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Contextual Variations in Trisyllabic Sequences of Thai Tones

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Abstract

It is well known that tones assimilate in much the same way as consonants and vowels do. In tonal assimilation, the height and shape of a given tone is altered by adjacent tones. Earlier studies on tonal assimilation in Thai have used two-tone sequences with an intervening obstruent between the two tones of interest. In the present study, three-tone sequences were used with continuously voiced syllables throughout the utterance. Assimilatory effects were expected to be greater between F_0 contours of two successive syllables that are continuous in voicing across the syllable boundary. Stimuli consisted of 125 possible three-tone sequences of the five Thai tones, superimposed on monosyllabic words in a carrier sentence. All syllables were stressed in order to eliminate potentially confounding interactions between stress and tonal assimilation. Acoustic analysis revealed that perseverative effects were assimilatory in nature; anticipatory effects, however, were dissimilatory in nature. Perseverative effects appear to be independent of tonal categories, and restricted to contiguous tones. Perseverative effects extend through more than half the duration of the following tone. Both the height and shape of the tones are affected. Anticipatory effects, on the other hand, are limited to the high and rising tones, and extend through less than half the duration of the preceding tone.

Introduction

One of the difficulties in describing speech in tone languages like Thai is that sequences of adjacent tones may influence each other phonetically. The fundamental frequency (F_0) contours associated with lexical tones in citation forms may undergo rather dramatic changes when they occur in running speech. The phenomenon is termed 'tonal assimilation', to be distinguished from tone sandhi which involves language-specific changes in F_0 contours with concomitant, perceptual shifts in tonal categories. Assimilatory effects are believed to reflect language-universal phonetic

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tendencies, though low-level phonetic detail may vary from language to language [Docherty and Ladd, 1992]. Changes in F_0 contours that result from tonal assimilation may or may not lead to changes in relationships among the lexical tones. Research on production and perception of tonal assimilation has been receiving an increasing amount of attention, especially in tone languages of the Far East [e.g., Gandour et al., 1994; Shen, 1990a, b; Shen and Lin, 1991; Xu, 1994a, b, 1995]. This attention is well deserved since the complex set of influences among tones results in a lack of simple acoustic invariance in the phonetic manifestation of tone in running speech.

Most acoustic studies on tonal assimilation have attempted to answer questions regarding the nature and temporal extent of the assimilatory effects. The weight of the evidence suggests that a target tone is more influenced by preceding tones than by following tones [Gandour et al., 1994; Han and Kim, 1974; Xu, 1994a; cf. Shen, 1990a]. That is, tones are more influenced by perseverative than anticipatory assimilation. The temporal extent of the effects appears to be restricted to contiguous tones [Shen, 1990a], though there is some disagreement over whether the effects extend over the entire F_0 contour of the adjacent syllable [Gandour et al., 1994]. Whether the assimilatory effects involve F_0 height or slope or both is expected to vary primarily as a function of the intervening consonants between adjacent syllables, stress factors, and speaking rate [cf. Shen, 1990a; Xu, 1994a]. As expected, perseverative effects have been shown to be of an assimilatory nature. Anticipatory effects, on the other hand, seem to reflect tonal dissimilation instead of assimilation. Several competing hypotheses have been offered to explain the exact mechanism underlying tonal dissimilation [see Xu, 1994b, 1995, for review]. None of them is wholly satisfactory, and the putative, dissimilatory nature of anticipatory effects remains a challenge to account for in terms of universal phonetic tendencies.

As a tone language, Thai offers many advantages in the phonetics laboratory for studying tonal assimilation. Thai has five lexical tones traditionally labeled 'mid' (M), 'low' (L), 'falling' (F), 'high' (H), and 'rising' (R) [Abramson, 1962]. Acoustic-phonetic information on Thai tones produced in citation forms of monosyllabic words is readily accessible in the literature [Abramson, 1962; Gandour et al., 1988, 1991, 1992a]. In general, the onsets of the high and falling tones are higher than low and rising, and the mid tone is intermediate. The offsets of the high and rising tones are higher than low and falling, and the mid tone is intermediate. F_0 contours associated with the mid and low tones fall steadily throughout, whereas those associated with the falling, high, and rising tones change abruptly in slope approximately halfway through their duration. The falling tone rises slightly and then falls sharply, the high and rising tones fall slightly and then rise. Tone sandhi is not significant as a possible confounding influence on F_0 contours [cf. Cheng, 1968; Shen, 1990a; Xu, 1994b].

Early acoustic-perceptual studies of tonal assimilation in Thai showed that some changes in F_0 height and slope occur as a function of the preceding or following tone [Palmer, 1969; Abramson, 1979a]. More recently, a quantitative procedure has been developed that permits continuous tracking of height and slope of F_0 contours [Gandour et al., 1992b]. This procedure was used to assess the magnitude and temporal extent of anticipatory assimilation in five bisyllabic noun compounds with a falling tone on the initial syllable and each of the five Thai tones on the final syllable [Gandour et al., 1992c, 1993]. Anticipatory assimilation was evident on both height and slope of the falling tone. Height effects extended backward to the onset of the falling tone. The falling tone was generally higher when occurring before the low/rising tones

than when occurring before the mid/falling/high tones. Instead of tonal assimilation, however, these anticipatory effects were surprisingly indicative of tonal dissimilation. Slope effects were restricted to the terminal portion of the falling tone. The falling tone before low/rising tones exhibited a steeper slope than before falling/high tones. Following these preliminary findings, Gandour et al. [1994] examined all 25 possible sequences of two tones from the five tones of Thai in a fixed syntactic and prosodic environment. The two tones were separated by voiceless obstruents. The stress pattern of the sentence was invariant. Both of the syllables on which the tones occurred were stressed. The findings of Gandour et al. suggested that assimilatory effects in two-tone sequences embedded in running speech are not symmetric in Thai. The extent of the effect of anticipatory assimilation on the preceding tone is less than that of perseverative assimilation on the following tone. Perseverative assimilation affects a greater number of Thai tones than anticipatory assimilation. Also, tonal assimilation in Thai primarily affects the height of the F_0 contour; slope is relatively unaffected. Again, anticipatory effects were indicative of tonal dissimilation. Perseverative effects, however, were of an assimilatory nature.

The robustness of these findings notwithstanding, the observed effects may not be due to tonal assimilation alone. The presence of an intervening voiceless obstruent between the two tones is likely to have minimized assimilatory effects. These effects are expected to be greater between F_0 contours of two successive syllables that are continuous in voicing across the syllable boundary. Previous studies of the interaction between tone and intonation have revealed that F_0 values of tones are affected by sentence intonation to varying degrees [Connell and Ladd, 1990; Abramson, 1979b; Shen, 1989]. In the two-tone sequences, no effort was made to control for the intonational effect. Anticipatory effects were measured on the earlier tone, perseverative effects on the later tone. Thus, tonal assimilation was confounded with the intonational effect because anticipatory and perseverative effects were measured on different syllables. Under these circumstances, it is impossible to assess and quantify their interaction on any given syllable.

It is imperative that longer tonal sequences be used if we are to incorporate assimilatory effects independent of intonation into the implementation of an automatic tone classification algorithm [Potisuk et al., 1995]. The use of three-tone sequences with continuously voiced syllables throughout the utterance should give us an accurate picture of the magnitude and temporal extent of tonal assimilation because (1) both anticipatory and perseverative assimilation can be measured on the same syllable and (2) assimilation patterns can be compared between contiguous and noncontiguous tones. As in Gandour et al. [1994], assimilatory effects between tones are expected to be primarily perseverative in nature. The temporal extent of assimilatory effects is expected to be restricted to contiguous tones. If this restriction is borne out in continuously voiced utterances, we will have established that three-tone sequences are clearly optimal to account for assimilatory effects in the tonal domain. The resulting assimilation patterns can then be incorporated into an algorithm for synthesizing Thai F_0 contours based on the extension Potisuk et al. [1995] of Fujisaki's [1983] model to a tone language.

Method

Subjects

Six speakers (3 men, 3 women) participated in this experiment. The ages of the six speakers ranged from 23 to 39 years (mean = 30). All subjects were monodialectal speakers from the Bangkok metropolitan area and were free of any speech or hearing disorders by self-report. All six speakers were graduate students at Purdue University.

Materials

Stimuli consisted of 125 possible three-tone sequences from the five Thai tones, superimposed on monosyllabic words in a carrier sentence with a fixed syntactic and prosodic environment. The syntactic frame was: subject + verb + object + post-verb auxiliary. Each sentence consisted of four monosyllabic words. The last word, /jùu/, which carries a low tone was held constant while the first three words were varied to give all 125 three-tone sequences (MMM, MML, MMF, MMH, MMR, LMM, ..., RRH, RRR). The stress pattern of the carrier sentence was invariant in order to eliminate the potentially confounding interaction between stress and tonal assimilation. All four words were stressed. The last word in the sentence was stressed by virtue of being in sentence-final position. For example, RML / nɔ̌ŋ jɔɔ lɔ̀n jùu / 'Nong is praising her' (see Appendix for complete list of test sentences). To enhance assimilatory effects, all four words began and ended with a sonorant, making the sentence continuously voiced throughout. For ease of syllable boundary segmentation, the first syllable began with an alveolar nasal, /n/, and ended with a velar nasal, /ŋ/. The second syllable was an open syllable beginning with an /l/, /j/, or /w/. The third syllable began with an /l/, or /n/ and ended with a nasal. The fourth syllable, /jùu/, always began with a /j/. The vowels of all four syllables were long vowels.

Recording Procedure

A reading task was chosen to maximize the likelihood of simulating normal speaking conditions as much as possible while at the same time controlling the syntactic, prosodic, and segmental characteristics of the spoken sentences. Most studies of prosody have used a reading task [Cooper and Paccia-Cooper, 1980]. Prosodic patterns obtained in reading tasks are quite similar to those observed in more natural speaking situations [Anderson and Cooper, 1986; cf. Lieberman et al., 1985].

Subjects were instructed to read target sentences typed in Thai script on index cards. Cards were presented in random order. Subjects were also instructed to produce the sentences at a conversational speaking rate. A sufficient pause was provided between test sentences to minimize changes in speaking rate and list-reading effects. By controlling the pace of presentation, we maximized the likelihood of obtaining natural-sounding productions. To avoid start and end effects, three extra cards were placed at the top and bottom of the deck.

Recordings were made in a soundproof booth using a Sony ECM-66B unidirectional microphone and a Marantz PMD-420 tape recorder in a single session. Subjects were seated and wore a custom-made headband that maintained the microphone at a distance of 20 cm from the lips. Before a recording session began, subjects were allowed to familiarize themselves with the target sentences. During the session, subjects were asked to reread any sentences that were judged to be 'off-target' until an acceptable version was produced. The session lasted about 1 1/2 h.

A total of 625 utterances was recorded (125 sequences × 5 repetitions) for each speaker. Due to waveform contamination by extraneous background noise or voicing overlap between the investigator and the subject during the recording session, about 1.6% (59/3,750) of utterances produced by all six speakers were eliminated from the corpus. Thus, a total of 3,691 utterances was retained for subsequent digitization and acoustic analysis.

Measurement Procedure

The tape-recorded stimuli were digitized at a sampling rate of 20 kHz by means of a 16-bit A/D converter with a 5-volt dynamic range using the Kay CSLTM (Computerized Speech Lab) model 4300 installed on a Gateway 2000 P5-90 microcomputer. The low-pass (anti-aliasing) filtering operation was done automatically by CSL during the digitization process to avoid aliasing effect.

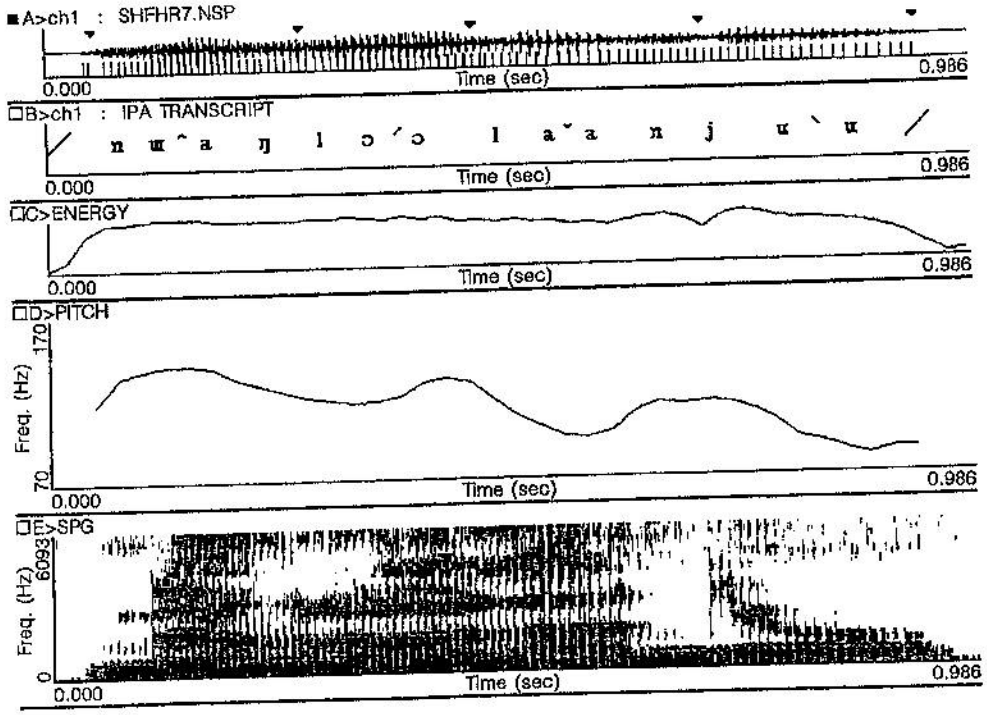

Fig. 1. A sample CSL display illustrating segmentation criteria for the FHR sequence. From top to bottom is the waveform, phonemic transcription, energy contour, F_0 contour, and wideband spectrogram. Tags are indicated by downward-pointing arrowheads on the audio waveform. The sample sentence is / nûaŋ lɔ̂ ɰaan jùu / 'Neuang is ridiculing our niece'.

Syllable onset and offset were determined from a simultaneous CSL display of an audio waveform, energy contour, F_0 contour, and wide-band spectrogram (see fig. 1). The first four tags mark the points of segmentation, in order from left to right: the beginning of the first, second, third, and fourth syllable, respectively. The last tag marks the end of the last syllable.

Tonal onset was defined as the first F_0 value that coincided with the onset of /n/ at the beginning of the first syllable; the onset of the /l/, /j/ or /w/ at the beginning of the second syllable; the onset of /n/ or /l/ at the beginning of the third syllable; and the onset of /j/ at the beginning of the fourth syllable. Spectrograms were demarcated in time following conventional rules for segmentation of the speech signal [Klatt, 1976; Peterson and Lehiste, 1960]. For example, the nasal-/l/ boundary was observed from the darkening, or increase in energy, in the F2 region. The nasal-/j/ boundary showed a discontinuity in the nasal murmur between the nasal and the glide. The nasal-/w/ boundary similarly showed a discontinuity between the nasal and the glide.

F_0 was computed directly from the waveform using a CSL algorithm that employs a time domain approach to F_0 analysis (modified autocorrelation with center clipping) with nonoverlapping variable frame length. For a particular speaker, frame length was determined by his/her F_0 range to ensure that there were at least two complete cycles within a frame. A typical frame length was 20–25 ms for male speakers, 15–20 ms for female speakers. Using the wide-band spectrogram, tonal onset was defined as the first F_0 value after voiceless obstruents that coincided with vertical striations in the second and higher formants, or as the first F_0 value after a nasal or lateral. Tonal offset was defined as the last F_0 value preceding the abrupt cessation of the second and higher formants of the vowel, or the last F0 value preceding the sudden offset of a nasal.

Data Normalization

F_0 contours of the target syllable were equalized for duration on a percentage scale to neutralize durational differences that are correlated with the five lexical tones. To evaluate anticipatory and perseverative effects on contiguous tones, the second syllable was the target syllable. To evaluate anticipatory effects on noncontiguous tones, the first syllable was the target syllable; to evaluate perseverative effects on noncontiguous tones, the third syllable was the target syllable.

After time-normalization, differences in the excursion size of F_0 movements related to differences in voice range between speakers were normalized by converting raw F_0 values to an ERB scale [Hermes and van Gestel, 1991]. Differences in the absolute height of F_0 movements between speakers were normalized by transforming the ERB values to a z-score scale because the mean and variance of nontransformed measures of F_0 tend to be correlated [Rose, 1987]. The normalization parameters (M, SD) were computed from raw F_0 values of all tokens for all sequences of all six speakers. Such normalization procedures facilitate comparison of the height and slope of F_0 contours across speakers.

Statistics

To evaluate changes in F_0 height and slope of the target syllable in the three-tone sequence, measurements were obtained at each of the 101 measurement locations throughout the total duration of that syllable. The slope at any point of the contour is computed by calculating the linear regression coefficients of a group of five F_0 values consisting of the current point, and its preceding and following two points except at the 0, 1, 99, and 100% measurement locations [Furui, 1986]. For these four locations, only the available three or four points are used in order to preserve transition information at the beginning and end of the contour. For statistical analysis purposes, only 11 measurement locations at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% of total duration are required to provide adequate resolution of the magnitude and temporal extent of F_0 assimilatory effects [Gandour et al., 1994]. In view of the perceptual dimensions underlying Thai tones, statistical analysis of the assimilatory effects is restricted to only F_0 height and slope [Gandour, 1983; Gandour and Harshman, 1978].

Analysis of variance (ANOVA) procedures were used to evaluate F_0 height and slope values in terms of the magnitude and the extent of anticipatory and perseverative assimilatory effects in the 125 three-tone sequences. This experiment is a randomized, fully crossed factorial design with replications in each cell. There are a total of 22 dependent variables, one for each of the 11 measurement locations for F_0 height and slope. Independent variables include tone (mid, low, falling, high, rising), preceding context (mid_, low_, falling_, high_, rising_), following context (_mid, _low, _falling, _high, _rising), and sampling location (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100%). Tone, preceding and following contexts, and sampling location were fully crossed factors. For each of the target tones that reached the 0.01 significance level in the overall ANOVA, post hoc Student-Newman-Keuls (SNK) paired comparisons ($a = 0.01$) were carried out to determine which of the five tones were responsible for assimilatory effects on the height and slope of the target tone. Post hoc SNK paired comparisons were also used to measure the temporal extent of the assimilatory effects. An assimilatory effect was considered to be present if significant differences in height or slope were obtained in at least two consecutive sampling locations.

A total of 50 ANOVAs were carried out separately for height (5 tones × 10 preceding/following contexts) and slope (5 tones × 10 preceding/following contexts) to assess anticipatory and perseverative effects on noncontiguous tones. Likewise, a total of 50 ANOVAs (5 tones × 10 preceding/following contexts) were carried out separately for height (5 tones × 10 preceding/following contexts) and slope (5 tones × 10 preceding/following contexts) to assess anticipatory and perseverative effects on contiguous tones.

Results

Assimilatory Effects on Individual Tones

Noncontiguous Context Effects. As shown in figures 2 and 3, tonal assimilatory effects do not extend beyond contiguous tones. In figure 2, each panel displays one of the five Thai tones in initial position of a three-tone sequence when followed by all

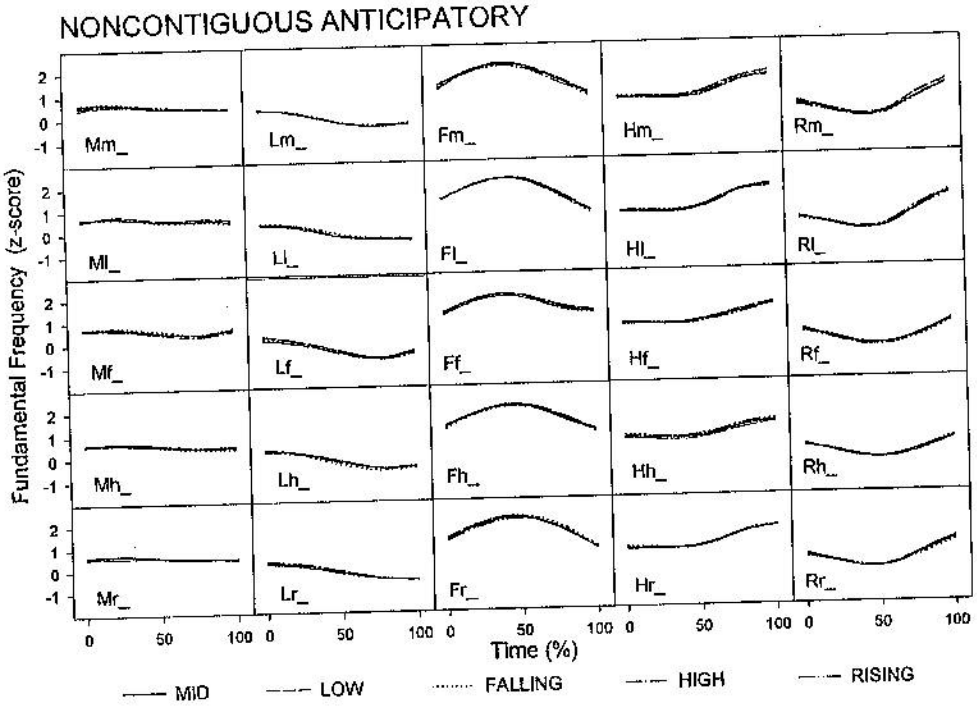

Fig. 2. Mean F_0 contours pooled across all six speakers of each of the 125 three-tone sequences showing anticipatory assimilatory effects from following noncontiguous tones. Within each panel, the initial uppercase letter indicates the target tone; the medial lowercase letter a fixed tonal context; and the final underscore the five varying tonal contexts (mid, low, falling, high, rising). M, m = Mid; L, l = low; F, f = falling; H, h = high; R, r = rising.

five tones in final position with an intervening fixed tone in medial position. In figure 3, each panel displays one of the five Thai tones in the final position of a three-tone sequence when preceded by all five tones in initial position with an intervening fixed tone in medial position. Neither anticipatory nor perseverative effects are evident on the height or slope of the five noncontiguous target tones. The lack of noncontiguous effects on the height or slope of the target tone is consistent across all five tones.

These graphical interpretations were confirmed by results of separate ANOVAs on height and slope. Regarding anticipatory assimilation of height and slope from noncontiguous tones, none of the main effects of tone, context, or sampling location reached significance. The two-way interaction between context and sampling location on both height and slope also failed to reach significance, indicating that all five tones exhibited like behavior with respect to anticipatory assimilation across contexts and sampling locations. Regarding perseverative assimilation of height and slope from noncontiguous tones, results of ANOVAs similarly failed to reach significance.

Contiguous Context Effects. Anticipatory effects from the following contiguous tones on the height and slope of a preceding target tone are displayed in figure 4. Each panel displays one of the five Thai tones in the medial position of a three-tone sequence when followed by all five tones in final position and preceded by a fixed

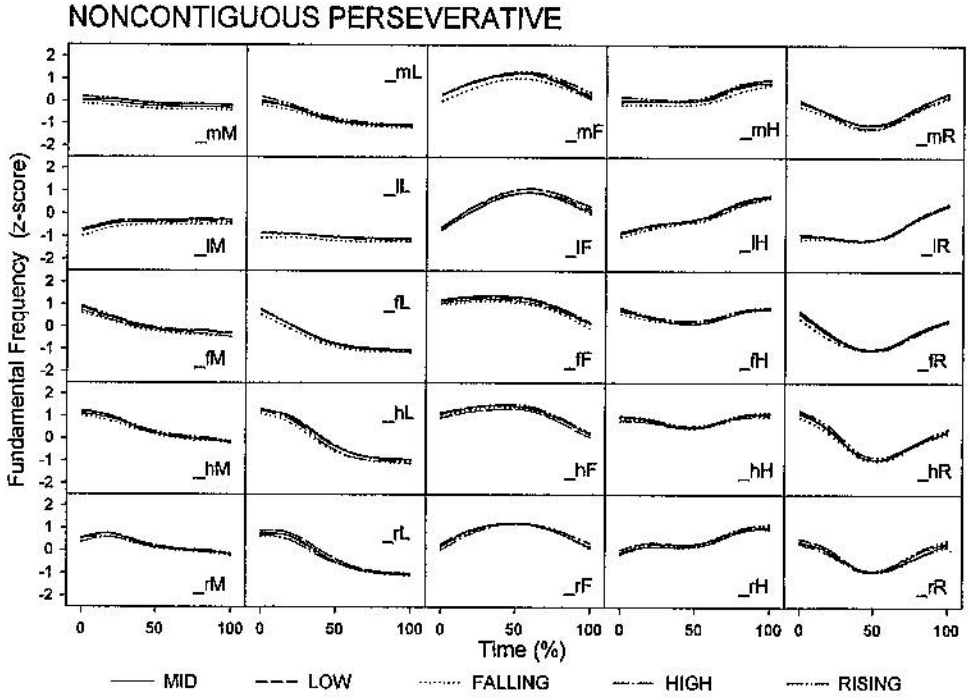

Fig. 3. Mean F_0 contours pooled across all six speakers of each of the 125 three-tone sequences showing perseverative assimilatory effects from preceding noncontiguous tones. Within each panel, the initial underscore represents the five varying tonal contexts (mid, low, falling, high, rising); the medial lowercase letter a fixed tonal context, and the final uppercase letter the target tone. M, m = Mid; L, l = low; F, f = falling; H, h = high; R, r = rising.

tone in initial position. Of the five tones, only the high and rising tones showed anticipatory effects on height, as indicated by significant two-way interactions between the following context and sampling location [high: $F(40,220) = 8.76$, $p < 0.0001$; rising: $F(40,204) = 5.32$, $p < 0.0001$]. The significant two-way interactions reflect the fact that the anticipatory effects did not extend throughout the entire duration of the high and rising tones. The anticipatory effects on height extended back from tonal offset approximately 20 and 30% of the total duration of the high and rising tones, respectively. These anticipatory effects were of a dissimilatory nature. Over the temporal extent of these anticipatory effects, post hoc SNK comparisons indicated that both the high and rising tones were significantly greater in height when followed by a low or rising tone than when followed by a falling or high tone. The slopes of the high and rising tones were not found to vary as a function of the following contiguous tone at any of the sampling locations. The mid, low, and falling tones, on the other hand, did not vary in either height or slope as a function of the following contiguous tone.

Perseverative effects from the preceding contiguous tones on the height and slope of a following target tone are displayed in figure 5. Each panel displays one of the five Thai tones in the medial position of a three-tone sequence when preceded by all five tones in initial position and followed by a fixed tone in final position. All five tones

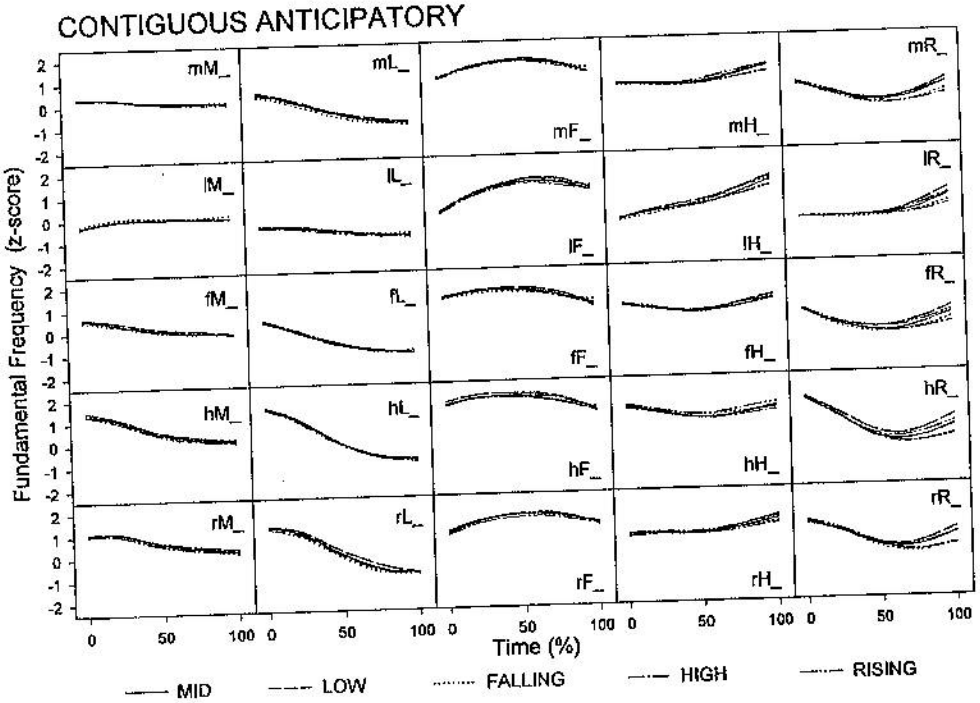

Fig. 4. Mean F_0 contours pooled across all six speakers of each of the 125 three-tone sequences showing anticipatory assimilatory effects from following contiguous tones. Within each panel, the initial lowercase letter represents a fixed tonal context; the medial uppercase letter the target tone, and the final underscore the five varying tonal contexts (mid, low, falling, high, rising). M, m = Mid; L, l = low; F, f = falling; H, h = high; R, r = rising.

showed perseverative effects on height [mid: $F(40,200) = 67.99$, $p < 0.0001$; low: $F(40,202) = 54.68$, $p < 0.0001$; falling: $F(40,203) = 37.32$, $p < 0.0001$; high: $F(40,201) = 40.58$, $p < 0.0001$, rising; $F(40,200) = 30.87$, $p < 0.0001$]. The perseverative effects on height extended forward from tonal onset to approximately 60–70% of the total duration of the target tones. Post hoc SNK comparisons revealed that the mid and low tones were significantly greater in height when preceded by the high or rising tone than when preceded by the low or falling tone from tonal onset to 70% of their total duration. The falling and high tones were significantly greater in height when preceded by the high tone than when preceded by the low tone from tonal onset to 60% of their total duration. The rising tone was significantly greater in height when preceded by the high or rising tone than when preceded by the low tone from the beginning to 60% of its duration. Across the five tones, tonal onset was highest when preceded by the high tone, and lowest when preceded by the low tone.

All five tones showed perseverative effects on slope [mid: $F(40,200) = 9.02$, $p < 0.0001$); low: $F(40,202) = 6.23$, $p < 0.0001$; falling: $F(40,203) = 3.55$, $p < 0.0001$; high: $F(40.201) = 5.66$, $p < 0.0001$; rising: $F(40,200) = 5.90$, $p < 0.0001$]. Congruent with the findings on perseverative effects on height, post hoc SNK comparisons revealed that the mid and low tones were significantly steeper in slope when preceded

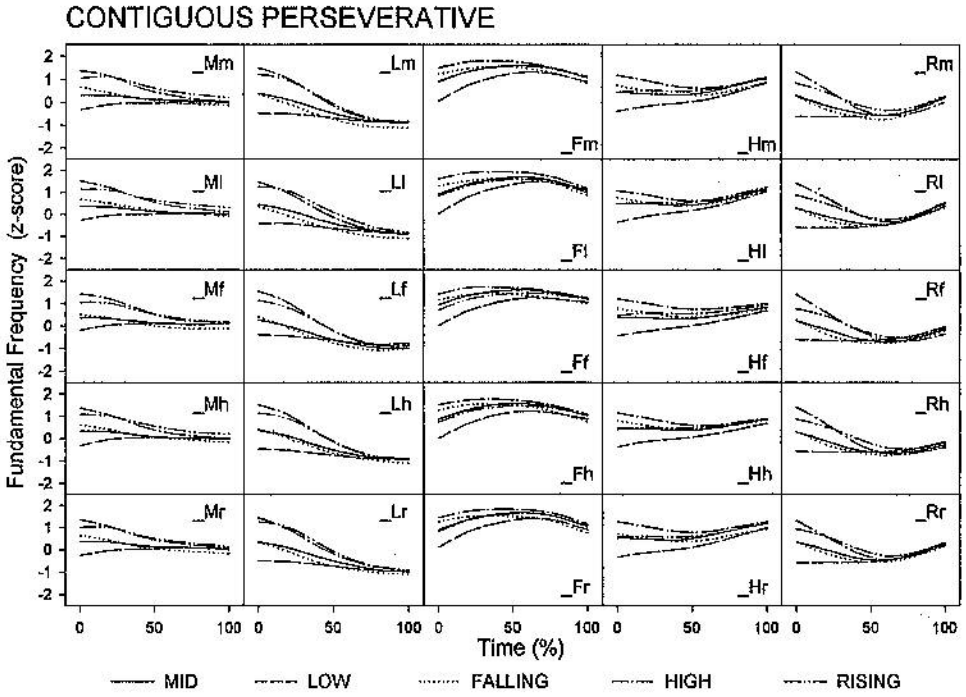

Fig. 5. Mean F_0 contours pooled across all six speakers of each of the 125 three-tone sequences showing perseverative assimilatory effects from preceding contiguous tones. Within each panel, the initial underscore represents the five varying tonal contexts (mid, low, falling, high, rising), the medial upercase letter the target tone; and the final lowercase letter a fixed tonal context. M, m = Mid; L, l = low; F, f = falling; H, h = high; R, r = rising.

by the high or rising tone than when preceded by the low tone from tonal onset to 70% of their duration. The falling and high tones were significantly steeper in slope when preceded by the low tone than when preceded by the high tone from tonal onset to 70% of their duration. The rising tone was significantly steeper in slope when preceded by the high or rising tone than when preceded by the low tone from tonal onset to 60% of its duration.

Context Effects on the Pattern of Contrast among the Five Tones

The contrastive relationship among the medial five tones in all possible three-tone sequences appeared to be maintained in all contexts (fig. 6). This contrastive relationship is preserved despite some variation in F_0 height and slope of the contours due to tonal assimilation. In agreement with the findings of Gandour et al. [1994] for two-tone sequences, none of the tonal contexts in these three-tone sequences resulted in overlapping F_0 contours for any two of the five tones. In comparison to their F_0 contours in citation forms [Gandour et al., 1988, 1991, 1992a], those of the falling and rising tones most noticeably exhibit less extreme F_0 offsets. The falling tone in running speech does not fall as far as it does in citation forms; the rising tone does not rise as far.

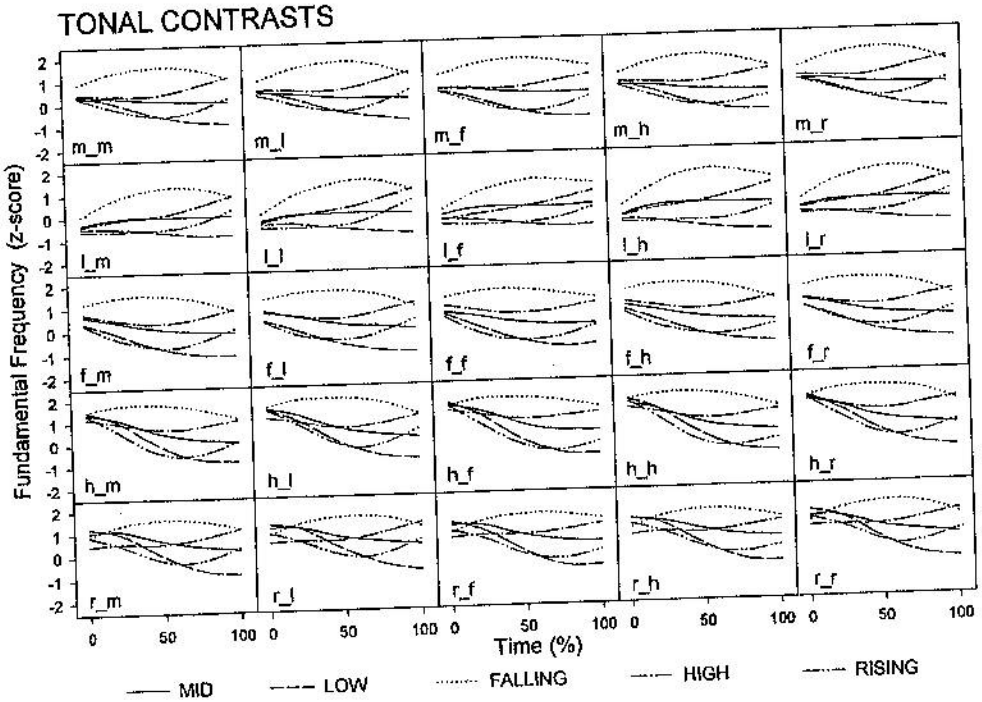

Fig. 6. Mean F_0 contours pooled across all six speakers of each of the 125 three-tone sequences showing the pattern of contrast among the five target tones in all possible contexts. Within each panel, the initial and final lowercase letters represent fixed tonal contexts: the medial underscore the five target tones (mid, low, falling, high, rising). M, m = Mid; L, l = low; F, f = falling; H, h = high; R, r = rising.

Discussion

Assimilatory effects in three-tone sequences embedded in Thai running speech are not symmetric. Thai tones are more greatly influenced by perseverative than anticipatory assimilation. Gandour et al. [1994] reported a similar, asymmetric pattern of tonal assimilation for two-tone sequences in Thai running speech. In this study, all five tones are affected by perseverative assimilation, whereas only the high and rising tones are affected by anticipatory dissimilation. Anticipatory dissimilation is restricted to those tones with rising F_0 trajectories in the terminal portion of their contours (H, R); those tones with falling F_0 trajectories in the terminal portion of their contours (M, L, F) are not affected by anticipatory dissimilation. The predominance of perseverative assimilation of tones has also been reported in other Asian tone languages [Taiwanese: Cheng, 1968; Vietnamese: Han and Kim, 1974; Mandarin: Xu, 1994a; cf. Shen, 1990a]. The restriction of anticipatory dissimilation to tonal contours in the upper pitch range has also been observed in Mandarin [Xu, 1994b, 1995].

The temporal extent of perseverative tonal assimilation is much greater than that of anticipatory assimilation. Perseverative effects in both height and slope extend forward to about 70% of the total duration of the following syllable, whereas anticipatory

effects in height, but not slope, extend backward to about 30% of the preceding syllable. These assimilatory effects are restricted to adjacent syllables, they do not extend to noncontiguous syllables. Moreover, they do not extend even throughout the entire duration of tonal contours of adjacent syllables. Contrary to earlier reports on tonal assimilation [Han and Kim, 1974; Shen, 1990a], not all parts of the tonal contours of adjacent syllables are affected in an all-or-none fashion. Instead, the temporal extent of assimilatory effects appears to vary depending on the direction of assimilation as well as the direction of F_0 trajectories in the terminal portion of affected tones.

In this study, the potentially confounding interaction between tonal assimilation and stress was not a factor. All syllables were stressed in the three-tone sequences. The fact that perseverative effects are stronger than anticipatory effects cannot be attributed to the dominance of stressed syllables over unstressed syllables. Whether assimilatory effects are restricted to contiguous tones only in stressed syllables is a topic for further investigation. It is possible that the temporal extent of tonal assimilation may extend beyond adjacent unstressed syllables.

Contrary to Gandour et al. [1994], tonal assimilation in Thai appears to affect the slope, at least in perseverative assimilation, as well as the height of tonal contours. Moreover, perseverative effects from the preceding tones are more extensive than those found in Gandour et al. In this study, the utterances were continuously voiced throughout the whole utterance; in Gandour et al., voiceless plosives occurred at the beginning of the target syllable. Evidently, the effect of voiced sounds on the F_0 contour results in stronger assimilatory effects between two successive syllables that are continuous in voicing across the syllable boundary [Chen et al., 1992].

Perseverative effects on the height and slope of F_0 contours are assimilatory in nature. A low offset of the preceding tone lowers the height of following target tones that have higher F_0 onsets. Conversely, a high offset of the preceding tone raises the height of following target tones that have lower F_0 onsets. In both cases, the assimilatory effect results in a steeper slope in the target tones, but in the opposite direction. The target tone with a lower onset than the offset of the influencing tone has a steeper negative slope, whereas the target tone with a higher onset than the offset of the influencing tone has a steeper positive slope.

Anticipatory effects on the height of F_0 contours are dissimilatory in nature. A low onset of the following tone raises the height of preceding target tones that have higher F_0 offsets whereas a high onset of the following tone lowers the height of preceding target tones with lower F_0 offsets. These findings are in agreement with previous studies on tonal assimilation in Thai [Gandour et al., 1992b, c, 1994] as well as in Mandarin Chinese [Xu, 1994b, 1995] and Yoruba [Akinlabi and Liberman, 1995]. It is further noted that Thai tones with a rising F_0 contour in the terminal portion (H, R) were affected by anticipatory assimilation, whereas tones with a falling contour in the terminal portion (M, L, F) were not. Thus, the dissimilatory nature of anticipatory effects may be due to the fact that rising contours generally take longer to reach their final target F_0 than falling contours [Ohala, 1978; Sundberg, 1979]. If the tones with rising F_0 contours are to maintain their perceptual separation from falling tones in such contexts, then a speaker presumably has to initiate the rising portion of the contour at an earlier point in time. In so doing, the height of the F_0 contour at tonal offset of the preceding target tone is higher than it would be otherwise. Of the five Thai tones, the mid, low, and falling tones are characterized primarily by a falling F_0 trajectory throughout their duration, whereas the high and rising tones are not. Moreover, dis-

similatory effects are much stronger for the rising tone than for the high tone, which suggests that the magnitude of the dissimilatory effect depends on the distance between tonal offset of the preceding target tone and tonal onset of the following tone. The rising tone has a higher tonal offset than the high tone. Therefore, the dissimilatory effect is greater in the rising tone than the high tone.

It is hypothesized that the peak F_0 of tones with rising F_0 trajectories is realized at an earlier point within the syllable in order to maintain tonal identity as well as to allow for a less abrupt change in acceleration that is required in making transition to a following tone with a low onset. The hypothesis is that the lower the onset of the following tone, the earlier the point at which the peak of the rising F_0 contour, and conversely, the higher the onset of the following tone, the later the peak of the rising F_0 contour will be reached in the preceding tone. The dissimilatory nature of anticipatory effects, as measured by F_0 values at tonal offset of the preceding syllable, is then seen to be a secondary consequence of these differences in timing transition.

Under this hypothesis rising F_0 contours may or may not be realized within the boundaries of a single syllable in running speech. In the case of syllables ending in sonorants, it is predicted that preceding tones with rising F_0 trajectories (H, R) will 'spread' into following tones with higher onsets. This spreading phenomenon has had phonological consequences in West African tone languages [Akinlabi and Liberman, 1995; Hyman and Schuh, 1974]. Thai, on the other hand, is believed to be at the other end of the spectrum with respect to the spreading phenomenon. Although it has not resulted in changes to Thai tonal phonology, the spreading tendency appears to be essential to maintaining the identity of tones with rising F_0 trajectories in running speech. The obvious next step in this line of research is to conduct perception experiments using synthetic F_0 contours superimposed on two-tone sequences. For example, it is predicted that a change in tonal identification can be affected by varying the timing of transition to following tones whose F_0 contours are similar in running speech (e.g., RM vs. RL; RF vs. RH).

In Thai, the high and rising tones require an abrupt change in direction when making transition to a following low tone. From an articulatory perspective, it is assumed that the goal is to minimize abrupt changes in acceleration. In these two cases (HL, RL), this is accomplished by reaching the peak F_0 earlier in the tonal contour, thus leading to a higher-than-expected F_0 value at the end of the preceding tone. Perceptually speaking, differences in timing transitions of rising F_0 movement to the following tone maximize perceptual separation of pairs of phonetically similar sequences of tone. Without these perceptual constraints on tonal production, such tonal distinctions would be compromised or neutralized.

The dissimilatory effect that has been reported in previous studies of tonal assimilation in Thai [Gandour et al., 1992c, 1993, 1994] is smaller in magnitude than in the current study. In those earlier studies, voiceless obstruents intervened between the adjacent tones. Spreading might be expected to be inhibited under those circumstances. According to Hyman and Schuh [1974], in some West African tone languages, spreading across intervening voiceless intervals is attested; in others, voiceless intervals may inhibit or block the spreading process. By Hyman and Schuh's account, if two contiguous syllables differ in tone, the natural process is for the tone of the first syllable to spread into the second syllable. Spreading is an assimilatory process of the perseverative type rather than of the anticipatory type. Tones spread to the right; i.e., the earlier tone appears to last too long rather than the later tone starting

too early. Tones apparently never or at least rarely spread to the left. This rightward spreading is presumably a reflection of the larynx as a 'sluggish' articulator. Phonetically, it is hypothesized that more time is required for laryngeal adjustments in controlling changes in the direction of F_0 movement than for supralaryngeal adjustments in the production of successive segments. Hyman and Schuh further state that spreading is most likely to occur where the interval between the two tones is greatest. Thus, in the case of Thai tonal assimilation, we find that the magnitude of the dissimilatory effect is greater for the rising tone than the high tone.

As pointed out by Xu [1995], this dissimilatory effect, whereby F_0 is raised when preceding a low tonal target, bears some similarities to tonal phenomena in West African languages. 'Downdrift' results in high tones after low tones being phonetically less high than any preceding high tone in the utterance. This process has traditionally been regarded as a type of perseverative assimilation with the low tone influencing the height of the succeeding high tone [Hyman, 1975]. Alternatively, it may be viewed as an instance of anticipatory dissimilation. In Yoruba, a high tone is raised before a contiguous low tone [Connell and Ladd, 1990]. To the extent that this process carries throughout an intonational phrase, it can be seen as an effort to counter the overall lowering of F_0 and the narrowing of the pitch range during the course of an utterance. As in Thai and Mandarin, the raising effect would enhance the perceptual separation of tonal categories in the face of a downward trend in F_0 throughout a sentence. Indeed, Laniran and Clements [1995] have provided evidence for anticipatory raising of Yoruba high tones induced by following noncontiguous low tones. A perceptually based mechanism would appear to best account for all these superficially disparate tonal phenomena in tone languages of the Far East and West Africa.

Although tonal contrasts were seemingly preserved despite tonal assimilation, it should be pointed out that all target syllables were stressed in these sentence contexts. Whether or not the tonal contrasts are maintained in unstressed syllables under tonal assimilation is a topic for future study. The influence of speaking rate is another obvious variable that must be explored systematically before we can tease apart the effects of stress, tonal assimilation, and speaking rate on the distinctiveness of tonal contours in Thai running speech [cf. Potisuk et al., in press, a, b]. In all contexts, the low and the rising tones appear to be distinguished primarily by slope differences in the terminal portion of their contours. The terminal portion of the rising tone tends to rise, whereas that of the low tone tends to fall. Such findings provide a point of departure for a series of perceptual tests using synthetic speech in order to ascertain the contrastive relationship among the five tones in running speech [cf. Abramson, 1978].

In conclusion, these findings support the view that perseverative and anticipatory effects on tones are assimilatory and dissimilatory in nature, respectively. Perseverative effects appear to apply across all tonal categories whereas anticipatory effects do not. Interestingly, anticipatory effects are limited to those tones whose terminal portions traverse the upper region of the tone space. Whether perseverative or anticipatory, contextual effects appear to be restricted to contiguous tones. Such effects do not encompass the whole of the duration of the target tone. Perseverative effects, however, extend through a larger part of the adjacent target tone than do anticipatory effects. Contextually induced variations affect both the height and shape of the target tones. The dissimilatory nature of anticipatory effects may be driven by perceptual factors, and not unrelated to tonal phenomena that have been reported in West African languages as well as other Far East tone languages.

Appendix. List of trisyllabic tonal sequences in Thai

Tonal sequence	Thai script	Phonetic transcription	English translation
MMM	เนียงยอนางอยู่	/ niaŋ jɔɔ naaŋ jùu /	'Niang is praising Naang.'
MML	เนียงยอหล่อนอยู่	/ niaŋ jɔɔ lɔ̌ɔn jùu /	'Niang is praising her.'
MMF	เนียงยอล่ามอยู่	/ niaŋ jɔɔ lâam jùu /	'Niang is praising the translator.'
MMH	เนียงยอน้ำอยู่	/ niaŋ jɔɔ náam jùu /	'Niang is praising Naam.'
MMR	เนียงยอหลานอยู่	/ niaŋ jɔɔ lăan jùu /	'Niang is praising our niece.'
LMM	โหน่งยอนางอยู่	/ nɔ̀ɔŋ jɔɔ naaŋ jùu /	'Noong is praisingNaang.'
LML	โหน่งยอหล่อนอยู่	/ nɔ̀ɔŋ jɔɔ lɔ̌ɔn jùu /	'Noong is praising her.'
LMF	โหน่งยอล่ามอยู่	/ nɔ̀ɔŋ jɔɔ lâam jùu /	'Noong is praising the translator.'
LMH	โหน่งยอน้ำอยู่	/ nɔ̀ɔŋ jɔɔ náam jùu /	'Noong is praising Naam.'
LMR	โหน่งยอหลานอยู่	/ nɔ̀ɔŋ jɔɔ lăan jùu /	'Noong is praising our niece.'
FMM	เนื่องยอนางอยู่	/ nɯ̂aŋ jɔɔ naaŋ jùu /	'Neuang is praising Naang.'
FML	เนื่องยอหล่อนอยู่	/ nɯ̂aŋ jɔɔ lɔ̌ɔn jùu /	'Neuang is praising her.'
FMF	เนื่องยอล่ามอยู่	/ nɯ̂aŋ jɔɔ lâam jùu /	'Neuang is praising the translator.'
FMH	เนื่องยอน้ำอยู่	/ nɯ̂aŋ jɔɔ náam jùu /	'Neuang is praising Naam.'
FMR	เนื่องยอหลานอยู่	/ nɯ̂aŋ jɔɔ lăan jùu /	'Neuang is praising our niece.'
HMM	น้องยอนางอยู่	/ nɔ́ɔŋ jɔɔ naaŋ jùu /	'Nong is praising Naang.'
HML	น้องยอหล่อนอยู่	/ nɔ́ɔŋ jɔɔ lɔ̌ɔn jùu /	'Nong is praising her.'
HMF	น้องยอล่ามอยู่	/ nɔ́ɔŋ jɔɔ lâam jùu /	'Nong is praising the translator.'
HMH	น้องยอน้ำอยู่	/ nɔ́ɔŋ jɔɔ náam jùu /	'Nong is praising Naam.'
HMR	น้องยอหลานอยู่	/ nɔ́ɔŋ jɔɔ lăan jùu /	'Nong is praising our niece.'
RMM	หนองยอนางอยู่	/ nɔ̌ɔŋ jɔɔ naaŋ jùu /	'Nong is praising Naang.'
RML	หนองยอหล่อนอยู่	/ nɔ̌ɔŋ jɔɔ lɔ̌ɔn jùu /	'Nong is praising her.'
RMF	หนองยอล่ามอยู่	/ nɔ̌ɔŋ jɔɔ lâam jùu /	'Nong is praising the translator.'
RMH	หนองยอน้ำอยู่	/ nɔ̌ɔŋ jɔɔ náam jùu /	'Nong is praising Naam.'
RMR	หนองยอหลานอยู่	/ nɔ̌ɔŋ jɔɔ lăan jùu/	'Nong is praising our niece.

Appendix (continued)

Tonal sequence	Thai script	Phonetic transcription	English translation
MLM	เนียงแหย่นางอยู่	/ niaŋ jɛ̀ɛ naaŋ jùu /	'Niang is teasing Naang.'
MLL	เนียงแหย่หล่อนอยู่	/ niaŋ jɛ̀ɛ lɔ̌ɔn jùu /	'Niang is teasing her.'
MLF	เนียงแหย่ล่ามอยู่	/ niaŋ jɛ̀ɛ lâam jùu /	'Niang is teasing the translator.'
MLH	เนียงแหย่น้ำอยู่	/ niaŋ jɛ̀ɛ náam jùu /	'Niang is teasing Naam.'
MLR	เนียงแหย่หลานอยู่	/ niaŋ jɛ̀ɛ lăan jùu /	'Niang is teasing our niece.'
LLM	โหน่งแหย่นางอยู่	/ nòoŋ jɛ̀ɛ naaŋ jùu /	'Noong is teasingNaang.'
LLL	โหน่งแหย่หล่อนอยู่	/ nòoŋ jɛ̀ɛ lɔ̌ɔn jùu /	'Noong is teasing her.'
LLF	โหน่งแหย่ล่ามอยู่	/ nòoŋ jɛ̀ɛ lâam jùu /	'Noong is teasing the translator.'
LLH	โหน่งแหย่น้ำอยู่	/ nòoŋ jɛ̀ɛ náam jùu /	'Noong is teasing Naam.'
LLR	โหน่งแหย่หลานอยู่	/ nòoŋ jɛ̀ɛ lăan jùu /	'Noong is teasing our niece.'
FLM	เนื่องแหย่นางอยู่	/ nɯ̂aŋ jɛ̀ɛ naaŋ jùu /	'Neuang is teasing Naang.'
FLL	เนื่องแหย่หล่อนอยู่	/ nɯ̂aŋ jɛ̀ɛ lɔ̌ɔn jùu /	'Neuang is teasing her.'
FLF	เนื่องแหย่ล่ามอยู่	/ nɯ̂aŋ jɛ̀ɛ lâam jùu /	'Neuang is teasing the translator.'
FLH	เนื่องแหย่น้ำอยู่	/ nɯ̂aŋ jɛ̀ɛ náam jùu /	'Neuang is teasing Naam.'
FLR	เนื่องแหย่หลานอยู่	/ nɯ̂aŋ jɛ̀ɛ lăan jùu /	'Neuang is teasing our niece.'
HLM	น้องแหย่นางอยู่	/ nɔ́ɔŋ jɛ̀ɛ naaŋ jùu /	'Nong is teasing Naang.'
HLL	น้องแหย่หล่อนอยู่	/ nɔ́ɔŋ jɛ̀ɛ lɔ̌ɔn jùu /	'Nong is teasing her.'
HLF	น้องแหย่ล่ามอยู่	/ nɔ́ɔŋ jɛ̀ɛ lâam jùu /	'Nong is teasing the translator.'
HLH	น้องแหย่น้ำอยู่	/ nɔ́ɔŋ jɛ̀ɛ náam jùu /	'Nong is teasing Naam.'
HLR	น้องแหย่หลานอยู่	/ nɔ́ɔŋ jɛ̀ɛ lăan jùu /	'Nong is teasing our niece.'
RLM	หนองแหย่นางอยู่	/ nɔ̌ɔŋ jɛ̀ɛ naaŋ jùu /	'Nong is teasing Naang.'
RLL	หนองแหย่หล่อนอยู่	/ nɔ̌ɔŋ jɛ̀ɛ lɔ̌ɔn jùu /	'Nong is teasing her.'
RLF	หนองแหย่ล่ามอยู่	/ nɔ̌ɔŋ jɛ̀ɛ lâam jùu /	'Nong is teasing the translator.'
RLH	หนองแหย่น้ำอยู่	/ nɔ̌ɔŋ jɛ̀ɛ náam jùu /	'Nong is teasing Naam.'
RLR	หนองแหย่หลานอยู่	/ nɔ̌ɔŋ jɛ̀ɛ lăan jùu/	'Nong is teasing our niece.

Appendix (continued)

Tonal sequence	Thai script	Phonetic transcription	English translation
MFM	เนียงว่านางอยู่	/ niaŋ wâa naaŋ jùu /	'Niang is scolding Naang.'
MFL	เนียงว่าหล่อนอยู่	/ niaŋ wâa lɔ̌ɔn jùu /	'Niang is scolding her.'
MFF	เนียงว่าล่ามอยู่	/ niaŋ wâa lâam jùu /	'Niang is scolding the translator.'
MFH	เนียงว่าน้ำอยู่	/ niaŋ wâa náam jùu /	'Niang is scolding Naam.'
MFR	เนียงว่าหลานอยู่	/ niaŋ wâa lăan jùu /	'Niang is scolding our niece.'
LFM	โหน่งว่านางอยู่	/ nòoŋ wâa naaŋ jùu /	'Noong is scoldingNaang.'
LFL	โหน่งว่าหล่อนอยู่	/ nòoŋ wâa lɔ̌ɔn jùu /	'Noong is scolding her.'
LFF	โหน่งว่าล่ามอยู่	/ nòoŋ wâa lâam jùu /	'Noong is scolding the translator.'
LFH	โหน่งว่าน้ำอยู่	/ nòoŋ wâa náam jùu /	'Noong is scolding Naam.'
LFR	โหน่งว่าหลานอยู่	/ nòoŋ wâa lăan jùu /	'Noong is scolding our niece.'
FFM	เนื่องว่านางอยู่	/ nûaŋ wâa naaŋ jùu /	'Neuang is scolding Naang.'
FFL	เนื่องว่าหล่อนอยู่	/ nûaŋ wâa lɔ̌ɔn jùu /	'Neuang is scolding her.'
FFF	เนื่องว่าล่ามอยู่	/ nûaŋ wâa lâam jùu /	'Neuang is scolding the translator.'
FFH	เนื่องว่าน้ำอยู่	/ nûaŋ wâa náam jùu /	'Neuang is scolding Naam.'
FFR	เนื่องว่าหลานอยู่	/ nûaŋ wâa lăan jùu /	'Neuang is scolding our niece.'
HFM	น้องว่านางอยู่	/ nɔ́ɔŋ wâa naaŋ jùu /	'Nong is scolding Naang.'
HFL	น้องว่าหล่อนอยู่	/ nɔ́ɔŋ wâa lɔ̌ɔn jùu /	'Nong is scolding her.'
HFF	น้องว่าล่ามอยู่	/ nɔ́ɔŋ wâa lâam jùu /	'Nong is scolding the translator.'
HFH	น้องว่าน้ำอยู่	/ nɔ́ɔŋ wâa náam jùu /	'Nong is scolding Naam.'
HFR	น้องว่าหลานอยู่	/ nɔ́ɔŋ wâa lăan jùu /	'Nong is scolding our niece.'
RFM	หนองว่านางอยู่	/ nɔ̌ɔŋ wâa naaŋ jùu /	'Nong is scolding Naang.'
RFL	หนองว่าหล่อนอยู่	/ nɔ̌ɔŋ wâa lɔ̌ɔn jùu /	'Nong is scolding her.'
RFF	หนองว่าล่ามอยู่	/ nɔ̌ɔŋ wâa lâam jùu /	'Nong is scolding the translator.'
RFH	หนองว่าน้ำอยู่	/ nɔ̌ɔŋ wâa náam jùu /	'Nong is scolding Naam.'
RFR	หนองว่าหลานอยู่	/ nɔ̌ɔŋ wâa lăan jùu/	'Nong is scolding our niece.

Appendix (continued)

Tonal sequence	Thai script	Phonetic transcription	English translation
MHM	เนียงล้อนางอยู่	/ niaŋ lɔ́ɔ naaŋ jùu /	'Niang is ridiculing Naang.'
MHL	เนียงล้อหล่อนอยู่	/ niaŋ lɔ́ɔ lɔ̀ɔn jùu /	'Niang is ridiculing her.'
MHF	เนียงล้อล่ามอยู่	/ niaŋ lɔ́ɔ lâam jùu /	'Niang is ridiculing the translator.'
MHH	เนียงล้อน้ำอยู่	/ niaŋ lɔ́ɔ náam jùu /	'Niang is ridiculing Naam.'
MHR	เนียงล้อหลานอยู่	/ niaŋ lɔ́ɔ lăan jùu /	'Niang is ridiculing our niece.'
LHM	โหน่งล้อนางอยู่	/ nòoŋ lɔ́ɔ naaŋ jùu /	'Noong is ridiculingNaang.'
LHL	โหน่งล้อหล่อนอยู่	/ nòoŋ lɔ́ɔ lɔ̀ɔn jùu /	'Noong is ridiculing her.'
LHF	โหน่งล้อล่ามอยู่	/ nòoŋ lɔ́ɔ lâam jùu /	'Noong is ridiculing the translator.'
LHH	โหน่งล้อน้ำอยู่	/ nòoŋ lɔ́ɔ náam jùu /	'Noong is ridiculing Naam.'
LHR	โหน่งล้อหลานอยู่	/ nòoŋ lɔ́ɔ lăan jùu /	'Noong is ridiculing our niece.'
FHM	เนื่องล้อนางอยู่	/ nɯ̀aŋ lɔ́ɔ naaŋ jùu /	'Neuang is ridiculing Naang.'
FHL	เนื่องล้อหล่อนอยู่	/ nɯ̀aŋ lɔ́ɔ lɔ̀ɔn jùu /	'Neuang is ridiculing her.'
FHF	เนื่องล้อล่ามอยู่	/ nɯ̀aŋ lɔ́ɔ lâam jùu /	'Neuang is ridiculing the translator.'
FHH	เนื่องล้อน้ำอยู่	/ nɯ̀aŋ lɔ́ɔ náam jùu /	'Neuang is ridiculing Naam.'
FHR	เนื่องล้อหลานอยู่	/ nɯ̀aŋ lɔ́ɔ lăan jùu /	'Neuang is ridiculing our niece.'
HHM	น้องล้อนางอยู่	/ nɔ́ɔŋ lɔ́ɔ naaŋ jùu /	'Nong is ridiculing Naang.'
HHL	น้องล้อหล่อนอยู่	/ nɔ́ɔŋ lɔ́ɔ lɔ̀ɔn jùu /	'Nong is ridiculing her.'
HHF	น้องล้อล่ามอยู่	/ nɔ́ɔŋ lɔ́ɔ lâam jùu /	'Nong is ridiculing the translator.'
HHH	น้องล้อน้ำอยู่	/ nɔ́ɔŋ lɔ́ɔ náam jùu /	'Nong is ridiculing Naam.'
HHR	น้องล้อหลานอยู่	/ nɔ́ɔŋ lɔ́ɔ lăan jùu /	'Nong is ridiculing our niece.'
RHM	หนองล้อนางอยู่	/ nɔ̌ɔŋ lɔ́ɔ naaŋ jùu /	'Nong is ridiculing Naang.'
RHL	หนองล้อหล่อนอยู่	/ nɔ̌ɔŋ lɔ́ɔ lɔ̀ɔn jùu /	'Nong is ridiculing her.'
RHF	หนองล้อล่ามอยู่	/ nɔ̌ɔŋ lɔ́ɔ lâam jùu /	'Nong is ridiculing the translator.'
RHH	หนองล้อน้ำอยู่	/ nɔ̌ɔŋ lɔ́ɔ náam jùu /	'Nong is ridiculing Naam.'
RHR	หนองล้อหลานอยู่	/ nɔ̌ɔŋ lɔ́ɔ lăan jùu/	'Nong is ridiculing our niece.

Appendix (continued)

Tonal sequence	Thai script	Phonetic transcription	English translation
MRM	เนียงหลีนางอยู่	/ niang lii naang jùu /	'Niang is flirting with Naang.'
MRL	เนียงหลีหล่อนอยู่	/ niang lii lɔ̌ɔn jùu /	'Niang is flirting with her.'
MRF	เนียงหลีล่ามอยู่	/ niang lii lâam jùu /	'Niang is flirting with the translator.'
MRH	เนียงหลีน้ำอยู่	/ niang lii náam jùu /	'Niang is flirting with Naam.'
MRR	เนียงหลีหลานอยู่	/ niang lii lăan jùu /	'Niang is flirting with our niece.'
LRM	โหน่งหลีนางอยู่	/ nòong lii naang jùu /	'Noong is flirting withNaang.'
LRL	โหน่งหลีหล่อนอยู่	/ nòong lii lɔ̌ɔn jùu /	'Noong is flirting with her.'
LRF	โหน่งหลีล่ามอยู่	/ nòong lii lâam jùu /	'Noong is flirting with the translator.'
LRH	โหน่งหลีน้ำอยู่	/ nòong lii náam jùu /	'Noong is flirting with Naam.'
LRR	โหน่งหลีหลานอยู่	/ nòong lii lăan jùu /	'Noong is flirting with our niece.'
FRM	เนื่องหลีนางอยู่	/ nɯ̂ang lii naang jùu /	'Neuang is flirting with Naang.'
FRL	เนื่องหลีหล่อนอยู่	/ nɯ̂ang lii lɔ̌ɔn jùu /	'Neuang is flirting with her.'
FRF	เนื่องหลีล่ามอยู่	/ nɯ̂ang lii lâam jùu /	'Neuang is flirting with the translator.'
FRH	เนื่องหลีน้ำอยู่	/ nɯ̂ang lii náam jùu /	'Neuang is flirting with Naam.'
FRR	เนื่องหลีหลานอยู่	/ nɯ̂ang lii lăan jùu /	'Neuang is flirting with our niece.'
HRM	น้องหลีนางอยู่	/ nɔ́ɔng lii naang jùu /	'Nong is flirting with Naang.'
HRL	น้องหลีหล่อนอยู่	/ nɔ́ɔng lii lɔ̌ɔn jùu /	'Nong is flirting with her.'
HRF	น้องหลีล่ามอยู่	/ nɔ́ɔng lii lâam jùu /	'Nong is flirting with the translator.'
HRH	น้องหลีน้ำอยู่	/ nɔ́ɔng lii náam jùu /	'Nong is flirting with Naam.'
HRR	น้องหลีหลานอยู่	/ nɔ́ɔng lii lăan jùu /	'Nong is flirting with our niece.'
RRM	หนองหลีนางอยู่	/ nɔ̌ɔng lii naang jùu /	'Nong is flirting with Naang.'
RRL	หนองหลีหล่อนอยู่	/ nɔ̌ɔng lii lɔ̌ɔn jùu /	'Nong is flirting with her.'
RRF	หนองหลีล่ามอยู่	/ nɔ̌ɔng lii lâam jùu /	'Nong is flirting with the translator.'
RRH	หนองหลีน้ำอยู่	/ nɔ̌ɔng lii náam jùu /	'Nong is flirting with Naam.'
RRR	หนองหลีหลานอยู่	/ nɔ̌ɔng lii lăan jùu /	'Nong is flirting with our niece.

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