

Prosodic disambiguation of questions in Korean

Theory and processing

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This study aims to identify the acoustic and perceptual properties that contribute to identifying the meaning of Korean sentences that are ambiguous between *wh*-question and yes-no question readings. While in most cases the Accentual Phrase (AP) tonal pattern (Jun 1993) differs between the two question readings, there are cases where the two readings are predicted to have the same AP tonal pattern. However, our experimental results indicate that even in those cases a typical AP tonal contrast between the two question interpretations, i.e. the presence vs. absence of the tone in the syllable that immediately follows the *wh*-word, is observed in production and plays a meaningful role in perception. The results suggest that there is a production and processing strategy to utilize a consistent contrast in accentual phrasing between the two types of questions for disambiguation.

Keywords: *wh*-indeterminates, *wh*-questions, intonation, ambiguity

1. Introduction

Korean *wh*-words are known to be ambiguous until a proper context from the discourse is given. For example, the *wh*-word *nwukwu* in the sentence (1) can be interpreted as a *wh*-interrogative ‘who’ or an indefinite pronoun ‘anyone’, rendering the sentence to either a *wh*-question (WHQ) or a yes-no question (YNQ).¹

1. The sentence can also have a declarative reading (e.g., ‘I am waiting for someone.’), in which the meaning of the subject *pro* may change depending on the context. The declarative reading is excluded from the discussion in this paper for the sake of simplicity, since the meaning of the *wh*-word in a declarative sentence is the same as that in a yes-no question.

- (1) 지금 누구 기다려?
Cikum nwukwu kitalye?
 now who wait.for
 i. YNQ: 'Are you waiting for anyone?'
 ii. WHQ: 'Who are you waiting for?'

It has been noticed that the meaning of Korean *wh*-words can be disambiguated not only by context but also by prosody. Several prosodic factors affecting the interpretation of *wh*-words have been identified, such as phonological phrasing after the *wh*-word (H.-Y. Lee 1990; Jun & Oh 1996; Yun 2019), the relative prominence of the *wh*-word (Chang 1973; Kang 1988; A.-R. Kim 2000), and sentence-final intonation (Martin 1951; K.-M. Lee et al. 1984; Hwang 2007). Among those factors, phonological phrasing in terms of Accentual Phrase (AP) has been argued to be the most crucial cue for disambiguation of *wh*-words (Jun & Oh 1996; Yun 2015; Yun 2019). The distinct phonological phrasing in terms of AP is usually manifested by distinct tonal patterns, according to the intonation model of Korean in Jun (1993). However, the tonal patterns predicted by Jun's model may remain indecisive between the two readings in certain cases (e.g. LHLH for a disyllabic *wh*-word followed by a disyllabic word at the end of the sentence). Thus, one might argue that in those cases phonological phrasing would not play a role and only the other intonational factors such as the relative prominence of *wh*-words or the sentence-final intonation would contribute to disambiguation. In this study, however, we have found that even in such a case, phrasing difference in terms of the tonal pattern still maintains in production, and the different tonal pattern plays a role in disambiguation in perception. Thus, our experimental findings reconfirm the importance of phonological phrasing in interpreting Korean *wh*-words and provide an implication for the tone implementation in the Korean intonation model of Jun (1993) such that a production/processing strategy to maximize the contrast may be a trigger for a tone deletion.

The paper is organized as follows. Section 2 describes in detail the prosodic factors that are known to help disambiguate the meaning of Korean *wh*-words. Section 3 presents a production experiment to find whether all the prosodic factors introduced in Section 2 are manifested in a special case where the factor of our interest (i.e. the tonal contrast due to Accentual Phrasing) is *not* expected to appear according to the theoretical assumptions. Section 4 presents a perception experiment to find whether the prosodic factors manifested in the production study contribute to the perceptual disambiguation of *wh*-words. Section 5 discusses the implications of the experimental results, and Section 6 concludes the paper.

2. Background

This section describes in detail the three prosodic factors that have been reported in the literature as relevant to the interpretation of sentences containing *wh*-words: (i) sentence-ending intonation, (ii) prominence of the *wh*-word, and (iii) phonological phrasing after the *wh*-word.

Many traditional Korean grammarians have described that statements and *wh*-questions have falling intonation, while yes-no questions have rising intonation at the end of the sentence (Martin 1951; K.-M. Lee et al. 1984; Suh 1989; Hur 1991; I.-S. Lee & Ramsey 2000; Kwon 2002). However, the choice of sentence-final intonation is rather complicated because it is also influenced by the speaker's emotion or attitude (H.-Y. Lee 1997: 109–115). It is not uncommon in Korean that statements have a rising intonation and questions have falling intonation. Nevertheless, it is generally the case that *wh*-questions and yes-no questions show different types of intonation at the end of the sentence in Seoul Korean. Jun & Oh (1996) report that the most common boundary tone for *wh*-questions was LH%, a low rising intonation, and the most frequent boundary tone for yes-no questions was H%, a high rising intonation, although other boundary tones were also observed for both types of questions.

Another factor for prosodic disambiguation that has been frequently mentioned by traditional Korean grammarians is the prominence of *wh*-words. It has been claimed in the literature that *wh*-questions are distinguished from other types of sentences by the fact that the *wh*-word is more prominent than other elements in the sentence (Chang 1973; Choe 1985; Kang 1988; Suh 1989; Cho 1990; A.-R. Kim 2002). The phonetic enhancement of the *wh*-word in *wh*-questions was verified by phonetic studies, such that the high tone of the *wh*-word in *wh*-questions is realized with a greater pitch range and higher pitch compared to that in yes-no questions (Jun & Oh 1996; D.-S Park 2010).

Yet another prosodic factor that contributes to the distinction of the question types is phonological phrasing. It has been noted in the phonological and phonetic studies that *wh*-interrogative words introduce a consistent phonological phrasing in the sentence. Cho (1990) claims that a *wh*-interrogative word forms a single phonological phrase with the following (unaccented) word, and Jun (1993) argues that the 'phonological phrase' relevant to the prosody of *wh*-words is the Accentual Phrase (AP). Jun & Oh (1996) confirm this point by an experimental study showing that *wh*-interrogative word is not immediately followed by a phonological phrase break. According to the intonation model of Jun (1993), an

AP is marked phonologically with the LHLH tone pattern as illustrated in (2),² while the phonetic realization of the LHLH pattern can vary depending on the number of syllables in an AP as shown in (3)³ (see also S. Kim 2004; H.- J. Lee 1999). Since *wh*-words introduce distinct phrasing patterns for the yes-no question interpretation and *wh*-question interpretation, the prosodic distinction between yes-no question interpretation and *wh*-question interpretation will be manifested by different AP tonal patterns as in (4), which shows the typical AP tones in the *wh*- and post-*wh* regions in sentences such as (1). That is, the distinct tonal pattern is a byproduct of the distinct phrasing and tone assignment rules in Korean.

(2)

L	(H)	(L)	H
σ	σ	(…)	σ

The typical tonal pattern of an Accentual Phrase in Seoul Korean. The second and penult tones may be deleted if the phrase consists of fewer than 4 syllables.

(3) a. 2-syllable AP

L	H
σ	σ

b. 3-syllable AP

L	H
σ	σ

c. 4-syllable AP

L	H	L	H
σ	σ	σ	σ

d. 5-syllable AP

L	H	L	H
σ	σ	σ	σ

(4) YNQ:

L	H	L	H
σ	σ	σ	σ

WHQ:

L	H	L	H
σ	σ	σ	σ

(solid vertical line: phrase boundary, shaded area: *wh*-word)

2. The underlying AP tone pattern can be HHLH if the first syllable of the AP starts with a tense or aspirated obstruent. The HHLH pattern is excluded from the discussion in this paper for the sake of simplicity, because the LHLH pattern is more frequently observed (S. Kim 2004) and all the experimental data in this paper are restricted to the L-initial pattern.

3. The tone representations in (3) are the most frequent ones that are reported in S. Kim (2004), but the intonation model does not exclude other tone patterns, e.g. LLH and LHH for the APs with three syllables (Jun 2000). Such uncertainty regarding the tonal mapping is yet to be resolved to provide a clear prediction of tonal patterns in any given AP.

Among the above three factors, phonological phrasing in terms of Accentual Phrase has been argued to be the most crucial cue for disambiguation. In the production study in Jun & Oh (1996), all speakers consistently produced WHQs and YNQs with distinctive accentual phrasing patterns, while other prosodic factors were employed to different degrees by speakers. In the perception studies using synthesized speech in Yun (2015, 2019), subjects relied more heavily on accentual phrasing than the prominence of the *wh*-word or sentence boundary tones to disambiguate the meaning of *wh*-words.

However, it is not always the case that different phrasings lead to different tonal patterns. As illustrated in (5), for instance, the same tonal pattern is predicted when a disyllabic *wh*-word is followed by a disyllabic word at the end of the sentence.

(5) YNQ:	<table style="border-collapse: collapse; text-align: center;"> <tr><td style="border: 1px solid black; padding: 2px 5px;">L</td><td style="border: 1px solid black; padding: 2px 5px;">H</td><td style="border: 1px solid black; padding: 2px 5px;">L</td><td style="border: 1px solid black; padding: 2px 5px;">H</td></tr> <tr><td style="border: 1px solid black; padding: 2px 5px;">σ</td><td style="border: 1px solid black; padding: 2px 5px;">σ</td><td style="border: 1px solid black; padding: 2px 5px;">σ</td><td style="border: 1px solid black; padding: 2px 5px;">σ</td></tr> </table>	L	H	L	H	σ	σ	σ	σ	WHQ:	<table style="border-collapse: collapse; text-align: center;"> <tr><td style="border: 1px solid black; padding: 2px 5px;">L</td><td style="border: 1px solid black; padding: 2px 5px;">H</td><td style="border: 1px solid black; padding: 2px 5px;">L</td><td style="border: 1px solid black; padding: 2px 5px;">H</td></tr> <tr><td style="border: 1px solid black; padding: 2px 5px;">σ</td><td style="border: 1px solid black; padding: 2px 5px;">σ</td><td style="border: 1px solid black; padding: 2px 5px;">σ</td><td style="border: 1px solid black; padding: 2px 5px;">σ</td></tr> </table>	L	H	L	H	σ	σ	σ	σ
L	H	L	H																
σ	σ	σ	σ																
L	H	L	H																
σ	σ	σ	σ																

Note that the YNQ and WHQ in (5) can have the same tonal patterns even though their phrasing patterns are different, as opposed to (4), where distinct tonal patterns follow from the distinct phrasing patterns. In other words, the Accentual Phrasing might not be as crucial for disambiguation of the *wh*-words in such cases as (5). Thus, one might argue that in those cases other intonational factors such as the relative prominence of *wh*-words or the sentence boundary tone that overrides the final AP tone would instead play a decisive role in disambiguation. The phrasing difference may still be manifested through phonetic differences (Jun & Oh 1996; Cho (2010), but whether such phonetic differences would affect perception is another question to be investigated. The purpose of the current study is to examine how Korean speakers distinguish the two types of questions in production and perception when the theory predicts that the phonological tonal pattern due to accentual phrasing is not distinctive.

3. Production experiment

3.1 Overview and prediction

A production experiment was conducted to explore prosodic differences between WHQ and YNQ readings of potentially ambiguous sentences. The syllable composition of the words in these sentences was controlled so that the *wh*-word was composed of two syllables and the post-*wh* word was also composed of two syllables. In this case, the pre-final tonal patterns are likely to be identical for both types of questions, according to the intonation model by Jun (1993, 1996). If this

is the case, the absence of the phonological phrasing cue may leave the sentences ambiguous, or other cues such as *wh*-word prominence or sentence-final boundary tone may play a significant role in the disambiguation of the sentences.

3.2 Method

3.2.1 Stimuli

Ten sentences were selected for target stimuli, controlling the following factors: the number of words in the sentence, the number of syllables in the *wh*-word and the immediately following word, and the consonant and vowel type. Each sentence was a simple clause that contained three words, and the second word was always a *wh*-word. *Wh*-words used in the stimuli were selected to include various kinds, including ‘who’, ‘what’, ‘where’, and ‘when’. All words in the stimuli were composed of two syllables. The consonants in the stimuli were mostly sonorants, but some were lenis stops. The vowels in the stimuli were selected to include several different ones, not limited to one or two same vowels, to prevent any potential biases or interactions that a certain vowel type may create. The complete set of the test sentences is listed in the Appendix.

Each target sentence was placed in two different conversational contexts to induce both YNQ and WHQ readings. For instance, the identical sentence *Nayil nwukwu manna?* was placed in two different conversations such as (6) and (7).

- (6) a. 내일 누구 만나?
Nayil nwukwu manna
 Tomorrow someone meet
 ‘Are you going to meet anyone tomorrow?’
- b. 아니, 아무도 안 만나.
Ani, Amwuto an manna
 No anyone not meet
 ‘No, I’m not going to meet anyone.’
- (7) a. 내일 누구 만나?
Nayil nwukwu manna
 Tomorrow someone meet
 ‘Who are you going to meet tomorrow?’
- b. 고등학교 때 친구.
Kotunghakkyo ttay chinkwu
 High school time friend
 ‘A friend at the time of my high school.’

3.2.2 Participants

Nine adult native speakers of Korean (average age: 30) were recruited through the personal network of the authors. Six of them were female and the other three were male speakers. All the participants spoke the standard Seoul variety of Korean. One male speaker (coded as M₁) was recorded in a quiet office at Georgetown University, and one female (coded as F₁) and the other seven speakers were recorded in sound-attenuated recording booths at Stony Brook University and at Seoul National University, respectively. The speaker M₁ was linguistically naïve, the speaker F₁ was a Korean language lecturer, and the remaining seven participants were graduate students of linguistics at Seoul National University. The Korean lecturer and the seven linguistics students, however, remained uninformed of the purpose of the experiment.

3.2.3 Procedure

Twenty short conversations (10 sentences × 2 contexts) were presented, one by one, to the speakers. Two speakers (M₁ and F₁) read the entire set of conversations twice, and the second utterance of each repetition was chosen for acoustic analysis. The other speakers only read target sentences once. The 180 recorded sentences were annotated by the second author using Praat (Boersma 2001) as in Figure 1.

- (8) Annotation tiers for recorded data
 - a. Words: *wh* and post-*wh* words
 - b. Consonants and vowels in the words
 - c. Tones: AP and IP tones in the words

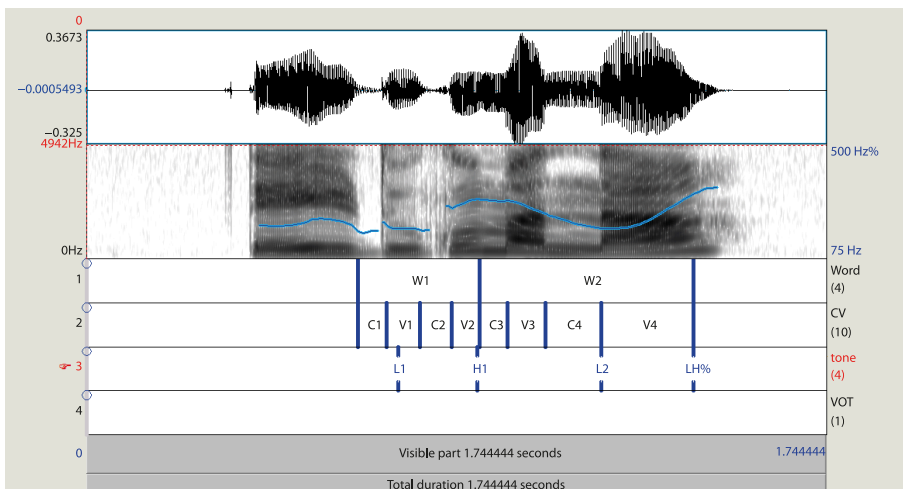


Figure 1. Annotation on a Praat window

After labeling, the onset and offset of each interval and the fundamental frequency of each tone were measured with a Praat script written by the first author.

3.3 Results

We have found that the YNQs and WHQs were different in all three prosodic factors mentioned in the literature: sentence-final intonation, post-*wh* phrasing, and *wh*-prominence, which were manifested in terms of the type of the IP boundary tone, the presence or absence of the post-*wh* L tone, and the F0 peak value of the *wh*-word, respectively.

3.3.1 IP boundary tone

Table 1 shows the frequency of various boundary tone types that occurred in the YNQ and WHQ readings. As shown in the table, the overall tendency is a strong correlation between H% and YNQs on one hand, and between LH% and WHQs on the other. For YNQs, the most common boundary tone was H% (79%), and LH% (18%) and HL% (3%) were less common. For WHQs, on the other hand, 63% of the sentences were read with LH%, and less frequently with H% (20%), L% (14%), and LHL% (2%).

Table 1. The frequency of the boundary tones

	H%	LH%	L%	HL%	LHL%
YNQ	79% (71/90)	18% (16/90)	–	3% (3/90)	–
WHQ	20% (18/90)	63% (57/90)	14% (13/90)	–	2% (2/90)

Figure 2 and Figure 3 show how each speaker used the sentence boundary tones in YNQs and WHQs, respectively. All speakers (except for F3) used H% to mark more than 50% of YNQs. On the other hand, only four speakers (F2, F3, F6, M1) out of nine used LH% to mark more than 50% of WHQs. This suggests that the correlation between LH% and WHQs is not as strong as the correlation between H% and YNQs across speakers. However, the use of H% for YNQs was not consistent across the speakers. One speaker (F3) used various boundary tones (H%, HL%, LH%) for YNQs with fairly equal frequencies. Also noteworthy is that one speaker (F4) used the same tone (H%) for both YNQs and WHQs in most utterances. In her speech, the sentence-final syllable sounds almost the same for all YNQ-WHQ pairs. In sum, the use of boundary tone showed a clear tendency, but there was a certain degree of variation across speakers.

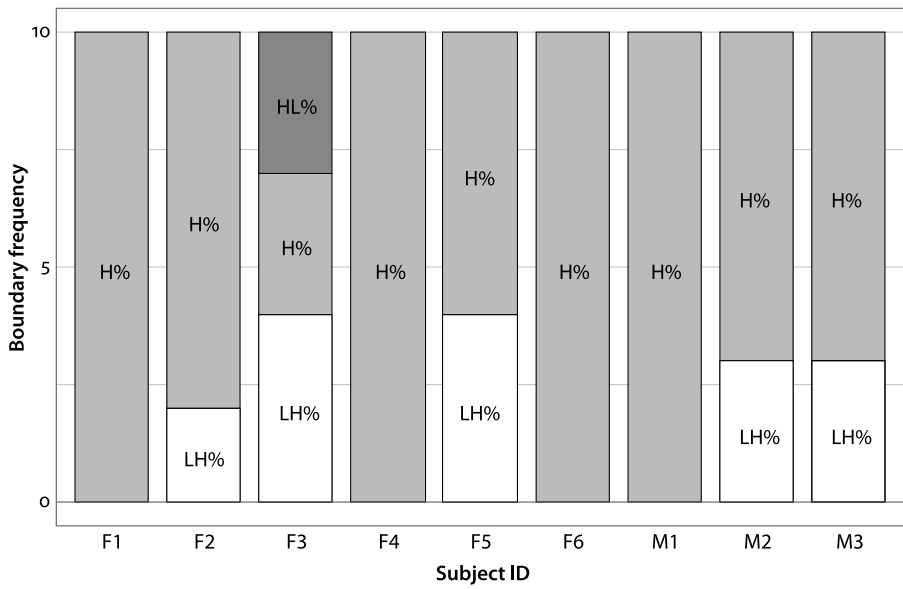


Figure 2. Boundary tones in YNQs

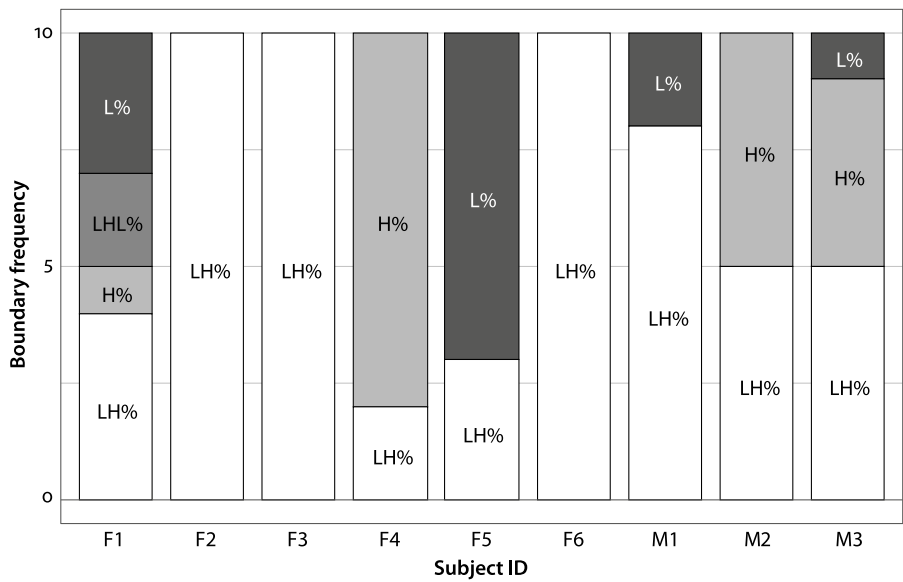


Figure 3. Boundary tones in WHQs

3.3.2 Post-*wh* L tone

As shown in Table 2, the first post-*wh* syllable was marked with an L tone 90% of the time in YNQs, but only 26.7% of the time in WHQs.

Table 2. The frequency of the L tone on the first post-*wh* syllable

	Present	Absent
YNQ	90% (81/90)	10% (9/90)
WHQ	26.7% (24/90)	73.3% (66/90)

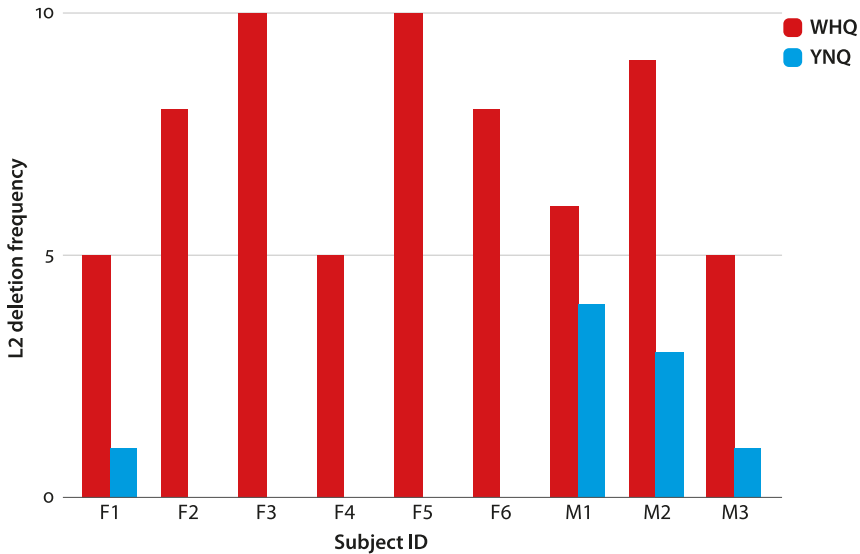


Figure 4. Frequency of post-*wh* L tone (L2) deletion

Figure 4 shows the post-*wh* L tone deletion frequency for each speaker. The post-*wh* L tone was absent more often for WHQs than for YNQs across all the speakers. The contrast between YNQs and WHQs in terms of the L-tone deletion rate was prominent in female speakers' speech, as every female speaker almost completely dropped the post-*wh* L tone in WHQs but not in YNQs.

Minor phonetic differences were also observed in the tokens where the post-*wh* L tone was realized: The post-*wh* L was realized lower in pitch and earlier in time for YNQs. For the speakers who realized the L tone on the syllable immediately following the *wh*-word, the average F0 on the L tone was higher in WHQs compared to YNQs, as shown in Table 3. The temporal realization of the post-*wh* L tone was also slightly different. As shown in Table 4, the post-*wh* L was realized slightly earlier in YNQ than WHQ. However, the differences are marginal, and as the number of tokens is limited to a small portion of WHQs, the statistical significance was not attested.

Table 3. The average F0 of the L tone immediately following the *wh*-word (Hz)

Post- <i>wh</i> L F0 (Hz)	Male	Female
YNQ	86.31	155.69
WHQ	89.74	162.06

Table 4. The average distance of post-*wh* L tone (L2) from the beginning of the sentence (W₁), the H tone on the *wh*-word (H₁), and the beginning of the vowel of the syllable immediately following the *wh*-word (V₃)

Distance (ms)	W ₁ -L ₂	H ₁ -L ₂	V ₃ -L ₂
YNQ	35.41	13.78	2.80
WHQ	38.19	13.08	3.39

3.3.3 *Pitch peak on the wh-word*

Figure 5 shows the F0 value of the pitch peak in the H tone in the *wh*-word. The F0 peak was higher for the WHQs than for the YNQs in all pairs across the speakers (paired *t*-test: $t(7.1) = 88, p < .001$). Most female speakers (F₁, F₂, F₃, F₆) had a tendency toward a greater difference in pitch between the two question readings than the male speakers (M₁ through M₃), although some female speakers (F₄ and F₅) produced relatively similar F0 peaks for both WHQs and YNQs. The interpretation of the variation among speakers is discussed further in Section 5.2.

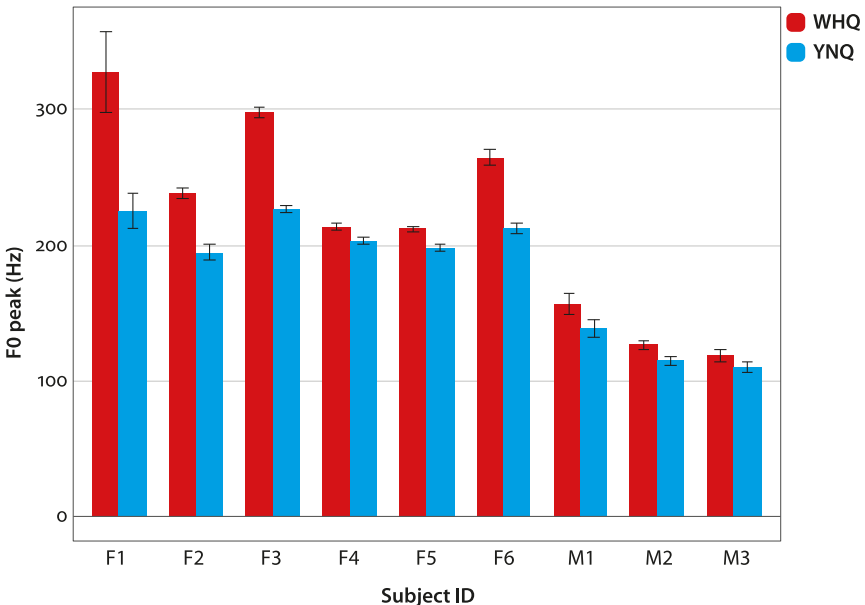
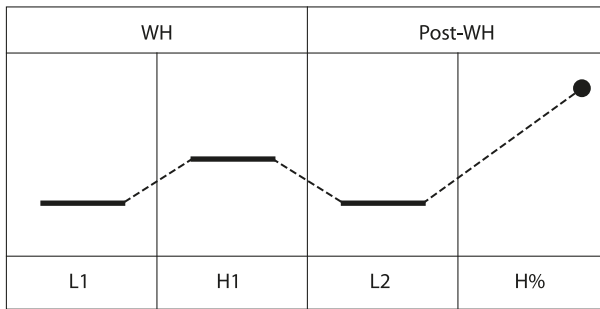


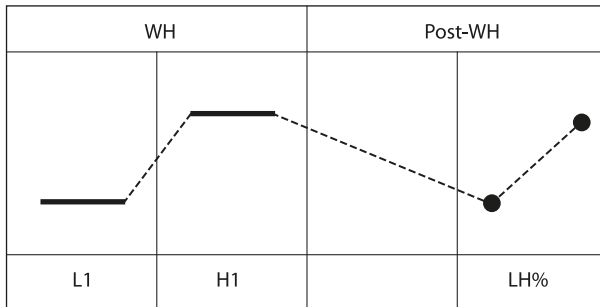
Figure 5. The F0 peaks of the *wh*-word

3.3.4 Summary

The canonical intonational contours of the two types of questions observed in the production study are illustrated in Figure 6. A WHQ is usually marked with the LH% boundary tone, whereas a YNQ is usually realized with the H% boundary tone. Also, a WHQ involves a higher F0 peak realized on the *wh*-word. These results are compatible with the results of the production study in Jun & Oh (1996), which also found differences in canonical boundary tones (YNQ: H%, WHQ: LH%) and the pitch of *wh*-words. In addition, our study also found that YNQs and WHQs were realized with the presence and absence of the post-*wh* L tone, respectively.



a.



b.

Figure 6. Canonical intonational contours of (a) YNQ and (b) WHQ

Note that an L tone on the post-*wh* syllable is expected to exist for both WHQ and YNQ readings in our experimental settings. For a WHQ reading, an L tone on the penultimate syllable is expected as a part of the canonical LHLH tones on a 4-syllable accentual phrase. For a YNQ reading, an L tone is expected as the initial tone of the last disyllabic AP. However, the production results indicate that the post-*wh* L tone was realized consistently in YNQs but *not* in WHQs. It should be

noted that the penultimate L tone can be deleted more often than others in an AP (Jun 2000; S. Kim 2004; Cho 2010). However, the penultimate L drop in WHQs in our experiment was a strong tendency rather than mere optionality. Thus, we contemplate that the L deletion in our specific experiment setting is related to the question type.

In the following section, we investigate the perceptual salience of each acoustic cue that is crucial in distinguishing WHQs from YNQs: the High F0 peak, the post-*wh* L tone, and the IP boundary tone.

4. Perception experiment

4.1 Overview and predictions

The results of the production experiment presented in the previous section suggest that a tonal contrast is still adopted in production to indicate the phrasing difference between YNQs and WHQs even in the case where the same tonal pattern is predicted by the theory. Then, a question arises whether this unpredicted tonal contrast has any influence on perception. Simply observing whether or not Korean speakers can distinguish the meaning of the *wh*-words by listening to the two types of questions does not tell the effect of tonal contrast, since there are other cues to the sentence type, such as the relative prominence of the *wh*-word and the sentence boundary tone. Moreover, with a holistic approach, it is hard to tell which component of the tonal contrast contributes to the different interpretations of the *wh*-words. Thus, we manipulated the sound files obtained from the production experiment to create stimuli in which the acoustic cues of the original sentence in one sentence type were switched to the counterparts of the other sentence type, as shown in Table 5. The manipulation process is described in detail in Section 4.2.

Table 5. Factors crossed in design of stimuli. 0 indicates no manipulation, and 1 indicates that the given factor is manipulated to exhibit the feature of the other sentence type

Stimuli	<i>Wh</i> -peak	Post- <i>wh</i> L tone	Boundary tone
p1	0	0	0
p2	1	0	0
p3	0	1	0
p4	0	0	1
p5	1	1	0
p6	1	0	1
p7	0	1	1
p8	1	1	1

Our prediction is that if the tonal contrast is meaningful in perception, switching the tonal pattern by one or more cues will have an influence on the perception of the sentence type. In other words, the perceived sentence type may alternate by swapping the tonal pattern.

4.2 Method

4.2.1 Stimuli

Twenty sentences (2 question types \times 10 sentences) recorded by one speaker (F3) from the production experiment were selected to create the stimuli for the perception experiment. As seen in the previous section, all the stimuli contained a 4-syllable sequence starting with a disyllabic *wh*-word, which has the same underlying Low-High-Low-High AP tones in both types of questions. Each sentence was manipulated and resynthesized in Praat by changing the values of one or more intonational parameters: the F0 peak height of the High tone in the *wh*-word (H1), the post-*wh* L tone (L2), or the type of the IP boundary tone (B), as shown in Figure 7 and Figure 8. Each parameter was binary, and the $2 \times 2 \times 2$ design yielded 160 stimuli (20 sentences \times 8 intonation types) in total.

The detailed procedure for the manipulation is as follows: first, we created the ‘base’ for manipulation by stylizing the pitch contour (Hermes 2006): i.e. representing the pitch contour as a minimal number of discrete tonal targets, in order to make the rest of the manipulation procedure easier and more consistent. There are various ways to express the tonal targets, such as straight-lines or points. We tried several different ways of stylization to find the best approximation that was perceptually closest to the original pitch contour, and we found that the best model was to represent each AP tones as short straight-lines (i.e. high or low plateau within a syllable), and sentence-final IP tones as points (i.e. single targets), as illustrated in Figure 6. Since all targets had to be represented as points in Praat, the straight lines of AP tonal targets were in fact represented by two points, the beginning and end points of the lines. Praat automatically operated linear interpolation between all pitch points. Auditory inspections on the stylized sentences confirmed that the “base” manipulation sounded almost the same as the original sentences. In addition, to make sure that all the YNQ-WHQ pairs contrast in terms of all the three prosodic factors presented in the previous section, additional manipulation was done when the original recording deviated from the canonical intonation (e.g. all the boundary tones of YNQs were set as H%). After all the necessary manipulation was done, the pitch contour was resynthesized by using PSOLA (Moulines & Charpentier 1990) to create the auditory stimuli.

The p_1 diagrams in Figure 7 and Figure 8 show the schematic representations of the base for YNQ and WHQ, respectively. The other diagrams in Figure 7 and Figure 8 illustrate that one, two, or three intonational parameters in one sentence type were manipulated to replicate the corresponding parameters of the other sentence type. For example, the p_2 diagrams show that the H1 value of the YNQ base was raised as high as that of its WHQ counterpart, while the H1 value of the WHQ base was lowered as low as that of its YNQ counterpart. For the manipulation of the post-*wh* L tone (L2), the low plateau representing the L2 tone was removed in the YNQ base to approximate the WHQ counterpart, while a low plateau was added to the immediate post-*wh* syllable in the WHQ base in a way that the result replicated the YNQ base, as shown in the p_3 diagrams. The manipulation of the sentence boundary tone (B) is illustrated in the p_4 diagrams: to switch from H% to LH% in the YNQ base, a pitch point was added to indicate an L boundary tone within the final syllable and the pitch value of the H tone was lowered to that of its WHQ counterpart. To switch from LH% to H% in the WHQ base, the pitch point for the L tone was removed and the pitch value of the H tone was raised to that of its YNQ counterpart. The rest of the stimuli (i.e. diagrams p_5 - p_8) were created in the same fashion, by manipulating two or three factors in combination.

4.2.2 Participants

57 Korean native speakers (age range: 18–38) participated in the perception experiment. One group of subjects ($N = 30$; average age: 30) were recruited online through various social networking sites. They volunteered their time (10 minutes on average) without payment. Another group of subjects ($N = 27$; average age: 22) was undergraduate students at Kyonggi University, and they received extra credit for participation. Responses from all subjects were analyzed and presented together in this paper because the response patterns of the two subject groups showed no significant difference.

4.2.2 Procedure

The subjects participated in the perception experiment through Qualtrics, an online survey tool. The 160 stimuli were divided into four groups of 40 stimuli each in a way that all sentence types and prosody types were counter-balanced in each group, and only one of the four groups of stimuli was presented to each subject. The assignment of the stimuli group to each subject was done randomly and evenly using block randomization in Qualtrics.

Before the experiment began, subjects were reminded that a question that contains a *wh*-word in Korean is ambiguous between a yes-no question and a *wh*-question. During the experiment, the target sentence, which is ambiguous

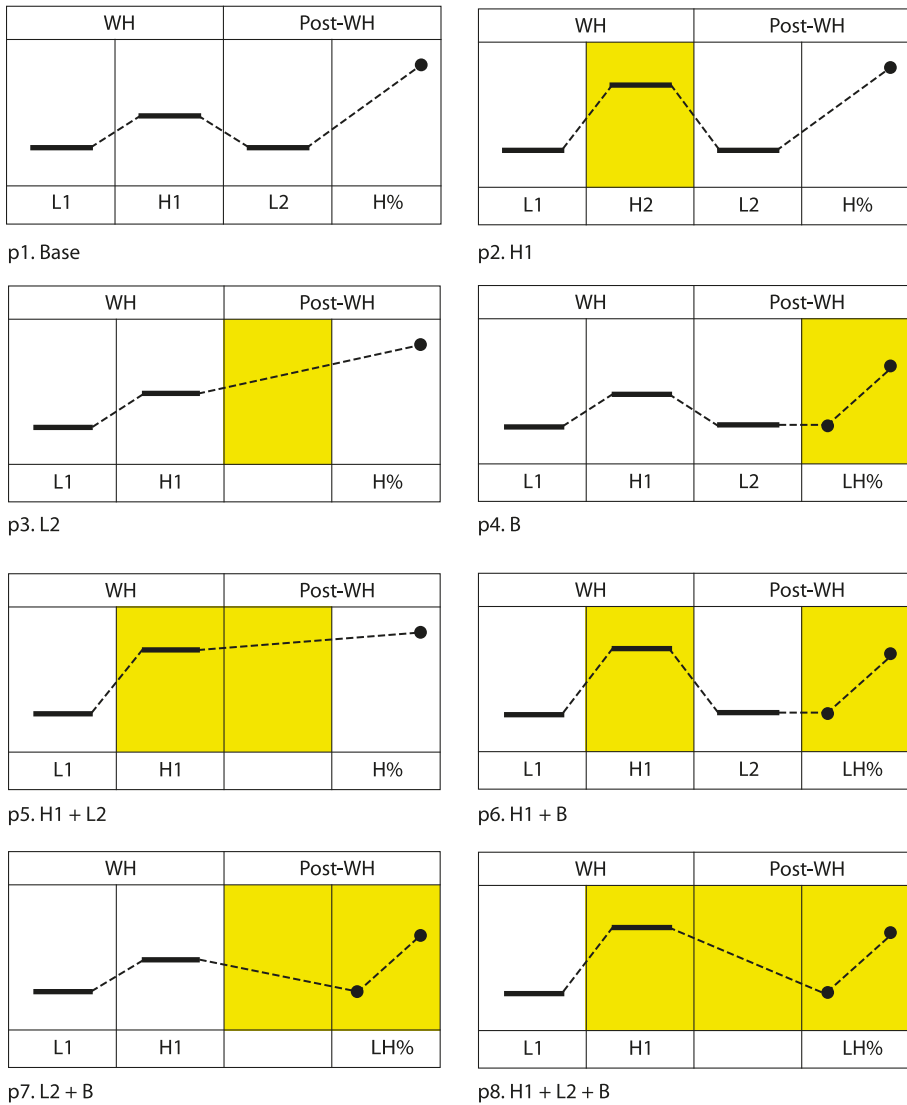


Figure 7. Schematic representation of YNQ-based stimuli

without proper intonation between a yes-no question and a *wh*-question, and its two possible answers were presented in written Korean on the screen. The two possible answers were appropriate answers to a yes-no question and a *wh*-question, respectively, as illustrated in (6) and (7) for the production test. The subjects clicked the play button to listen to the question, and then chose the answer that they considered appropriate in a natural conversation. A screenshot of the online survey is provided in Figure 9.

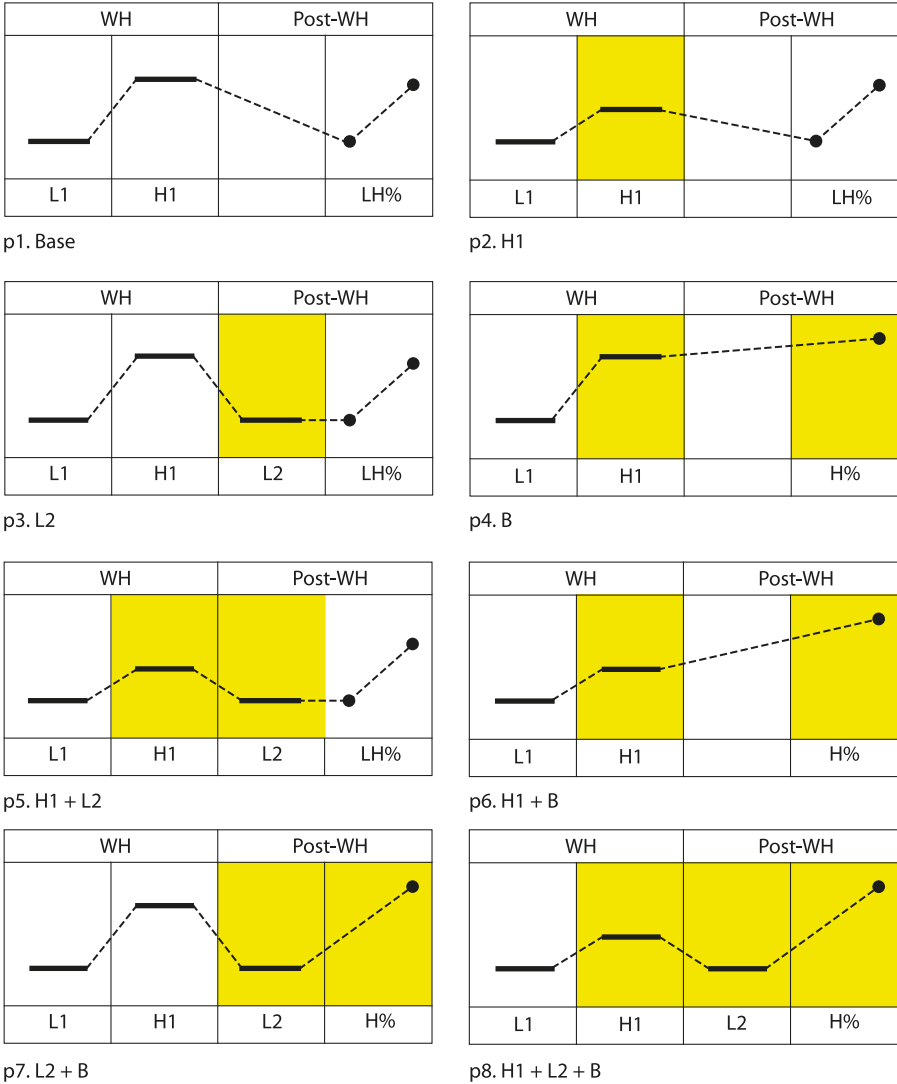


Figure 8. Schematic representation of WHQ-based stimuli

The subjects listened to the stimuli, one question at a time, and then selected their answer to the given question. They were allowed to play the stimuli multiple times, but once they moved to the next question, they were not allowed to go back to the previous one. The stimuli in each group were presented to each subject in random order.

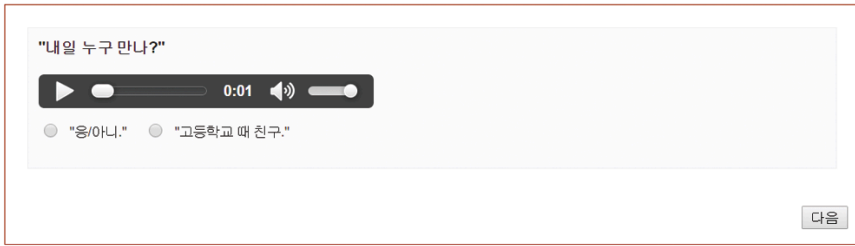


Figure 9. Screenshot of the online survey

4.3 Results

Table 6 and Table 7 present the number of responses for YNQ-based stimuli and WHQ-based stimuli, respectively. The ‘alternation rate’ indicates the ratio of altered interpretations, i.e. WHQ responses to YNQ-based stimuli or YNQ responses to WHQ-based stimuli. The alternation rate for YNQ-based stimuli and WHQ-based stimuli are visualized in Figure 10 and Figure 11, respectively.

Table 6. Responses to YNQ-based stimuli

Prosody type	Manipulated features	WHQ responses	YNQ responses	Alternation rate
p1	–	15	128	0.10
p2	H1	16	126	0.11
p3	L2	57	83	0.41
p4	B	83	73	0.53
p5	H1+L2	59	79	0.43
p6	H1 + B	101	28	0.78
p7	L2 + B	107	34	0.76
p8	H1 + L2 + B	135	5	0.96

Table 7. Responses to WHQ-based stimuli

Prosody type	Manipulated features	WHQ responses	YNQ responses	Alternation rate
p1	–	142	2	0.01
p2	H1	137	5	0.04
p3	L2	138	3	0.02
p4	B	92	64	0.41
p5	H1 + L2	137	6	0.04
p6	H1 + B	106	34	0.24
p7	L2 + B	53	85	0.62
p8	H1 + L2 + B	37	88	0.70

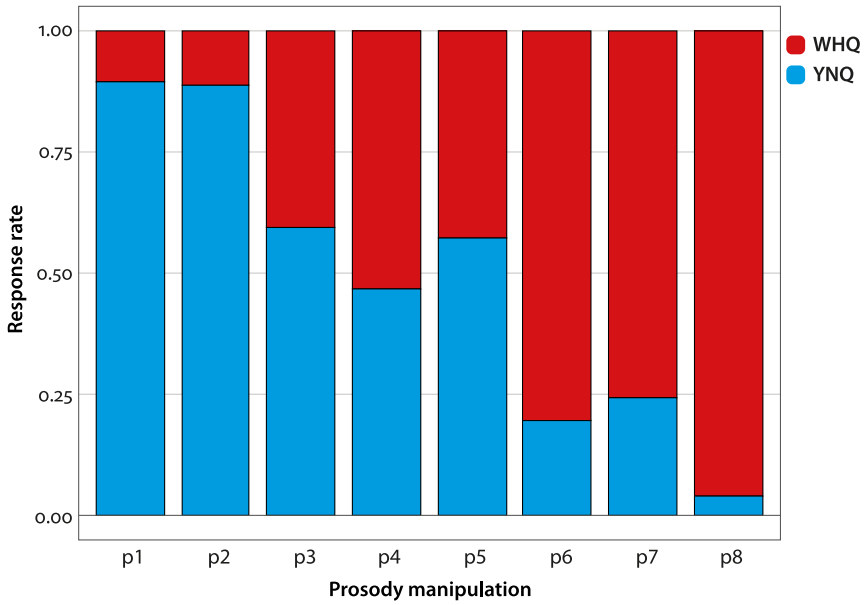


Figure 10. Response rate for YNQ-based stimuli

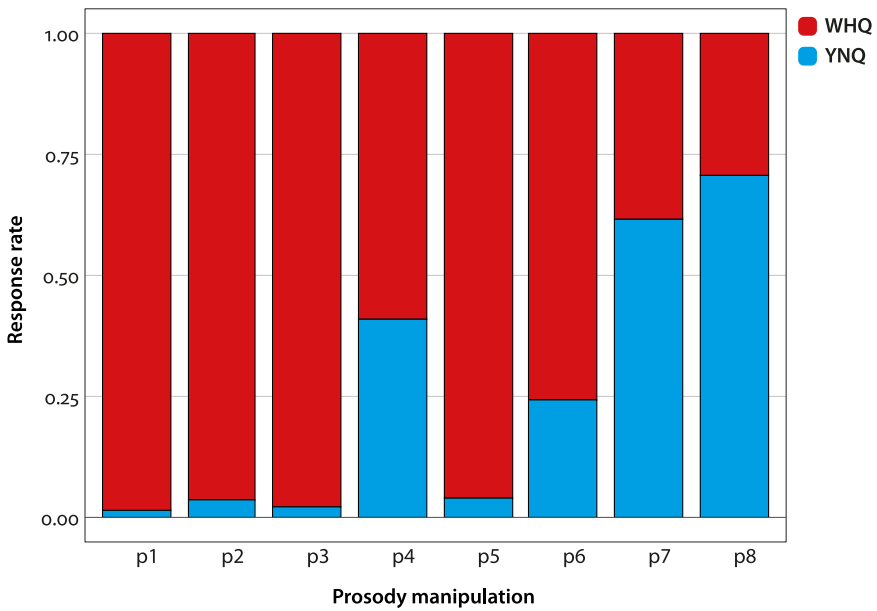


Figure 11. Response rate for WHQ-based stimuli

First of all, the base intonation (p_1) was almost always identified correctly for both readings (90% of YNQs and 99% of WHQs). This confirms that Korean speakers can disambiguate the meaning of a sentence with a *wh*-word solely by intonation. For the manipulated stimuli, we found a general tendency that more manipulation led to more altered responses, but the specific response patterns were a little different for YNQ-based stimuli and WHQ-based stimuli.

For YNQ-based stimuli, removing the post-*wh* L tone (L2) and changing the sentence boundary tone (B) from H% to LH% increased the preference for a WHQ interpretation (alternation rate change: 10% to 41% and 53%, respectively). On the other hand, increasing the F0 peak value of the *wh*-word (H1) had no significant effect on the interpretation (alternation rate change: 10% to 11%). H1 had an effect on interpretation when it was combined with B: in that case, the response alternation rate (78%) was boosted, compared to the stimuli in which only B was manipulated (53%).

For WHQ-based stimuli, changing the sentence boundary tone (B) from LH% to H% was effective in alternating the response (alternation rate change: 1% to 41%). Adding the post-*wh* L tone (L2) was not effective by itself (alternation rate: 2%), but when it was combined with B, the alternation rate increased compared to B only (from 41% to 62%). On the other hand, lowering the F0 peak value of the *wh*-word (H1) did not increase the alternative response rate significantly (alternation rate change: 1% to 4%). Moreover, when the effect of H1 and B were combined together, the alternative YNQ response rate (24%) was even lower than B only (41%).

To assess the statistical significance of these effects, we modeled the results with mixed-effects logistic regression using the *glmer* function from the *lme4* package (Bates et al. 2014) in R (R Core Team 2015). The logistic regression evaluated the likelihood of a WHQ response vs. a YNQ response. As fixed effects, we entered H1, L2, and B and their interactions into the model. Maximal random effects were found by a series of likelihood ratio tests. As a result, we had random intercepts for subjects and items, as well as random slopes for L2 and B by subject as random effects. The results of the statistical analysis are reported in Table 8 and Table 9.

The models shown in Table 8 and Table 9 confirmed the effects described earlier. The coefficient for the intercept was significant for both YNQ- and WHQ-based stimuli (2.89 and -8.33, respectively), reflecting the baseline preference for the original interpretation before manipulation. The higher coefficient for the WHQ-based stimuli indicates that the preference for the original interpretation was stronger for the WHQ-based stimuli than the YNQ-based stimuli. There was no significant effect of H1 for either type of stimuli, indicating that changing the pitch range of the *wh*-word did not affect the interpretation of the sentence. There

Table 8. Model for the responses to YNQ-based stimuli

Predictor	Coefficient	Standard error	Z	p
(Intercept)	2.89	0.50	5.74	< 0.001
H1	-0.24	0.42	-0.57	0.569
L2	-2.30	0.47	-4.90	< 0.001
B	-3.08	0.45	-6.78	< 0.001
H1 × L2	0.16	0.52	0.30	0.766
H1 × B	-1.51	0.53	-2.83	< 0.01
L2 × B	0.64	0.54	1.18	0.238
H1 × L2 × B	-1.32	0.86	-1.55	0.122

Table 9. Model for the responses to WHQ-based stimuli

Predictor	Coefficient	Standard error	Z	p
(Intercept)	-8.33	1.75	-4.75	< 0.001
H1	1.74	1.11	1.57	0.116
L2	2.22	1.31	1.69	0.091
B	7.68	1.71	4.48	< 0.001
H1 × L2	-0.86	1.35	-0.64	0.525
H1 × B	-2.97	1.17	-2.55	< 0.05
L2 × B	-0.92	1.31	-0.71	0.480
H1 × L2 × B	2.66	1.44	1.86	0.064

was a significant main effect of B for both types of stimuli ($p < .0001$), indicating that changing the IP boundary tone at the end of the sentence contributed significantly to altering the likelihood of YNQ- and WHQ-interpretations. The main effect of the L2 manipulation was significant for the YNQ-based stimuli ($p < .0001$) but not for the WHQ-based stimuli ($p = .091$), indicating that removing a tonal target after the *wh*-word contributed to alternating a YNQ to a WHQ, but adding a post-*wh* tonal target did not contribute to alternating a WHQ to a YNQ. There was a significant interaction of H1 and B for both types of stimuli (YNQ-base: $p < .01$, WHQ-base: $p < .05$). Note that the estimate of the coefficient for the interaction of H1 and B was negative for WHQ-based stimuli (-2.97), which indicates that the combination of H1 and B rather increased the preference for the original interpretation instead of the alternative interpretation. No other interaction was found to reach statistical significance.

To summarize the experimental results, we found that (i) the boundary tone affected the interpretation of questions including *wh*-words, whether they were WHQs and YNQs, (ii) the absence of the post-*wh* L tone helped alternating the interpretation in the case of YNQs, and (iii) changing the F0 height of the

wh-word did not affect the interpretation at all when it was not combined with other prosodic factors.

5. Discussions

5.1 Post-*wh* AP tone in production: Phonetics or phonology?

The results of the production study indicate that all three prosodic factors (i.e. the F0 peak height of the *wh*-word (H1), the post-*wh* L tone (L2), and the IP boundary tone (B)) are valid cues that native speakers adopt to distinguish the indefinite and interrogative readings of *wh*-words. A particularly interesting finding is that there was a contrast between the YNQ and WHQ readings in terms of the presence versus absence of the L2 tone, even though L2 was expected to be present in both readings (at least optionally) according to the theoretical model by Jun (1993). How can we explain such a discrepancy between the theory and the actual observation?

One possible explanation is that the post-*wh* tone deletion in WHQs is due to tonal compression in the given phonetic environment. First, it was usually the case that the phonetic realization of the H tone in the *wh*-word in WHQs is not only raised but also delayed compared to YNQs. Figure 12 indicates the location of the highest F0 point in the H tone that is supposed to be associated with the second syllable of the *wh*-word, in proportion to the onset of the second vowel of the *wh*-word. As shown in the figure, the F0 peak was realized later in WHQs than in YNQs, and for some speakers (F3 and F5) the average F0 peak was realized even after the *wh*-word in WHQs. Also, recall that most WHQs ended with the bitonal LH%, which has an extra tone compared to the monotonal H% for most YNQs. Putting these factors together, it might have been the case that the delayed H peak in the preceding syllable and the bitonal boundary tone in the following syllable limited the temporal space for the L tone in the immediate post-*wh* syllable and resulted in the suppression of the post-*wh* L tone. However, it is possible and natural to have multiple tones on the sentence-final syllable as a boundary tone without necessarily affecting the tonal composition of the sentence-final AP before the boundary tone. It is often the case that when a single syllable is associated with an LH tone in Seoul Korean, that syllable is lengthened to realize both tones (Jun 1996: 56). The interaction between segments and tones when there are more tones than syllables in a certain domain seems to realize in both directions, tonal compression or truncation, or segmental lengthening in Korean (S. Kim 2004). Moreover, it is not evident what is the cause and what is the effect in the relation between L2-deletion and H1-delay. It could be the case that the extra space cre-

ated by the L2-deletion, which was caused for an independent reason, might have allowed the H1-delay, rather than the reverse.

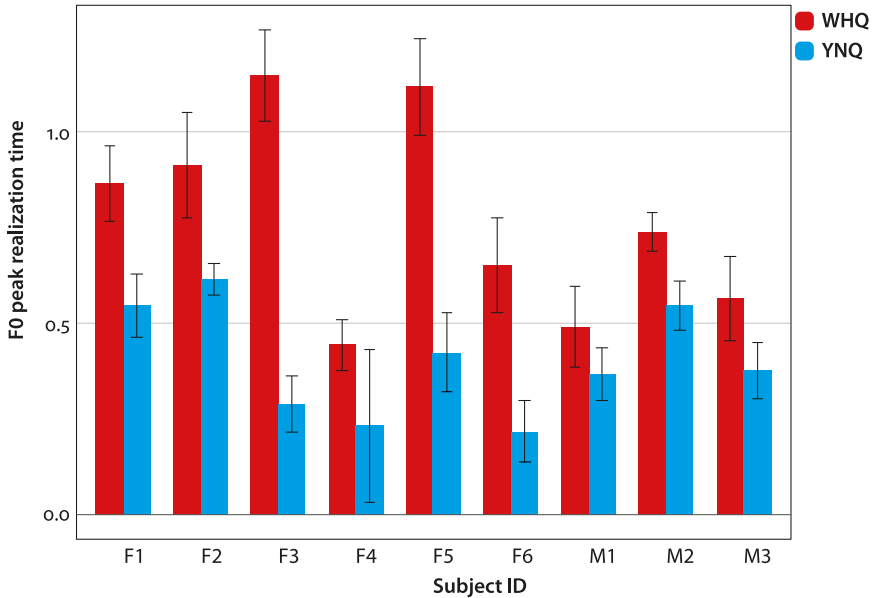
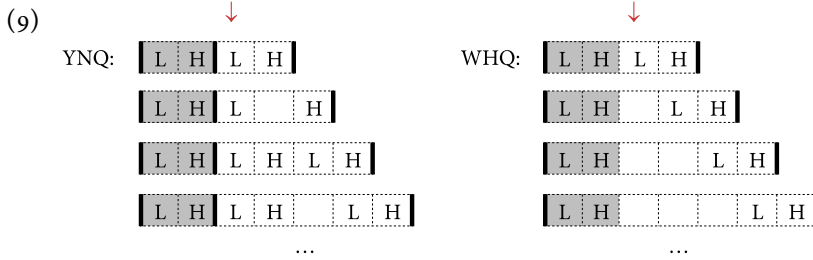


Figure 12. Timing of the F0 peak realization from the onset of the second vowel of the *wh*-word. *o* indicates the starting point of the vowel, and *l* indicates the ending point

Another possible account for the post-*wh* AP tone drop in WHQs is a production strategy to maximize the phonological contrast between YNQs and WHQs. The diagram in (9) illustrates the AP tonal patterns for YNQs and WHQs that include a disyllabic *wh*-word and a variable-length post-*wh* word. As shown in the diagram, the difference in tonal patterns between YNQs and WHQs can be characterized as the presence and absence of the L tone that comes immediately after the *wh*-word, as indicated by the arrows, except when the post-*wh* word is disyllabic. Thus, we can speculate that speakers may choose to drop the post-*wh* L tone in WHQ to maintain the same paradigm even when they do not have to. This could be the speakers' effort not to mislead the listeners.



In either case, the experimental results indicate a strong tendency of post-*wh* L deletion in WHQs. We leave to a further study whether this phonological tone deletion is driven by a phonetic or phonological constraint.

5.2 Role of the intonational factors in Perception

A natural expectation from the production study is that the disambiguation cues identified in the production study would affect the perception of *wh*-words. Thus, it is not surprising that the IP boundary tone at the end of the sentence had a significant effect on the interpretation of *wh*-words in our perception study. What was unexpected is that changing the High tone pitch value of the *wh*-word had no significant effect on the interpretation of *wh*-words. There are two possible explanations for this finding: the prominence due to the boosted High tone is either (i) underrepresented in our perception experiment or (ii) insignificant when it comes to the perceptual disambiguation of sentence types. Let us consider the possibility of underrepresentation first. Prominence could be manifested by more than just an expanded pitch range. The production experiment in Jun & Oh (1996) and a speech corpus study in Yun (2013) both identified higher intensity as another characteristic of *wh*-interrogatives compared to *wh*-indefinites in Korean. That is, manipulating the pitch only might not have been strong enough to alter the participants' perception. If it is the case, increasing both pitch and intensity could have enhanced the perceptual salience of the *wh*-word, which in turn might have increased the preference for the *wh*-interrogative reading. Another possible explanation is that the prominence is indeed not a salient cue of *wh*-interrogatives. In her perception experiments by using a Rapid Prosody Transcription Method, You (2012) found that cues to prosodic phrasing are more salient than those to prominence, which is consistent with Mo, Cole & Lee (2008) where they found a similar result with American English. Then we can say that in our perception experiment the enhanced prominence on the *wh*-word did not play a role because it was not perceptually salient enough for the listeners. In other words, although phonetic effects such as higher pitch and intensity on the *wh*-word are among the prevalent acoustic attributes of the *wh*-interrogatives in production,

they are only secondary for disambiguating the question types in perception. Recall that there was variation among speakers with respect to the differences in High tone pitch between YNQs and WHQs in the production experiment. This variation provides additional evidence for the secondary status of the High tone prominence. While it calls for further investigation to confirm, we contemplate that the phonetically enhanced prominence of the *wh*-word is unlikely to be a significant factor for the interrogative interpretation in perception.⁴

Another puzzling result is that there was an apparent asymmetry between YNQs and WHQs in the effect of manipulating the post-*wh* AP tone in the perception. While deleting the post-*wh* AP tone in YNQs increased the WHQ interpretation rate, adding the post-*wh* AP tone to WHQs did not show a significant effect in interpretation. However, the asymmetry is not because adding a post-*wh* tone has no effect in perception, but because there are other segmental attributes that were not taken into account in our experiment. In addition to tonal contrasts, AP-initial devoicing (Jun 1998; Choi & Mazuka 2003) or AP-initial strengthening (Fourgeron & Keating 1997, Cho & Keating 2001) can also provide cues to phrasing. Thus, adding a post-*wh* L tone to a WHQ may have not necessarily created a perceptually clear AP boundary because the unchanged segmental attribute, e.g., AP-medial voicing, would still signal that the post-*wh* syllable was AP-medial. On the other hand, when the post-*wh* L tone was removed from a YNQ, the unchanged segmental attribute, e.g., the unvoiced segments, may not strictly indicate that the post-*wh* syllable was AP-initial because while voicing in the AP-initial position is strictly prohibited in Korean, the absence of voicing in the AP-medial position is not disallowed. Hence, the segmental cues to phrasing might have strongly conflicted with the tonal cues to phrasing in the case of WHQ manipulations, which would have led to the apparent lack of any tonal manipulation effect, but not in the case of YNQ manipulations.

The interaction between the F0 peak of the *wh*-word (H1) and the boundary tone (B) also calls for an account. For the YNQ-based stimuli, raising H1 did not have a significant effect by itself on the interpretation, but it boosted the WHQ response rate when it was combined with B. This indicates that speakers were not completely insensitive to the manipulation of pitch range and that multiple cues to WHQs created a gang-up effect. The H1-B interaction for the WHQ-based

4. A reviewer suggested a possibility that prominence might still have a local processing effect: with the prominent *wh*-word, the subjects would start to process it as a *wh*-interrogative word, but at the later stage of processing when they detect post-*wh* dephrasing or sentence-final intonation, they would realize that it must be a yes-no question and rebuild the syntactic/semantic structure. Investigating the incremental processing pattern will be another interesting topic for future work.

stimuli, however, is still puzzling. Recall that the general pattern we observed in the perception experiment was that the more factors were altered, the more alternative responses were obtained. However, the H₁-B interaction for the WHQ-based stimuli presents the opposite pattern to the general trend. When both H₁ and B were altered, the alternative response (YNQ) rate (24%) was lower than when only B was altered (41%). One possible account is that it might have something to do with the overall shape of the pitch contour rather than individual factors. As shown in the diagrams p4 (H₁ manipulation) and p6 (H₁+B manipulation) in Figure 8, repeated below in Figure 13 for convenience, the two contours look similar, except that the H₁+B contour is closer to a flat line. We suspect that the smoother pitch contour from the *wh*-word to the end of the sentence in the H₁+B case could have created a pseudo-dephrasing effect since it could make the *wh*-word and the following word as one chunk of sound, and thus it could have increased a bias toward a WHQ reading.⁵

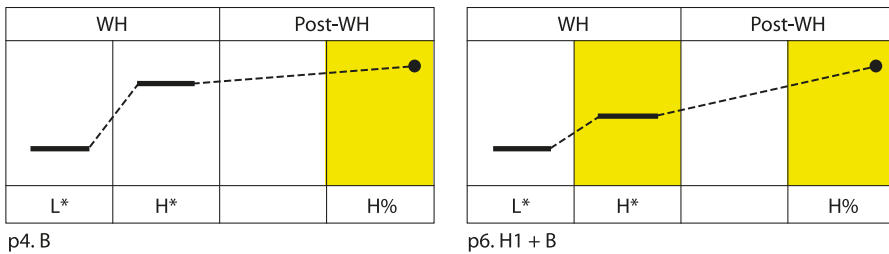


Figure 13. Schematic representation of some WHQ-based stimuli

6. Conclusion

In this study, we have examined a particular case of questions in Korean that are ambiguous between yes-no question and *wh*-question readings, for which the tonal pattern due to accentual phrasing predicted by the model in Jun (1993) is likely to be identical regardless of the reading. In production, speakers distin-

5. This account is not supported by the YNQ-based stimuli with similar shapes because for the stimuli represented by the diagrams p3 and p5 in Figure 7, the WHQ/YNQ ratio in their responses was almost the same (WHQ response rate: 41% and 43%, respectively). This does not directly undermine the proposed account because we have already seen that the stimuli with the same shape were perceived differently depending on whether they were originally derived from YNQs or WHQs. The reason for the discrepancy is not completely clear at the moment, though. Given the relatively low significance level (.05) compared to other findings in this experiment, the H₁-B interaction for WHQ-based stimuli should be explored further in the future study.

guished the two readings not only by different boundary tones and the pitch peak of the *wh*-word but also by distinctive AP tonal patterns (namely, by deleting the immediate post-*wh* AP tone for WHQs). In perception, deleting the post-*wh* AP tone did increase the preference for a WHQ reading. The results of the production and perception experiments reconfirm the importance of phonological phrasing in interpreting Korean *wh*-words argued in Jun & Oh (1996) and Yun (2015, 2019). Finally, the study showed that the tonal contrast related to the distinct phrasing is maintained in the two different readings of the *wh*-words. The finding provides an insight for the theory of Korean prosody in that a listener-oriented production/processing strategy to maximize the contrast may be another factor that triggers a tone deletion.

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Appendix. List of stimuli

1. 내일 누구 만나?
nayil nwukwu manna
tomorrow who see
i. 'Do you see anyone tomorrow?'
ii. 'Who do you see tomorrow?'
2. 요즘 어디 나와?
yocum eti nawa
nowadays where appear
i. 'Does she appear anywhere nowadays?'
ii. 'Where does she appear nowadays?'
3. 거기 누가 나가?
keki nwuka naka
there who go out
i. 'Does anyone go out there?'
ii. 'Who goes out there?'
4. 오늘 누가 남아?
onul nwuka nama
today who remain
i. 'Does anyone remain today?'
ii. 'Who remains today?'
5. 밤엔 어디 묵어?
pameyn eti mwuke
at night where stay
i. 'Do you stay anywhere at night?'
ii. 'Where do you stay at night?'
6. 거긴 언제 놀아?
kekin encey nola
there when off
i. 'Are they off anytime there?'
ii. 'When are they off there?'
7. 요즘 어디 다녀?
yocum eti tanye
nowadays where go
i. 'Do you go anywhere nowadays?'
ii. 'Where do you go nowadays?'

8. 뒤에 누가 밀어?
twiey nwuka mile
 behind who push
 i. 'Is anyone pushing me from behind?'
 ii. 'Who is pushing me from behind?'
9. 거기 뭐가 많아?
keki mweka manha
 there what plentiful
 i. 'Is anything plentiful there?'
 ii. 'What is plentiful there?'
10. 지금 누가 먹어?
cikum nwuka meke
 now who eat
 i. 'Is anyone eating now?'
 ii. 'Who is eating now?'

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