

Twelfth Annual AATK Conference and Professional Development Workshop

University of Chicago, June 14 – June 16, 2007

How do non-heritage students learn to make the three-way contrast of Korean stops?

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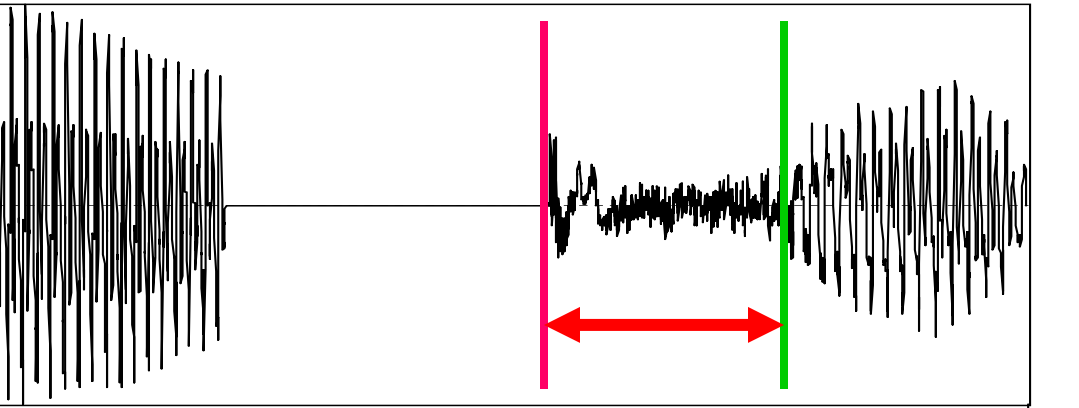
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The three-way contrast of Korean stops

- One of the difficulties that first-time non-heritage Korean learners most often face is the three-way contrast of stops, ㄱ , ㅋ , ㆁ (lax) vs. ㄲ , ㆁ , ㅃ (tense) vs. ㅋ , ㆁ , ㆁ (aspirated).

How do native speakers of Korean make the three-way contrast of stops?

1. Voice Onset Time (VOT)

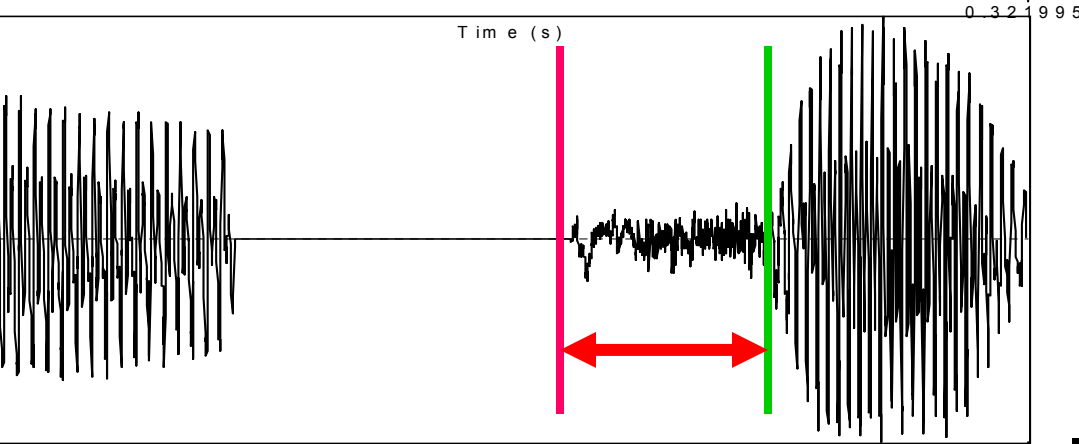


⊃

Lax

ㄱ, ㅋ, ㆁ

Time (s) 0.321995

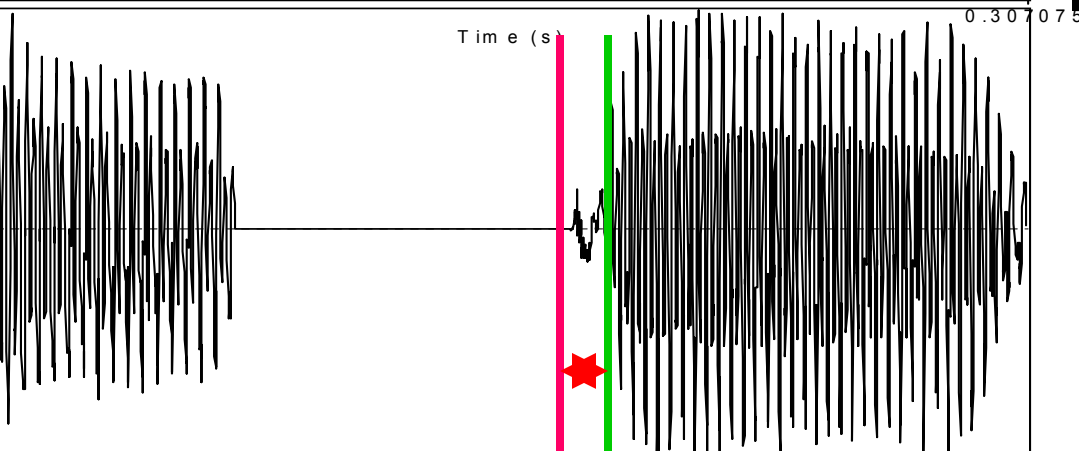


⊃

Aspirated

ㅋ, ㆁ, ㆁ

Time (s) 0.307075

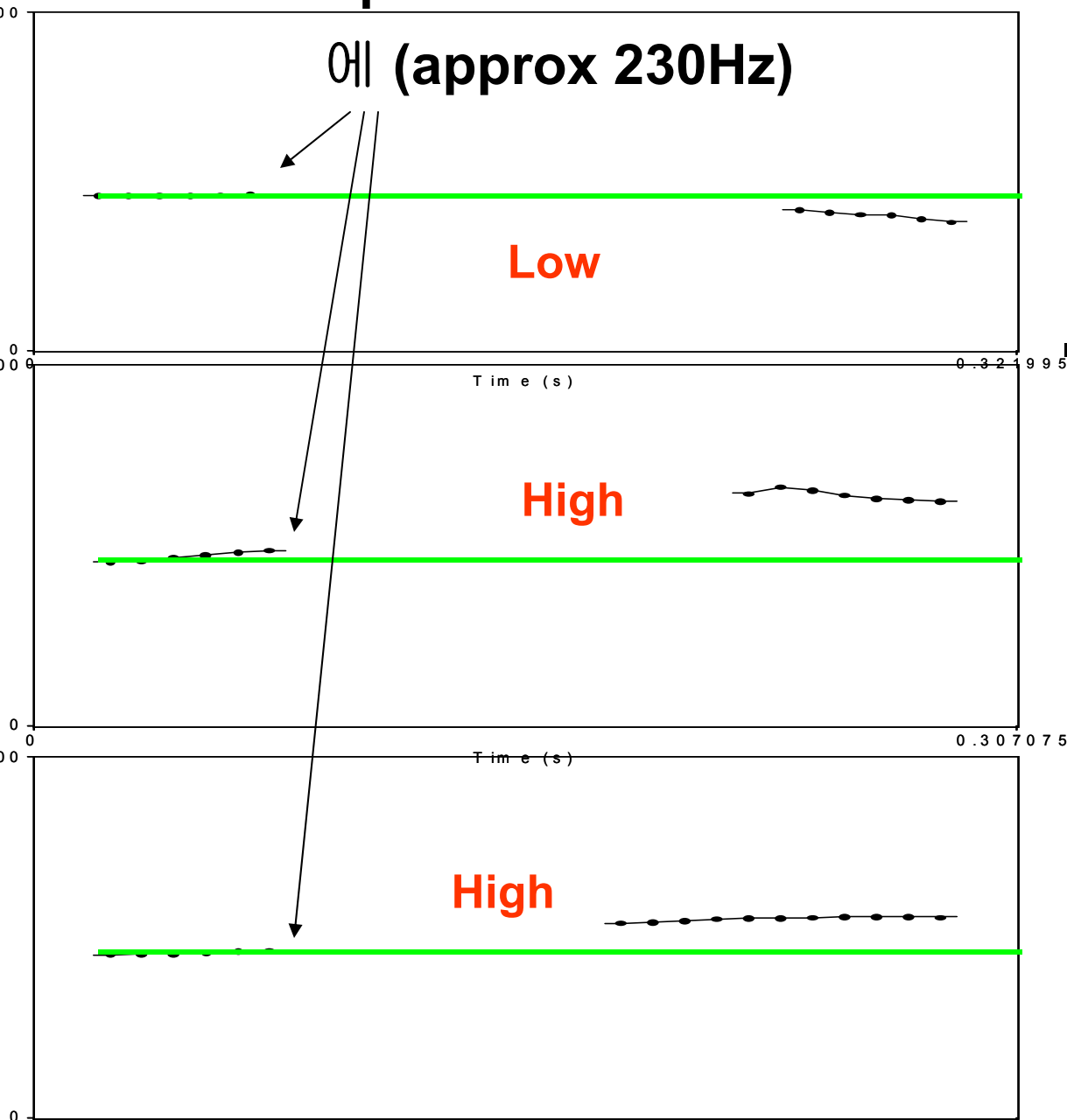


⊃

Tense

ㄱ, ㄲ, ㆁ₄

2. Pitch perturbation of the following vowel



ʌ

Lax

ʌ, ʌ̃, ʌ̄

ɪ

Aspirated

ɪ̃, ɪ̄, ɪ̅

ʌ̅

Tense

ʌ̅, ʌ̅̃, ʌ̅̄

Summary

	Lax ㄱ, ㄷ, ㅂ	Tense ㄱ, ㄷ, ㅂ	Aspirated ㅋ, ㆁ, ㆁ
VOT	(medium) Long	Short	Long
Pitch of the following vowels	Low	High	High

Goals

- To examine how non-heritage learners of Korean make the three-way contrast.
 - How do their language backgrounds affect their learning of the Korean consonant type?
 - Tone language speakers are more sensitive to pitch even in foreign languages. Do tone language speakers make the three-way contrast of Korean consonants in different ways from non-tone language speakers (e.g. using the pitch cue)?
- To investigate a possibly better way of teaching Korean consonant pronunciation.

Experiment design

I. Production

Recording

II. Perception

Listening and Identifying

1. Initial diagnosis
2. Training (Learning)
3. Final test

III. Production

Recording

I. Production

Recording

II. Perception

Listening and Identifying

1. Initial diagnosis
2. Training (Learning)
3. Final test

III. Production

Recording

Recording

- Read 5 sets of 가, 까, 카, 다, 대, 타, 바, 뵀, ㅍ written on index cards (3'x5'), randomly shuffled.
- Subjects were asked to maintain the intonation of each token consistent.

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III. Production

Recording

Stimuli in Perception Experiment

1. Initial diagnosis

(a) Unaltered tokens

(b) i. Spliced tokens

ii. Edited tokens

Stimuli in Perception Experiment

1. Initial diagnosis

(a) Unaltered tokens

(b) i. Spliced tokens

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Stimuli in Perception Experiment

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(a) Unaltered tokens

(b) i. Spliced tokens

ii. Edited tokens

Stimuli in Perception Experiment

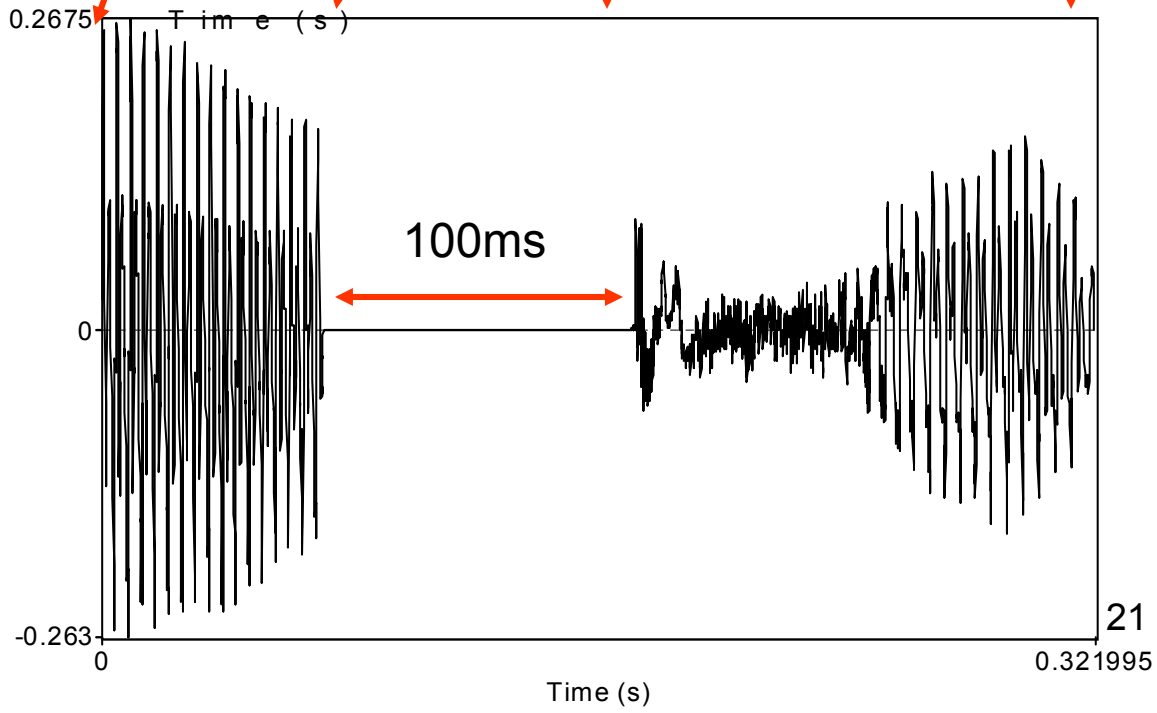
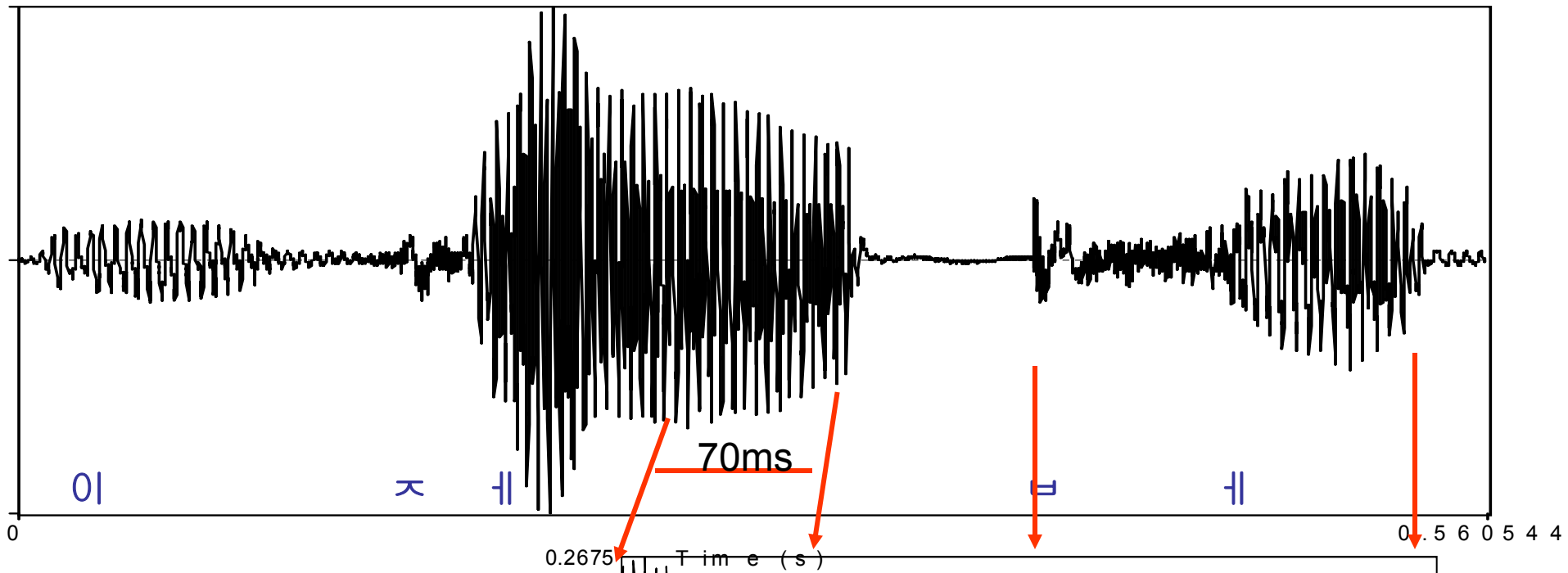
1. Initial diagnosis

(a) Unaltered tokens

- One male and one female native speakers of Korean recorded “기우다, 키우다, 끼우다, 베다, 패다, 빼다, 데우다, 태우다, 때우다” in a carrier sentence “이제 _____ 읽으세요.”

(b) i. Spliced tokens

ii. Edited tokens



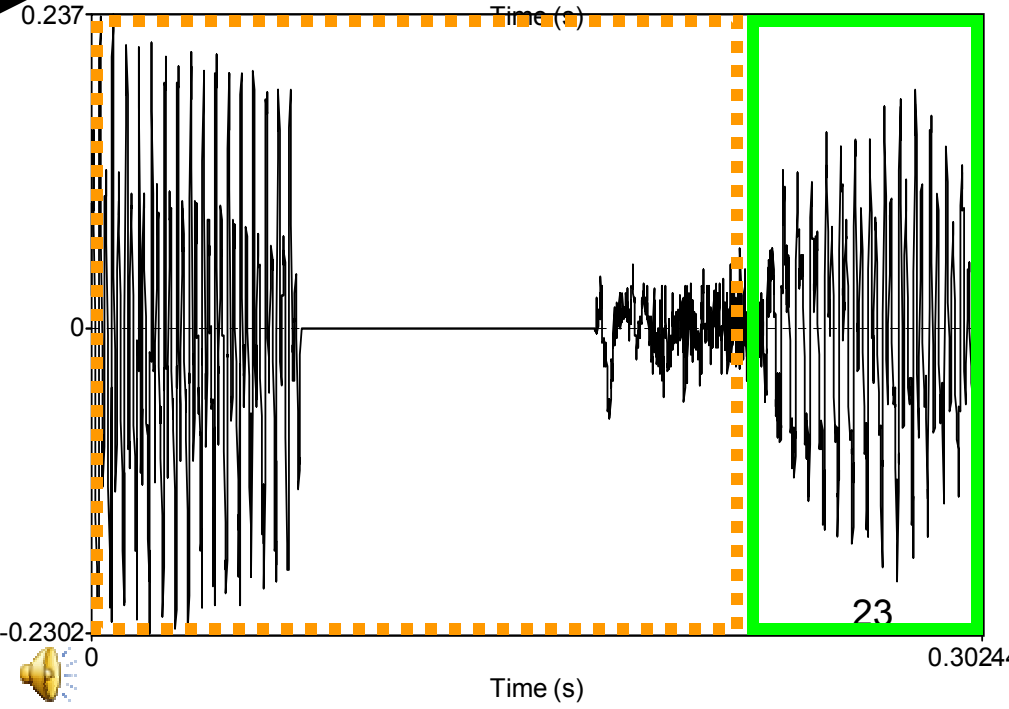
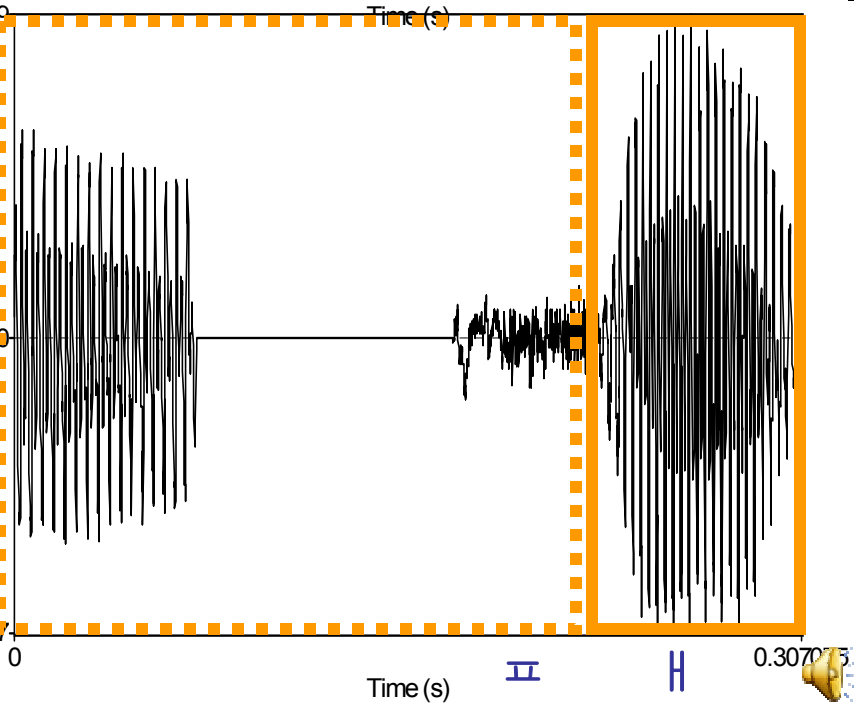
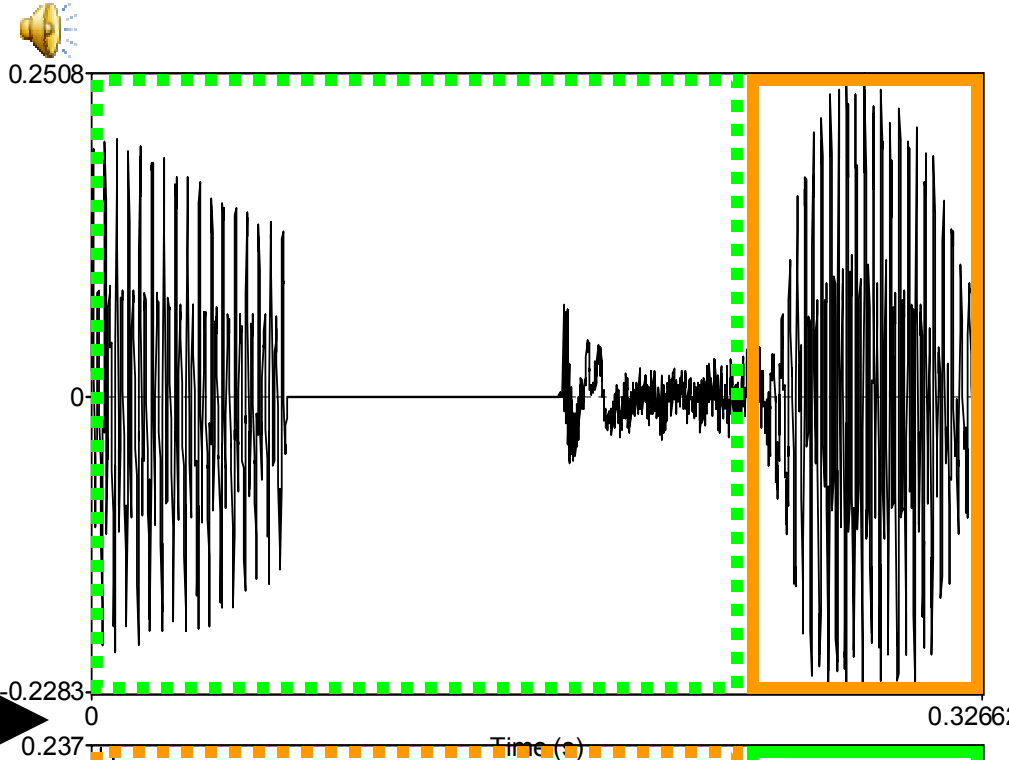
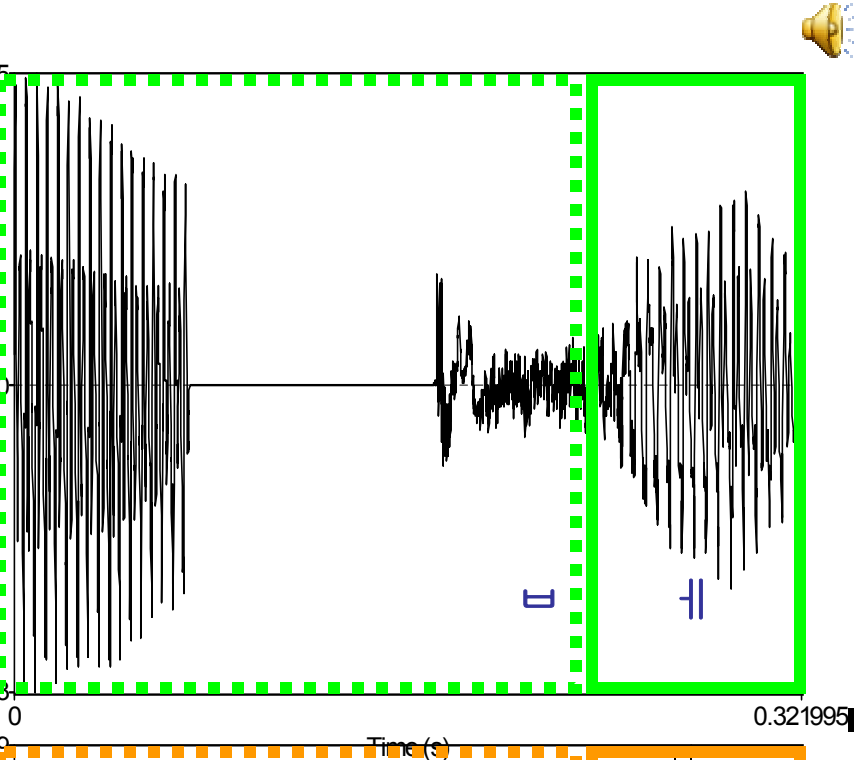
Stimuli in Perception Experiment

1. Initial diagnosis

(a) Unaltered tokens

(b) i. Spliced tokens

ii. Edited tokens



Stimuli in Perception Experiment

1. Initial diagnosis

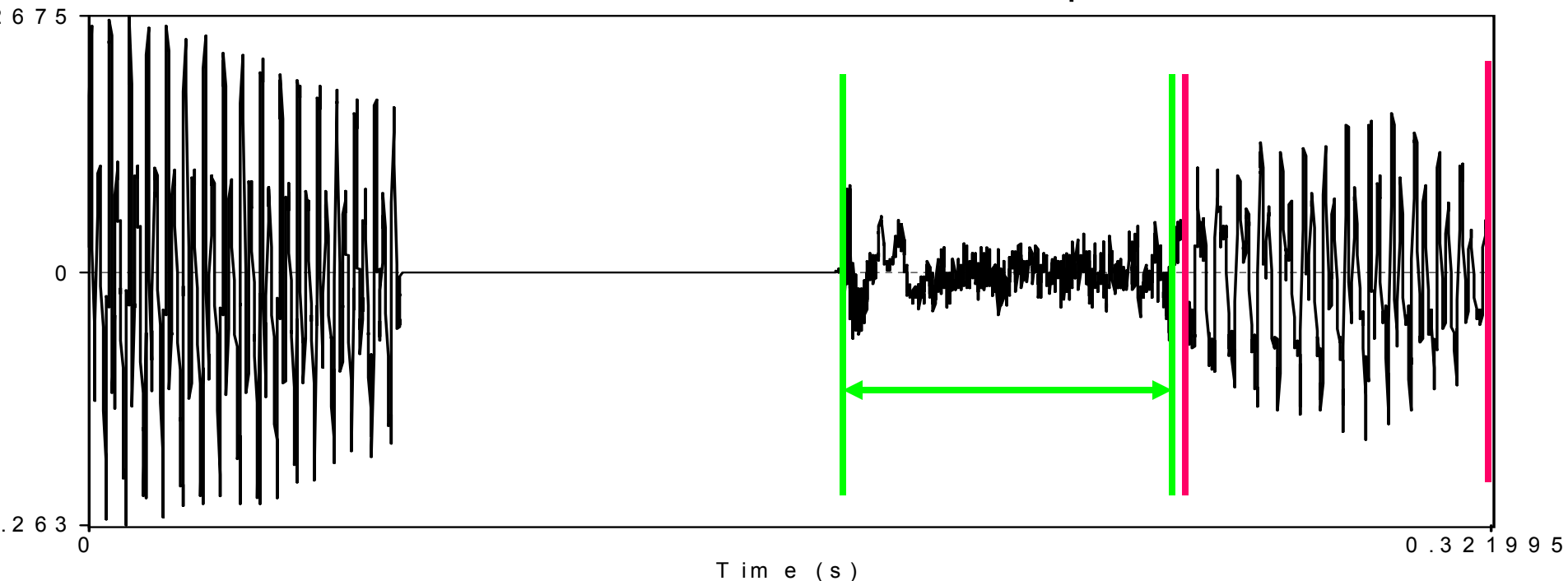
(a) Unaltered tokens

(b) i. Spliced tokens

ii. Edited tokens

VOT of 배: increased 5 steps in 10 ms interval














Pitch of 배: increased 5 steps in 15 Hz interval



VOT of 패: decreased 5 steps in 10 ms interval

Pitch of 패: decreased 5 steps in 15 Hz interval

Edited tokens

Original 베 	10ms ↑ 	20ms ↑ 	30ms ↑ 	40ms ↑ 	50ms ↑ 
	15Hz ↑ 	30Hz ↑ 	45Hz ↑ 	60Hz ↑ 	75Hz ↑ 
Original 피 	10ms ↓ 	20ms ↓ 	30ms ↓ 	40ms ↓ 	50ms ↓ 
	15Hz ↓ 	30Hz ↓ 	45Hz ↓ 	60Hz ↓ 	75Hz ↓ 

I. Production

Recording

II. Perception

Listening and Identifying

1. Initial diagnosis

2. Training (Learning)

3. Final test

III. Production

Recording

Stimuli in Perception Experiment

2. Training (Learning)

- Only unaltered tokens were used in training session.
- Same stimuli recorded by one male and one female native speakers of Korean (different from the initial diagnosis session).
- Edited and presented in the same way as the initial diagnosis session.
- Feedbacks were given after each response, whether the subject's response is correct or incorrect, and what is the correct choice in case of incorrect.

I. Production

Recording

II. Perception

Listening and Identifying

1. Initial diagnosis
2. Training (Learning)
3. Final test

III. Production

Recording

Stimuli in Perception Experiment

3. Final test

- Final test was same as initial diagnosis in every aspect, except that different speakers from the previous session recorded the stimuli for the unaltered tokens.

I. Production

Recording

II. Perception

Listening and Identifying

1. Initial diagnosis
2. Training (Learning)
3. Final test

III. Production

Recording

Same as previous recording

Subjects

- Seven female and four male non-heritage students enrolled in UCB elementary Korean course for non-heritage learners.
- Participated in the study after approximately 25 weeks of learning Korean in class.

Subjects' language backgrounds

	Sex	First	Mostly used	Other
T1	F	Mandarin	English	Spanish
T2	M	Cantonese	English	
T3	F	Indonesian	English	Mandarin
T4	F	Mandarin	Mandarin, English	Taiwanese, Japanese, French
T5	F	Cantonese	Cantonese, English	French, Mandarin
T6	F	Taishanese	English	Spanish, Mandarin, Cantonese
N1	M	English	English	Arabic, Spanish, Latin
N2	M	English	English	Spanish
N3	F	English	English	
N4	F	English	English	
N5	M	English	English	Tagalog

Results: Production

Did subjects make the three-way contrast?

	Before training		After training		Improved?
	Contrast	Using	Contrast	Using	
T1	No		No		Yes
T2	Yes	VOT, pitch	Yes	VOT, pitch	No change
T3	Yes	VOT	Yes	VOT	No change
T4	No		No		Yes
T5	Yes	VOT, pitch	No		No
T6	No		No		No change
N1	No		No		Yes
N2	Yes	VOT	Yes	VOT	No change
N3	No		Yes	VOT	Yes
N4	No		Yes	VOT	Yes
N5	Yes	VOT	Yes	VOT	Yes

Did subjects make the three-way contrast?

	Before training		After training		Improved?
	Contrast	Using	Contrast	Using	
T1	No		No		Yes
T2	Yes	VOT, pitch	Yes	VOT, pitch	No change
T3	Yes	VOT	Yes	VOT	No change
T4	No		No		Yes
T5	Yes	VOT, pitch	No		No
T6	No		No		No change
N1	No		No		Yes
N2	Yes	VOT	Yes	VOT	No change
N3	No		Yes	VOT	Yes
N4	No		Yes	VOT	Yes
N5	Yes	VOT	Yes	VOT	Yes

Did subjects make contrast?

	Before training			After training		
	ㄱ VS ㄲ	ㄱ VS ㅋ	ㄲ VS ㅋ	ㄱ VS ㄲ	ㄱ VS ㅋ	ㄲ VS ㅋ
	ㄷ VS ㄸ	ㄷ VS ㅌ	ㄸ VS ㅌ	ㄷ VS ㄸ	ㄷ VS ㅌ	ㄸ VS ㅌ
	ㅃ VS ㅄ	ㅃ VS ㅆ	ㅄ VS ㅆ	ㅃ VS ㅄ	ㅃ VS ㅆ	ㅄ VS ㅆ
T1	Y: V	N	Y: V	Y: V	Y: V	Y: V
T2	Y: P	Y: V, P	Y: V	Y: P	Y: V, P	Y: V
T3	Y: V, P	Y: V, P	Y: V	Y: V, P	Y: V, P	Y: V
T4	Y: V	N	Y: V	Y: V	N	Y: V, P
T5	N	Y: P	Y: V	N	Y: P	N
T6	Y: P	Y: P	N	Y: P	Y: P	N
N1	N	Y: V	Y: V	N	Y: V, P	Y: V, P
N2	Y: V	Y: V	Y: V	Y: V	Y: V	Y: V
N3	Y: V	N	Y: V	Y: V	Y: V	Y: V
N4	N	N	N	Y: V	Y: V	Y: V
N5	Y: V	Y: V	Y: V	Y: V	Y: V, P	Y: V

Did subjects make contrast?

	Before training			After training		
	⌈ VS ⌈	⌈ VS Ɔ	⌈⌈ VS Ɔ	⌈ VS ⌈	⌈ VS Ɔ	⌈⌈ VS Ɔ
	⌌ VS ⌌	⌌ VS Ǝ	⌌⌌ VS Ǝ	⌌ VS ⌌	⌌ VS Ǝ	⌌⌌ VS Ǝ
	⌐ VS ⌐	⌐ VS Ǝ	⌐⌐ VS Ǝ	⌐ VS ⌐	⌐ VS Ǝ	⌐⌐ VS Ǝ
T1	Y: V	N	Y: V	Y: V	Y: V	Y: V
T2	Y: P	Y: V, P	Y: V	Y: P	Y: V, P	Y: V
T3	Y: V, P	Y: V, P	Y: V	Y: V, P	Y: V, P	Y: V
T4	Y: V	N	Y: V	Y: V	N	Y: V, P
T5	N	Y: P	Y: V	N	Y: P	N
T6	Y: P	Y: P	N	Y: P	Y: P	N
N1	N	Y: V	Y: V	N	Y: V, P	Y: V, P
N2	Y: V	Y: V	Y: V	Y: V	Y: V	Y: V
N3	Y: V	N	Y: V	Y: V	Y: V	Y: V
N4	N	N	N	Y: V	Y: V	Y: V
N5	Y: V	Y: V	Y: V	Y: V	Y: V, P	Y: V

Did subjects make contrast?

	Before training			After training		
	ㄱ VS ㄴ	ㄱ VS ㅋ	ㄴ VS ㅋ	ㄱ VS ㄴ	ㄱ VS ㅋ	ㄴ VS ㅋ
	ㄷ VS ㄸ	ㄷ VS ㅌ	ㄸ VS ㅌ	ㄷ VS ㄸ	ㄷ VS ㅌ	ㄸ VS ㅌ
	ㅍ VS ㅑ	ㅍ VS ㅓ	ㅑ VS ㅓ	ㅍ VS ㅑ	ㅍ VS ㅓ	ㅑ VS ㅓ
T1	Y: V	N	Y: V	Y: V	Y: V	Y: V
T2	Y: P	Y: V, P	Y: V	Y: P	Y: V, P	Y: V
T3	Y: V, P	Y: V, P	Y: V	Y: V, P	Y: V, P	Y: V
T4	Y: V	N	Y: V	Y: V	N	Y: V, P
T5	N	Y: P	Y: V	N	Y: P	N
T6	Y: P	Y: P	N	Y: P	Y: P	N
N1	N	Y: V	Y: V	N	Y: V, P	Y: V, P
N2	Y: V	Y: V	Y: V	Y: V	Y: V	Y: V
N3	Y: V	N	Y: V	Y: V	Y: V	Y: V
N4	N	N	N	Y: V	Y: V	Y: V
N5	Y: V	Y: V	Y: V	Y: V	Y: V, P	Y: V

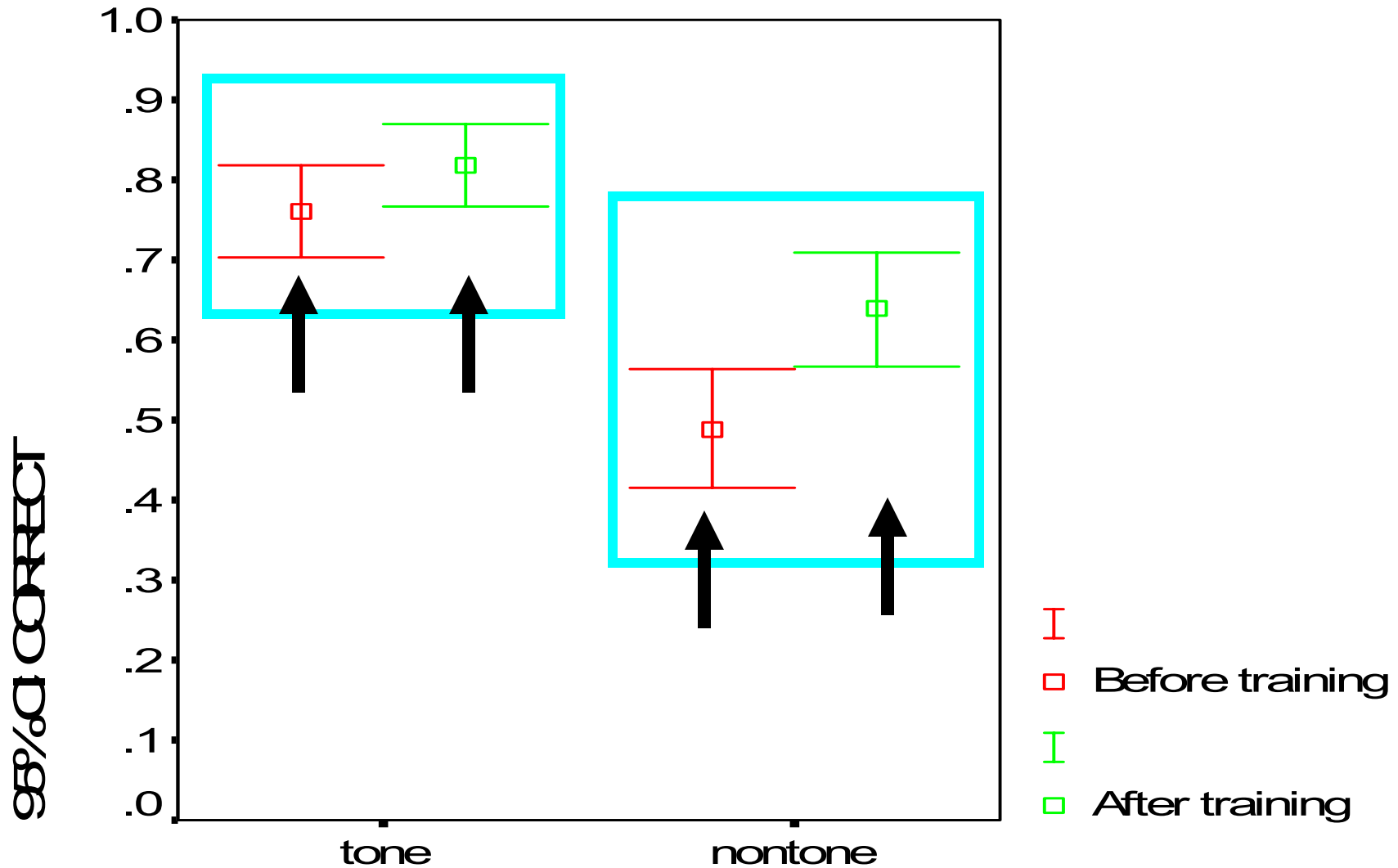
Conclusion: production

- Pronunciation of both groups improved after training.
- Tone language speakers tend to use the pitch of the following vowels as a cue to consonant types more than non-tone language speakers do.
- Non-tone language speakers tend to mainly rely on VOT to make the contrast.

Results: Perception

Responses for unaltered tokens

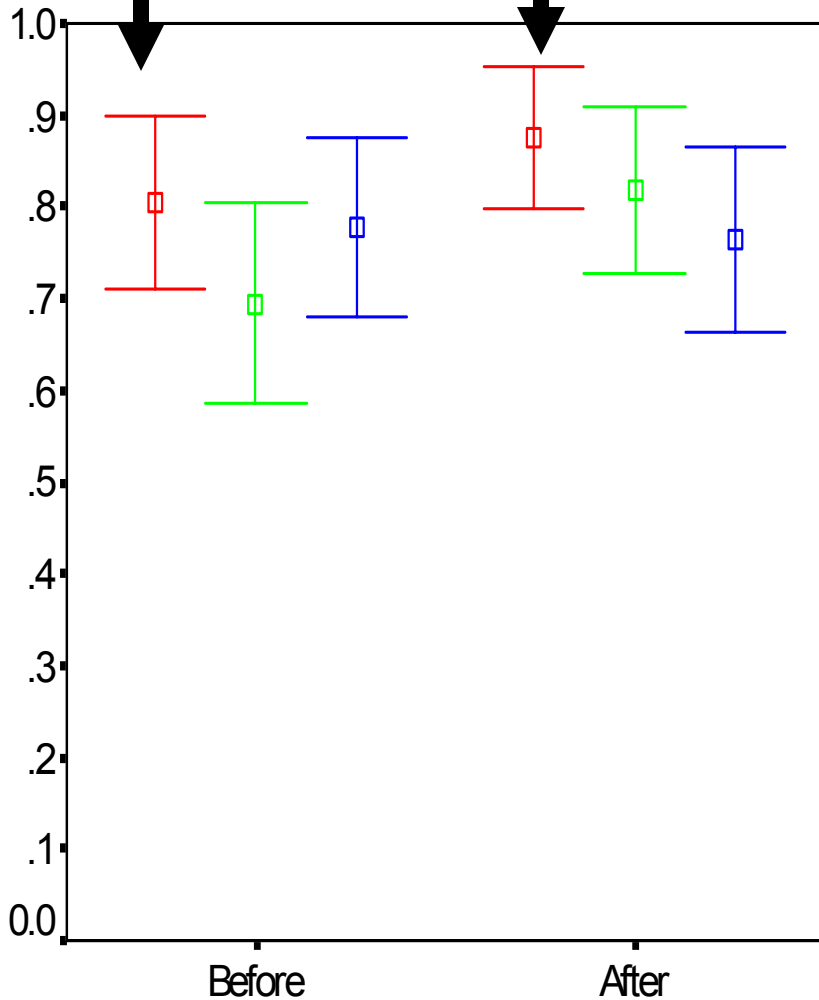
Overall results



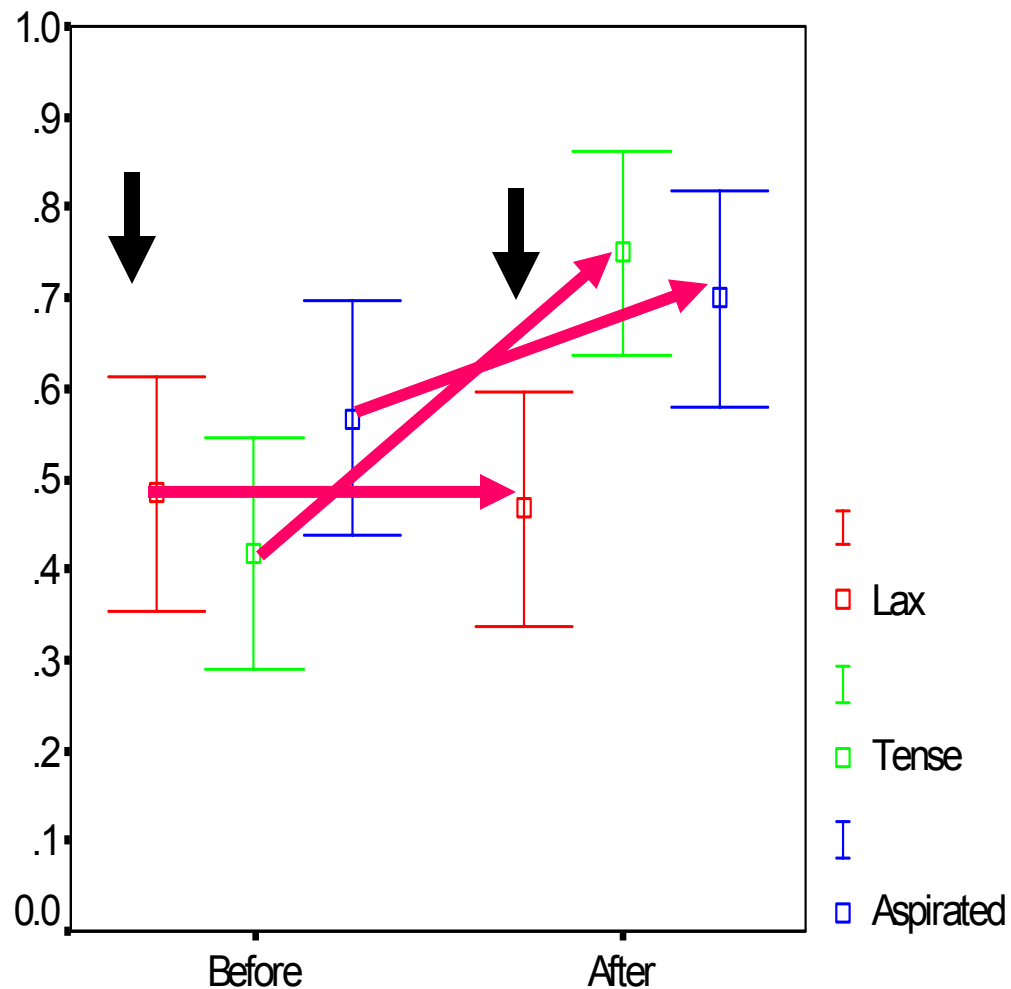
Responses for unaltered tokens

Results by consonant type

Tone speakers



Non-tone speakers



Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for spliced tokens

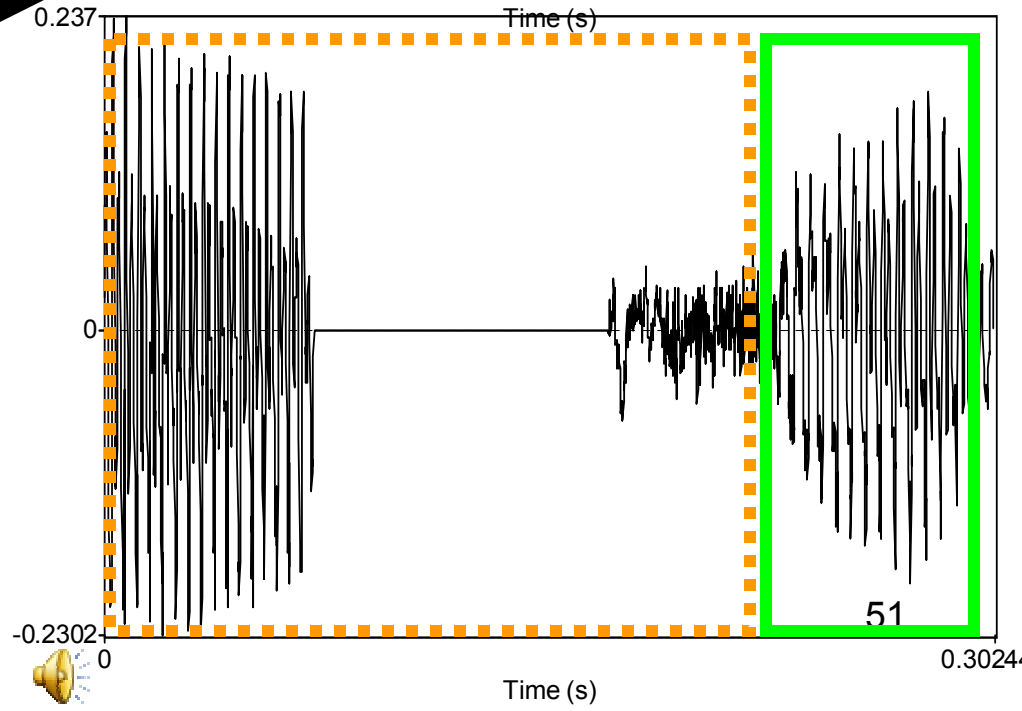
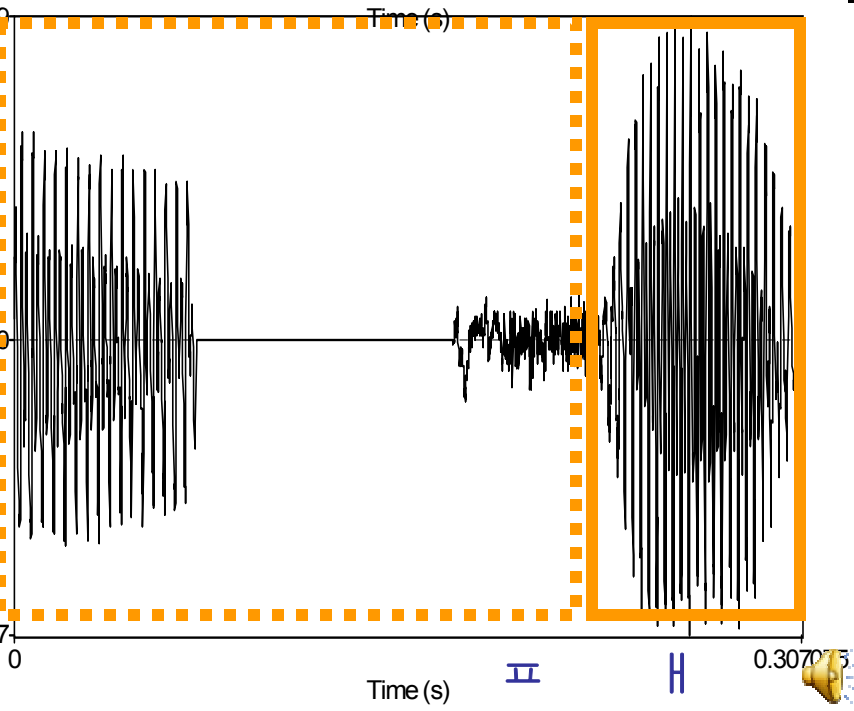
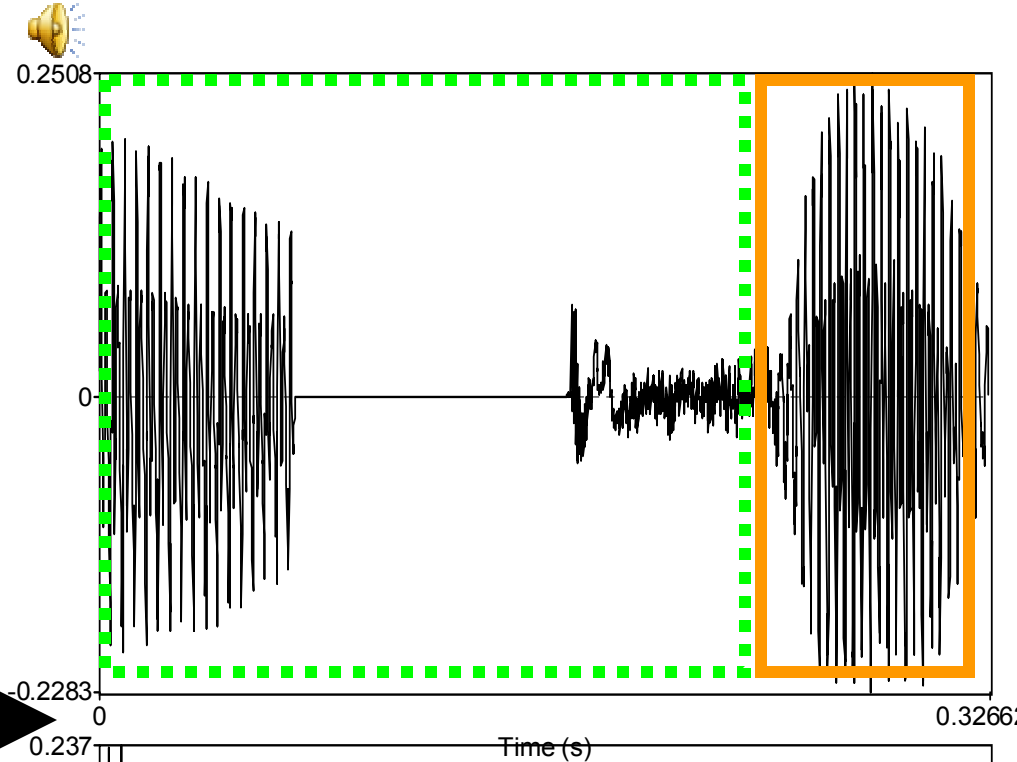
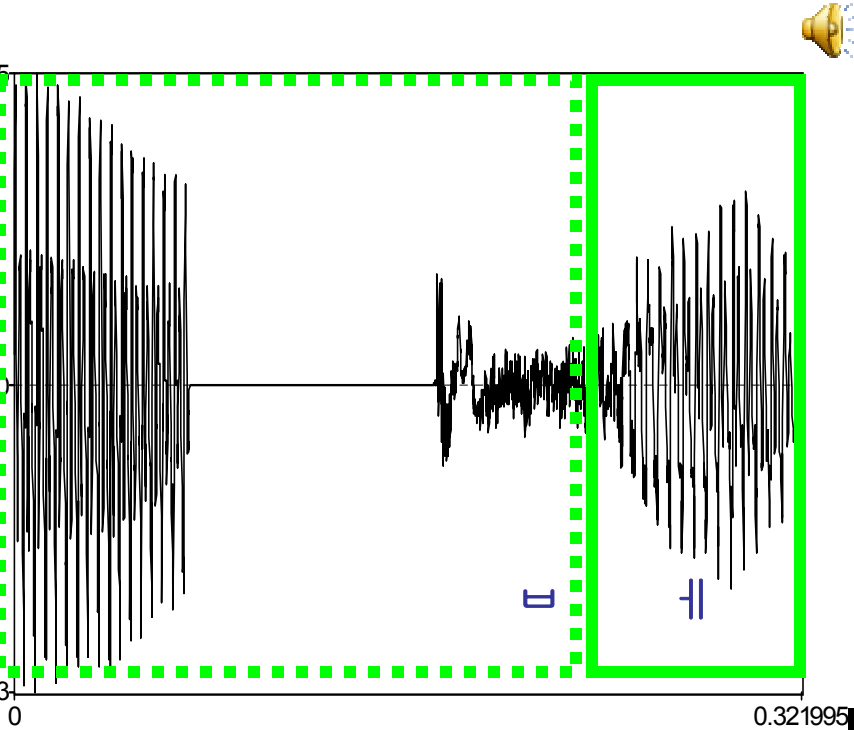
ㄹ + ㅍ and ㅍ + ㅍ

Before training

After training

	Tone group	Nontone group
Judged by consonant burst (i.e. VOT)	5/36 (13.9%)	17/30 (56.7%)
Judged by vowel portion (i.e. pitch)	31/36 (86.1%)	13/30 (43.3%)

	Tone group	Nontone group
Judged by consonant burst (i.e. VOT)	1/36 (2.8%)	15/30 (50%)
Judged by vowel portion (i.e. pitch)	35/36 (97.2%)	15/30 (50%)



Responses for spliced tokens

ㄹ + ㅍ and ㅍ + ㅍ

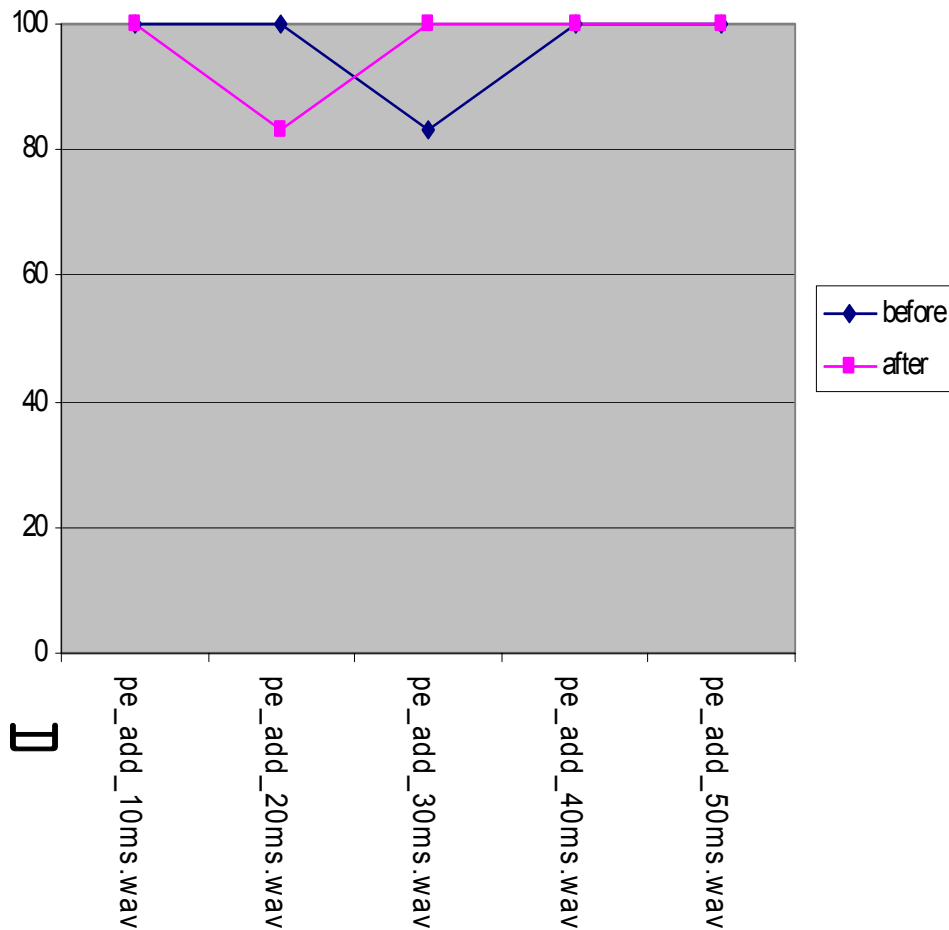
Before training

After training

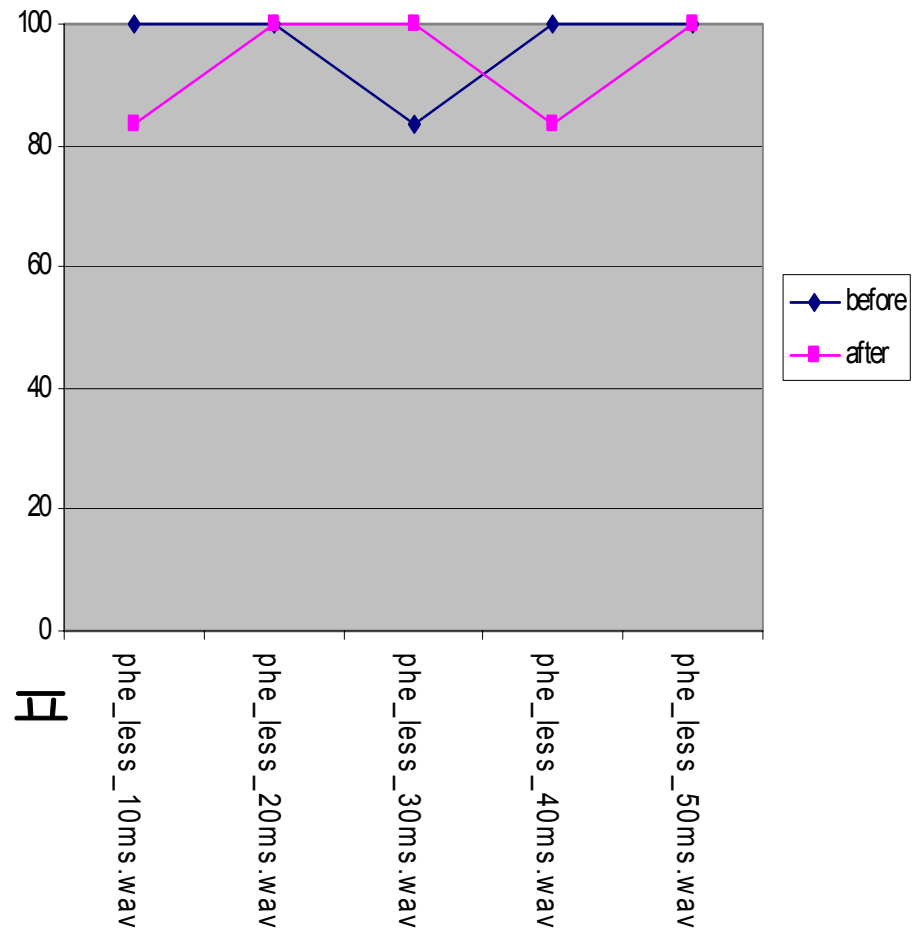
	Tone group	Nontone group		Tone group	Nontone group
Judged by consonant burst (i.e. VOT)	5/36 (13.9%)	17/30 (56.7%)	Judged by consonant burst (i.e. VOT)	1/36 (2.8%)	15/30 (50%)
Judged by vowel portion (i.e. pitch)	31/36 (86.1%)	13/30 (43.3%)	Judged by vowel portion (i.e. pitch)	35/36 (97.2%)	15/30 (50%)

Responses for edited tokens (1): Tone group










% responses for \sqcup



% responses for \sqcap

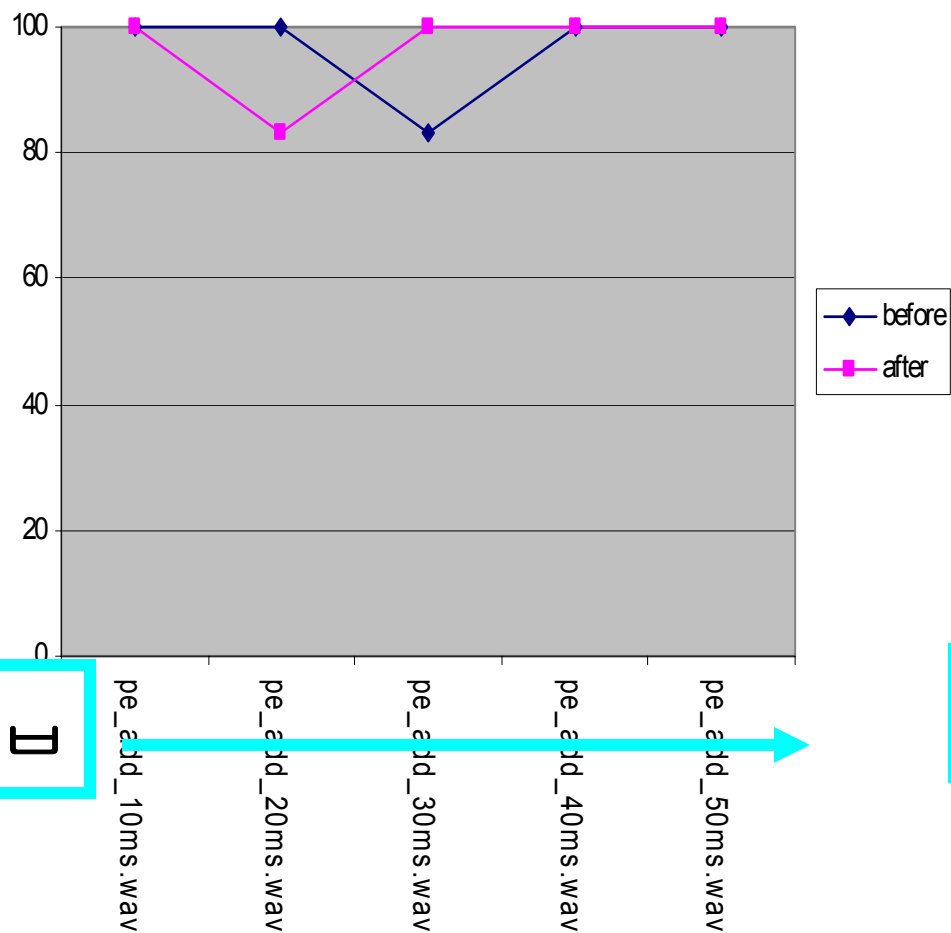


Edited tokens

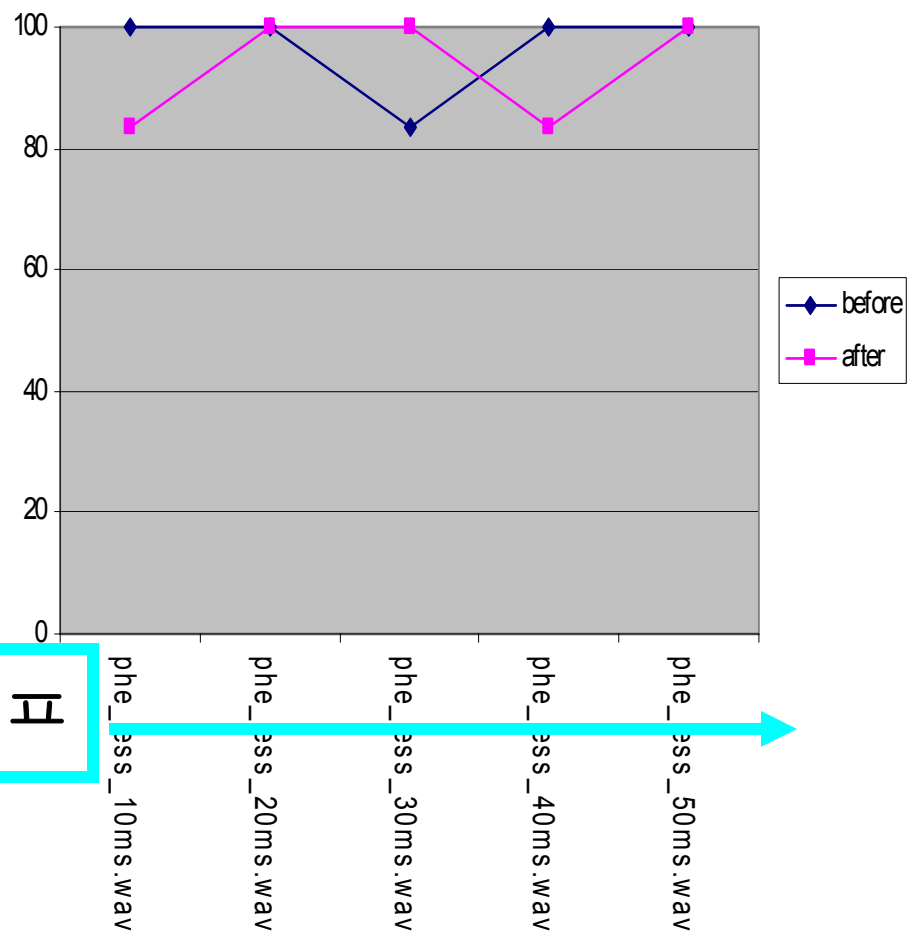
Original 배 	10ms ↑ 	20ms ↑ 	30ms ↑ 	40ms ↑ 	50ms ↑ 
	15Hz ↑ 	30Hz ↑ 	45Hz ↑ 	60Hz ↑ 	75Hz ↑ 
Original 패 	10ms ↓ 	20ms ↓ 	30ms ↓ 	40ms ↓ 	50ms ↓ 
	15Hz ↓ 	30Hz ↓ 	45Hz ↓ 	60Hz ↓ 	75Hz ↓ 

Responses for edited tokens (1): Tone group

% responses for 𐄂

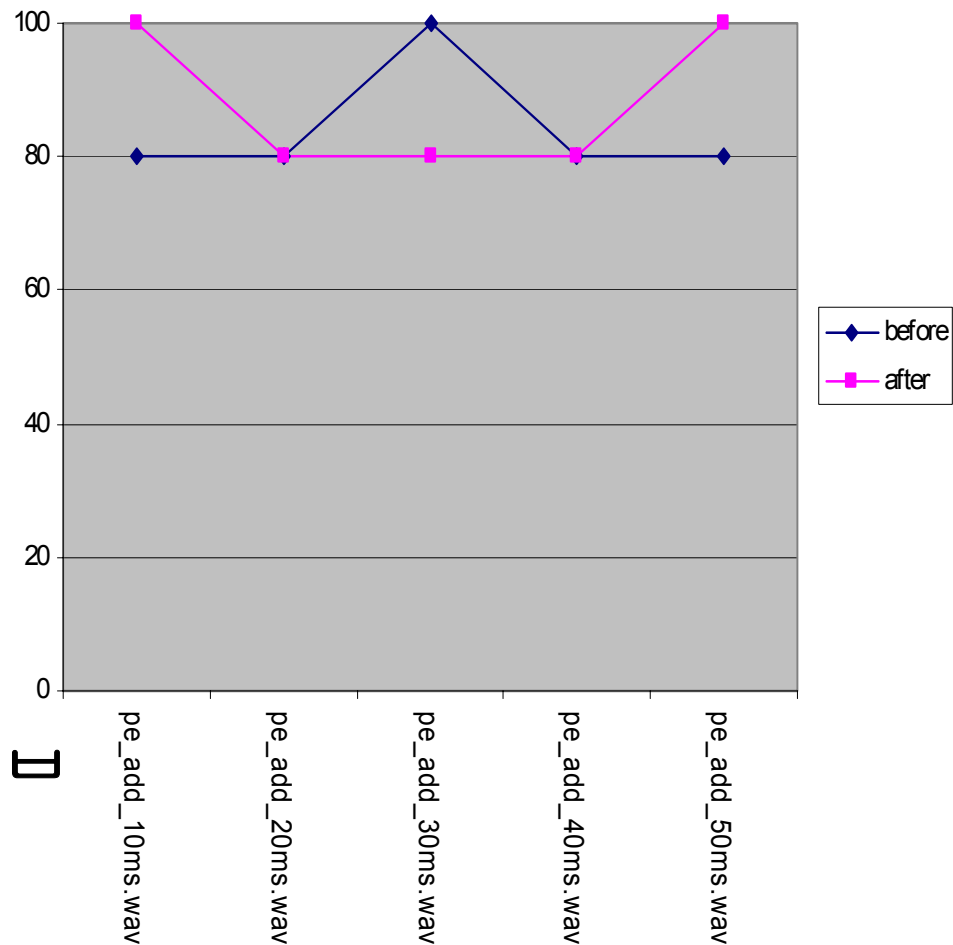


% responses for 𐄃

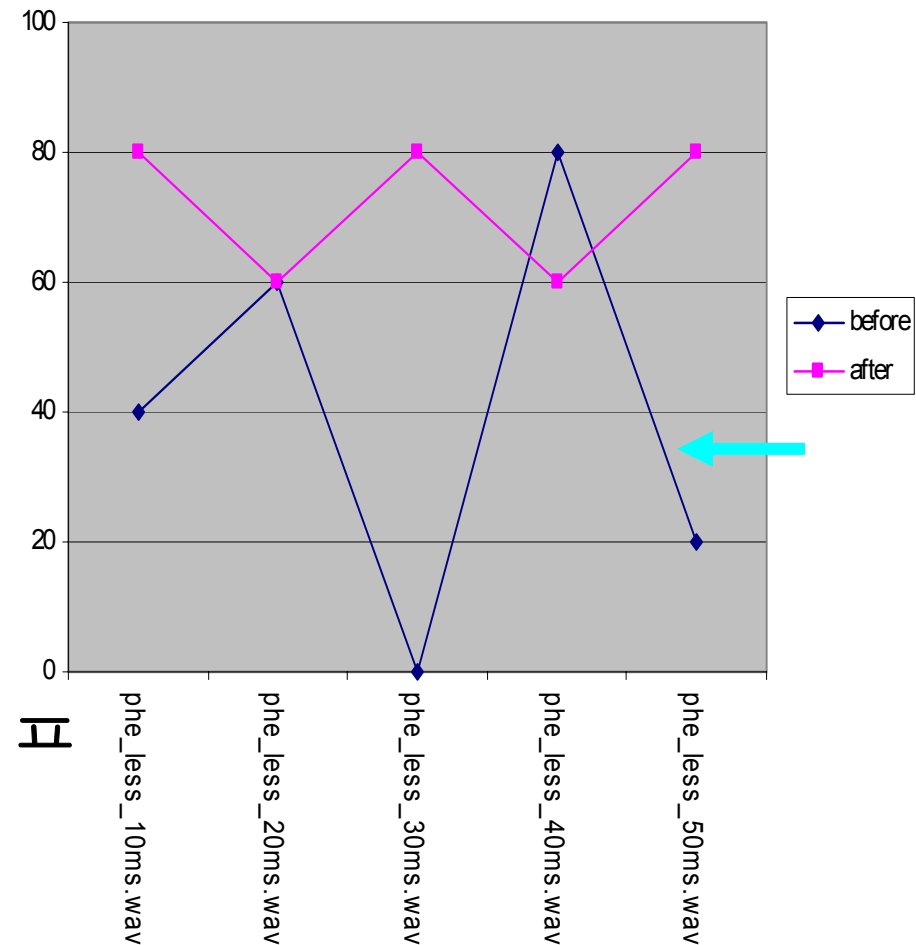


Responses for edited tokens (2): Non-tone group










% responses for H



% responses for H

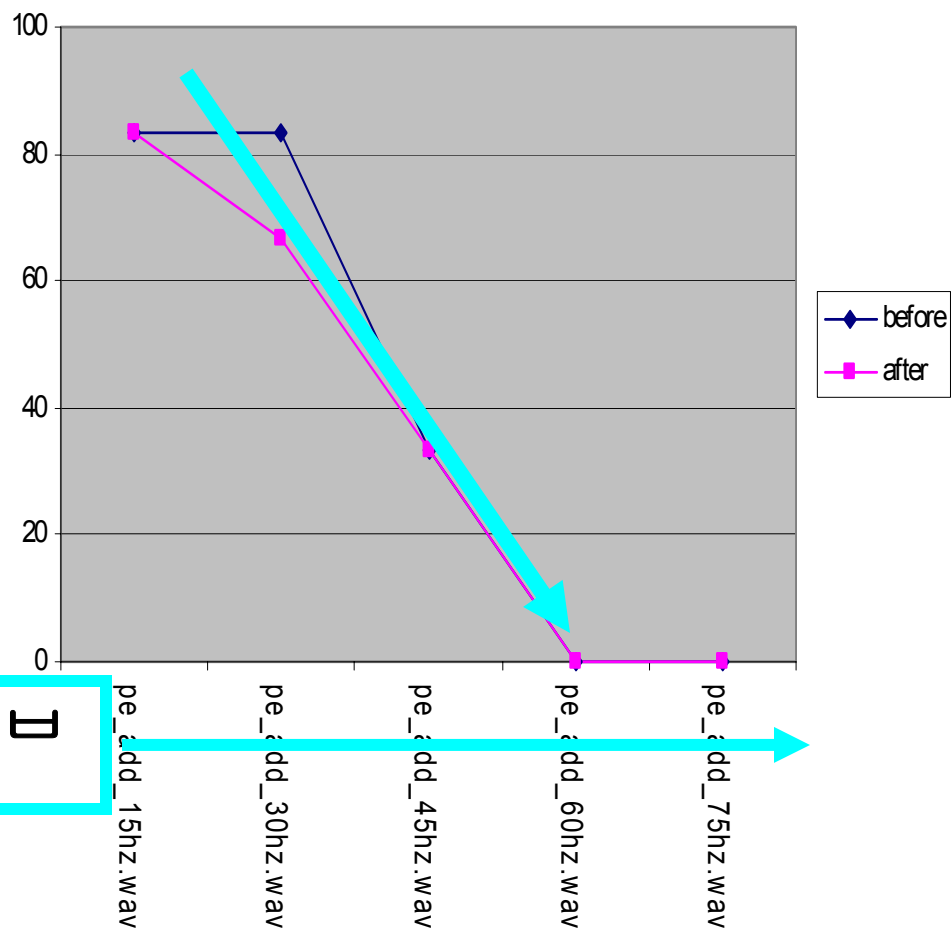


Edited tokens

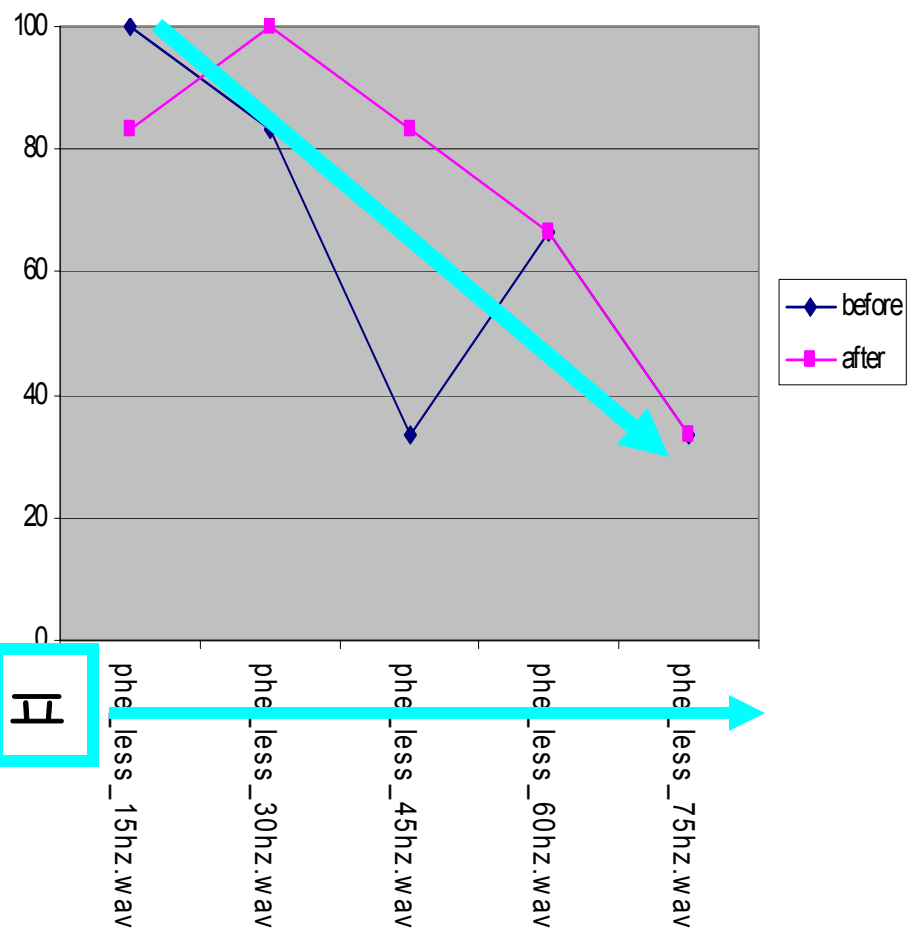
Original 배 	10ms ↑ 	20ms ↑ 	30ms ↑ 	40ms ↑ 	50ms ↑ 
	15Hz ↑ 	30Hz ↑ 	45Hz ↑ 	60Hz ↑ 	75Hz ↑ 
Original 패 	10ms ↓ 	20ms ↓ 	30ms ↓ 	40ms ↓ 	50ms ↓ 
	15Hz ↓ 	30Hz ↓ 	45Hz ↓ 	60Hz ↓ 	75Hz ↓ 

Responses for edited tokens (3): Tone group

% responses for 𐄂

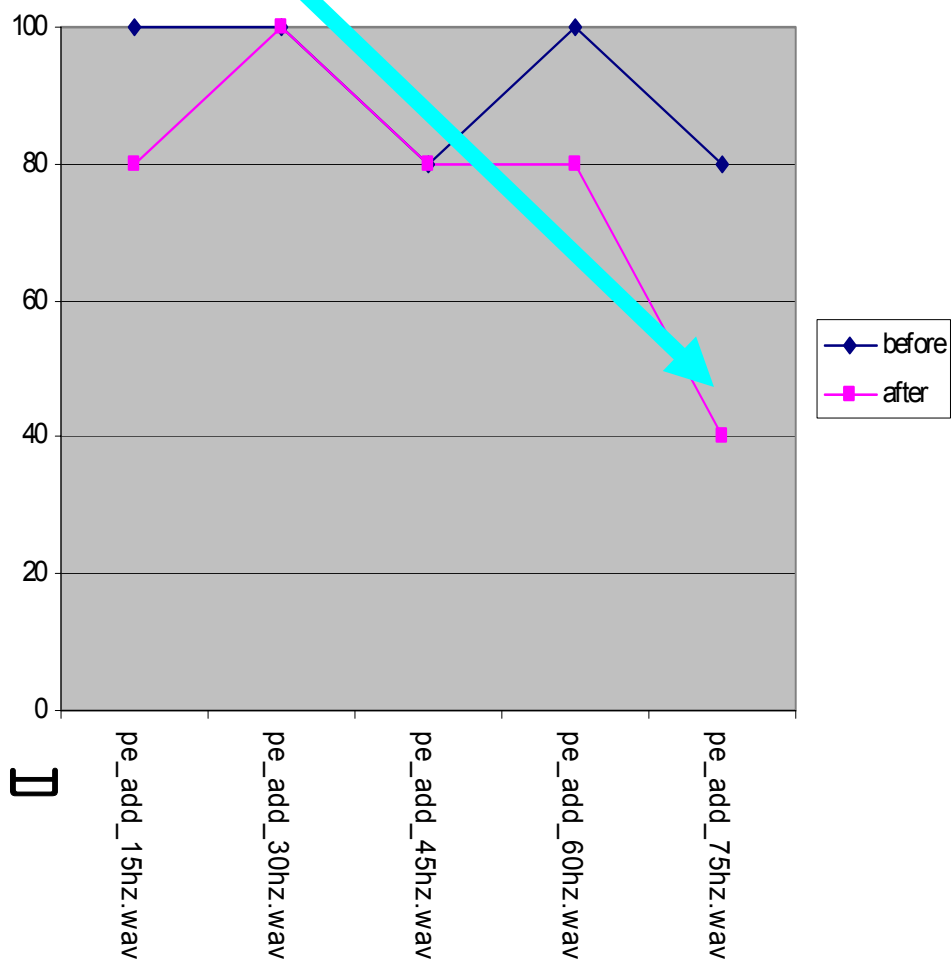


% responses for 𐄃

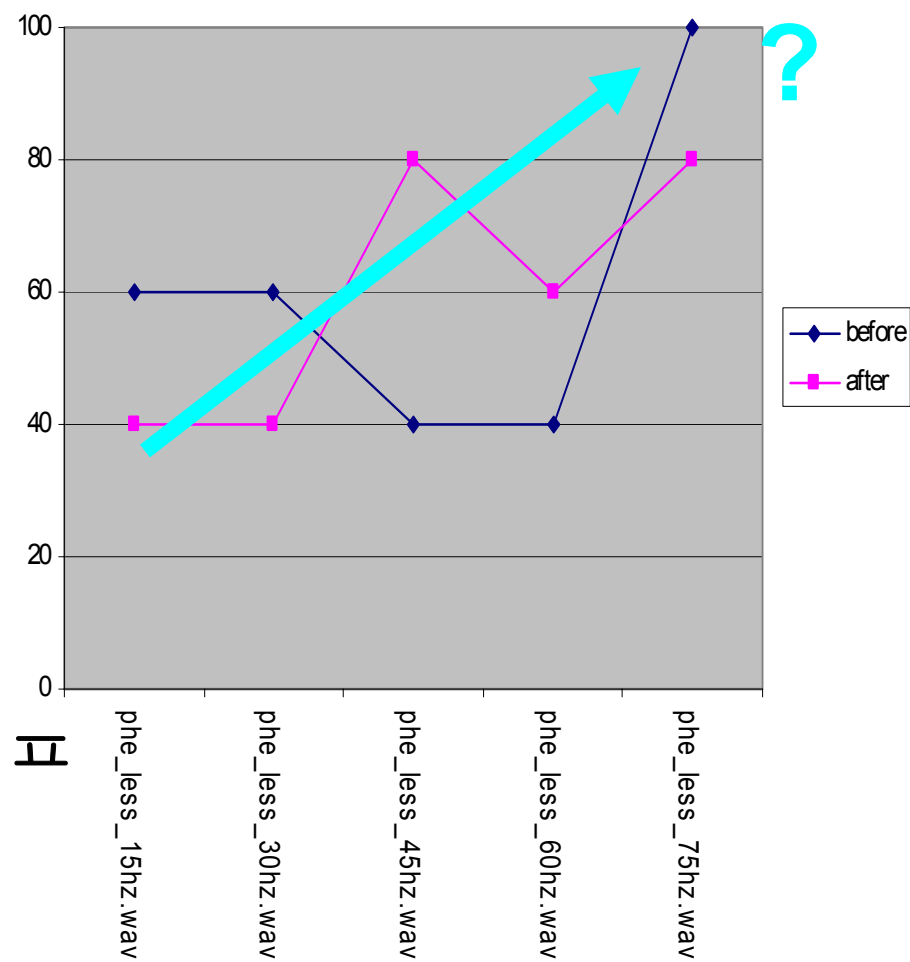


Responses for edited tokens (4): Non-tone group

% responses for 𐄂



% responses for 𐄃



Conclusion: perception

- Both groups improved in the perception of the contrast after training.
- Tone-language speakers seemed to rely on the pitch even before the training, and this trend became clearer after training.
- Non-tone language speakers did not learn that pitch is an important cue to the contrast even after training, which suggests that they mainly rely on VOT.

Conclusion

- Both groups of subjects improved in both production and perception after training.
 - Long-term effect?
- Tone language speakers and non-tone language speakers were different in the sensitivity to pitch as a cue to consonant type.
 - Tone language speaker were sensitive to pitch cue from the beginning, and the training session seems to have reinforced it.
 - Non-tone language speakers were not sensitive to pitch cue from the beginning, and the training session did not help them much to recognize the pitch difference.

Implication

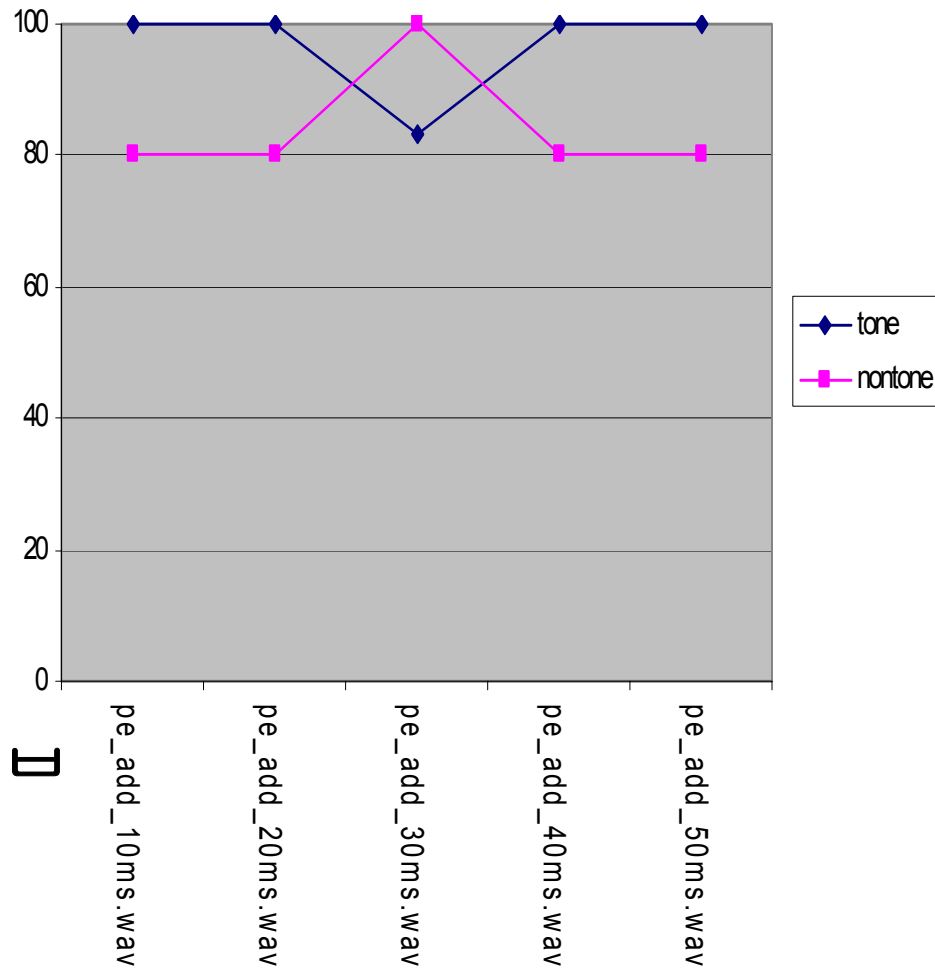
- Relatively short simple training can help students to learn the three-way contrast better.
 - 72 tokens with correct/incorrect feedbacks, which take approximately 5 minutes, made a significant improvement at least for some learners in this study.
- Drawing learners' attention to specific characteristics of Korean sounds could help students learning.
 - Pitch of the following vowels as well as VOT (extra amount of air)
- Learners' various language backgrounds need to be considered in teaching pronunciation.
 - e.g. Tone language vs. non-tone language speakers

Acknowledgements

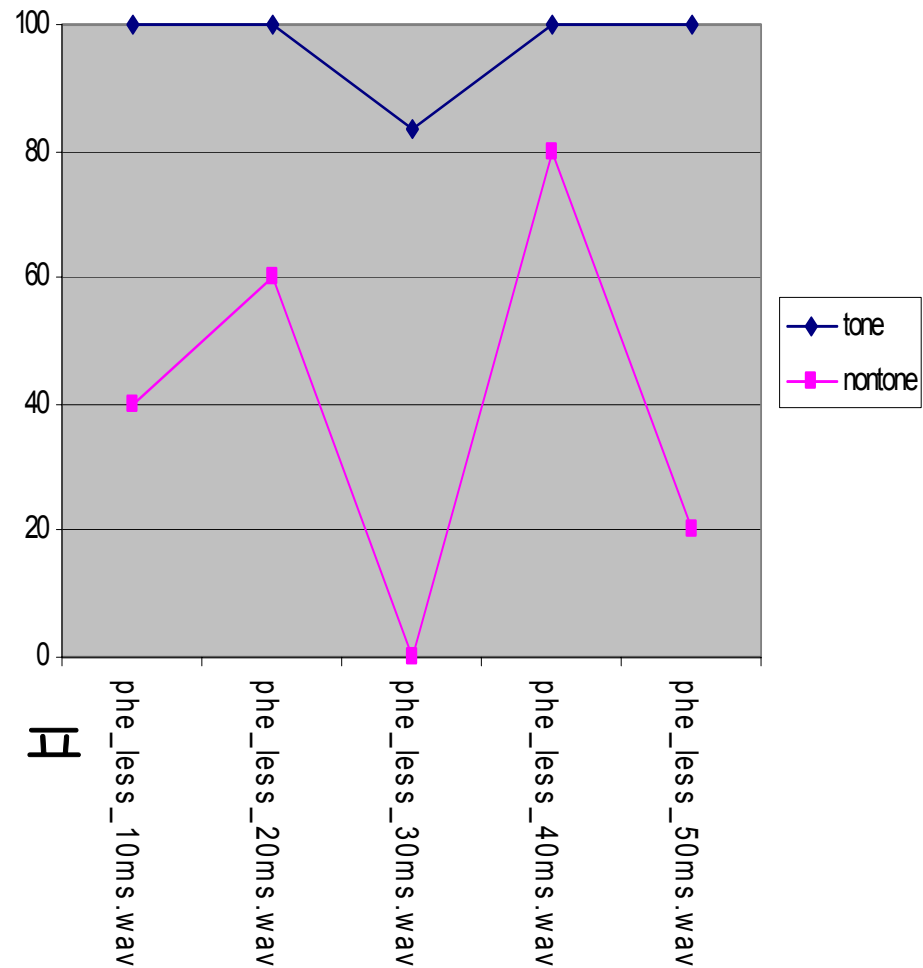
- I thank the participants of this study for their time and valuable comments, all the Korean SSNs at UC Berkeley for their constant help, and the Center for Korean Studies, UC Berkeley, for offering the travel grant. All errors are of course mine.

Manipulated tokens (1): Before trial

% responses for \sqcup

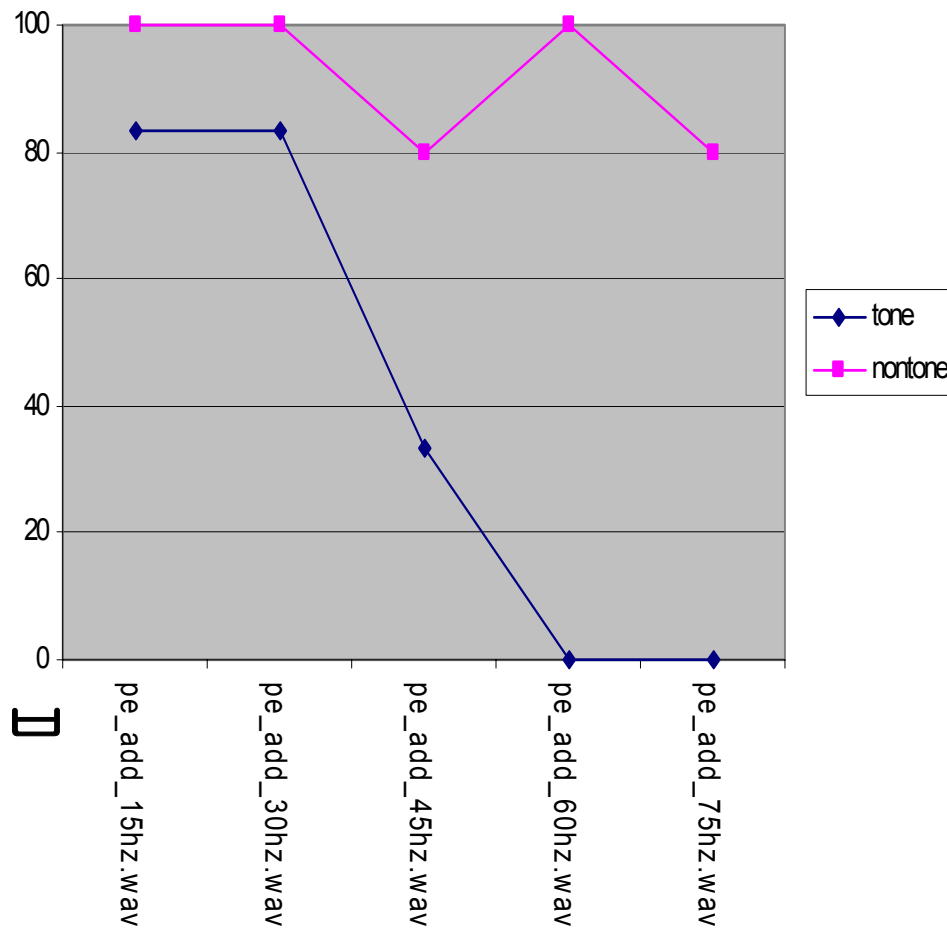


% responses for \sqcap

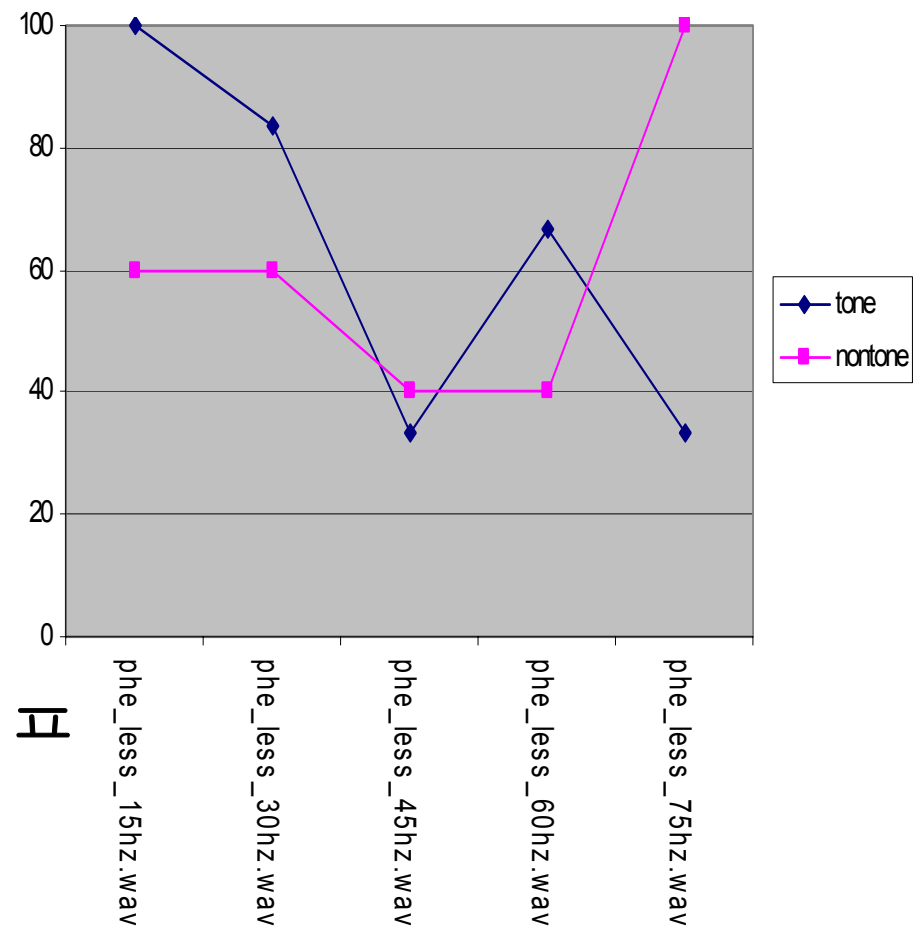


Manipulated tokens (2): Before training

% responses for p^{H}

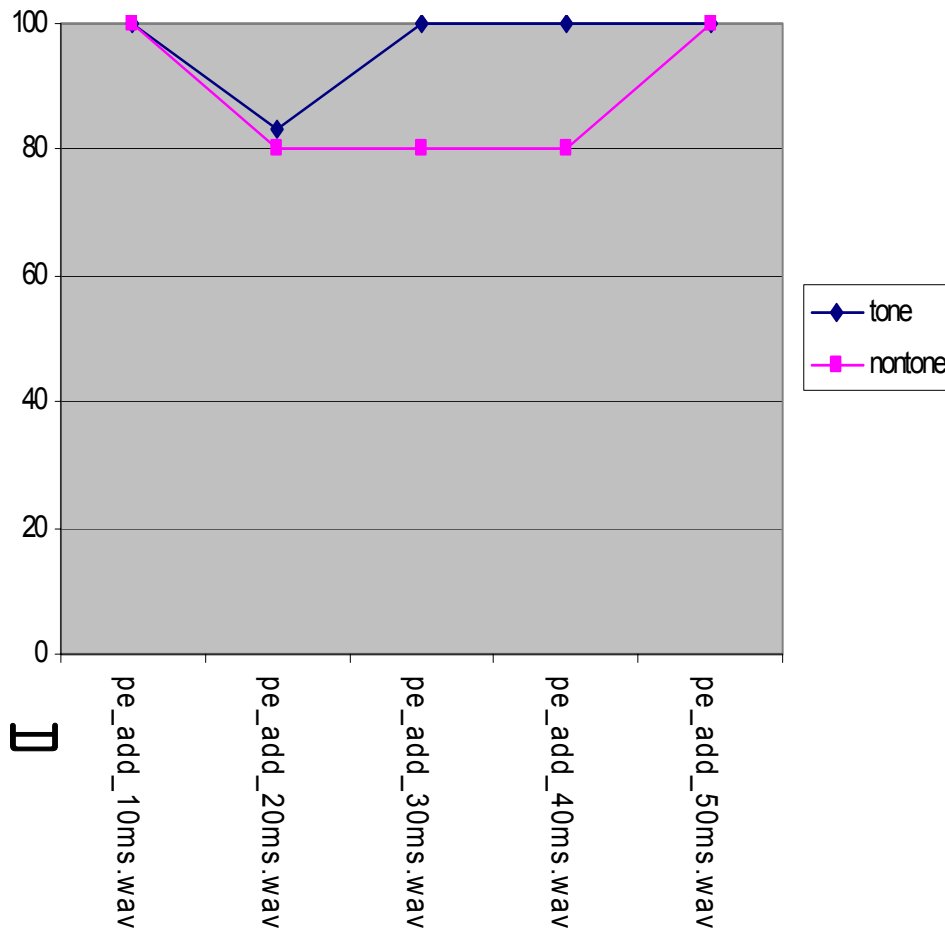


% responses for p^{H}

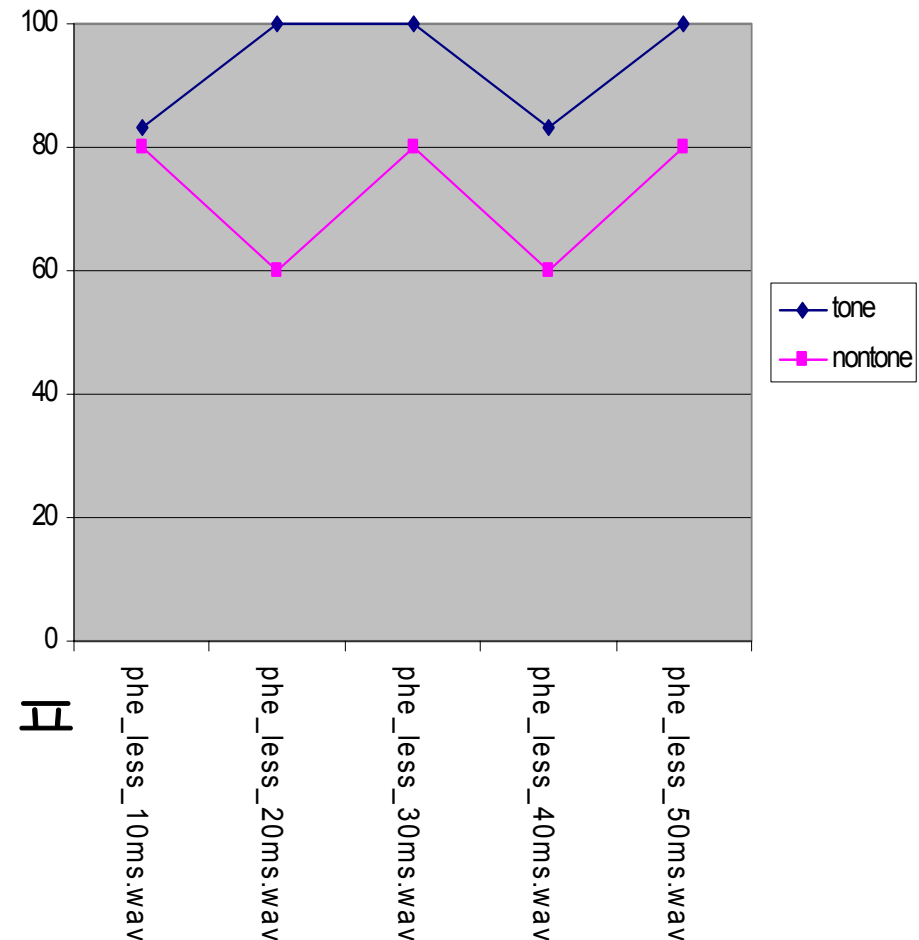


Manipulated tokens (3): After training

% responses for p^{H}

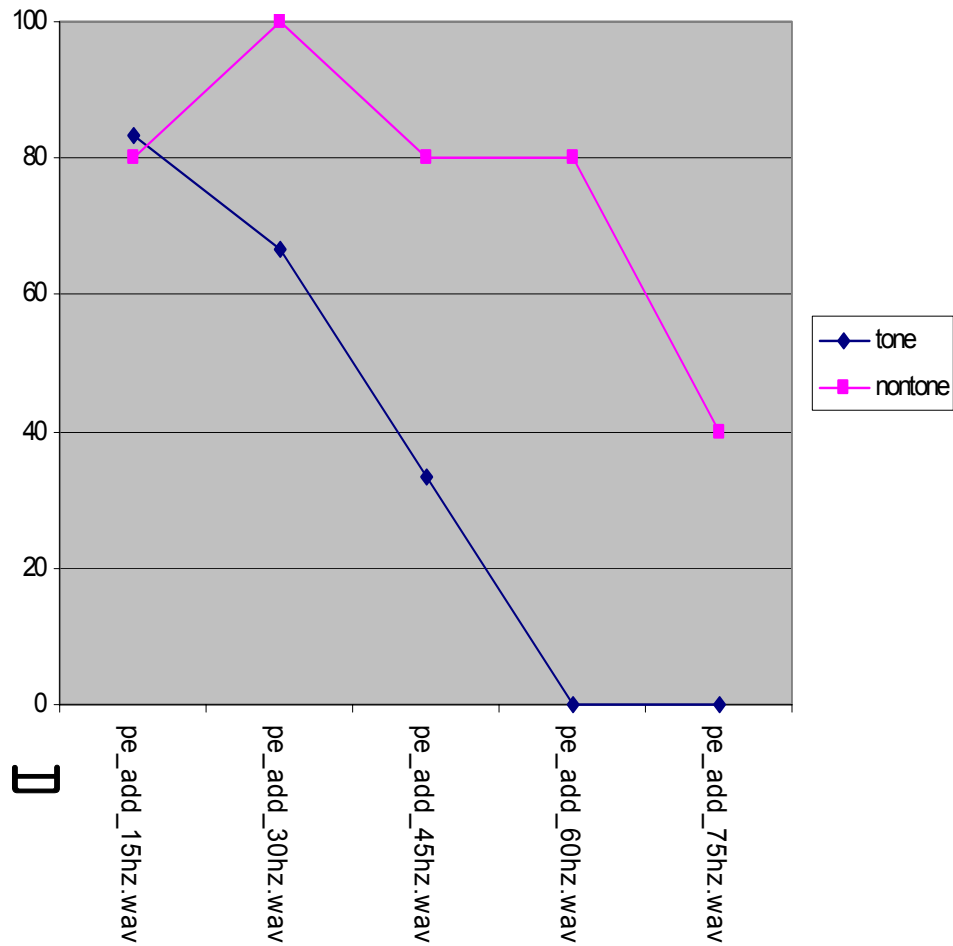


% responses for p^{H}

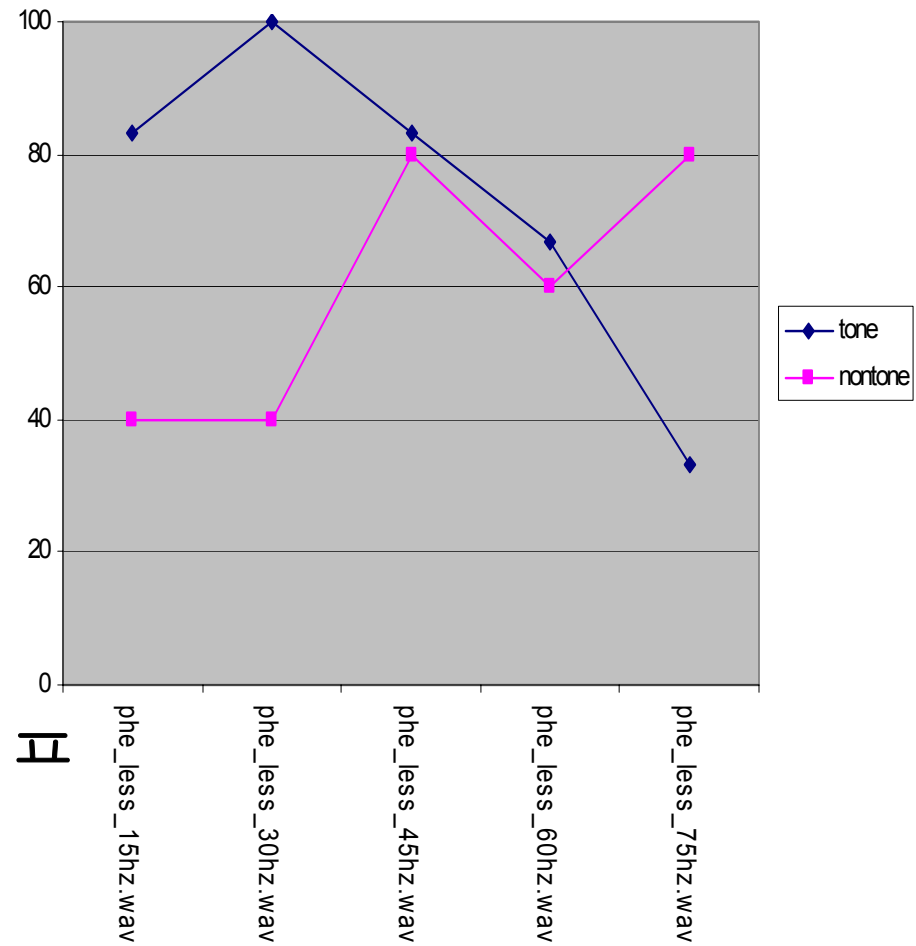


Manipulated tokens (4): After training

% responses for H



% responses for H



Responses for spliced tokens (1):

ㄹ + ㅅ and ㅅ + ㅅ

Before training

After training

	Tone group	Nontone group		Tone group	Nontone group
Lax	17/18 (94.4%)	6/15 (40%)	Lax	16/18 (88.9%)	4/15 (26.7%)
Aspirated	16/18 (88.9%)	12/15 (80%)	Aspirated	16/18 (88.9%)	14/15 (93.3%)

Did subjects make contrast?

	Before			After		
	¬ vs ㄸ	¬ vs ㄹ	ㄸ vs ㄹ	¬ vs ㄸ	¬ vs ㄹ	ㄸ vs ㄹ
T1	Y	N	Y	Y	Y	Y
T2	Y	Y	Y	Y	Y	Y
T3	Y	Y	Y	Y	Y	Y
T4	Y	N	Y	Y	N	Y
T5	N	Y	Y	N	Y	N
T6	Y	Y	N	Y	Y	N
N1	N	Y	Y	N	Y	Y
N2	Y	Y	Y	Y	Y	Y
N3	Y	N	Y	Y	Y	Y
N4	N	N	N	Y	Y	Y
N5	Y	Y	Y	Y	Y	Y

Did subjects make contrast?

	Before			After		
	ㄱ vs ㄷ	ㄱ vs ㅋ	ㄷ vs ㅋ	ㄱ vs ㄷ	ㄱ vs ㅋ	ㄷ vs ㅋ
T1	Y	N	Y	Y	Y	Y
T2	Y	Y	Y	Y	Y	Y
T3	Y	Y	Y	Y	Y	Y
T4	Y	N	Y	Y	N	Y
T5	N	Y	Y	N	Y	N
T6	Y	Y	N	Y	Y	N
N1	N	Y	Y	N	Y	Y
N2	Y	Y	Y	Y	Y	Y
N3	Y	N	Y	Y	Y	Y
N4	N	N	N	Y	Y	Y
N5	Y	Y	Y	Y	Y	Y

Did subjects make contrast?

	Before			After		
	¬ vs ㄸ	¬ vs ㄹ	ㄸ vs ㄹ	¬ vs ㄸ	¬ vs ㄹ	ㄸ vs ㄹ
T1	Y	N	Y	Y	Y	Y
T2	Y	Y	Y	Y	Y	Y
T3	Y	Y	Y	Y	Y	Y
T4	Y	N	Y	Y	N	Y
T5	N	Y	Y	N	Y	N
T6	Y	Y	N	Y	Y	N
N1	N	Y	Y	N	Y	Y
N2	Y	Y	Y	Y	Y	Y
N3	Y	N	Y	Y	Y	Y
N4	N	N	N	Y	Y	Y
N5	Y	Y	Y	Y	Y	Y

Did subjects make contrast?

	Before			After		
	ㄱ vs ㄷ	ㄱ vs ㅋ	ㄷ vs ㅋ	ㄱ vs ㄷ	ㄱ vs ㅋ	ㄷ vs ㅋ
T1	Y	N	Y	Y	Y	Y
T2	Y	Y	Y	Y	Y	Y
T3	Y	Y	Y	Y	Y	Y
T4	Y	N	Y	Y	N	Y
T5	N	Y	Y	N	Y	N
T6	Y	Y	N	Y	Y	N
N1	N	Y	Y	N	Y	Y
N2	Y	Y	Y	Y	Y	Y
N3	Y	N	Y	Y	Y	Y
N4	N	N	N	Y	Y	Y
N5	Y	Y	Y	Y	Y	Y

Responses for unaltered tokens

Results by consonant type

Before training

After training

	Tone group	Nontone group		Tone group	Nontone group
Lax ㄱ, ㅋ, ㆁ	58/72 80.6%	29/60 48.3%	Lax ㄱ, ㅋ, ㆁ	63/72 87.5%	28/60 46.7%
Tense ㄲ, ㄳ, ㅃ	50/72 69.4%	25/60 41.7%	Tense ㄲ, ㄳ, ㅃ	59/72 81.9%	45/60 75%
Aspirated ㆁ, ㆁ, ㆁ	56/72 77.8%	34/60 56.7%	Aspirated ㆁ, ㆁ, ㆁ	55/72 76.4%	42/60 70%

Did subjects make contrast?

	Before training			After training		
	\neg VS \neg	\neg VS \neg	\neg VS \neg	\neg VS \neg	\neg VS \neg	\neg VS \neg
T1	Y: V	N	Y: V	Y: V	Y: V	Y: V
T2	Y: P	Y: V, P	Y: V	Y: P	Y: V, P	Y: V
T3	Y: V, P	Y: V, P	Y: V	Y: V, P	Y: V, P	Y: V
T4	Y: V	N	Y: V	Y: V	N	Y: V, P
T5	N	Y: P	Y: V	N	Y: P	N
T6	Y: P	Y: P	N	Y: P	Y: P	N
N1	N	Y: V	Y: V	N	Y: V, P	Y: V, P
N2	Y: V	Y: V	Y: V	Y: V	Y: V	Y: V
N3	Y: V	N	Y: V	Y: V	Y: V	Y: V
N4	N	N	N	Y: V	Y: V	Y: V
N5	Y: V	Y: V	Y: V	Y: V	Y: V, P	Y: V

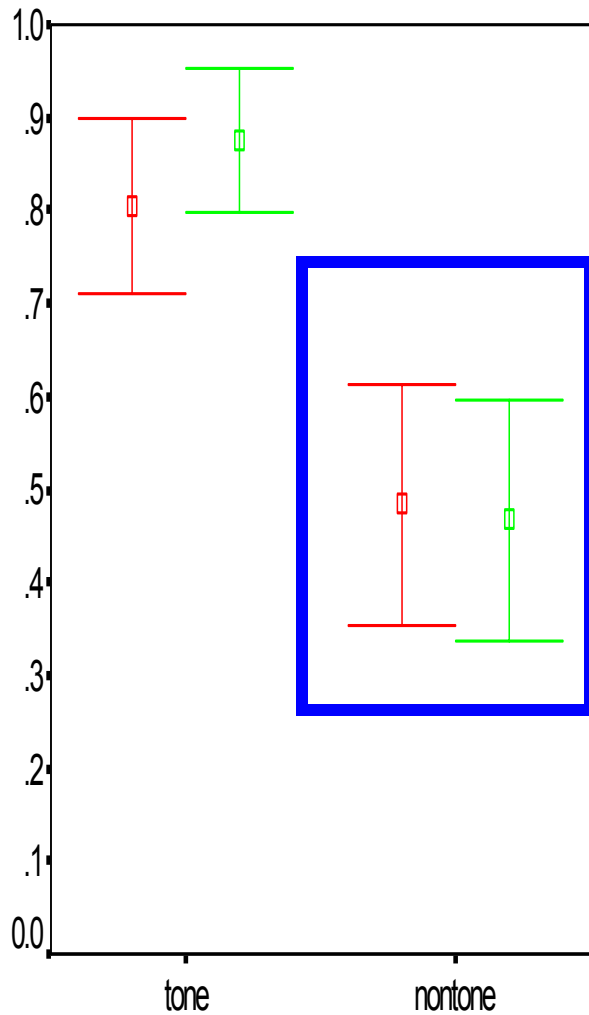
Did subjects make contrast?

	Before training			After training		
	\neg VS \neg	\neg VS \neg	\neg VS \neg	\neg VS \neg	\neg VS \neg	\neg VS \neg
T1	Y: V	N	Y: V	Y: V	Y: V	Y: V
T2	Y: P	Y: V, P	Y: V	Y: P	Y: V, P	Y: V
T3	Y: V, P	Y: V, P	Y: V	Y: V, P	Y: V, P	Y: V
T4	Y: V	N	Y: V	Y: V	N	Y: V, P
T5	N	Y: P	Y: V	N	Y: P	N
T6	Y: P	Y: P	N	Y: P	Y: P	N
N1	N	Y: V	Y: V	N	Y: V, P	Y: V, P
N2	Y: V	Y: V	Y: V	Y: V	Y: V	Y: V
N3	Y: V	N	Y: V	Y: V	Y: V	Y: V
N4	N	N	N	Y: V	Y: V	Y: V
N5	Y: V	Y: V	Y: V	Y: V	Y: V, P	Y: V

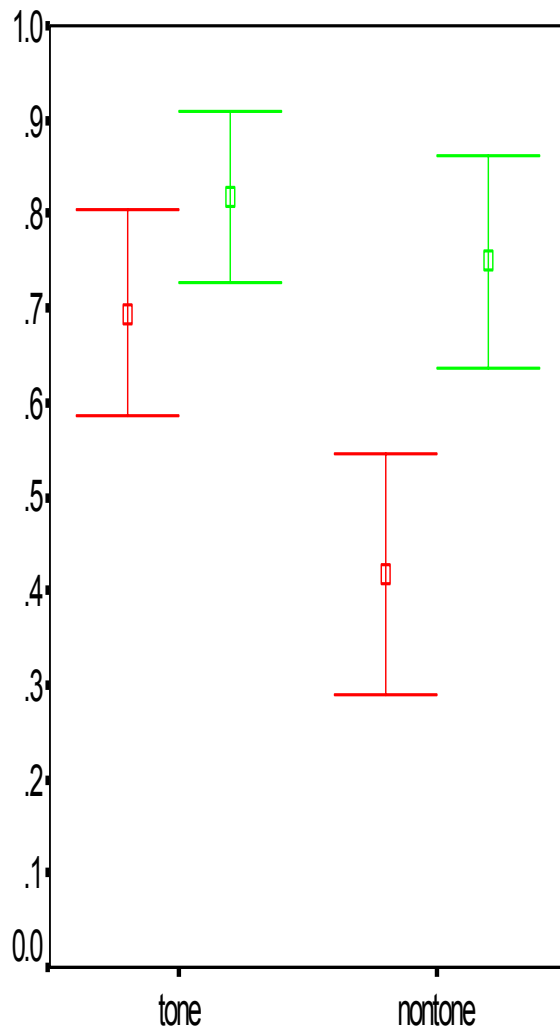
Responses for unaltered tokens

Results by consonant type

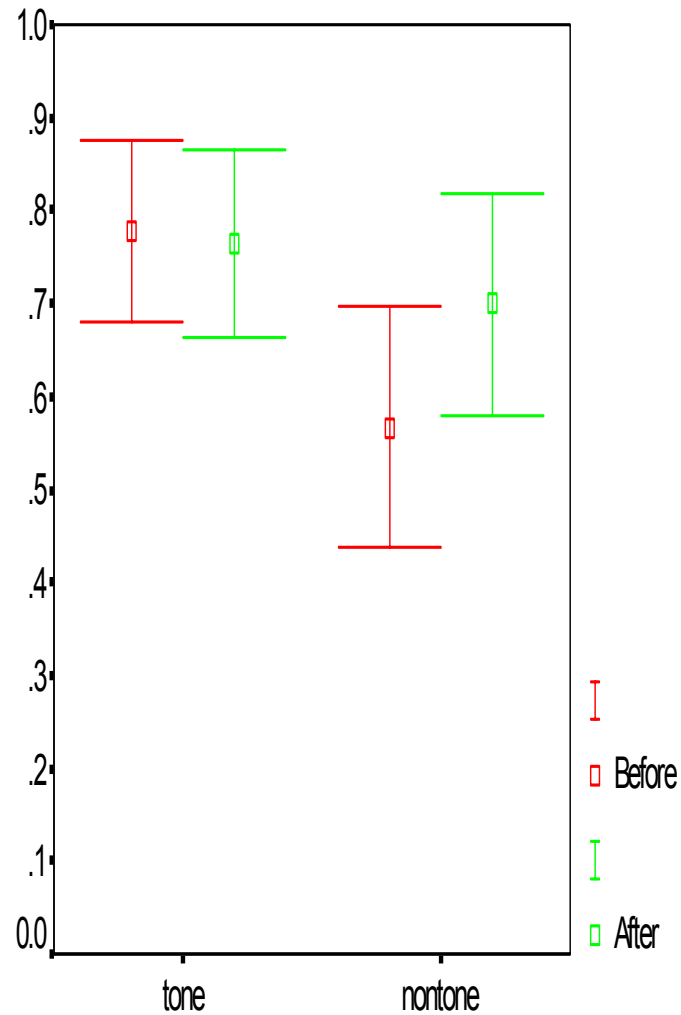
Lax



Tense



Aspirated



Before
After

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Responses for unaltered tokens

Results by subject

	Overall				Lax		Tense		Aspirated	
	Before	After	Better?	Sig	Better?	Sig	Better?	Sig	Better?	Sig
T1	89%	83%	N	N	Y	N	N	N	N	N
T2	92%	94%	Y	N	N	N	N	N	Y	N
T3	94%	94%	N	N	Y	N	N	N	N	N
T4	72%	89%	Y	N	Y	N	Y	N	N	N
T5	56%	75%	Y	N	N	N	Y	Y	Y	N
T6	53%	56%	Y	N	Y	N	N	N	N	N
N1	56%	64%	Y	N	N	N	Y	Y	N	N
N2	67%	72%	Y	N	N	N	Y	N	N	N
N3	47%	53%	Y	N	N	N	Y	N	Y	N
N4	25%	81%	Y	Y	Y	N	Y	Y	Y	Y
N5	50%	50%	N	N	Y	N	Y	N	N	N

Did subjects make contrast?

	Before training			After training		
	\neg VS $\neg\neg$	\neg VS $\neg\neg$	$\neg\neg$ VS $\neg\neg$	\neg VS $\neg\neg$	\neg VS $\neg\neg$	$\neg\neg$ VS $\neg\neg$
T1	Y	N	Y	Y	Y	Y
T2	Y	Y	Y	Y	Y	Y
T3	Y	Y	Y	Y	Y	Y
T4	Y	N	Y	Y	N	Y
T5	N	Y	Y	N	Y	N
T6	Y	Y	N	Y	Y	N
N1	N	Y	Y	N	Y	Y
N2	Y	Y	Y	Y	Y	Y
N3	Y	N	Y	Y	Y	Y
N4	N	N	N	Y	Y	Y
N5	Y	Y	Y	Y	Y	Y

Did subjects make the three-way contrast?

	Before training		After training		Improved?
	Contrast	Using	Contrast	Using	
T1	No		No		Yes
T2	Yes	VOT, pitch	Yes	VOT, pitch	No change
T3	Yes	VOT	Yes	VOT	No change
T4	No		No		Yes
T5	Yes	VOT, pitch	No		No
T6	No		No		No change
N1	No		No		Yes
N2	Yes	VOT	Yes	VOT	No change
N3	No		Yes	VOT	Yes
N4	No		Yes	VOT	Yes
N5	Yes	VOT	Yes	VOT	Yes

Did subjects make the three-way contrast?

	Before training		After training		Improved?
	Contrast	Using	Contrast	Using	
T1	No		No		Yes
T2	Yes	VOT, pitch	Yes	VOT, pitch	No change
T3	Yes	VOT	Yes	VOT	No change
T4	No		No		Yes
T5	Yes	VOT, pitch	No		No
T6	No		No		No change
N1	No		No		Yes
N2	Yes	VOT	Yes	VOT	No change
N3	No		Yes	VOT	Yes
N4	No		Yes	VOT	Yes
N5	Yes	VOT	Yes	VOT	Yes

The three-way contrast of Korean stops

- One of the difficulties that first-time non-heritage Korean learners most often face is the three-way contrast of stops, ㄱ vs ㅋ vs ㆁ , ㄷ vs ㅌ vs ㄴ , ㅈ vs ㅊ vs ㅉ .
- How do non-heritage learners make the contrast?
- Do their language backgrounds affect the learning? If so, how?
- How can we teach this contrast better?

Subjects' language backgrounds

- Chinese (Mandarin, Cantonese)
 - Tone language
 - /p/, /p^h/ (unaspirated vs. aspirated)
- Indonesian
 - Tone language
 - /p/, /b/ (unaspirated vs. voiced)
- English
 - Non-tone language
 - /b/, /p/ (voiced vs. voiceless)