Differences in Vowel Duration Due to the Underlying Voicing of the Following Coda Stop in Russian and English: Native and Non-native Values*

Eunjin Oh**

ABSTRACT

This study explores whether Russian, known to have a process of syllable-final devoicing, reveals differences in vowel duration as a function of the underlying voicing of the coda stop. This paper also examines whether non-native speakers of Russian and English learn typical L2 values in vowel duration. The results indicate that vowels in Russian have a slightly longer mean duration before a voiced stop than before a voiceless stop (a mean difference of 9.52 ms), but in most cases the differences did not exhibit statistical significance. In English the mean difference was 60.05 ms, and the differences were in most cases statistically significant. All native Russian speakers of English produced larger absolute differences in vowel duration for English than for Russian, and all native English speakers of Russian produced smaller absolute differences for Russian than for English. More experienced learners seemed to achieve more native-like values of vowel duration than less experienced learners did, suggesting that learning occurs gradually as the learners gain more experience with the L2.

Keywords: vowel duration, underlying voicing, coda consonant, neutralization, non-native acquisition

1. Introduction

It is a well-established fact that the duration of a vowel is affected by voicing in a following coda consonant in English and many other languages (e.g., Chen 1970, Peterson and Lehiste 1960, Zimmerman and Sapon 1958). Vowels tend to become longer before voiced consonants and shorter before voiceless consonants. For example, the vowel in *bad* is in general longer than the vowel in *bat*. An explanation for this difference in vowel duration is that the vowel and consonant lengths vary to keep the duration of the syllable relatively constant. Since voiceless stops are longer than voiced stops, vowels tend to be shorter before voiceless stops

* This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2005-003-A00071). I am grateful to two anonymous reviewers of *Speech Sciences* for valuable comments and suggestions.

** Department of English Language and Literature, Ewha Womans University

than before voiced stops (e.g., Lehiste 1970, Flemming 1997).

In the case of German, voiced obstruents are devoiced in syllable-final positions. As a result of this phonological process, voicing contrasts are 'neutralized' in the specific context. The final stops of the German words *Bund* /bund/ 'association' and *bunt* /bunt/ 'colorful' have been assumed to be phonetically identical, and both are transcribed as [bunt].

Experimental studies on German final devoicing, however, revealed small but statistically significant differences in many properties between the two underlying obstruents (e.g., Port and O'Dell 1985). Among others, the duration of the preceding vowel and the stop closure voicing were longer in the underlying voiced stops than in the underlying voiceless ones, and the duration of the stop closure and the burst were shorter. Similar phenomena have been found in syllable-final obstruents in Dutch, Polish, and Catalan (e.g., Dinnsen 1985, Slowiaczek and Dinnsen 1985, Warner, Jongman, Sereno, and Kemps 2004).

Of these differences in duration, the most consistently found effect was of underlying voicing of the coda consonants on vowel duration. Vowels before underlying voiced obstruents showed significantly longer durations than before voiceless obstruents. Slowiaczek and Dinnsen (1985) reported a statistically significant difference of approximately 10 ms in vowel duration due to the underlying voicing of the coda consonants in Polish. Port and O'Dell (1985) and Warner, Jongman, Sereno, and Kemps (2004) also found significant effects of the underlying voicing on vowel duration in German (approximately 15 ms) and in Dutch (approximately 3.5 ms), respectively. Previous analyses of the final devoicing have assumed that a phonological rule changes voiced obstruents into voiceless ones in a coda position, resulting in the phonetic merger of the underlying voicing contrast. The phenomenon of duration differences in the neutralizing environments, known as 'incomplete neutralization', called for some revision of the standard phonological view because it cannot be explained by the theory of categorical distinctions among segments (see also Gafos 2003).

This paper aims to explore Russian final devoicing, which has been less investigated, to see whether Russian reveals differences in vowel duration as a function of the underlying voicing of the coda stop. This paper also examines whether non-native speakers of Russian and English learn typical L2 values in vowel duration. Gradual acquisition data of durational differences in L2 vowels would offer additional support for the revision of the rule-based formulation of the process.

This study focuses on the following research questions: (1) Does Russian also reveal differences in vowel durations as a function of the underlying voicing of the coda stops? (2) Are the differences statistically significant across speakers and consistent across differing vowels? (3) Do native Russian speakers of English and native English speakers of Russian learn their typical L2 values in vowel duration? (4) Does the acquisition of durational differences in L2 occur gradually? Section 2 summarizes the experimental procedure, and sections 3 and 4 present the

results on native Russian values and the comparison between Russian and English, respectively. Data of non-native speakers and one bilingual speaker of Russian and English are presented in sections 5 and 6. Section 7 summarizes and concludes this study.

2. Procedure

Four native speakers of Russian (Group R, 2 males and 2 females, mean age 25, range 19 to 28) and four native speakers of English (Group E, 2 males and 2 females, mean age 25.5, range 22 to 28), among the population of undergraduate and graduate students at a university in the U.S., participated in this study. All speakers in Group R and in Group E also served in the non-native experiment as Group RE (native Russian speakers of English) and Group ER (native English speakers of Russian), respectively. A bilingual speaker of Russian and English was also a participant.

Speakers read randomized /bVd/ and /bVt/ lists in carrier phrases, where the medial V context was /ɛ, a, i, u, o/ for Russian and /i, ɪ, eɪ, ɛ, æ, ʌ, u, oʊ, ɔ, ɑ/ for English, as presented in (2).

(2) a. Russian *Povtori "bVd/bVt" eshche raz.*[1]
'Repeat "bVd/bVt" one more time.'
bed, bid, bad, bud, bod
bet, bit, bat, but, bot[2]

b. English *Say "bVd/bVt" to me.*
bead, bid, bayed, bed, bad, bud, bood, bowed, bawed, bod
beat, bit, bait, bet, bat, but, boot, boat, bought, bot

Real word stimuli were used when possible, but nonsense words were constructed when a real word could not be found, in order to match the phonological shapes of the target words as closely as possible.

The recordings were made on a Panasonic professional digital audio tape recorder SV-3800 using a Neumann KM184 microphone in a sound-attenuated room. The speakers were asked to read the materials first for practice, then for recording. They read a one-paragraph short story in the language to be recorded before reading the target sentences to help the speakers switch from one language mode to the other. The speakers first read the native language materials,

1) A reviewer pointed out that, since the target words were followed by a vowel, it is possible that resyllabification would produce codaless words. However, since the target words were marked by quotation marks, all the speakers read the Russian words as closed-syllable words with a coda stop.

2) Russian materials were given in Russian orthography.

took a break, and then read the non-native language materials. They each produced three tokens of each test sentence. This amounted to 810 tokens [(10 vowels*2 voicing*3 repetitions + 5 vowels*2 voicing*3 repetitions)*9 speakers)]. The sentences were converted to WAV files at a 22.05 kHz sampling rate.

Vowel durations of the target words were measured using PCquirer software. Measurements were obtained from a spectrogram display with each measurement confirmed in a waveform display. The beginning and end of periodic striation in formants were taken as the beginning and end of vowels surrounded by stops. Care was taken to apply consistent segmentation criteria throughout the data set.

Duration differences of vowels were compared using two simple indices. *Absolute differences* were calculated by taking differences between the mean vowel duration before the voiced stop and the mean vowel duration before the voiceless stop. *Duration ratio* values were also obtained by dividing the mean vowel duration before the voiced stop by the mean vowel duration before the voiceless stop.[3)]

3. Results for the native speakers of Russian

The results for the native Russian speakers are summarized in Table 1. The average vowel duration of each test word is given in the 3rd and 5th columns. The 6th and 7th columns represent the absolute differences and the duration ratios, respectively.

The mean absolute difference of vowel duration across speakers was 9.52 ms (range 18.53 to -1.54 ms) and the mean duration ratio was 1.0728, indicating that the vowels preceding the voiced consonant have slightly longer durations than the vowels before the voiceless consonant. Results were subjected to *t*-tests to see whether vowel durations of a given word before the voiced consonant (3 tokens) are significantly different from vowel durations before the voiceless consonant (3 tokens). In most cases, the differences were not statistically significant, except in the vowel [i] for R1 and [u] for R3. The bold-faced values in the last column of Table 1 represent statistically insignificant productions of vowel duration before the voiced and voiceless consonant in Russian.

There was some individual variability. The two female speakers of Russian showed relatively longer mean absolute differences (18.53 ms for R1 and 17.13 ms for R2) than the two male speakers did (3.95 ms for R3 and -1.54 for R4), although these differences did not exhibit statistical significance also in the speech of the female speakers. R4 produced even shorter vowels before the voiced consonant than before the voiceless consonant. The vowels showing

3) The mean duration values before the voiced and voiceless consonants were rounded off to the nearest hundredth, and then the absolute differences and the duration ratio values were calculated from the rounded-off values.

large absolute differences were different from speaker to speaker. The vowels [ɛ, i] for R1, [a, o] for R2, [u] for R3, and [a] for R4 exhibited large differences in vowel duration compared to the other vowels.

Table 1. Results for the native speakers of Russian

Speaker (initial, sex)	Voiced coda context	Mean vowel duration in ms	Voiceless coda context	Mean vowel duration in ms	Absolute difference in ms	Duration ratio	*T*-test
R1 (OD, F)	bɛd	129.63	bɛt	107.17	22.47	1.2096	***p*=0.0812**
	bad	133.27	bat	115.67	17.60	1.1522	***p*=0.1293**
	bud	117.40	but	100.80	16.60	1.1647	***p*=0.1435**
	bid	103.80	bit	82.17	21.63	1.2633	*p*<0.05
	bod	129.97	bot	115.63	14.33	1.1240	***p*=0.1273**
	mean				**18.53**	**1.1827**	
R2 (BM, F)	bɛd	199.80	bɛt	189.63	10.17	1.0536	***p*=0.5535**
	bad	217.73	bat	196.17	21.57	1.1099	***p*=0.0739**
	bud	181.90	but	169.07	12.83	1.0759	***p*=0.4169**
	bid	181.23	bit	166.47	14.77	1.0887	***p*=0.1262**
	bod	208.47	bot	182.13	26.33	1.1446	***p*=0.2013**
	mean				**17.13**	**1.0946**	
R3 (IG, M)	bɛd	152.50	bɛt	158.87	-6.37	0.9599	***p*=0.4953**
	bad	176.20	bat	172.67	3.53	1.0205	***p*=0.7638**
	bud	174.27	but	153.77	20.50	1.1333	*p*<0.01
	bid	146.60	bit	144.93	1.67	1.0115	***p*=0.8864**
	bod	163.40	bot	163.00	0.40	1.0025	***p*=0.9645**
	mean				**3.95**	**1.0255**	
R4 (LB, M)	bɛd	102.50	bɛt	97.93	4.57	1.0466	***p*=0.3279**
	bad	117.67	bat	106.53	11.13	1.1045	***p*=0.1039**
	bud	106.67	but	107.00	-0.33	0.9969	***p*=0.9445**
	bid	85.13	bit	96.60	-11.47	0.8813	***p*=0.0791**
	bod	119.60	bot	131.20	-11.60	0.9116	***p*=0.3526**
	mean				**-1.54**	**0.9882**	

4. Comparison of Russian and English

The results for the native English speakers are summarized in Table 2. The speakers exhibited large durational differences in both absolute and ratio values. The mean absolute difference was 60.05 ms (range 38.27 to 75.93 ms) and the mean duration ratio was 1.4378. This indicates that vowels are significantly longer before the voiced consonant than before the voiceless consonant. The differences were in most cases statistically significant. The bold-faced values in the last column of Table 2 represent statistically significant productions of vowel duration before the voiced and voiceless consonant in English.

As for individual variability, while E1, E2, and E4 showed absolute differences greater than 60 ms, E3 exhibited relatively shorter mean differences of approximately 38 ms. The vowels showing large durational differences were [oʊ, ɔ] for E1, [eɪ, oʊ, ɔ] for E2, [oʊ] for E3, and [i, eɪ, oʊ] for E4. All the speakers produced large absolute differences in the vowel [oʊ].

Comparing the two groups, Group E exhibited noticeably larger durational differences than Group R in both absolute and ratio values. The mean absolute difference was 9.52 ms for Russian and 60.05 ms for English, and the mean duration ratio was 1.0728 for Russian and 1.4378 for English. Figure 1 presents the mean duration ratio values of Group R and Group E.

Table 2. Results for the native speakers of English

Speaker (initial, sex)	Voiced coda context	Mean vowel duration in ms	Voiceless coda context	Mean vowel duration in ms	Absolute difference in ms	Duration ratio	*T*-test
E1 (LA, F)	bæd	193.80	bæt	133.00	60.80	1.4571	***p*<0.05**
	beɪd	197.87	beɪt	128.83	69.03	1.5358	***p*<0.05**
	bɔd	219.37	bɔt	134.40	84.97	1.6322	***p*<0.01**
	bɑd	196.27	bɑt	128.43	67.83	1.5282	***p*<0.05**
	boʊd	213.57	boʊt	124.60	88.97	1.7140	***p*<0.05**
	bid	172.77	bit	110.83	61.93	1.5588	***p*<0.005**
	bɪd	118.50	bɪt	85.90	32.60	1.3795	***p*<0.05**
	bɛd	146.70	bɛt	101.93	44.77	1.4392	***p*<0.05**
	bud	169.73	but	102.83	66.90	1.6506	***p*<0.005**
	bʌd	127.93	bʌt	101.73	26.20	1.2575	***p*<0.05**
	mean				**60.40**	**1.5153**	
E2 (KB, F)	bæd	264.23	bæt	185.93	78.30	1.4211	***p*<0.01**
	beɪd	269.77	beɪt	165.93	103.83	1.6258	***p*<0.05**
	bɔd	267.73	bɔt	158.50	109.23	1.6892	***p*<0.0005**
	bɑd	239.33	bɑt	155.83	83.50	1.5358	***p*<0.0001**
	boʊd	262.20	boʊt	157.50	104.70	1.6648	***p*<0.05**
	bid	237.30	bit	151.17	86.13	1.5698	***p*<0.05**
	bɪd	156.70	bɪt	111.53	45.17	1.4050	***p*<0.05**
	bɛd	190.87	bɛt	112.57	78.30	1.6956	***p*<0.0005**
	bud	197.50	but	145.23	52.27	1.3599	*p*=0.0740
	bʌd	143.43	bʌt	125.53	17.90	1.1426	*p*=0.2096
	mean				**75.93**	**1.5109**[4)]	
E3 (CS, M)	bæd	227.07	bæt	181.23	45.83	1.2529	***p*<0.005**
	beɪd	220.83	beɪt	183.13	37.70	1.2059	***p*<0.05**
	bɔd	222.43	bɔt	188.87	33.57	1.1777	***p*<0.01**
	bɑd	231.00	bɑt	195.47	35.53	1.1818	***p*<0.001**
	boʊd	234.27	boʊt	177.80	56.47	1.3176	***p*<0.005**
	bid	196.13	bit	146.43	49.70	1.3394	***p*<0.005**
	bɪd	162.67	bɪt	115.13	47.53	1.4129	***p*<0.05**
	bɛd	156.70	bɛt	136.53	20.17	1.1477	*p*=0.2025
	bud	192.63	but	154.33	38.30	1.2482	***p*<0.05**
	bʌd	151.57	bʌt	133.70	17.87	1.1336	*p*=0.0609
	mean				**38.27**	**1.2418**	
E4 (TR, M)	bæd	231.63	bæt	158.03	73.60	1.4657	***p*<0.05**
	beɪd	231.93	beɪt	135.43	96.50	1.7125	***p*<0.05**
	bɔd	236.50	bɔt	173.10	63.40	1.3663	***p*<0.01**
	bɑd	220.83	bɑt	144.60	76.23	1.5272	***p*<0.01**
	boʊd	242.73	boʊt	147.30	95.43	1.6479	***p*<0.005**
	bid	207.53	bit	116.03	91.50	1.7886	***p*<0.05**
	bɪd	137.77	bɪt	110.60	27.17	1.2456	*p*=0.2822
	bɛd	148.30	bɛt	114.40	33.90	1.2963	*p*=0.1215
	bud	197.73	but	126.03	71.70	1.5689	***p*<0.05**
	bʌd	151.53	bʌt	125.10	26.43	1.2113	***p*<0.05**
	mean				**65.59**	**1.4830**	

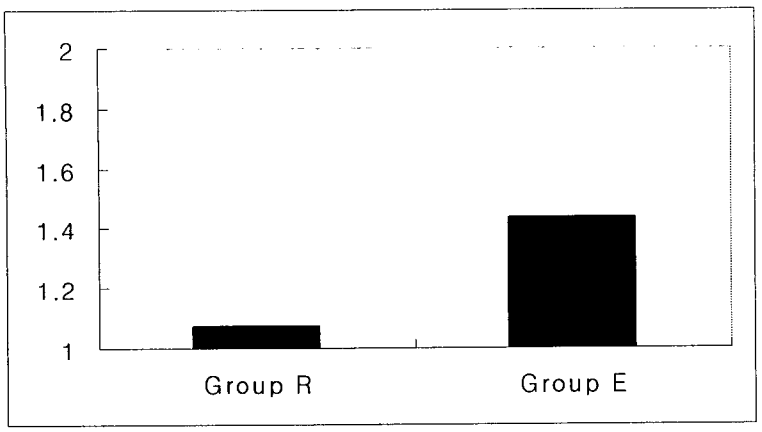


Figure 1. Mean ratios of vowel duration before the voiced stop to vowel duration before the voiceless stop: Group R and Group E

5. Results for non-native speech

All the speakers in Group RE produced larger absolute differences for their L2 English (mean 38.33 ms) than for their L1 Russian (mean 9.52 ms), and larger duration ratios for English (mean 1.2422) than for Russian (mean 1.0728). However, these are still notably smaller values than the mean absolute difference of 60.05 ms and the mean duration ratio of 1.4378 produced by Group E. The mean duration ratios of Russian and English produced by Group RE are compared in Figure 2.[5)]

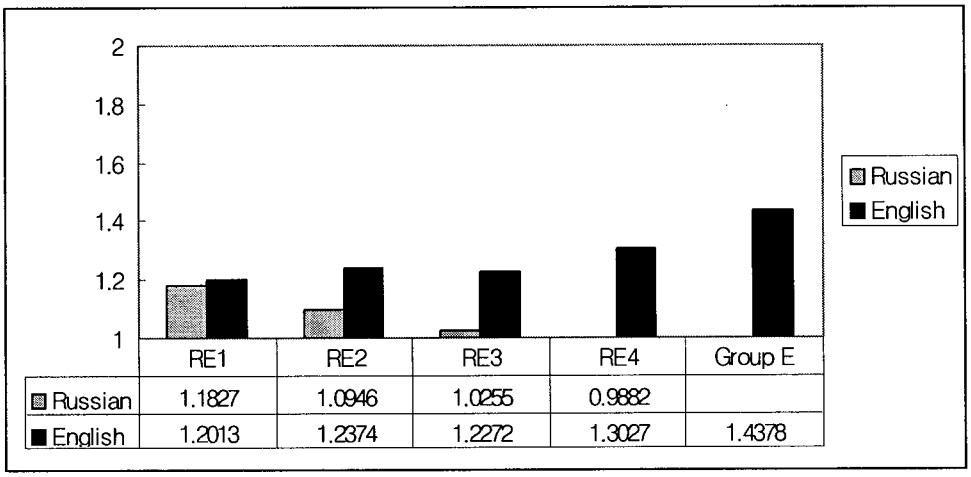
The individual values are presented in Table 3. A series of *t*-tests were carried out on the results from the individual speakers. As shown in the last column, four vowels ([i, ɛ, oʊ, ɔ]) of RE1, five vowels ([eɪ, ɛ, æ, oʊ, ɔ]) of RE2, three vowels ([i, ɛ, ɔ]) of RE3, and five vowels ([eɪ, ɛ, oʊ, ɔ, ɑ]) of RE4 were produced with statistically significant differences between the voiced

4) There were cases in which the absolute differences are not directly proportionate to the duration ratios. In the production of E1, for example, the absolute difference of [eɪ] was longer (69.03 ms) than that of [u] (66.90 ms), but the relation is reversed in the duration ratios, i.e., the ratio of the vowel [u] (1.6506) was larger than that of the vowel [eɪ] (1.5358). In the cases in which the absolute differences are the same, longer vowels would exhibit a smaller ratio value than shorter vowels, as shown in the hypothetical example below.

(i)	voiced context	voiceless context	absolute difference	duration ratio
	100	80	20	1.25
	50	30	20	1.67

5) The duration ratio of English for RE4 was not presented in the graph because it was a smaller value than 1 (i.e., 0.9882).

consonant context and the voiceless consonant context, which is the typical pattern of L2 (English).[6] Table 4 lists the speakers' language background, which summarizes their experience with English. The speakers RE2 and RE4, who exhibited significant differences in five vowels, turned out to have had a longer length of stay in the U.S. (5.5 and 13 years, respectively) than the speakers RE1 and RE3, who exhibited significant differences only in four and three vowels, respectively (their length of stay in the U.S. was 2.5 and 3 years). Moreover, RE2 and RE4 started to learn English at a younger age (11 and 4 years old) than RE1 and RE3 (12 and 19 years old). This suggests that learning of the L2 temporal aspects occurs gradually as the learners gain more experience with L2.



	RE1	RE2	RE3	RE4	Group E
Russian	1.1827	1.0946	1.0255	0.9882	
English	1.2013	1.2374	1.2272	1.3027	1.4378

Figure 2. Mean duration ratios of Russian and English produced by Group RE

6) There were cases in which p-values are high in spite of the high duration ratio values. The larger degree of variation among raw data (indexed by standard deviation) seems to cause this result. Compare the following examples from RE1.

(i) word	standard deviation	word	standard deviation	duration ratio	p-value
bæd	29.33	bæt	16.27	1.3688	p=0.0587
boʊd	9.14	boʊt	8.60	1.1711	p<0.05

It may be the case that non-native speech shows larger degree of variation among tokens than native speech does, reflecting the indeterminacy in L2 speech production, although it needs to be independently tested in another study,

Table 3. Results for the Russian speakers of English

Speaker (initial, sex)	Voiced coda context	Mean vowel duration in ms	Voiceless coda context	Mean vowel duration in ms	Absolute difference in ms	Duration ratio	*T*-test
RE1 (OD, F)	bæd	209.57	bæt	153.10	56.47	1.3688	p=0.0587
	beɪd	196.37	beɪt	187.67	8.70	1.0464	p=0.2368
	bɔd	218.40	bɔt	175.33	43.07	1.2456	***p*<0.05**
	bɑd	140.93	bɑt	129.63	11.30	1.0872	p=0.4479
	boʊd	222.63	boʊt	190.10	32.53	1.1711	***p*<0.05**
	bid	205.00	bit	136.47	68.53	1.5022	***p*<0.05**
	bɪd	106.00	bɪt	89.67	16.33	1.1822	p=0.0605
	bɛd	158.23	bɛt	124.00	34.23	1.2761	***p*<0.05**
	bud	164.03	but	161.03	3.00	1.0186	p=0.8439
	bʌd	121.90	bʌt	109.30	12.60	1.1153	p=0.1259
	mean				**28.68**	**1.2013**	
RE2 (BM, F)	bæd	248.23	bæt	202.80	45.43	1.2240	***p*<0.05**
	beɪd	274.03	beɪt	215.00	59.03	1.2746	***p*<0.05**
	bɔd	281.20	bɔt	214.63	66.57	1.3101	***p*<0.005**
	bɑd	246.57	bɑt	203.37	43.20	1.2124	p=0.0655
	boʊd	310.47	boʊt	209.20	101.27	1.4841	***p*<0.005**
	bid	196.70	bit	166.27	30.43	1.1830	p=0.0706
	bɪd	163.63	bɪt	136.63	27.00	1.1976	p=0.1133
	bɛd	204.37	bɛt	161.73	42.63	1.2636	***p*<0.05**
	bud	205.87	but	176.97	28.90	1.1633	p=0.1495
	bʌd	164.47	bʌt	155.00	9.47	1.0611	p=0.4990
	mean				**45.39**	**1.2374**	
RE3 (IG, M)	bæd	237.97	bæt	150.03	87.93	1.5861	p=0.0602
	beɪd	239.23	beɪt	201.43	37.80	1.1877	p=0.1165
	bɔd	284.03	bɔt	206.33	77.70	1.3766	***p*<0.005**
	bɑd	143.40	bɑt	136.90	6.50	1.0475	p=0.5704
	boʊd	263.47	boʊt	222.13	41.33	1.1861	p=0.1145
	bid	214.73	bit	174.70	40.03	1.2292	***p*<0.05**
	bɪd	93.37	bɪt	96.23	-2.87	0.9702	p=0.8338
	bɛd	211.63	bɛt	131.33	80.30	1.6114	***p*<0.005**
	bud	228.20	but	230.03	-1.83	0.9920	p=0.9286
	bʌd	126.57	bʌt	116.63	9.93	1.0852	p=0.3430
	mean				**37.68**	**1.2272**	
RE4 (LB, M)	bæd	194.30	bæt	154.77	39.53	1.2554	p=0.0625
	beɪd	190.23	beɪt	141.47	48.77	1.3447	***p*<0.05**
	bɔd	209.80	bɔt	166.27	43.53	1.2618	***p*<0.05**
	bɑd	200.40	bɑt	155.93	44.47	1.2852	***p*<0.005**
	boʊd	205.37	boʊt	143.77	61.60	1.4285	***p*<0.05**
	bid	191.50	bit	152.33	39.17	1.2571	p=0.2270
	bɪd	151.97	bɪt	111.27	40.70	1.3658	p=0.0618
	bɛd	146.63	bɛt	115.47	31.17	1.2699	***p*<0.01**
	bud	180.73	but	148.97	31.77	1.2132	p=0.1778
	bʌd	136.50	bʌt	101.50	35.00	1.3448	p=0.0555
	mean				**41.57**	**1.3027**	

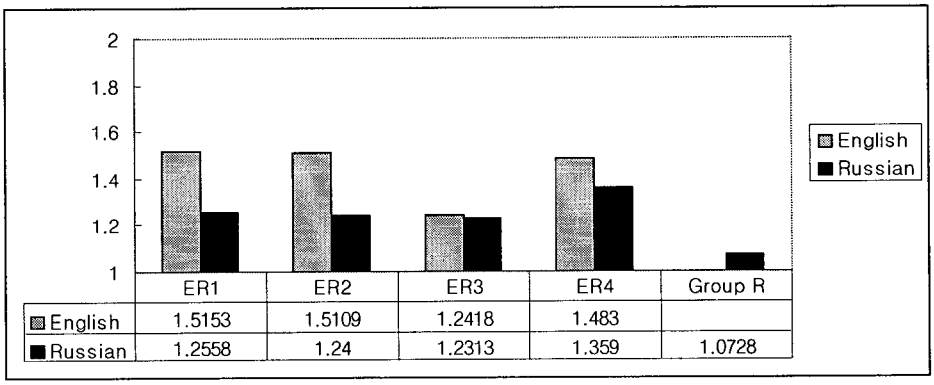
Table 4. Speaker information (Group RE)

Speaker (initial, sex)	Age at the time of recording	Length of stay in the U.S.	Age when s/he started to learn English	Frequency of speaking English with natives at the time of recording	Self-evaluation of English pronunciation
RE1 (OD, F)	26	2.5 years	12	daily	noticeable accent
RE2 (BM, F)	19	5.5 years	11	daily	no accent
RE3 (IG, M)	28	3 years	19	daily	strong accent
RE4 (LB, M)	27	13 years	4	daily	slight accent

The mean duration ratios of English and Russian produced by Group ER are compared in Figure 3. All the speakers produced smaller absolute differences for their L2 Russian (mean 32.40 ms) than for their L1 English (mean 60.05 ms), and smaller duration ratios for Russian (mean 1.2715) than for English (mean 1.4378). However, these are still notably larger values than the mean absolute difference of 9.52 ms and the mean duration ratio of 1.0728 produced by Group R.

The individual values are presented in Table 5. As seen in the last column, differences for vowel durations were statistically insignificant in [u, o] for ER1, [ɛ, u] for ER2, [ɛ, o] for ER3, and [ɛ] for ER4, demonstrating the acquisition of the typical pattern of L2 (Russian) in those vowels.

Table 6 lists the speakers' language background, which summarizes their experience with Russian. The speakers in Group ER who participated in this study had significantly less naturalistic exposure to L2 (mean 9 months) than did the speakers in Group RE (mean 71.5 months). Thus, it may not be appropriate to examine clear effects of language experience in the data of Group ER. Instead, it was found that the two female speakers ER1 and ER2 showed more drastic changes from L1 (English) to L2 (Russian) than the two male speakers ER3 and ER4 (see Figure 3).



	ER1	ER2	ER3	ER4	Group R
English	1.5153	1.5109	1.2418	1.483	
Russian	1.2558	1.24	1.2313	1.359	1.0728

Figure 3. Mean duration ratios of English and Russian produced by Group ER

Table 5. Results for the English speakers of Russian

Speaker (initial, sex)	Voiced coda context	Mean vowel duration in ms	Voiceless coda context	Mean vowel duration in ms	Absolute difference in ms	Duration ratio	*T*-test
ER1 (LA, F)	bɛd	139.80	bɛt	105.70	34.10	1.3226	$p<0.01$
	bad	185.10	bat	145.17	39.93	1.2751	$p<0.005$
	bud	150.47	but	126.23	24.23	1.1920	***p*=0.1971**
	bid	146.20	bit	113.27	32.93	1.2908	$p<0.05$
	bod	150.40	bot	125.47	24.93	1.1987	***p*=0.0612**
	mean				**31.23**	**1.2558**	
ER2 (KB, F)	bɛd	158.03	bɛt	147.90	10.13	1.0685	***p*=0.6723**
	bad	173.83	bat	131.40	42.43	1.3229	$p<0.05$
	bud	144.73	but	116.77	27.97	1.2395	***p*=0.1225**
	bid	165.03	bit	129.30	35.73	1.2764	$p<0.05$
	bod	157.33	bot	121.70	35.63	1.2928	$p<0.005$
	mean				**30.38**	**1.2400**	
ER3 (CS, M)	bɛd	140.85	bɛt	116.30	24.55	1.2111	***p*=0.0957**
	bad	178.87	bat	144.47	34.40	1.2381	$p<0.05$
	bud	127.93	but	112.13	15.80	1.1409	$p<0.05$
	bid	167.60	bit	115.97	51.63	1.4452	$p<0.005$
	bod	150.50	bot	134.23	16.27	1.1212	***p*=0.0934**
	mean				**28.53**	**1.2313**	
ER4 (TR, M)	bɛd	148.60	bɛt	118.13	30.47	1.2579	***p*=0.0983**
	bad	160.27	bat	119.43	40.83	1.3419	$p<0.001$
	bud	147.77	but	95.23	52.53	1.5516	$p<0.05$
	bid	153.33	bit	114.40	38.93	1.3403	$p<0.05$
	bod	148.47	bot	113.93	34.53	1.3031	$p<0.005$
	mean				**39.46**	**1.3590**	

Table 6. Speaker information (Group ER)

Speaker (initial, sex)	Age at the time of recording	Length of stay in Russia	Age when s/he started to learn Russian	Frequency of speaking Russian with natives at the time of recording	Self-evaluation of Russian pronunciation
ER1 (LA, F)	28	14 months	13	rarely	slight accent
ER2 (KB, F)	22	4 months	19	once a week	noticeable accent
ER3 (CS, M)	25	1 year	19	2-3 times a month	slight accent
ER4 (TR, M)	27	6 months	19	daily	slight accent

6. Data from a bilingual speaker of Russian and English

This section presents the results from a bilingual speaker of Russian and English (LW, female). We will see whether the present data suggest if a bilingual speaker operates two separate systems for the temporal aspects of the two languages. As for the language

background of the bilingual speaker, she was born in Russia and was 21 years old at the time of recording. The length of her stay in the U.S. was 16 years, and she considered both Russian and English as her native languages. The language which she was using daily at the time of recording was English, and she evaluated her English pronunciation as having no Russian accent.

The mean absolute differences between vowels before voiced and voiceless consonants were 63.69 ms for Russian and 75.47 ms for English, and the mean duration ratios were 1.3950 for Russian and 1.5377 for English. Apparently, these values are similar to the values produced by Group ER in that her English values are typical of the values of Group E and her Russian values are far from the values of Group R. This appears to result from the fact that English is the language that she used daily at the time of recording.

However, the results from the *t*-tests showed that her Russian follows the typical patterns of Group R, revealing statistically insignificant differences in vowel durations between the voiced and voiceless consonant context. Her English shows the typical patterns of Group E with statistically significant differences in vowel durations between the two consonant contexts (see the last column of Table 6). That is, the results from the statistical analyses appear to indicate that the speaker retains the Russian-like characteristic of indistinctness in vowel durations depending on the voicing of the following consonant for Russian, and that she was operating two separate systems for the temporal aspects of Russian and English.

Table 6. Results from a bilingual speaker of Russian and English

Language	Voiced coda context	Mean vowel duration in ms	Voiceless coda context	Mean vowel duration in ms	Absolute difference in ms	Duration ratio	*T*-test
Russian	bɛd	219.63	bɛt	176.53	43.10	1.2441	***p*=0.2922**
	bad	253.00	bat	192.83	60.17	1.3120	***p*=0.1010**
	bud	242.57	but	165.23	77.33	1.4680	***p*=0.1094**
	bid	220.33	bit	129.43	90.90	1.7023	***p*=0.0633**
	bod	236.10	bot	189.13	46.97	1.2483	***p*=0.1359**
	mean				**63.69**	**1.3950**	
English	bæd	259.40	bæt	158.20	101.20	1.6397	***p*<0.01**
	beɪd	238.83	beɪt	151.40	87.43	1.5775	***p*<0.05**
	bɔd	256.17	bɔt	160.17	96.00	1.5994	***p*<0.01**
	bɑd	251.03	bɑt	147.60	103.43	1.7008	***p*<0.005**
	boʊd	238.20	boʊt	142.60	95.60	1.6704	***p*<0.0005**
	bid	198.90	bit	128.47	70.43	1.5483	***p*<0.01**
	bɪd	167.50	bɪt	111.43	56.07	1.5031	***p*<0.005**
	bɛd	180.43	bɛt	134.97	45.47	1.3369	***p*<0.05**
	bud	182.40	but	141.17	41.23	1.2921	*p*=0.1412
	bʌd	171.53	bʌt	113.67	57.87	1.5091	***p*<0.005**
	mean				**75.47**	**1.5377**	

7. Summary and conclusions

To summarize the results of this study, the vowels in Russian had slightly longer duration before a voiced stop than before a voiceless stop (a mean difference of 9.52 ms). In most cases, however, the differences did not exhibit statistical significance. In English the mean difference was 60.05 ms, and the differences were in most cases statistically significant. All the native Russian speakers of English produced larger absolute differences in vowel duration for English than for Russian, and all the native English speakers of Russian produced smaller absolute differences for Russian than for English. More experienced learners seemed to achieve more native-like values of vowel duration than less experienced learners did. This result suggests that learning occurs gradually as the learners gain more experience with L2.

In the rule-based model (e.g., Chomsky and Halle 1968), final devoicing changes the voicing value of the final obstruent to a voiceless value. This eliminates the contrast between the voiced and voiceless consonants syllable-finally. In this approach, the grammar is categorical in that a segment may either be [+voice] or [-voice] but an intermediate or gradual feature value is not allowed. Language-specific differences in vowel length variation at the sub-phonemic level cause difficulties for the traditional rule-based phonology. In fact, they complicate the explanation of the continuous phonetic output even for the more recent standard Optimality Theory (Prince and Smolensky 1993). The findings of this study regarding the acquisition of L2 vowel durations also run contrary to the categorical formulations of segments and segment changes. Learners did not demonstrate either acquisition or non-acquisition of the L2 typical temporal aspect, but instead they approximated the native-like values gradually. This evidence also points to the need for a revision of the standard categorical feature-based phonology.

A unified scalar model of phonetics and phonology proposed by Flemming (2001), an exemplar model of memory and categorization with the capacity of dealing with continuous dimensions (e.g., Hawkins 2003), or a direct realist model of gestural phonology by Best (1995) may be a better alternative for modeling the language-specific variations of durational aspects and the gradual acquisition of the durational differences in L2. For example, in the direct realist model by Best (1995), perceptual primitives are distal articulatory gestures, and perceptual learning involves direct pick-up of the distal information. This approach assumes a common gestural domain for both phonetic details and phonological structure, in which language-specific gestural details are structured to form the phonological elements of the language (also Browman and Goldstein 1990). Since "phonetic details are informationally continuous with phonological structure and speech provides a rich flow of direct information rather than an impoverished collection of static cues or features (Best 1995: 182)," learners can actively explore lower-order phonetic details in utterances, which in turn would permit the discovery of higher-order invariants that constitute the native language structures. Then, perceptual learning would make it possible for

the learners to pick up the language-specific differences in sub-phonemic durations gradually, and this would lead to the acquisition of phonological organizations regarding the relation of the segmental durations to the duration of a larger constituent such as the syllable.

Lastly, the results from the one bilingual speaker of Russian and English appeared to indicate that the speaker was operating two separate systems for the temporal aspects of Russian and English. Since this was intended as a pilot study to examine patterns that bilingual speakers exhibit regarding the differences in segmental duration between two languages, a more extensive study is expected to follow on this subject.

References

Best, C. B. 1995. A direct realist view of cross-language speech perception. In Strange, W. (ed.), *Speech Perception and Linguistic Experience: Issues in Cross-language Speech Research*, 171-204. York Press.

Browman, C. P. & Goldstein, L. 1990. Tiers in articulatory phonology, with some implications for casual speech. In Kingston, J., & M. E. Beckman (eds.), *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*, 341-376. Cambridge University Press.

Chen, M. 1970. Vowel length variation as a function of the voicing of the consonant environment. *Phonetica* 22, 129-159.

Chomsky, N. & Halle, M. 1968. *The Sound Pattern of English*. Harper and Row.

Dinnsen, D. A. 1985. A re-examination of phonological neutralization. *Journal of Linguistics* 21, 265-279.

Flemming, E. 1997. Phonetic optimization: compromise in speech production. *University of Maryland Working Papers in Linguistics 5: Selected Phonology Papers from H-OT-97.*

Flemming, E. 2001. Scalar and categorical phenomena in a unified model of phonetics and phonology. *Phonology* 18, 7-44.

Gafos, A. I. 2003. Dynamics: the non-derivational alternative to modeling phonetics- phonology. Ms. New York University.

Hawkins, S. 2003. Roles and representations of systematic fine phonetic detail in speech understanding. *Journal of Phonetics* 31, 373-405.

Lehiste, Ilse. 1970. *Suprasegmentals*. MIT Press.

Peterson, G. & Lehiste, I. 1960. Duration of syllable nuclei in English. *Journal of the Acoustical Society of America* 32, 693-703.

Port, R. & O'Dell, M. 1985. Neutralization of syllable-final voicing in German. *Journal of Phonetics* 13, 455-471.

Slowiaczek, L. & Dinnsen, D. A. 1985. On the neutralizing status of Polish word-final devoicing. *Journal of Phonetics* 13, 325-341.

Warner, N., Jongman, A., Sereno, J. & Kemps, R. 2004. Incomplète neutralization and other sub-phonemic durational differences in production and perception: evidence from Dutch. *Journal of Phonetics* 32, 251-276.

Zimmerman, S. A. & Sapon, S. M. 1958. Note on vowel duration seen crosslinguistically. *Journal of the Acoustical Society of America* 30, 152-153.

received: July 27, 2006
accepted: August 28, 2006

▲ Eunjin Oh
Department of English Language and Literature Ewha Womans University
11-1 Daehyun-dong, Seodaemun-gu Seoul 120-750, Korea
Tel: +82-2-3277-3357
E-mail: ejoh@ewha.ac.kr