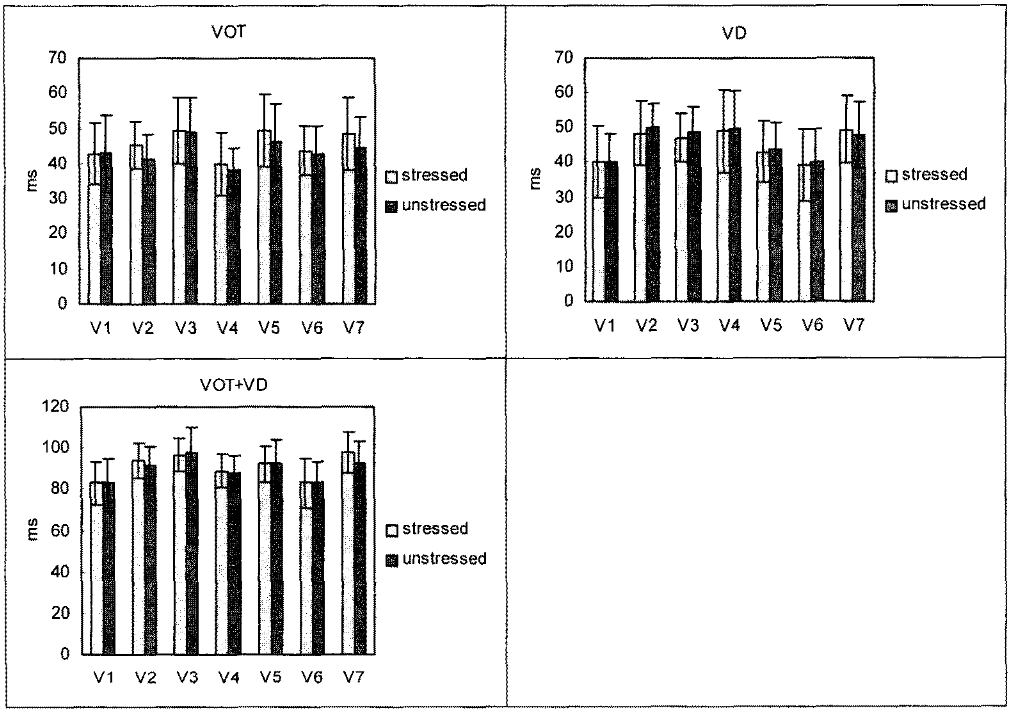
<Table 2> Statistical results of paired t-tests for VD, VOT, VOT+VD, F0 and intensity between stressed and unstressed vowels across the 4 speakers and 7 vowels

	N	Difference	SD	T	P
VD	280	-0.657	8.8	-1.25	0.213 ns
VOT	280	2.075	9.9	3.5	0.001 **
VOT+VD	280	1.418	9.4	2.53	0.012 *
F0	280	50.07	25.7	32.58	0.000 ***
Intensity	280	1.354	2.4	9.38	0.000 ***

ns: not significant ($p > 0.05$), *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

The results of three-way ANOVAs with Speaker, Vowel and Stress as factors showed that Stress had no significant main effects on VD ($F [1, 504] = 1.27$, $p = 0.260$) but significant effects on VOT ($F [1, 504] = 11.44$, $p = 0.001$) and on VD+VOT ($F [1, 504] = 4.36$, $p = 0.037$). There were very highly significant main effects of Stress on F0 ($F [1, 504] = 6176.96$, $p = 0.000$) and on intensity ($F [1, 504] = 47.28$, $p = 0.000$). Besides, there were main effects of the other two factors, Speaker and Vowel on VOT, VD, VOT+VD, F0 and intensity respectively. Significant interactions were also observed of Speaker×Vowel and Speaker×Stress on every target of measurement, but no significant interaction effects of Vowel×Stress or Speaker×Vowel×Stress on any except Vowel×Stress on F0. However our major concern lies in stress effects, and considering the F-ratios and p-values of ANOVAs and the t- and p-values of paired t-tests together, it is assumed that stress gives the greatest effects on F0 and the second greatest effects on intensity and the weakest effects on duration. The different stress effects on the three variables - duration, F0 and intensity - are confirmed by regression analyses, i.e., the relationship between stress and each of the three variables was stronger in the order of F0 (R2 = 16.2***), intensity (R2 = 2.2***) and duration: VOT (R2 = 1.2*); VD (R2 = 0.1, ns); VOT+VD (R2 = 0.4, ns) (ns: not significant ($p > 0.05$), *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). This indicates that stress does not play a significant role in Korean rhythm as far as rhythm is counted to be a realization of timing, i.e., duration.

Stress effects were tested on the same aspects - duration, F0 and intensity in each of the seven vowels. The results are suggested in <Figure 3> and <Table 3> (for convenience, the vowels were numbered as follows: /i/-V1, /ɛ/-V2, /a/-V3, /o/-V4, /u/-V5, /ɨ/-V6, /ə/-V7).



<Figure 3> Mean values of VD, VOT and VOT+VD with standard error bars for seven pairs of stressed *vs.* unstressed Korean vowels across the four speakers (n = 40)

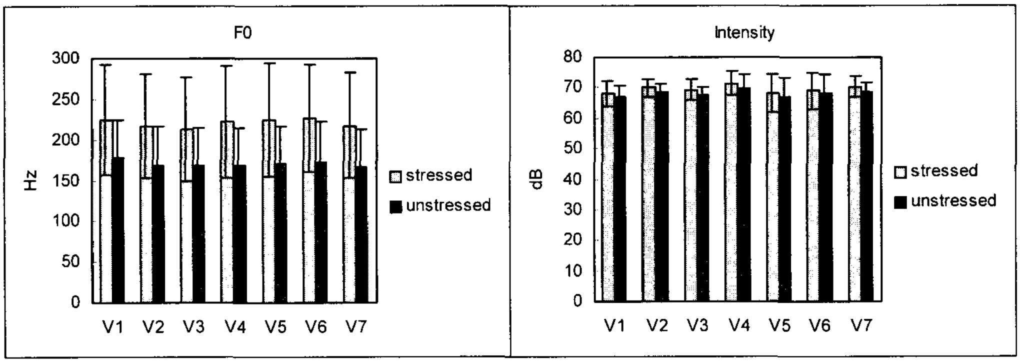
Duration was not different between the seven stressed vowels and their unstressed counterparts (p>0.05 by paired t-tests in every pair of vowels). Irrespective of stress, VOT also changed little but in two vowels (V2: p=0.004; V7: p=0.011). Similar results were obtained in VOT+VD, with only two vowels showing significant durational increase due to stress (V2: p=0.031; V7: p=0.000).

<Table 3> Paired t-test results for VD, VOT and VOT+VD in each pair of stressed vs. unstressed vowels (4 speakers and 7 pairs of Korean vowels, n = 40)

Vowel	VD		VOT		VOT+VD	
	T	P	T	P	T	P
V1 - /i/	0.11	0.916 ns	-0.09	0.927 ns	0	1.000 ns
V2 - /ɛ/	-1.42	0.165 ns	3.02	0.004 **	2.23	0.031 *
V3 - /a/	-1.73	0.091 ns	0.35	0.731 ns	-1.05	0.301 ns
V4 - /o/	-0.46	0.647 ns	1.31	0.199 ns	0.89	0.381 ns
V5 - /u/	-0.8	0.426 ns	1.55	0.128 ns	1.46	0.151 ns
V6 - /ɨ/	-0.57	0.569 ns	0.74	0.461 ns	0.04	0.969 ns
V7 - /ə/	1.11	0.272 ns	2.66	0.011 *	4.31	0.000 ***

ns: not significant (p > 0.05), *p < 0.05, **p < 0.01, ***p < 0.001

Stressed vowels consistently showed significantly higher F0 than their cognates while they generally produced significantly stronger intensity with an exception - V5 with stress did not show a significant increase in intensity (see <Figure 4> and <Table 4>). V6 also revealed only a small, though significant, increase (1.075 dB) of intensity when stressed (p = 0.031).



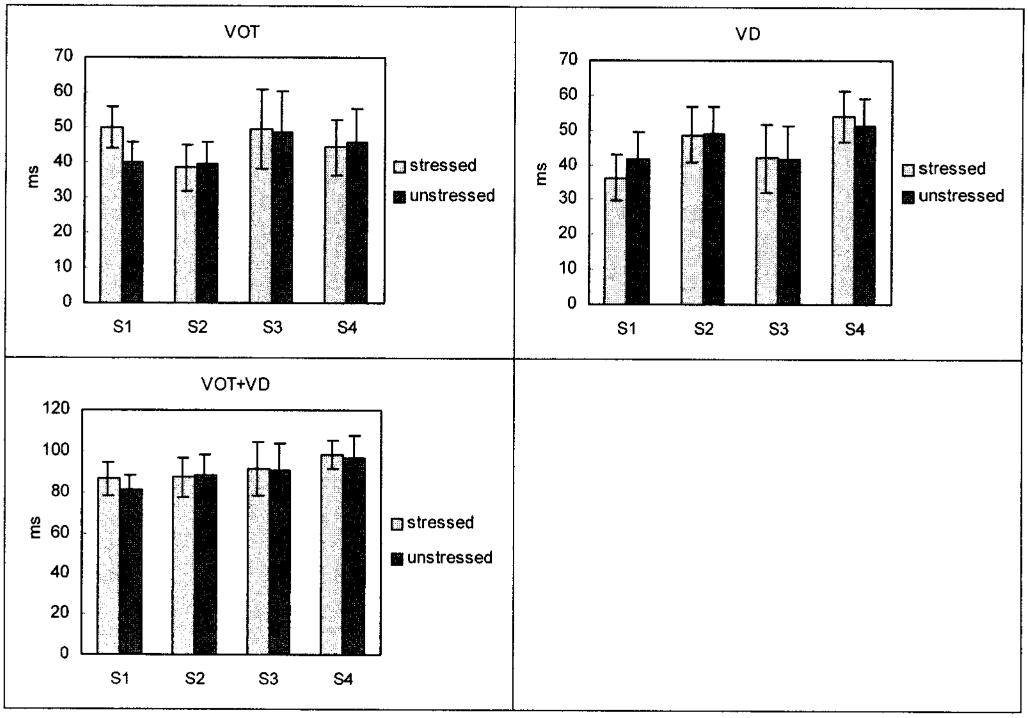
<Figure 4> Mean F0 and intensity of stressed and unstressed vowels with standard error bars (four speakers, seven Korean vowels, n = 40)

<Table 4> Paired t-test results for F0 and intensity in each pair of stressed and unstressed vowels (4 speakers and 7 pairs of Korean vowels, n = 40)

Vowel	F0		Intensity	
	T	P	T	P
V1 - /i/	10.93	0.000 ***	3.57	0.001 ***
V2 - /ɛ/	13.63	0.000 ***	3.93	0.000 ***
V3 - /a/	13.18	0.000 ***	8.59	0.000 ***
V4 - /o/	12.53	0.000 ***	3.80	0.000 ***
V5 - /u/	11.34	0.000 ***	1.99	0.054 ns
V6 - /ɨ/	12.29	0.000 ***	2.24	0.031 *
V7 - /ə/	13.25	0.000 ***	4.20	0.000 ***

ns: not significant (p > 0.05), *p < 0.05, **p < 0.01, ***p < 0.001

3.2. Individual results and discussion



<Figure 5> Mean values of stressed and unstressed VD, VOT and VOT+VD with standard error bars for each of the four speakers (7 Korean vowels, n = 70)

<Table 5> Paired t-test results for VOT, VD and VOT+VD between stressed and unstressed vowels (4 speakers and 7 pairs of Korean vowels, n = 70)

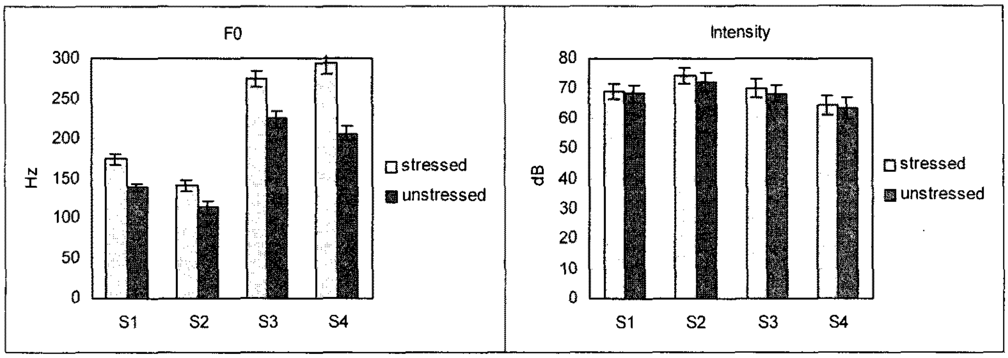
Speaker	VOT		VD		VOT+VD	
	T	P	T	P	T	P
1	10.22	0.000 ***	-6.10	0.000 ***	5.46	0.000 ***
2	-1.44	0.153 ns	-0.59	0.559 ns	-1.63	0.108 ns
3	0.43	0.668 ns	0.11	0.914 ns	0.54	0.591 ns
4	-1.28	0.204 ns	2.98	0.004 **	1.13	0.263 ns

ns: not significant ($p > 0.05$), $*p < 0.05$, $**p < 0.01$, $***p < 0.001$

<Figure 5> and <Table 5> demonstrate each speaker's duration data and paired t-test results. First, Speaker 1 produced significantly shorter VD with stress while Speaker 4 yielded longer VD. In contrast, Speaker 1 pronounced remarkably longer

VOT when stressed, but Speaker 4 revealed even shorter VOT even if the difference was not significant. On the other hand, stress significantly affected neither VD nor VOT for speakers 2 and 3. Interestingly, however, speakers 2 and 3 revealed opposite durational variations (though the variations were not significant), i.e., speaker 3 produced longer VOT and longer VD while speaker 2 shorter VOT and shorter VD with stress. This is confirmed by the t-values in <Table 5>: they are all minus for speaker 2 and are all plus for speaker 3. Considering all, there was great inter-speaker variability regarding durational variations due to stress. That is, every speaker showed different responses to stress with regard to duration. Finally, significant increase of VOT+VD due to stress was found for only Speaker 1. Two-way ANOVAs with Vowel and Stress as factors were performed for each speaker. For Speaker 1, Stress gave significant effects on VOT ($F [1, 126] = 100.08$, $p = 0.000$), VD ($F [1, 126] = 21.48$, $p = 0.000$) and VOT+VD ($F [1, 126] = 20.31$, $p = 0.000$), while Vowel had significant effects on VD and VOT+VD only. There were weak interactions of Vowel×Stress on VOT ($p = 0.024$) and VOT+VD ($p = 0.021$), but not on VD. For Speakers 2 and 3, Stress had no significant effects on VOT, VD and VOT+VD, whereas Vowel showed significant effects on each of them. No interactions of Vowel×Stress on them were observed. For Speakers 4, Stress had a significant effect only on VD ($F [1, 126] = 6.92$, $p = 0.010$), but Vowel significantly affected every durational target (VOT, VD, VOT+VD). There were no significant interactions of Vowel×Stress on VOT, VD and VOT+VD. The results of ANOVAs with regard to stress effects on duration, therefore, were in general agreement with those of paired t-tests.

Unlike duration, both F0 and intensity were consistently and significantly higher or stronger for every speaker when the target vowels were stressed (see <Figure 6> and <Table 6>). Two-way ANOVAs with Vowel and Stress as factors also showed that Stress had main effects on F0 and intensity for every speaker except on intensity for Speaker 1 (see <Table 7>), and Vowel also had main effects on F0 and intensity for every speaker. There were no interactions of Vowel×Stress on F0 and intensity for every speaker, save on F0 for Speaker 1 ($F [6, 126] = 7.70$, $p = 0.000$) and Speaker 4 ($F [6, 126] = 5.03$, $p = 0.000$). The results tell us more than the above, however. First, it is likely that stress more significantly influenced F0 than intensity for every speaker, considering the F-ratios and p-values of ANOVAs and the t- and p-values of paired t-tests in <Tables 6 and 7> - aside from the generally greater significance of p-values, F-ratios and t-values are much bigger in F0 than in intensity. Second, the bigger the t-value for F0 differences between stressed and unstressed vowels, the smaller the t-value for intensity differences between them. So the t-value for F0 differences was bigger in the order of speaker 4>1>3>2 while that for intensity differences was greater in the order of speaker 2>3>1>4. The differences of t-values were sometimes very small, i.e., negligible between speakers, but it is notable that speakers generally have tactics to reversely use F0 and intensity in stressing an utterance rather than proportionately strengthening both of the two acoustic correlates of stress. This is supported by the p-values and F-ratios of ANOVAs: Speakers 1 and 4 who revealed relatively stronger stress effects on F0 (higher F-ratios) showed weak or non-significant stress effects on intensity (lower F-ratios), while Speakers 2 and 3 who had relatively weaker stress effects on F0 (lower F-ratios) manifested very highly significant stress effects on intensity (higher F-ratios).



<Figure 6> Mean values of stressed and unstressed F0 and intensity with standard error bars for each of the four speakers (7 Korean vowels, n = 70)

<Table 6> Paired t-test results for F0 and intensity between stressed and unstressed vowels (4 speakers and 7 pairs of Korean vowels, n = 70)

Speaker	F0		Intensity	
	T	P	T	P
1	42.20	0.000 ***	2.89	0.005 **
2	30.81	0.000 ***	7.80	0.000 ***
3	37.60	0.000 ***	7.60	0.000 ***
4	45.36	0.000 ***	2.44	0.017 *

ns: not significant (p > 0.05), *p < 0.05, **p < 0.01, ***p < 0.001

<Table 7> ANOVA results for F0 and intensity between stressed and unstressed vowels for each speaker (7 pairs of Korean vowels, n = 70)

Speaker	F0		Intensity	
	F [1, 126]	P	F [1, 126]	P
1	2754.84	0.000 ***	2.43	0.112 ns
2	556.94	0.000 ***	21.07	0.000 ***
3	1235.16	0.000 ***	27.12	0.000 ***
4	2936.86	0.000 ***	6.65	0.011 *

ns: not significant ($p > 0.05$), *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Regression analyses confirmed the relationships between F0 and intensity with regard to stress. First, there were strong relationships between F0 and stress (R2 = 88.8 for Speaker 1; R2 = 78.4 for Speaker 2; R2 = 86.0 for Speaker 3; R2 = 94.2 for Speaker 4) while the relationships were weak between intensity and stress (R2 = 1.5 for Speaker 1; R2 = 8.6 for Speaker 2; R2 = 11.3 for Speaker 3; R2 = 1.7 for Speaker 4). These results indicate that stress more significantly influenced F0 than intensity for every speaker. Second, Speakers 1 and 4, who showed relatively stronger relationships between F0 and stress (R2 = 88.8 and 94.2), revealed relatively weaker relationships between intensity and stress (R2 = 1.5 and 1.7) than Speakers 2 and 3 (R2 = 8.6 and 11.3). Also, the relationships between F0 and intensity were non-significant and relatively weaker for Speakers 1 and 4 (R2 = 0.1 and 1.3) while they were significant and relatively stronger for Speakers 2 and 3 (R2 = 13.7 and 11.0). This means that even if every speaker basically uses F0 much more than intensity for stressing, some speakers raise F0 relatively more and strengthen intensity relatively less while other speakers raise F0 relatively less and strengthen intensity relatively more. That is, the correlations between F0 and intensity vary depending on the degree of preference speakers have for F0 or intensity when they realize stress.

Data for the seven vowels in each speaker were also examined. Speaker 1 significantly increased VOT in every stressed vowel except V6, but significantly decreased VD excluding V3 and V7; altogether, VOT+VD significantly lengthened save at V4 and V6. F0 was significantly higher at all stressed vowels, and intensity also was stronger but the differences were significant only at V2, V3, V4 and V7. Speaker 2 did not reveal significant increments in VOT, VD and VOT+VD of any stressed vowel, while he produced significantly higher F0 in every stressed vowel and significantly stronger intensity except in V4 and V6. For speaker 3, stress did not significantly change either VD or VOT or VOT+VD, leaving some exceptions (V1 and V2 in VOT; V1 and V7 in VOT+VD), while F0 went significantly higher at all stressed vowels and intensity also became significantly stronger except at V5 and V6. For speaker 4, stress caused no significant variations of VD or VOT or VOT+VD in any vowels but two exceptions: shortening of VD in V1; lengthening of VOT in V3. On the other hand, as the other three speakers did, speaker 4 raised F0 very significantly at every stressed vowel, but produced with significantly stronger intensity only two vowels: V3 and V4, and she even showed slightly weaker intensity at vowels 2 and 7 when they were stressed. These individual results at each of the seven vowels are in strong support of the earlier finding: stress effects are greatest on F0, second greatest on intensity and weakest on duration.

4. Conclusion

The first purpose of this study was to investigate durational variations of Korean vowels due to stress, and the measuring targets were vowel duration (VD) and VOT. VOT+VD was also calculated as the two elements generally showed negative correlations. Secondly, we examined stress effects on F0 and intensity as well. The pooled and individual results accompanied by paired t-tests and ANOVAs revealed that stress effects on duration were neither great nor consistent across speakers or vowels but there were generally significant and consistent stress effects on F0 and intensity for all speakers. On the other hand, great inter-speaker variability was found especially in duration, i.e., VOT, VD and VOT+VD. Speaker 1 was marked in both the decrease of VD and the increase of VOT at stressed vowels. Conversely Speaker 4 produced longer VD and shorter VOT with stress. Stress showed non-significant but negative effects on both VOT and VD for Speaker 2 while it had non-significant but positive effects on them for Speaker 3. Unlike duration, every speaker yielded consistent and significant increases in F0 and generally significantly greater intensity at stressed vowels. What is noted is that speakers basically produce higher F0 and stronger intensity with stress but a speaker who uses F0 relatively more for stress tends to use intensity relatively less while a speaker who uses intensity relatively more tends to use F0 relatively less. All in all it can be said that for Korean speakers stress effects are reflected first in F0, second in intensity, and third but little in duration. Regression analyses between stress and each of the three acoustic measures confirmed the assumption. And it explains why Korean native speakers easily realize pitch, compared to duration in the production of English stress (see also [18]). Here, it is necessary to remember that stress is not phonemic in Korean [21][16][10], as opposed to contrastive variations in vowel length [21][16][13]. This can be interpreted as meaning that stress gives little effect on Korean rhythm but the intrinsic duration of vowel in each word does affect the timing of the language though the distinction of short vs. long vowels has been disappearing especially among younger generation. All other things being equal, therefore, the results of the present experiment suggest that Korean is not a stress-timed language. Besides, Korean has neither significant nor consistent anticipatory or backwards compression effects on a target vowel due to the addition of neighbouring syllables at sentence level [26], which also rejects the possibility of stress timing of Korean speech. However it should be noted that even in Germanic languages like English which is regarded as the most representative stress-timed language, stressed syllables do not completely determine the regularity of timing between stresses [13]. Furthermore, not a few authors [13][25][5][7][10] insisted that so as to find out rhythm in a language, investigations should be performed beforehand into the number of syllables within the stress group, syllable complexity, degree of stress, the types of phoneme, intonation patterns, voice source dynamics, articulatory patterning, etc. As stated in the above introduction the present study aimed at supplying some basic data to identify Korean rhythm, and its results give us restricted information with a small number of speakers. Thus, more systematic and extensive research will be needed to reach the final goal: Korean rhythm.

Acknowledgement

I thank anonymous reviewers for their comments, indications and suggestions, which improved this paper.

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접수일자: 2008년 3월 27일
게재결정: 2008년 9월 4일

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