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Anticipatory tonal coarticulation in Thai noun compounds*

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It is commonly known that speech sounds are subject to influences from adjacent sounds which alter their phonetic manifestation. This phenomenon is called *coarticulation*. Of particular interest is *anticipatory* or *look ahead* coarticulation, which involves one speech sound being influenced by subsequent sounds, and *perseverative* or *carryover* coarticulation, which involves one speech sound being influenced by preceding sounds.

In consonants and vowels, coarticulatory effects are bidirectional, which means that both anticipatory and perseverative effects are found to occur in languages of the world. In tones, coarticulatory effects occur in much the same way as they do between consonants and vowels. Ladefoged (1982) has suggested that coarticulation between tones tends to be perseverative rather than anticipatory.

Acoustic phonetic studies of tonal coarticulation are scarce. In Vietnamese, Han and Kim (1974) found that the six lexical tones vary in both height and slope. Perseverative effects were greater than anticipatory. Shen (1990) reported that the four Mandarin tones vary in height but not slope. Anticipatory and perseverative influences, however, were comparable in magnitude of effect. Palmer (1969) found that the five Thai tones vary in height and slope. Perseverative effects were predominant. Abramson (1979) provided a few more examples of tonal coarticulation in Thai.

Due to methodological limitations in these earlier studies on tonal coarticulation, it is difficult to determine to what extent coarticulatory effects are symmetric or asymmetric across tone languages, and to what extent both F_0 height and slope vary as a function of preceding or following

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tones. What is needed is a quantitative procedure that will make it possible to determine both the nature and extent of coarticulatory influences into adjacent tones across languages. In a preliminary study of Thai tonal coarticulation, Gandour, Potisuk, Dechongkit, and Ponglorpisit (1992) have proposed a quantitative method for assessing coarticulatory effects on fundamental frequency (F_0) height and slope. Their preliminary investigation was limited to perseverative effects in six disyllabic utterances. Within their limited sample, lexical tones did not vary in height as a function of the preceding tone. The slope of the mid tone, however, did vary depending upon the preceding tone, rising in the beginning portion when following a low tone, falling when following a falling tone.

The aim of this study is to apply Gandour et al.'s methodology to an investigation of anticipatory effects between Thai tones in bisyllabic noun compounds. As such, it is part of a larger series of studies designed to explore tonal coarticulation in Thai brain-damaged patients with unilateral left hemisphere and right hemisphere lesions. Both young and old normal speakers are included to permit us to distinguish whether differences in tonal coarticulation are to be attributed to the normal aging process rather than neurological lesions.

I. Method

1. *Subjects*

Twenty adult speakers of Thai participated in the study: 11 'young' adults and 9 'old' adults. Except for one additional young adult, these speakers were the same as those who participated in a previous study on tonal coarticulation in Thai (Gandour et al., in press). All 11 speakers in the young group were male and had completed 13 years of formal education; the average age of the young group was 26.4 (*SD* = 2.7). Four of the speakers in the old group were male, five were female; all had completed 4 years of formal education; the average age of the old group was 56.9 (*SD* = 2.3). All speakers had spent their entire lives in the Bangkok metropolitan area. Two different age groups as well as female speakers in the old group were included for purposes of comparison in a larger project on tonal coarticulation in Thai brain-damaged adults.

2. *Speech Materials*

A set of five bisyllabic noun compounds was chosen to investigate anticipatory tonal coarticulation (see Table 1). The first syllable was identical both phonemically and tonemically across the five noun compounds. The falling tone occurred on the first syllable. The second syllables were similar phonemically, each beginning with a voiceless aspirated velar stop and ending with a sonorant. Each of the five Thai tones occurred on these second syllables: mid, low, falling, high, and rising. Thus, we were able to assess the influence of following tones on preceding tones in an otherwise relatively homogeneous phonetic context.

Table 1

Test Stimuli

tônkhɛɛ	'Sesbania tree'
tônkhàa	'galangal bush'
tônkhâav	'rice stalk'
tônkhɔ́ɔ	'Ceylonese oak'
tônkhɛ̌m	'ixora tree'

3. Recording Procedure

All noun compounds were printed in large Thai script on 3" x 5" cards. A total of 50 cards (5 noun compounds x 10 tokens) was presented in random order to subjects. They were instructed to read the noun compounds at a comfortable speaking rate. To avoid start and end effects, extra cards were placed at the top and bottom of the deck. To avoid list reading effects, a sufficient pause was provided between items to ensure that subjects maintained a uniform speaking rate. Subjects' utterances were recorded in a reasonably quiet room in a single session using a Sony ECM-66B microphone and a Marantz PMD-420 taperecorder.

4. Listening Procedure

Each subject's utterances were presented in random order to the second author for assessment of the correctness of the consonants, vowels, and tones in the noun compounds. He was instructed to indicate whether subject's productions were "correct" or not. Test tapes were played on a Marantz PMD420 taperecorder, and the signal was presented through TDH-39 headphones at a comfortable listening level.

5. Measurement Procedure

A total of 988 utterances were low-pass filtered at 4 kHz and digitized at a 10 kHz sampling rate for speech analysis using ILS (Interactive

Laboratory System, Signal Technology, Inc.) programs implemented on a Zenith 386 PC-AT computer. F_0 contours were extracted using a cepstral method of analysis. To minimize effect of consonantal perturbations at the beginning of F_0 contours, changes in F_0 that were 10 Hz or greater across a 10 ms time frame were excluded. Cepstral analysis sometimes failed to extract an F_0 contour from an obviously periodic audio waveform or from an audio waveform with lengthy stretches of aperiodicity. Because of such measurement problems, 3% and 5% of utterances produced by young and old speakers, respectively, were eliminated from the corpus.

6. Data Analysis

Of the remaining 951 utterances, only those utterances which were identified correctly by the second author, a native speaker of Thai, were retained for analysis. By this criterion, all of the remaining utterances of both young and old speakers were retained for data analysis.

Because all tokens of each tone were not of equal duration, the F_0 contours were equalized for duration on a percentage scale. Because the mean and variance of nontransformed measures of F_0 tends to be correlated, the F_0 contours were also normalized on a *z* score scale (cf. Rose, 1987). By such normalization, F_0 contours may be compared across speakers.

Average F_0 contours do not provide any indication of intraspeaker token-to-token variation in tonal production. Unless we quantify intra-speaker variation, it is difficult to assess inter- and intraspeaker variability in the production of Thai tones. To compare the point-to-point variability of F_0 contours for all tokens of each tone, an ensemble-averaging approach was taken (cf. Atkinson, 1976, pp. 441-442). All tokens of a tone made up an ensemble of F_0 contours for that tone by that speaker. The ensemble mean and standard deviation were determined at each 10% interval. The ensemble mean can be considered as the target F_0 contour for a particular tone and the ensemble standard deviation as a measure of the random perturbations that result in deviations from the target contour.

To assess changes in F_0 height and slope of the preceding syllable as a function of the tonal category of the following syllable, six measurement intervals and measurement points, respectively, were selected in the preceding syllable. In the case of F_0 height, there were six different time intervals varying in duration. Starting from the end of the preceding syllable, these six time intervals provided measures of average F_0 height over 10%, 20%, 30%, 40%, 50%, and 100% of the total duration. Similarly, in the case of F_0 slope, there were six different points of measurement. Starting from the end of the preceding syllable, these six time points provided measures of F_0 slope at 10%, 20%, 30%, 40%, 50%, and 100% of the total duration. The normalized F_0 contour of each syllable was fitted with a polynomial curve of fifth degree using the least squares method ($f(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5$). The fifth degree polynomial provided the best overall fit to the data. Higher degree polynomials resulted in little or no improvement in overall fit. Given an F_0 contour, the slope of $f(x)$ at any point x was computed by evaluating the derivative of $f(x)$.

II. Results

Figures 1 and 2 display average F_0 contours of each of the five tonal sequences for groups of young and old speakers, respectively.

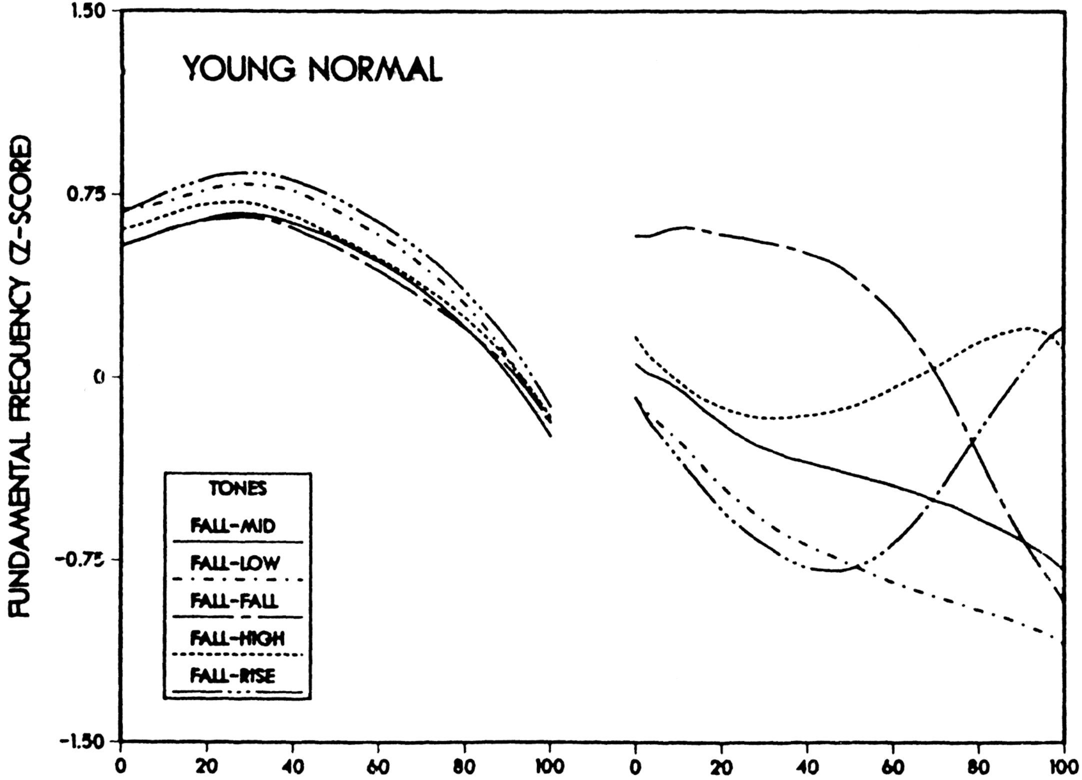

Figure 1

Average F_0 contours in each bisyllabic noun compound produced by a group of young speakers (n=11). Each syllable is normalized for time on a percentage scale.

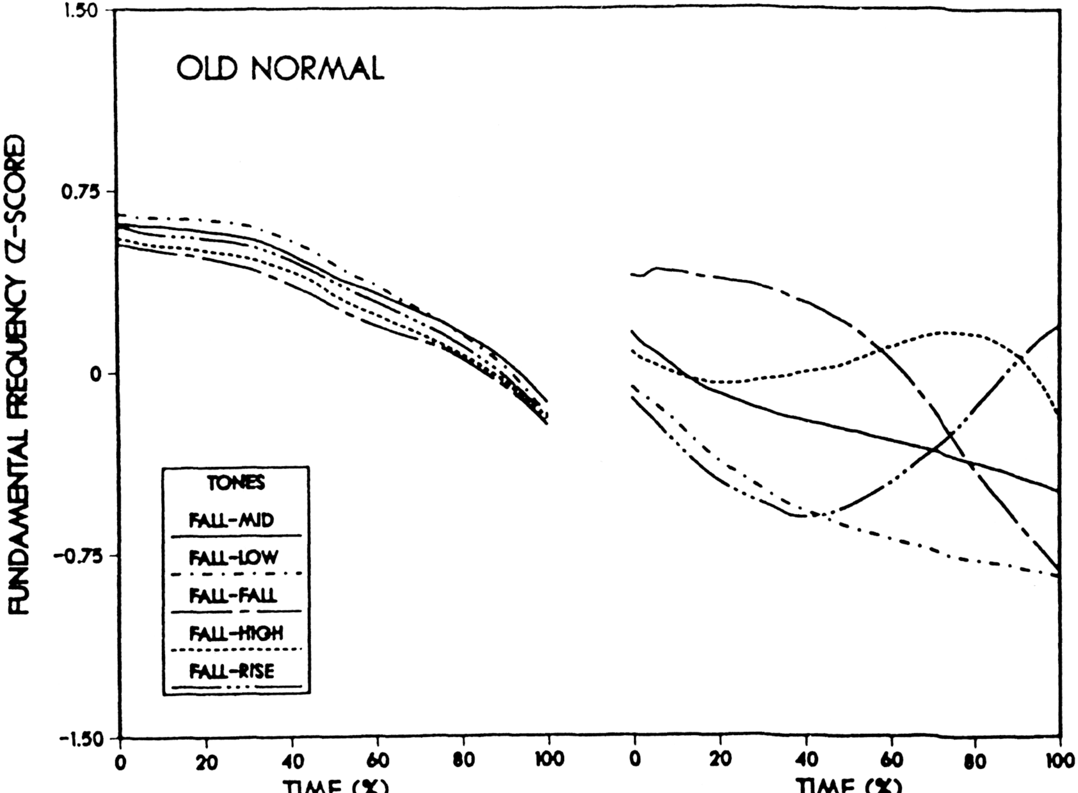

Figure 2

Average F_0 contours in each bisyllabic noun compound produced by a group of old speakers (n=9). Each syllable is normalized for time on a percentage scale.

To evaluate the magnitude of differences in F_0 height and slope of the preceding syllable, a series of two factor analyses of variance (group x preceding syllable) was performed with preceding syllable as the repeated measures variable. F_0 values and slope coefficients were assessed at the 0%, 50%, 60%, 70%, 80%, and 90% timing positions in the preceding syllable. Results indicated a significant ($\alpha = .01$) main effect of following tone at four of the six timing positions in the preceding syllable for both F_0 height and slope. In the case of F_0 height, tonal influences from the following syllable were significant at the 0%, 50%, 60%, and 70% timing positions (see Figures 1-2). Posthoc Student-Newman-Keuls multiple comparisons revealed significant ($p < .01$) differences between the low/ rising and the mid/falling/high tones. In the case of F_0 slope, tonal influences from the following syllable were significant at the 60%, 70%, 80%, and 90% timing positions (see Figures 1-2). Posthoc Student-Newman-Keuls multiple comparisons revealed significant ($p < .01$) differences between the low/ rising tones and falling at the 60% and 70% timing positions, between the mid/low/rising tones and falling at the 80%, and between the low and falling tones at the 90%. Neither the group main effect nor the two-way interaction of group and preceding syllable reached significance for either F_0 height or slope, meaning that both young and old speakers exhibited essentially the same pattern of tonal coarticulation across the five noun compounds.

Figures 3 and 4 display the ensemble-averaged F_0 contours and their standard deviations for a young (NR) and old (BJ) speaker, respectively. To evaluate the magnitude of differences in variability as a function of age group and tone sequence, an analysis of variance was performed on log-transformed ensemble standard deviations in z-score units. Results from a two factor analysis of variance (group x sequence) with sequence as repeated measures revealed a significant main effect of sequence, $F(4,72) = 3.848$, $p < .0069$, indicating that there were differences in variability of production of the five tonal sequences. Neither the main effect of group, $F(1,18) = 0.159$, $p < .6946$, nor the two-way interaction of group and sequence, $F(4,72) = 1.387$, $p < .2471$, reached significance, meaning that young and old speakers exhibited essentially the same parallel patterns of variability across the five noun compounds.

Pooling across groups, the mean ensemble standard deviations in z-score units, ranked in order from greater to lesser variability, were 0.30, 0.30, 0.27, 0.27, and 0.26 for falling-falling, falling-low, falling-high, falling-rising, and falling-mid, respectively. Posthoc Student-Newman-Keuls multiple paired comparisons indicated that variability in F_0 of the falling-falling/falling-low sequences were significantly ($\alpha = .01$) greater than the others. No other differences in variability between tonal sequences reached significance.

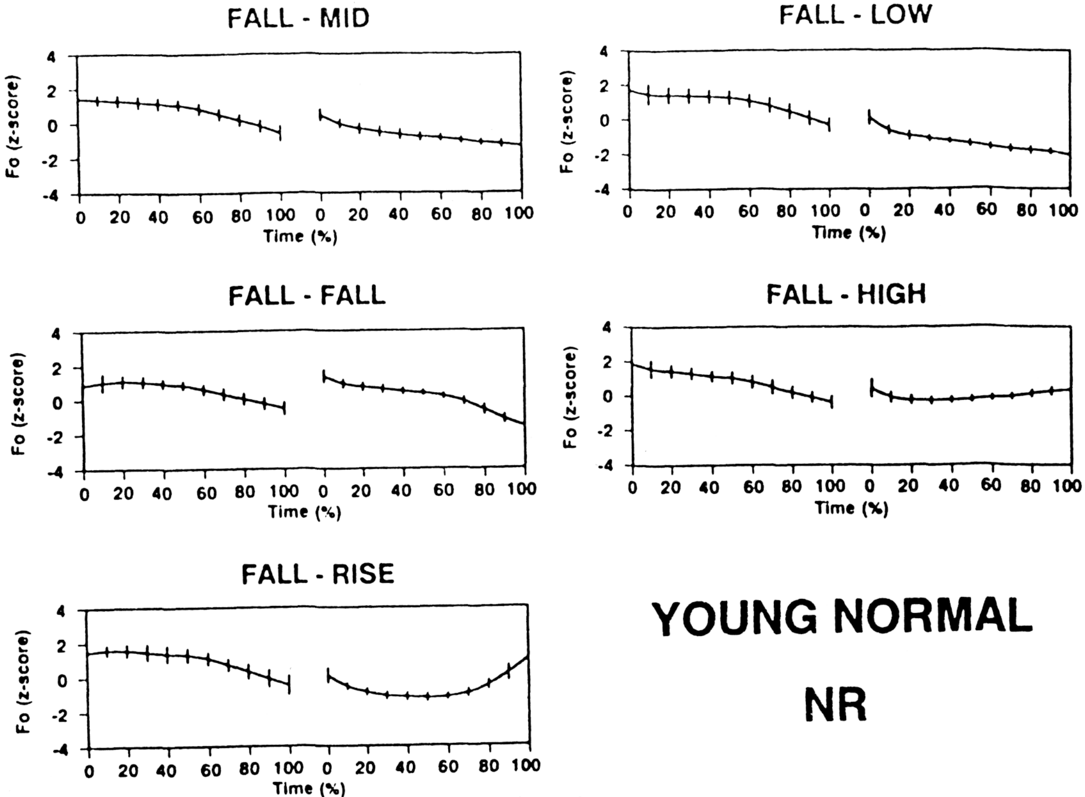

Figure 3

Variability of F_0 contours in each bisyllabic noun compound produced by a young speaker (NR). Each syllable is normalized for time on a percentage scale.

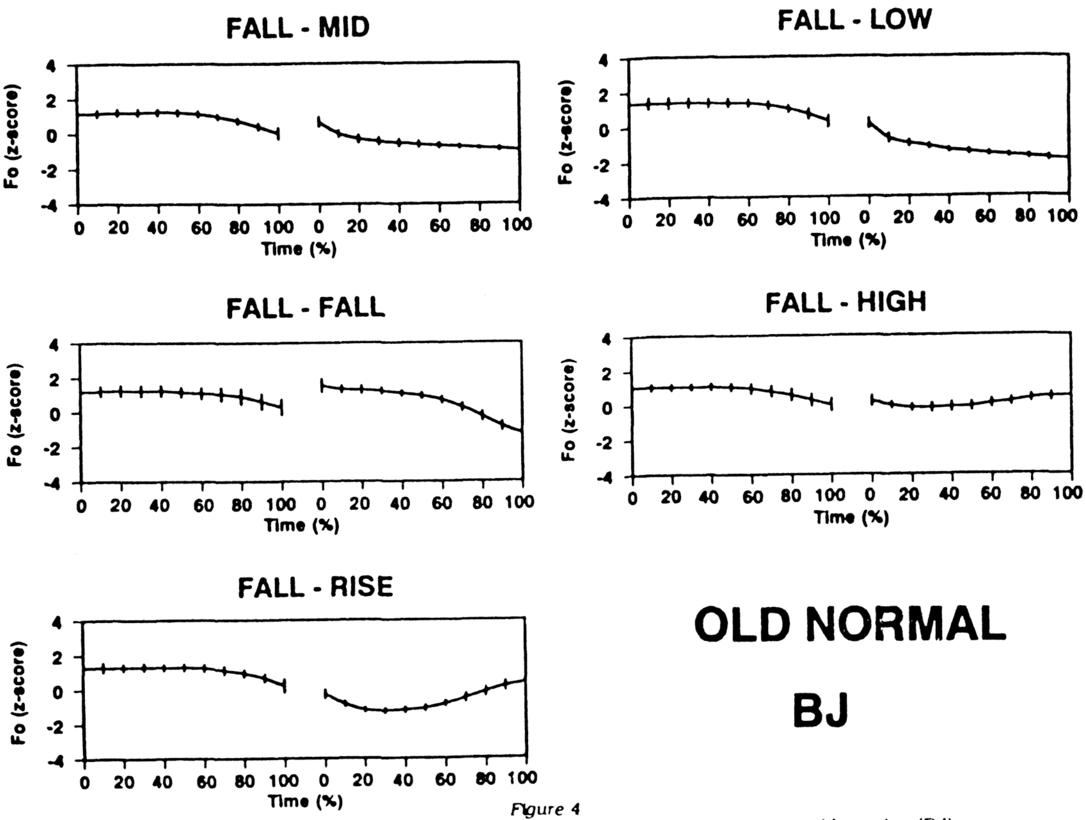

Figure 4

Variability of F_0 contours in each bisyllabic noun compound produced by an old speaker (BJ). Each syllable is normalized for time on a percentage scale.

III. Discussion

The findings from this study show clear evidence of anticipatory effects between Thai tones. The F_0 contour of the preceding falling tone is generally higher and steeper when occurring before the low and rising tones, both of which have a low F_0 onset. But when occurring before the falling tone, which has a high F_0 onset, it is lower and shallower. The anticipatory effects on the height of the preceding falling tone run counter to expectation. Instead of a lowering effect, the low and rising tones induced a raising of F_0 in the preceding falling tone. Such findings indicate that a full-scale model of tonal coarticulation must take into account more than simply the offset and onset of adjacent tones. In this particular case, the transition is from a tone that traverses the high region of the voice range to tones that initially traverse the low region. This transition requires complex adjustments of the vocal folds. Because of vocal fold dynamics, one may speculate it is easier in some articulatory sense to move from an even higher F_0 to an extremely low F_0. This vocal fold adjustment is analogous to what happens when a semi-trailer swings wide to make a sharp right or left turn. The extra wide turn facilitates the movement from a street going in one direction to a street cutting off at a 90 degree angle. The anticipatory effects on the slope of the preceding falling tone are believed to follow as a consequence of the adjustments in height. From a given height to a fixed F_0 onset, the slope must necessarily be steeper from a higher F_0. Back to the semi-trailer analogy, the angle of the turn varies as a direct consequence of the wider swing around the corner. Another possible factor influencing this particular outcome is the presence of a stop consonant between syllables instead of a sonorant. Coarticulatory effects may depend on the nature of the intervening consonant type (cf. Hyman & Schuh, 1974).

In Gandour et al. (1992), perseverative effects between Thai tones were minimal. In Vietnamese, perseverative effects are greater than anticipatory (Han & Kim, 1974). In Mandarin, anticipatory and perseverative effects are comparable in magnitude of effect (Shen, 1990). Only five of the 25 possible combinations of the five Thai tones were analyzed in this study. Whether or not anticipatory effects are greater than perseverative in Thai tonal coarticulation remains an open question.

Height and slope are independently controllable parameters of pitch variation. In the current study, the height of the F_0 contour of the preceding falling tone shows anticipatory effects earlier than the slope. Coarticulatory effects on the slope are restricted to the terminal portion. Thus, using this methodology, we are able to separate coarticulatory effects due to height from those due to slope, and moreover, track the course of these effects independently in the time domain.

The current findings are generally consistent with those of Palmer (1969) and Abramson (1979). Since no graphs of anticipatory tonal coarticulation are presented in Abramson's study, a direct comparison is possible only with Palmer's. In Palmer's study, the height and slope of the falling tone is noticeably lower and steeper, respectively, when preceding the low or rising tone than when preceding other tones (p. 298). In the current study, the falling tone similarly displayed a steeper slope when occurring before the low or rising tone. Instead of a lower height, however, the falling tone displayed a higher F_0 when preceding the low or rising tone. Because of methodological differences between this study and those of Palmer and Abramson, however, one must exercise caution in comparing findings from one study to another (cf. Gandour et al., 1992).

In her study of tonal coarticulation in Mandarin, Shen (1990) makes the claim that "tonal coarticulation affects only F_0 height, not F_0 direction [slope]" (p.293). Our findings on tonal coarticulation in Thai indicate otherwise. The slope of the falling tone was steeper in the terminal portion of the F_0 contour when preceding a low or rising tone than when preceding a mid, falling, or high tone. Gandour et al. 1992 also reported changes in slope as a result of perseverative coarticulatory effects. These differences in coarticulatory effects between Thai and Mandarin may reflect language-specific characteristics, or perhaps limitations of Shen's measurement procedure. The method used herein to quantify F_0 slope and height offers a far more sensitive measure of changes in F_0 slope due to tonal coarticulation.

The degree of variability of F_0 production varies depending on the particular combination of tones in a tonal sequence. In this study, the falling-falling and falling-low sequences exhibited the largest degree of variability. In contrast, Gandour et al. (1991) reported that tones produced in isolated monosyllables were ranked in order from greater to lesser variability: high, mid, low, rising, falling. Gandour et al. (1992) further reported that the falling-low tonal sequence was of lesser variability than other sequences containing high and rising tones. These findings taken together suggest that F_0 variability depends not simply on the tone itself, but rather the particular combination of tones in specific contexts.

One of the most pervasive characteristics of aging is reduction in speed due to neural and muscular changes. The fine motor control required to adjust vocal fold vibration in connected speech might be expected to change as a function of normal aging. There was no significant increase in variability of tonal productions by older speakers in this study. This finding is in agreement with earlier studies involving the same speakers. Variability did not differ significantly as a function of age in production of either stop consonants (Gandour, Ponglorpisit, & Dechongkit, in press) or disyllabic tone sequences (Gandour et al., 1992).

In this study of anticipatory tonal coarticulation in Thai, we have applied a sound, rigorous methodology for exploring the effects of tonal coarticulation as measured by changes in F_0 height and slope. This method makes it possible to quantify anticipatory and perseverative coarticulatory effects independently, and to measure the duration of these effects in the adjacent syllable. To extend this line of research to a full-scale investigation of tonal coarticulation in Thai, we are currently studying the effects of both anticipatory and perseverative tonal coarticulation in all 25 possible tonal sequences produced in a sentence context.

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