# $F_0$ correlates of stress in Thai*

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## Abstract

An experiment was conducted to investigate changes in the fundamental frequency ($F_0$) contours of Thai tones in connected speech as a function of stress. Thai has five tones: mid, low, falling, high, and rising. Stimuli consisted of 25 pairs of ambiguous target sentences with disambiguating context, produced at a conversational speaking rate. One member of each pair contained a 2-syllable noun-verb sequence exhibiting a - - stress pattern, the other member a 2-syllable noun compound exhibiting a ⌣ - stress pattern. Acoustic analysis revealed that $F_0$ contours of stressed syllables more closely approximate $F_0$ contours in citation forms than those of unstressed syllables. The degree of approximation is primarily determined by syllable structure and the interaction between adjacent tones. In contrast, $F_0$ contours of unstressed syllables undergo a more complex process. The average height of all five tones can be classified into three tonal registers: low, mid, and high. The low register comprises the low and the rising tones, the mid register the mid tone, and the high register the falling and the high tones. Based on shape, the falling and high tones are distinguished within the high register, the low and rising tones within the low register. Therefore, a five-way contrast among all five tones appears to be maintained in both stressed and unstressed syllables. In addition, two statistical parameters, average $F_0$ and coefficient of variation, are proposed for a machine model to automatically detect stressed and unstressed syllables.

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## Introduction

The impetus for this research arose during an investigation on automatic detection of stress in Thai by computer—part of an ongoing research project on automatic speech understanding of Thai at Purdue University. It is of primary interest to be able to formulate an algorithm that will extract and utilize acoustic correlates of stress such as fundamental frequency ($F_0$), duration, and intensity of the speech waveform to identify the location of stressed and unstressed syllables and, if possible, to assign them to their appropriate tonal categories. Thus, it is necessary to develop quantitative measures that will enable computers to accurately perform the task.

Stress in Thai has been investigated in the past by many linguists (Henderson, 1949; Noss, 1964; Warotamasikkhadit, 1967; Hiranburana, 1971; Surintramont, 1973; Gandour,1975; Luangthongkam, 1977; Sutadarat, 1978; Luksaneeyanawin, 1983), and many stress placement rules have been postulated. In terms of pitch, those researchers generally agreed on the phonetic realization of stress in "linker syllables" (Bee, 1975). However, the effects of stress on $F_0$ contours of unstressed non-linker syllables remain a subject of much controversy up to the present. The disagreement revolves around the issue of whether or not lexical tones of unstressed syllables undergo tone neutralization, i.e., whether or not $F_0$ contours of all or some of the five tones lose their identities in both height and shape. Of those earlier studies, only a few have presented acoustic-phonetic information on the realization of stress in terms of $F_0$.

Hiranburana (1971, 1972) presented instrumental findings on stress at the word level. Changes in $F_0$ contours were shown to vary depending on degree of stress. Her results were based on observations of the pattern of changes in $F_0$ contours of unstressed syllables obtained from non-final syllables of polysyllabic words, monosyllabic grammatical words, the first syllable of institutionalized compounds, and the reduplicator of the completely reduplicative forms. She concluded that $F_0$ contours of the five lexical tones are neutralized to three level tones: high, mid, and modified low.

Gandour (1975) argued against tone neutralization in fast casual speech by presenting acoustical measurements of $F_0$ contours of the initial syllable in pairs of bisyllabic noun compounds distinguished minimally or near-minimally by the lexical tone of the initial syllable. His findings indicated no changes in contour tones of unstressed syllables. He concluded that the five lexical tones of unstressed syllables maintain their basic canonical shapes as in citation forms, despite being shorter in duration, so that the five-way contrast is intact.

Luksaneeyanawin (1983) extended the phonetic analysis of stress beyond the word level. Based on acoustic and auditory analyses of passages read by two speakers, her descriptions of $F_0$ contours of unstressed non-linker syllables were generally in agreement with Hiranburana's, except those of the

rising tone. It appears that she also favors the existence of tone neutralization in unstressed non-linker syllables.

The findings in all three aforementioned studies are unfortunately very difficult to interpret because none of them isolated stress from other confounding factors affecting the realization of $F_0$ contours, such as tonal coarticulation, declination and intonation. It is well known that tonal coarticulation or the interaction between adjacent tones plays a major role in determining the height and shape of $F_0$ contours of tones (Shen 1990). Therefore, their results might not be due to the manifestation of stress alone, but to other factors as well.

The aim of this study is to investigate changes in $F_0$ contours of the five Thai tones in connected speech as a function of stress by using a more systematically controlled experiment so that the effects of stress may be accurately assessed and quantified. The focus will primarily be on the effects of stress occurring in bisyllabic noun compounds. Compounds in Thai are very important not only because of their high frequency of occurrence, but because they provide us with a window to see how prosody may potentially be used by listeners to resolve ambiguities in Thai. The study will attempt to answer questions concerning the effects of stress on individual tones and the constrastive relationship of lexical tones in both stressed and unstressed syllables. Findings will be interpreted in terms of their relevance to the description of sentence prosody in Thai. Implementation issues regarding automatic stress detection will also be addressed.

## Method

*Subjects*

Three native speakers of Thai at Purdue University participated in this preliminary study. CT, male, 22 years old, was an undergraduate student; KW and SU, female, 25 and 32 years old, respectively, were graduate students. All three subjects were native speakers of Bangkok Thai dialect and were naive with respect to the purpose of the experiment.

*Materials*

Stimuli consisted of 25 pairs of ambiguous target sentences. The two members of each pair contained six segmentally identical syllables including two target syllables. The first member (a) contained a 2-syllable noun-verb sequence exhibiting a - - stress pattern, the second member (b) a 2-syllable noun compound exhibiting a ˇ - stress pattern. The diacritic ˇ represents an unstressed syllable, - a stressed syllable. To minimize tonal coarticulation

effects, the two target syllables were embedded at the beginning of the sentence, hence only anticipatory coarticulation on the first syllable is present, while carryover coarticulation is eliminated. Thai tones are more greatly influenced by carryover than anticipatory coarticulations (Gandour et al., in press). The tones of the two target syllables were also varied to represent all possible two-tone combinations of five Thai tones so that anticipatory coarticulations in all contexts are considered. Of 25 two-tone combinations, only four were fully voiced throughout (MH, MR, LF, and FH); the other 21 two-tone combinations had intervening voiceless obstruents. To maximize the speaker's likelihood of being able to naturally produce the utterence according to its intended meaning, each utterance was preceded by a few sentences of disambiguating context. A list of the target sentences with their disambiguating contexts is included in the Appendix.

*Recording Procedure*

Speakers were asked to read a target sentence along with a few sentences of disambiguating context typed in Thai script on a 5 x 8 in. card. Cards were presented in random order and speakers were not told which of the sentences in the paragraph was the target sentence. They were also instructed to produce the sentences at a conversational speaking rate, i.e., at a rate they considered representative of their conversational speech. A random order of presentation and a sufficient pause provided between items were intended to minimize changes in speaking rate and learning or list-reading effects, thus maximizing the likelihood of speakers being able to produce natural sounding utterances. To avoid start and end effects, 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. Speakers were seated and wore a custom-made headband that maintained the microphone at a distance of 20 cm. from the lips. For each speaker, the total corpus contained 250 utterances (2 members x 25 tonal combinations x 5 repetitions). There were two recording sessions separated by one week to minimize the possibility of speakers' exaggerating the contrast between the two members (Price et al.,1990). The (a) members of all pairs were assigned to the first recording session, the (b) members to the second session. Before the recording session began, the speakers were allowed to familiarize themselves with the target sentences. During the session, speakers were asked to reread any sentences that the investigators deemed "off-target" until an acceptable version was produced. Each session lasted about 45 minutes.

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*Measurement Procedure*

The tape-recorded stimuli were low-pass filtered at 10 KHz and digitized at a sampling rate of 20 KHz by means of a 16-bit A/D converter with a 5-V dynamic range using the KAY CSL (Computerized Speech Lab) Model 4300 installed on a Gateway 2000 486/33C microcomputer. Cursors were positioned on a spectrographic display (8 KHz frequency range, 300 Hz bandwidth) to mark the beginning and end of the target sentence. Total duration of the target sentence was measured from the release burst of the consonant at the beginning of the sentence to the cessation of the second and higher formants at the end of the sentence. Measurement precision was 4 ms, which simply reflected the resolution of the CSL window when the entire utterance was on the screen. Pooled across speakers, the mean and standard deviation of sentence duration were 1.29 s and 0.23 s, respectively, with a range from 0.98 to 1.87 s. The average speaking rate, therefore, was 4.65 syllables per second.

$F_0$ was computed directly from the waveform using a CSL alogorithm that employs a time domain approach to pitch analysis (modified autocorrelation with center clipping), with nonoverlapping variable framelength. For a particular speaker, frame length was determined by his/her pitch range to ensure that there were at least two complete cycles within a frame. A typical frame length was 20 to 25 ms. for male speakers, 15 to 20 ms. for female speakers. $F_0$ analysis sometimes failed to extract a contour from an audio waveform with lengthy stretches of aperiodicity. Other waveforms were contaminated by extraneous background noise or voicing overlap. About 3% of utterances produced by all three speakers were eliminated from the corpus, which resulted in a total of 752 utterances that were retained for subsequent analysis.

In this study, only the acoustic features of the first syllable of each two-tone combination were of primary interest. Its onset and offset were determined from a simultaneous display of a wide-band (300 Hz) spectrogram with a scale from 0-8 KHz, energy contour, $F_0$ contour, and audio waveform (see Figure 1). 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 of a nasal or liquid. Tonal offset was defined as the last $F_0$ value preceding the abrupt cessation of the second and higher formants of the vowel, or as the last $F_0$ value preceding the sudden onset of a nasal or liquid based on auditory impression.

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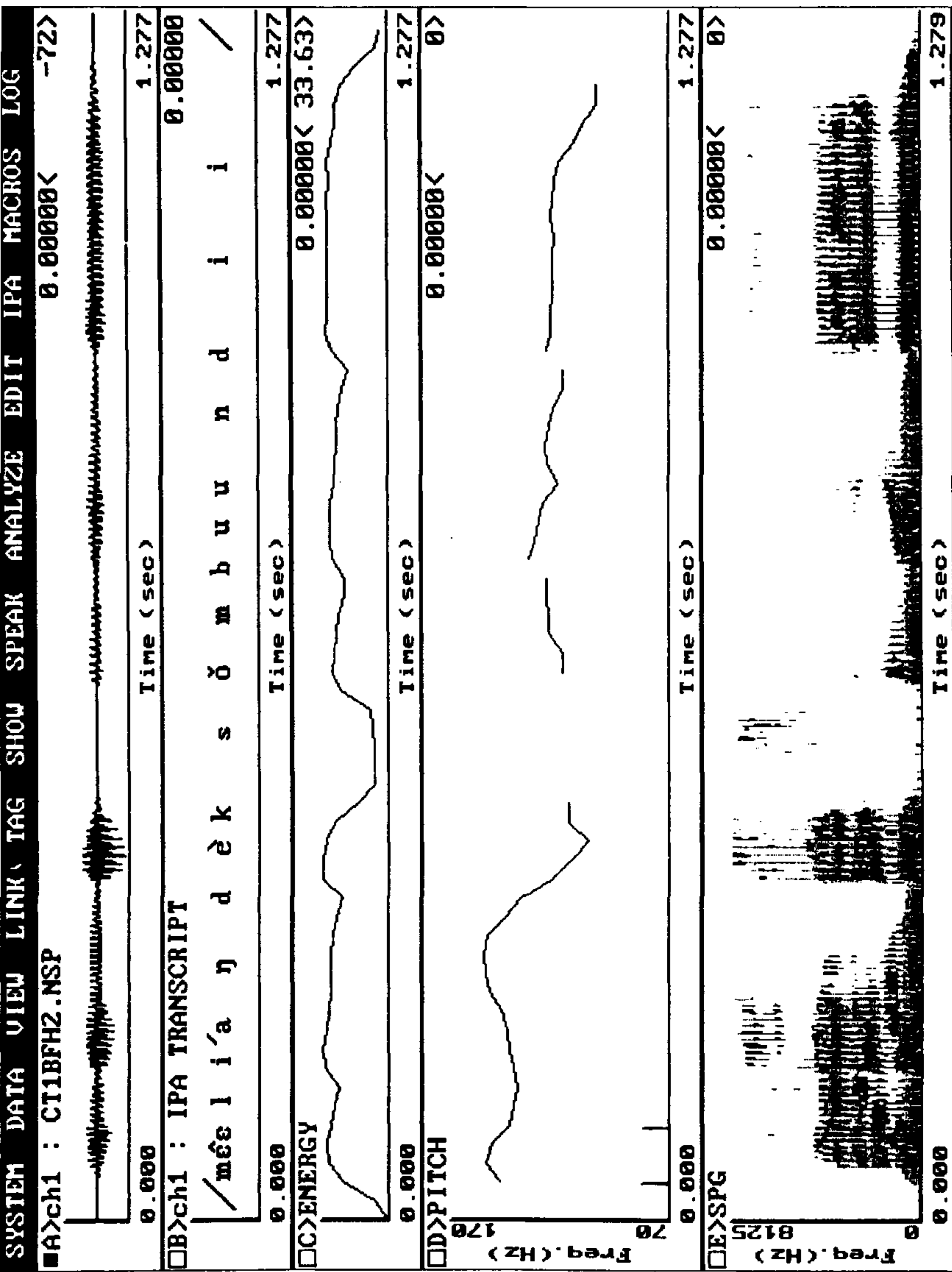


*Figure 1.*

Sample display of a sentence containing an FH tonal sequence in a noun compound context. Vertical marks indicate the onset and offset of the first syllable in the sequence.

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Back:mid, Text:mid :: mid-W:0.21, B-Peak:84 :: gamma:1, B:145, W:220

*Statistical Analysis*

$F_0$ contours of individual syllables were equalized for duration on a percentage scale. Since inter-speaker comparisons were not of interest in this study, $F_0$ contours were not normalized on a z score scale (Rose, 1987). Only for display purposes were $F_0$ contours smoothed by curve-fitting.

In view of the perceptual dimensions underlying Thai tones (Gandour & Harshman, 1978; Gandour, 1983), statistical analysis was restricted to $F_0$ height and shape. To evaluate changes in $F_0$ height and shape of the stressed and unstressed syllables of each tone, mean and standard deviation of raw $F_0$ trajectories were computed by pooling across all tokens of all sequences of all three speakers for that particular tone. The mean and standard deviation were used to assess overall changes in $F_0$ height and shape, respectively. The standard deviation was further transformed into coefficient of variation to allow meaningful comparisons across all tones. Coefficient of variation is defined as the ratio of the standard deviation to the mean expressed as a percentage. Since raw $F_0$ values are always positive, coefficient of variation is an appropriate measure of the relative variability with respect to the mean. The reason for using coefficient of variation as a measure of changes in tone shape instead of a finer measure of slope at various points along the contours will be discussed later with respect to the automatic speech recognition applications.

## Results

*Stress Effects on Individual Tones*

The means and standard deviations of stressed and unstressed syllables of all 25 two-tone combinations are presented in Table 1, and their corresponding mean $F_0$ contours are shown in Figure 2.

Back:mid, Text:mid :: mid-W:0.24, B-Peak:90 :: gamma:1, B:145, W:220

*Table 1.*

The mean and standard deviation in Hz of each tone in all 25 two-tone
combinations for both stressed and unstressed syllables.

| Tone | Sequence | Unstressed syllable | | Stressed syllable | |
|---|---|---|---|---|---|
| | | M | SD | M | SD |
| Mid | MM | 178.70 | 4.2015 | 169.61 | 5.9036 |
| | ML | 177.75 | 1.9424 | 167.84 | 4.6796 |
| | MF | 175.21 | 2.6439 | 170.24 | 2.7572 |
| | MH | 177.88 | 0.8967 | 167.21 | 2.8790 |
| | MR | 174.75 | 0.4719 | 169.75 | 2.7126 |
| Low | LM | 157.00 | 3.0314 | 151.41 | 7.2660 |
| | LL | 162.39 | 2.481 | 163.15 | 6.1326 |
| | LF | 160.72 | 3.2189 | 153.74 | 9.6238 |
| | LH | 163.62 | 3.1215 | 159.31 | 6.6696 |
| | LR | 162.25 | 3.1435 | 150.35 | 6.3734 |
| Falling | FM | 215.73 | 1.6502 | 208.25 | 14.606 |
| | FL | 203.2 | 0.8178 | 210.13 | 8.2688 |
| | FF | 200.47 | 0.7144 | 201.90 | 8.7898 |
| | FH | 210.96 | 2.9327 | 193.7 | 9.9143 |
| | FR | 202.02 | 0.2921 | 211.55 | 6.8270 |
| High | HM | 205.97 | 3.1677 | 184.07 | 7.9676 |
| | HL | 195.08 | 5.5785 | 174.44 | 8.9659 |
| | HF | 186.56 | 2.9353 | 177.15 | 9.5601 |
| | HH | 191.58 | 2.8525 | 176.12 | 8.7743 |
| | HR | 201.94 | 5.9971 | 184.39 | 11.003 |
| Rising | RM | 161.08 | 1.3424 | 158.75 | 6.5621 |
| | RL | 169.06 | 4.0278 | 167.26 | 12.011 |
| | RF | 164.19 | 1.8365 | 155.30 | 5.8922 |
| | RH | 159.00 | 2.3062 | 157.01 | 6.7814 |
| | RR | 168.41 | 0.14804 | 165.43 | 7.3035 |

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Back:dark, Text:mid :: mid-W:0.26, B-Peak:92 :: gamma:1.4, B:145, W:220
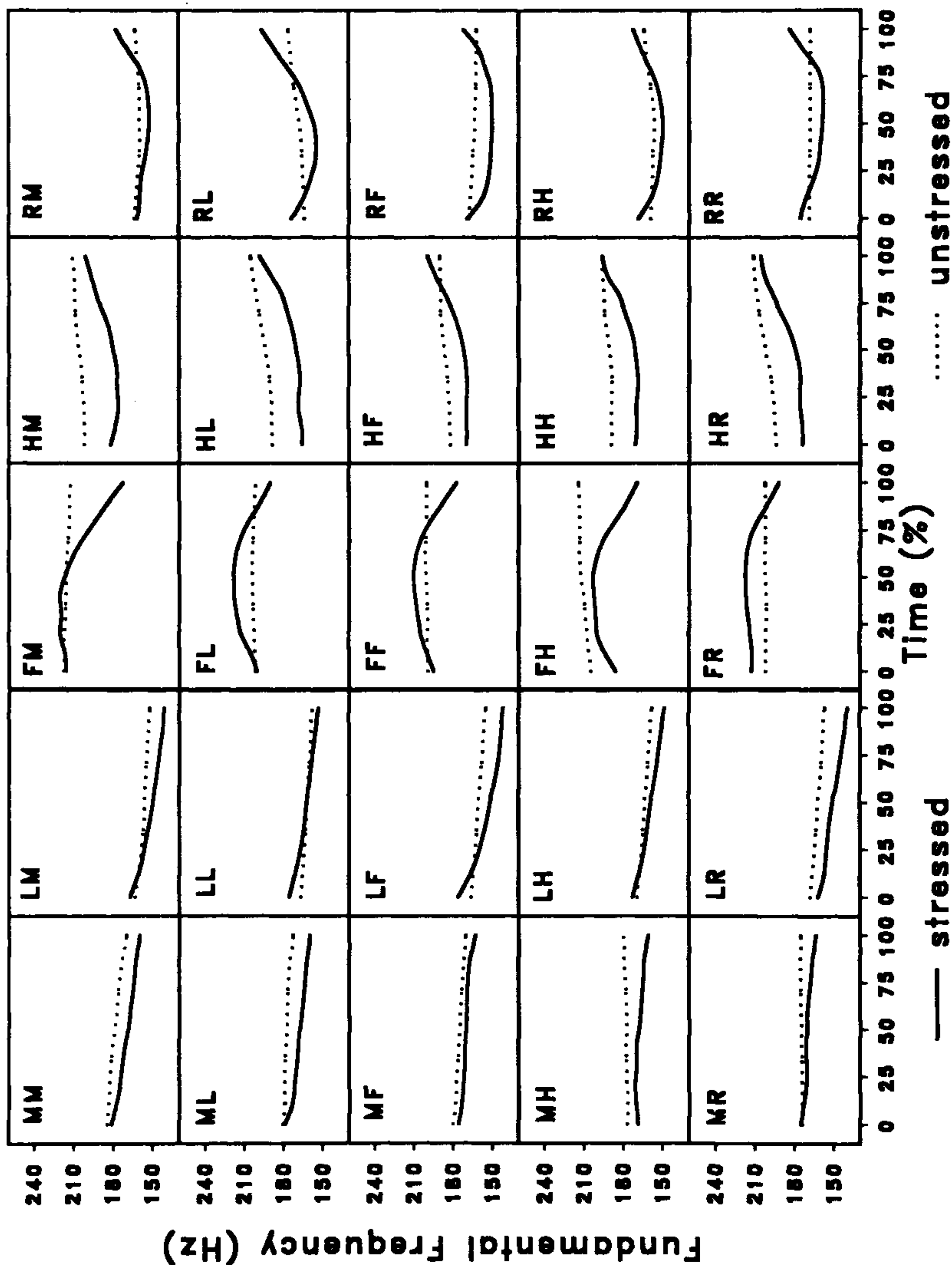
Figure 2.

Mean F0 contours of each of the 25 two-tone sequences for both stressed and unstressed syllables.

Back:mid, Text:mid :: mid-W:0.19, B-Peak:91 :: gamma:1, B:145, W:220

Pooled across all tokens of all sequences of each individual tone, $F_0$ contours of stressed syllables more closely approximate $F_0$ contours in citation forms (Abramson, 1962; Gandour et al., 1991) than those of unstressed syllables in both average $F_0$ height and shape. The degree of approximation is primarily determined by syllable structure and the interaction between adjacent tones. In stressed syllables preceding a major phrase boundary, i.e., the first syllable in the noun-verb sequence, $F_0$ contours of the so-called static tones (mid, low, and high) remained virtually unchanged while those of the so-called dynamic tones (falling and rising) undergo a slight modification and exhibit less extreme $F_0$ offsets (see Figure 3a). The falling tone does not fall as far as it does in citation forms; the rising tone does not rise as far. In contrast, $F_0$ contours of unstressed syllables in noun compounds (see Figure 3b) differ from those of either citation forms or stressed syllables occurring prepausally. By comparison to $F_0$ contours in stressed syllables (see Figure 3a), the average height of all five tones in unstressed syllables is raised. With respect to shape, the mid, low, and falling tones exhibit relatively level to slightly falling contours, whereas the high and rising tones show a sharp rise in the terminal portions of their contours.

Back:dark, Text:mid :: mid-W:0.25, B-Peak:93 :: gamma:1.4, B:145, W:220
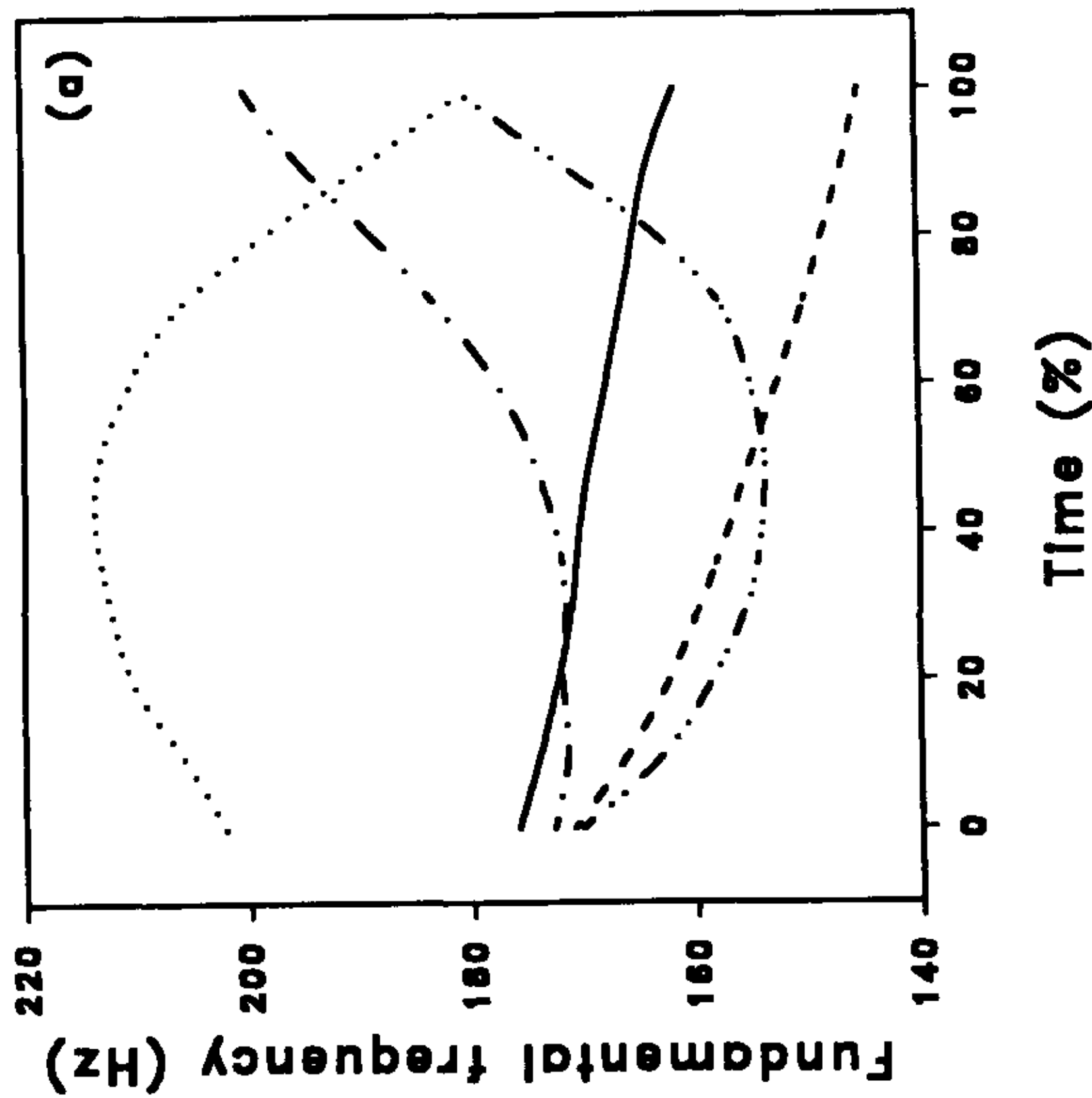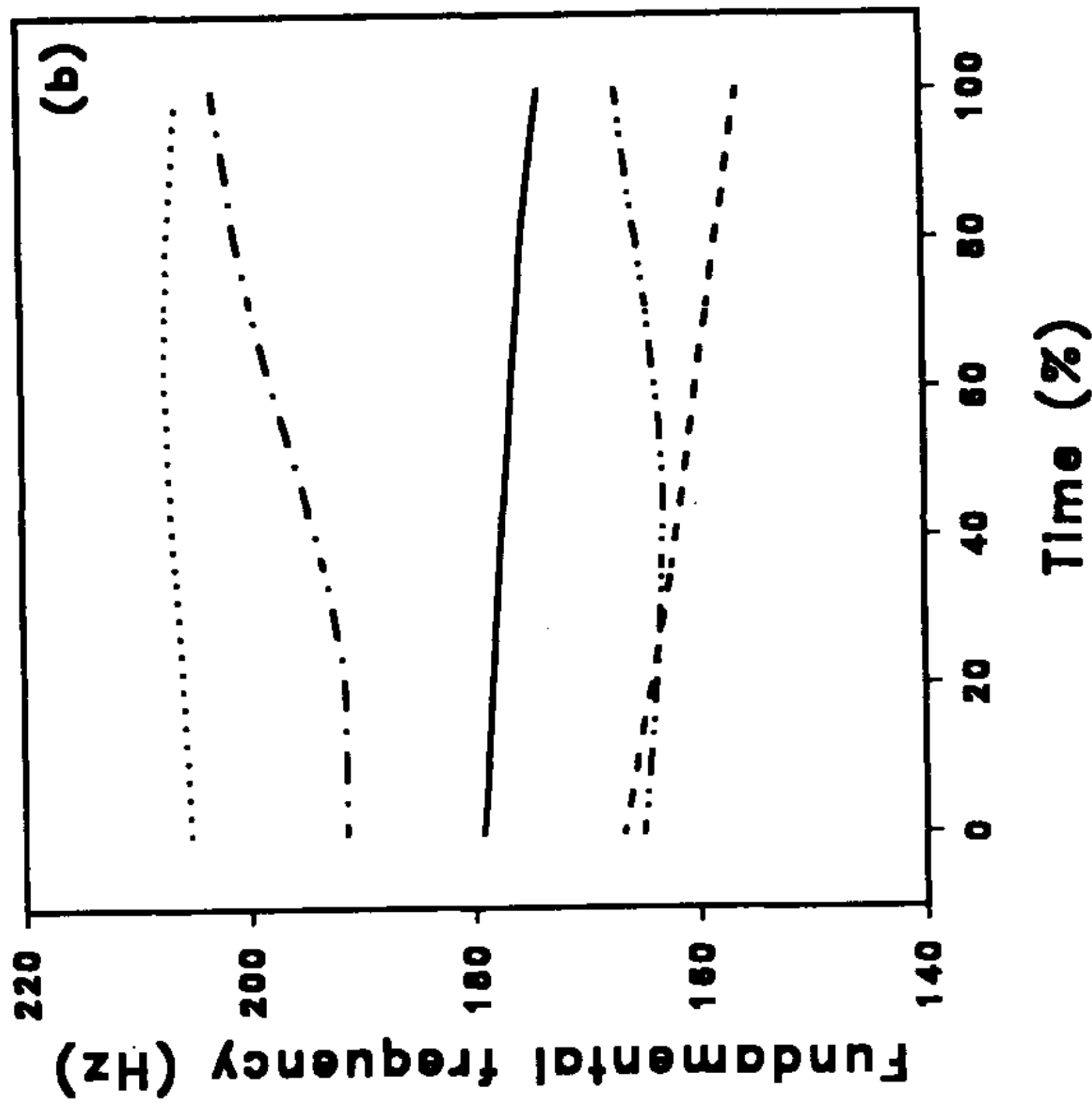
*Figure 3.*

Overall mean F0 contours of all five tones for both stressed and unstressed syllables.

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai",  in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27.  (purl.org/sealang/potisuk1994f0.pdf)

Back:mid, Text:mid :: mid-W:0.15, B-Peak:87 :: gamma:1, B:145, W:220

The overall mean, standard deviation, and coefficient of variation of each tone in stressed and unstressed syllables are given in Table 2. Comparisons in average $F_0$ height and coefficient of variation between stressed and unstressed syllables are also shown in Figure 4a and 4b, respectively.

### Table 2.
The overall mean, standard deviation, and coefficient of variation of all five tones for stressed and unstressed syllables.

| Tone | Overall mean (Hz) | | Standard deviation (Hz) | | Coefficient of variation (%) | |
|---|---|---|---|---|---|---|
| | Unstressed | Stressed | Unstressed | Stressed | Unstressed | Stressed |
| Mid | 176.86 | 168.93 | 1.4882 | 3.6970 | 0.8415 | 2.1885 |
| Low | 161.20 | 155.59 | 2.9913 | 7.1780 | 1.8557 | 4.6133 |
| Falling | 206.48 | 205.11 | 0.6186 | 9.3419 | 0.2996 | 4.5547 |
| High | 196.23 | 179.24 | 4.0700 | 9.1970 | 2.0741 | 5.1313 |
| Rising | 164.35 | 160.75 | 1.1114 | 7.3636 | 0.6762 | 4.5808 |

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

Back:dark, Text:mid :: mid-W:0.29, B-Peak:86 :: gamma:1.4, B:145, W:220

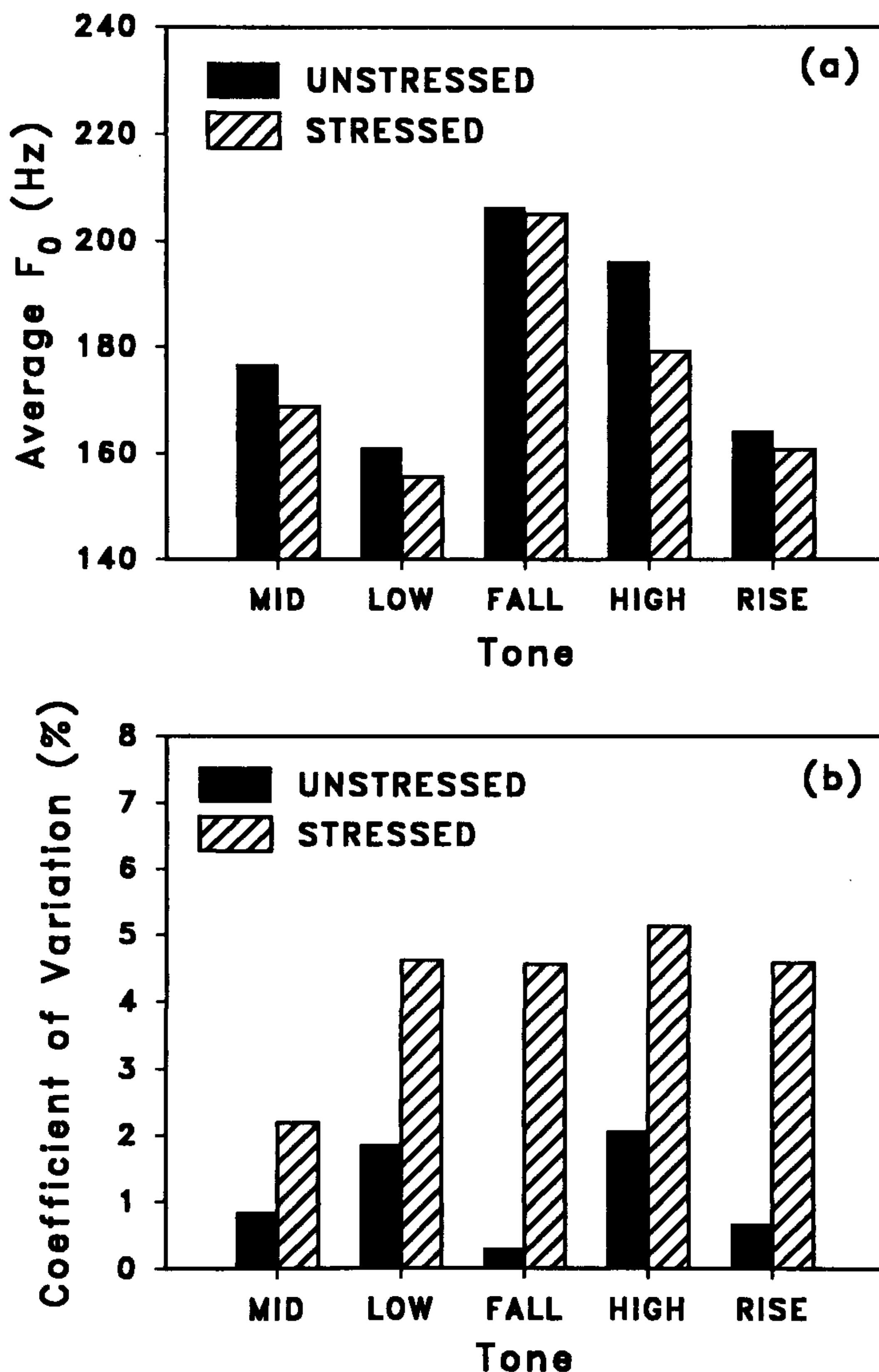*Figure 4.*
Comparison of (a) average F0 heights (b) coefficients of variation between stressed and unstressed syllables.

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

Back:mid, Text:mid :: mid-W:0.14, B-Peak:89 :: gamma:1, B:145, W:220

With respect to average $F_0$ (see Figure 4a), all five tones of unstressed syllables appear to have higher average $F_0$ than those of stressed syllables. Dynamic tones (falling and rising) have less of a difference in average $F_0$ than static tones (mid, low, and high). With respect to coefficient of variation (see Figure 4b), the opposite seems to be the case. All five tones of unstressed syllables appear to have smaller coefficient of variation than those of stressed syllables (see Figure 4a). Dynamic tones have more of a difference in coefficient of variation than static tones. Furthermore, the difference in coefficient of variation appears to be more dramatic than the difference in average $F_0$.

*Stress Effects on the Pattern of Contrast among the Five Tones*

The contrastive relationship among the five tones is maintained in both stressed and unstressed syllables (see Figure 3). In stressed syllables, as in citation forms, a five-way contrast is maintained in terms of both average $F_0$ height and shape despite less extreme $F_0$ offsets of the falling and the rising tones. In unstressed syllables (see Figure 5a), the five lexical tones can be divided into three subgroups with respect to average $F_0$: 1) falling and high, 2) low and rising, and 3) mid. The falling and high tones appear to be higher than the mid, low, or rising tones; the low and rising tones appear to be lower than the mid, falling, or high tones; the mid tone, in turn, is intermediate between these other two subgroups. Hence, it appears that a three-level tonal register is maintained: low, mid, and high. The low register corresponds to the subgroup with the low and rising tones, the mid register to the subgroup with the mid tone, and the high register to the subgroup with the falling and high tones. Also, in unstressed syllables, the two tones within each of the high and low tonal registers appear to be distinguished on the basis of coefficient of variation (see Figure 5b). Within the high register, the high tone exhibits greater variability than the falling; within the low register, the low tone shows greater variability than the rising. These differences in coefficient of variation correspond to differences in shape between the falling and high and between the low and rising tones (see Figure 3b). The high and rising tones exhibit rising contours in their terminal portions, whereas the falling and low tones do not. Therefore, despite differences in height and shape of the tones in unstressed and stressed syllables, a five-way tonal distinction appears to be maintained but in a different tonal space (compare Figures 3a and 3b).

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# UNSTRESSED SYLLABLES ONLY



Figure 5.

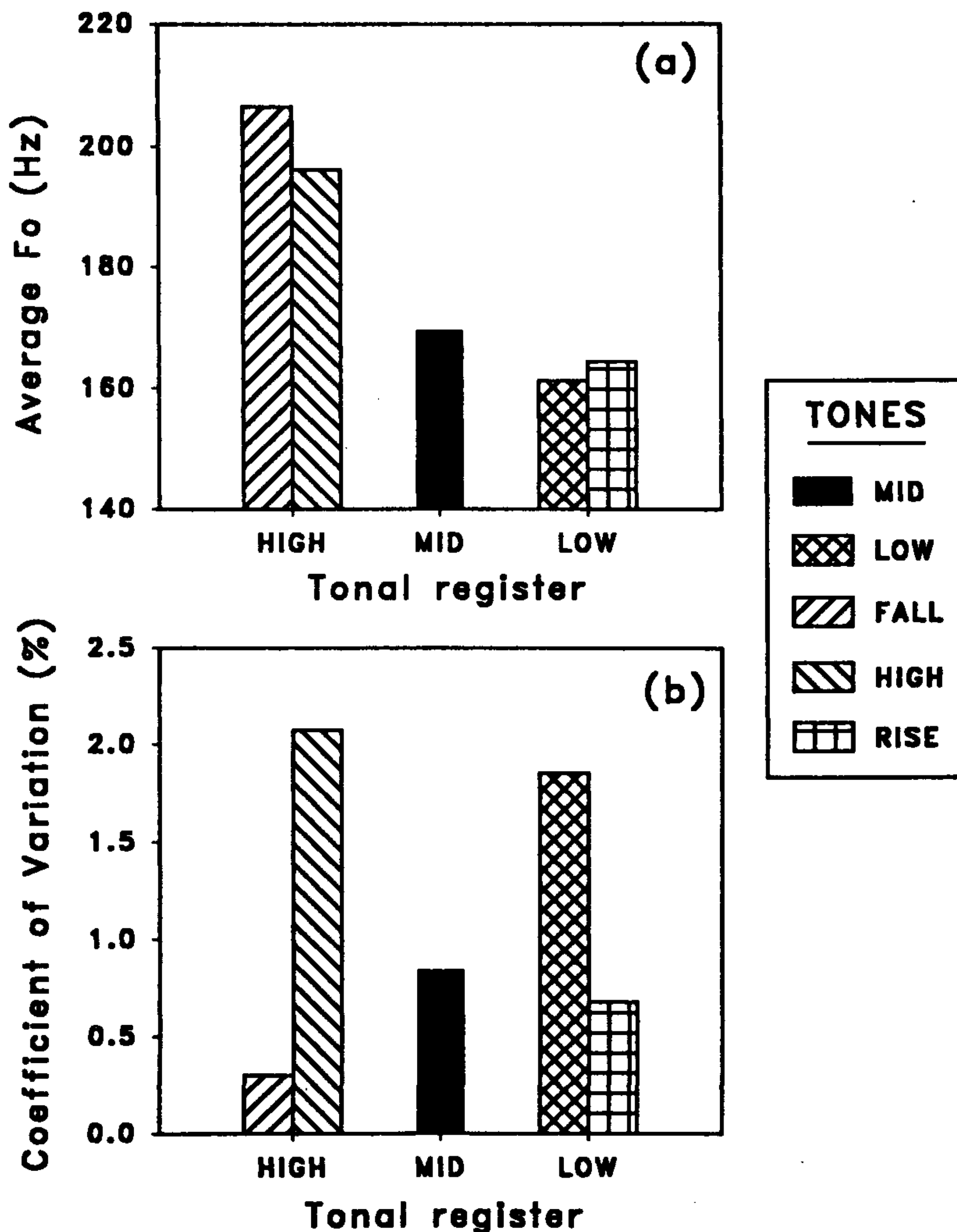Comparison of (a) average $F_0$ heights (b) coefficients of variation among all five tones of unstressed syllaibles grouped into three tonal registers.

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

Back:mid, Text:mid :: mid-W:0.13, B-Peak:83 :: gamma:1, B:145, W:220

## Discussion

*Tonal Contrasts in Stressed and Unstressed Syllables in Thai*

The major finding of this study is that tonal contrast among all five Thai tones are preserved in both stressed and unstressed syllables in a context of bisyllabic noun compound versus a noun-verb sequence despite changes in both average $F_0$ height and shape of tonal contours. The observed changes in $F_0$ contours are clearly different from those observed in linker syllables where tone neutralization occurs. The function of the stress rule observed in this study appears to be to distinguish between compounds, noun or verb, and other syntactic phrases. It signals the difference between a major phrase boundary and internal words of a compound, and thus the effects of stress at the sentence level. We, of course, are aware that a more complicated picture may emerge when extending the study of stress to other sentence positions. In the present study, other factors affecting $F_0$ contours such as tonal coarticulation, and declination were kept to a minimum. As a result, tonal contrasts in unstressed syllables may or may not be preserved when all factors are taken into account.

Concerning the phonetic realization of $F_0$ contours of unstressed syllables in noun compounds in Thai, our findings are generally in agreement with earlier studies (Hiranburana, 1971, 1972; Gandour, 1975; Luksaneeyanawin, 1983). However, some discrepancies regarding tone neutralization remain. First, Hiranburana suggested that in unstressed syllables, the five-way contrast is reduced to three and furthermore, that this three-way contrast is maintained on the basis of $F_0$ height alone. Falling and high tones are neutralized; low and rising tones are neutralized. Though we agree that three tonal registers are maintained based on $F_0$ height, a contrast is still maintained within the high and low registers based on shape. Falling and high tones are distinguished in the high register; low and rising tones in the low register. Secondly, we agree with Gandour that tone neutralization does not occur. But Gandour reported no changes in the shape of contour tones whereas our findings show a dramatic change in their shapes. Finally, our findings are consistent with Luksaneeyanawin's descriptions of $F_0$ contours of all five tones in unstressed syllables except that of the rising tones. She stated, "the unstressed rising tone is always realized with a rising contour no matter how much the syllable is reduced in duration....". Our results do not show a rise in certain contexts due to anticipatory coarticulation, i.e., RF and RR (Figure 2). The aforementioned discrepancies, we believe, can be attributed to variations in speaking rate from study to study. Gandour used carrier sentences to solicit speech while Luksaneeyanawin based her studies on read passages. Speaking rate in both studies can be classified as low to moderate. Hiranburana used an *allegretto* or moderately fast style of speech. However, it

is unclear how her speech samples were solicited. The average speaking rate in this study is 4.65 syllables per second which is considered moderate. For the low to moderate rate, Gandour's and Luksaneeyanawin's schema is the likely scenario while Hiranburana's schema prevails for the moderately fast rate. Our findings herein are compatible with the moderate speaking rate.

*Acoustic Correlates of Stress*

Although no measurements were made, visual inspection of acoustic records seems to suggest that stressed syllables are produced with relatively longer duration and higher intensity than unstressed syllables. These findings are consistent with what we know from other languages of the world. However, our data show that the opposite is true for average $F_0$ height. Unstressed syllables in bisyllabic noun compounds are produced with a higher pitch than when they are stressed in noun-verb sequences. This finding runs contrary to what is usually found in other languages of the world. Other things being equal, stressed syllables are usually higher in pitch than unstressed syllables. Our data is insufficient to draw a firm conclusion. Nevertheless, we offer the following interpretation for such a phenomenon. In this study, bisyllabic noun compounds are made up of a noun and a verb. When the noun-verb sequence is intended by speakers, both syllables will be produced with a stress by virtue of being content words. Hence, a syntactic break signaling a phrase boundary occurs between them by a lowering of pitch in a stressed syllable occurring prepausally. When a compound is intended, speakers destress the first syllable by raising its pitch to maximize the perceptual contrast between compound and phrase boundaries. Thus, pitch raising in unstressed syllables appears to be motivated primarily for the listener's benefit. This phenomenon, we believe, is a manifestation of the tendency for sound patterns in languages of the world to act in accordance with the principle of "sufficient perceptual separation" (Ladefoged, 1993). In Thai, unstressed syllables are raised in pitch so as to make it easier for the listener to distinguish one type of syntactic constituent from another.

*Application to Automatic Speech Understanding*

The findings of this study suggest that prosodic structure of an utterance plays a crucial role in the processing of sentences in Thai, where local ambiguities may occur due to the syntax of the sentence. In this study, speakers, with the aid of disambiguating context, were able to resolve the syntactic ambiguities between a noun-verb sequence and a noun compound and then produce them with varying stress patterns according to the context. Listeners, on the other hand, can utilize those varying stress patterns to arrive at the intended meaning. A machine capable of performing this intricate task of

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human listeners will come a step closer toward understanding human speech. One of the obstacles preventing us from realizing such a machine is the complexity of the algorithm we use to emulate human listeners. The more complex the algorithm, the larger the amount of processing time. Our findings suggest that two statistical parameters derived from the acoustic records, average $F_0$ height and coefficient of variation, may be used in a machine to successfully detect stressed and unstressed syllables in a reasonable amount of time. These parameters are easily computed from the raw $F_0$ values. Whether or not these parameters will be effective for a machine model remains the subject of future research.

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

Back:mid, Text:mid :: mid-W:0.18, B-Peak:92 :: gamma:1, B:145, W:220

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# APPENDIX

1. a) ถ้าจะไปกินข้าวด้วยกันวันนี้ ฉันไม่เลี้ยงหรอกนะ **คนจน**จะแย่อยู่แล้ว

/ kʰon # con ca jɛ̂ɛ jùu lɛ́ɛw /

' If you want to go to dinner with me today, you will have to pay for your own meal. I am broke.'

b) รัฐบาลประกาศขึ้นราคาน้ำมัน ไม่เห็นใจชาวบ้านเลย **คนจน**จะแย่อยู่แล้ว

/ kʰoncon ca jɛ̂ɛ jùu lɛ́ɛw /

' The government annouces a price hike on gasoline. They don't seem to care about working people. The poor are suffering tremendously.'

2. a) คุณปรุงรสอาหารได้อร่อยทุกอย่างเลย แต่ขอติสักนิด

แกงจืดมากไปหน่อยนึง

/ kɛɛŋ # cɯ̂ɯt mâak paj nɔ̀ɔj nɯɯŋ /

' Every dish you made tasted really good. Only the curry was a little bit too bland.'

b) ปริมาณอาหารสำหรับงานเลี้ยงกำลังดี ยกเว้นอย่างเดียว

แกงจืดมากไปหน่อยนึง

/ kɛɛŋcɯ̂ɯt mâak paj nɔ̀ɔj nɯɯŋ /

' The amount of food for the party is about right. But, there is a little bit too much soup.'

3. a) ตาอายุมากแล้ว ฉันไม่ไว้ใจเวลาให้ตาชั่งของเลย **ตาชั่ง**ไม่ค่อยจะตรง

/taa # cʰâŋ mâj kʰɔ̂j ca troŋ /

' Grandfather is quite old. I don't trust him to do a weighing job at all. Grandfather has difficulties weighing accurately.'

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b) รู้แล้วว่าทำไมหมู่นี้ดูเหมือนน้ำหนักขึ้นมากกว่าปกติ **ตาชั่งไม่ค่อยจะตรง**

/ taac<sup>h</sup>âŋ mâj k<sup>h</sup>ɔ̂j ca troŋ /

' I've just found out why lately it seems I have gained a lot of weight. The scale is not quite accurate.'

4. a) ช่วงหน้าแล้ง ผู้คนอพยพออกจากเมืองไปกันเกือบหมด

**เมืองร้างอยู่เป็นหย่อม ๆ**

/ mɯɯaŋ # ráaŋ jùu pen jɔ̀ɔm jɔ̀ɔm /

' During the dry season, a lot of people migrate out of town. Deserted areas are scattered across the town.'

b) ตอนไปเที่ยวทางตะวันตก เห็นเมืองร้างเต็มไปหมด **เมืองร้างอยู่เป็นหย่อมๆ**

/ mɯɯaŋráaŋ jùu pen jɔ̀ɔm jɔ̀ɔm /

' When I was vacationing in the West, I saw a lot of ghosttowns. Ghosttowns are scattered across the land.'

5. a) เมื่อคืนฝนตกหนัก บ่อปลาน้ำท่วม **ปลาไหลไปหมดแล้วละ**

/ plaa # lǎj paj mòt lɛ́ɛw lá? /

' It rained cats and dogs last night. The fish pool overflowed. The fish have all escaped.'

b) คนแย่งซื้อปลาที่ตลาดกันใหญ่ เหลือปลาไม่กี่ชนิดเลย

**ปลาไหลไปหมดแล้วละ**

/ plaalǎj paj mòt lɛ́ɛw lá? /

' People rush to buy fish at the market. Not many kinds of fish are left. The eels are all gone.'

6. a) ข้อสอบเติมคำที่ให้ต่อทำ ตรวจเสร็จแล้ว **ต่อเติมไม่ได้ความเลย**

/ tɔ̀ɔ # tɤɤm mâj dâjk<sup>h</sup>waam lɤɤj /

' I've finished grading that fill-in-the-blank exam Tor was tested on. Tor had done a poor job completing it.'

b) บริษัทที่จ้างมาทำบ้านห่วยจริง ๆ **ต่อเติมไม่ได้ความเลย**

/ tɔ̀ɔtɤɤm mâj dâjk<sup>h</sup>waam lɤɤj /

' The company we hired to remodel our house was no good. They have done a poor job with those additions.'

7. a) คุณปรุงรสอาหารได้อร่อยทุกอย่างเลย แต่ขอติสักนิด

**ผัดผักมากไปหน่อยนึง**

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

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/ pʰàt # pʰêt mâak paj nɔ̀ɔj nɯɯŋ /
' Every dish you made tasted really good. Only the stir-fry was a little bit too hot.'

b) ปริมาณอาหารสำหรับงานเลี้ยงกำลังดี ยกเว้นอย่างเดียว
ผัดเผ็ดมากไปหน่อยนึง
/ pʰàtpʰêt mâak paj nɔ̀ɔj nɯɯŋ /
' The amount of food for the party is about right.  But, there is a little bit too much spicy stir-fry.'

8. a) สวนครัวชักเป็นรูปเป็นร่างขึ้นมาแล้ว ครั้งสุดท้ายที่ดู
ถั่วงอกวานจะหมดแล้ว
/ tʰùa # ŋɔ̂ɔk cuan ca mòt lɛ́ɛw /
' Our vegetable garden is shaping up very nicely.  The last time I checked, almost all of the beans have sprouted.'

b) ถ้าคุณจะไปตลาด ฝากซื้อของด้วยนะ ถั่วงอกวานจะหมดแล้ว
/ tʰùaŋɔ̀ɔk cuan ca mòt lɛ́ɛw /
' If you plan to go to the market, pick something up for me.  The bean sprouts are almost all gone.'

9. a) วันนี้ไปเที่ยวสวนสัตว์มา น่าเอ็นดูจริง ๆ สัตว์เลี้ยงลูกอยู่ในกรง
/ sàt # líaŋ lûuk jùu naj kroŋ /
' I went to the zoo today.   It was really cute the way the animal cared for her young in the cage.'

b) ไปนอนเถอะลูกไม่ต้องเป็นห่วง สัตว์เลี้ยงลูกอยู่ในกรง
/ sàtlíaŋ lûuk jùu naj kroŋ /
' Son, go to bed. Don't worry.  Your pet is in the cage.'

10. a) ต่อไปขโมยคงไม่กล้ามาอีก เขาพึ่งปักหลักกั้นรั้วใหม่ หลักแหลมดีจริง ๆ
เลย
/ làk # lɛ̌ɛm dii ciŋ ciŋ ləəj /
' From now on, no thief will dare break in. We've just put up new poles and fences. The poles are quite sharp.'

b) คุณเอาตัวรอดจากวิกฤตการณ์มาได้ด้วยปัญญาแท้ ๆ หลักแหลมดีจริง ๆเลย
/ làklɛ̌ɛm dii ciŋ ciŋ ləəj /
' You were able to come out of the crisis unscathed only because of your wit.  You are very clever.'

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai",  in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27.  (purl.org/sealang/potisuk1994f0.pdf)

11. a) ริบแต่งตัวเข้า เสื้อกางเกงรีดให้เรียบร้อยแล้ว เสื้อคลุมอยู่หลังเก้าอี้

/ sɯ̂a # kʰlum jùu lɛ́ŋ kâwʔîi /

' Hurry up and get dressed.  I've ironed your shirt and pants. The shirt is on the back of the chair.'

b) อากาศข้างนอกหนาวมาก อย่าลืมหยิบเสื้อคลุมไปด้วยนะ

เสื้อคลุมอยู่หลังเก้าอี้

/ sɯ̂akʰlum jùu lɛ́ŋ kâwʔîi /

' The weather is really cold outside. Don't forget to bring your coat. Your coat is on the back of the chair.'

12. a) มานี่หน่อยลูก ดูนะ ถ้าต้องการใช้น้ำร้อน ลูกบิดอันทางขวามือ

/ lûuk # bìt ʔan tʰaaŋ kʰwǎa mɯɯ /

' Come here, son. Look. If you want hot water, turn the knob on the right.'

b) ตรงทางเข้ามีประตูสองประตูติดกัน ลืมบอกไป ลูกบิดอันทางขวามือ

/ lûukbìt ʔan tʰaaŋ kʰwǎa mɯɯ /

' At the entrance, there are two doors side by side.  I forgot to tell you. It's the knob on the right.

13. a) เกิดอุบัติเหตุขึ้นกับลูกวันนี้ ลูกกลิ้งตกมาจากโต๊ะ

/ lûuk # klîŋ tòk maa càak tóʔ /

' A bad accident happened to our child today. Our child fell off the table.'

b) ไม่ได้ตั้งใจวางมันไว้ที่พื้นหรอก ลูกกลิ้งตกมาจากโต๊ะ

/ lûukklîŋ tòk maa càak tóʔ /

' I didn't mean to put it on the floor. The roller fell off the table.'

14. a) ถ้ามีลูกจะเอาไปฝากให้แม่ดูแล แม่เลี้ยงเด็กสมบูรณ์ดี

/ mɛ̂ɛ # líaŋ dèk sǒmbuun dii /

' I want mother to take care of my kid.  Mother does an excellent job of raising children.'

b) เห็นครอบครัวที่พิ่งย้ายมาใหม่หรือยัง แม่เลี้ยงเด็กสมบูรณ์ดี

/ mɛ̂ɛlíaŋ dèk sǒmbuun dii /

' Have you seen the family that has just moved in? The child's stepmother is a bit chubby.'

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai",  in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27.  (purl.org/sealang/potisuk1994f0.pdf)

15. a) ในบรรดาญาติพี่น้อง ป้าสวยที่สุด **ป้าขาวดีจังเลยนะ**

/ pâa # kʰǎaw dii caŋ ləəj ná? /

' Among all the relatives, my aunt is the prettiest. Aunt has a very clear complexion.'

  b) วันนี้ไปบ้านคุณลุงมา เจอป้าขาวด้วย **ป้าขาวดีจังเลยนะ**

/ pâakʰǎaw dii caŋ ləəj ná? /

' We went to visit uncle today. Aunt Khao was home, too. Aunt Khao is very kind to us.'

16. a) คุณเชื่อไม่ว่าเกิดอะไรขึ้นวันนี้ **ช้างพังบ้านคุณลุงหาญ**

/ cʰáaŋ # pʰaŋ bâan kʰunluŋhǎan /

' You wouldn't believe what happened today. The elephant destroyed Uncle Hahn's house.'

  b) เห็นช้างตัวนั้นไม้ **ช้างพังบ้านคุณลุงหาญ**

/ cʰáaŋpʰaŋ bâan kʰunluŋhǎan /

' Do you see that elephant? That female elephant belongs to Uncle Hahn.'

17. a) เราไปถึงสนามม้าช้าไปหน่อย ตอนที่ไปถึง **ม้าแข่งอยู่ในสนามแล้ว**

/ máa # kʰὲŋ jùu naj sanǎam lέεw /

' We arrived at the track too late. When we arrived, the horses had already begun racing.'

  b) ฉันมีหน้าที่พาม้าแข่งไปกินหญ้าในสนาม แต่ไม่รู้ยังไง

**ม้าแข่งอยู่ในสนามแล้ว**

/ máakʰὲŋ jùu naj sanǎam lέεw /

' I was supposed to take the racehorses to the field to graze. But to my surprise, the racehorses were already on the field.'

18. a) ฉันจะออกไปข้างนอกสักครู่ วานดูในครัวให้หน่อย **น้ำต้มอยู่บนเตานะ**

/ náam # tôm jùu bon taw ná? /

' I'm going to step outside for a moment. Keep an eye on the kitchen, will you? The water is boiling on the stove.'

  b) ถึงเวลาต้องทานยาแล้ว หยิบน้ำให้แก้วนึงซิ **น้ำต้มอยู่บนเตานะ**

/ náamtôm jùu bon taw ná? /

' It's time for me to take medicine. Please bring me a glass of water. Boiled water is on the stove.'

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

19. a) เดินบนสนามหญ้าตอนเพิ่งรดน้ำเสร็จรองเท้าจะเปียกนะ
น้ำค้างอยู่บนยอดหญ้า

/ náam # kʰáaŋ jùu bon jɔ̀ɔt jâa /

' Your shoes will get wet when walking on the lawn after it has been watered. Droplets of water still rest on the blades of grass.'

b) ตอนเช้า ๆ เดินบนสนามหญ้าระวังรองเท้าเปียกนะ น้ำค้างอยู่บนยอดหญ้า

/ náamkʰáaŋ jùu bon jɔ̀ɔt jâa /

' Be careful when walking on the lawn in the morning. Your shoes will get wet. The morning dew is still on the blades of grass.'

20. a) น้ำแก้วนี้น่าดื่มจัง น้ำหอมกลิ่นดอกกุหลาบ

/ náam # hɔ̌ɔm klìn dɔ̀ɔkkulàap /

' I want to drink this glass of water. The water has the fragrance of roses.'

b) หล่อนดีใจมากเมื่อเปิดดูของขวัญที่ได้รับ น้ำหอมกลิ่นดอกกุหลาบ

/ náamhɔ̌ɔm klìn dɔ̀ɔk kulàap /

' She was ecstatic after opening her present. It was the tea rose perfume.

21. a) ทำไมอาการของเขายังไม่ดีขึ้นเลย หมอดูไม่ถูกแน่ ๆ

/ mɔ̌ɔ # duu mâj tʰùuk nɛ̂ɛ nɛ̂ɛ /

' How come his condition has not improved at all? The doctor must surely have made a misdiagnosis.'

b) มันจะไม่เป็นจริงตามคำทำนายหรอก หมอดูไม่ถูกแน่ ๆ

/ mɔ̌ɔduu mâj tʰùuk nɛ̂ɛ nɛ̂ɛ /

' It will never happen as predicted. The fortune teller is definitely wrong.'

22. a) รู้ไม้ว่าเจออะไรตอนล้มตัวลงนอน เข็มกลัดอยู่บนที่นอน

/ kʰěm # klàt jùu bon tʰîinɔɔn /

' Do you know what I found when I lay down? The needle was on the mattress.'

b) ติดเครื่องหมายบนเสื้อให้หน่อย ใช้เข็มกลัดนะ เข็มกลัดอยู่บนที่นอน

/ kʰěmklàt jùu bon tʰîinɔɔn /

' Put the insignia on the shirt for me. Use a safety-pin. The safety-pins are on the bed.'

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

23. a) ไม่ค่อยชอบใจกางเกงที่สั่งตัดเลย ขาทั้นน้อยกว่าที่สั่ง

   / kʰǎa # sân nɔ́ɔj kwàa tʰîi sàŋ /

   ' I don't like those tailored pants at all. The pants' legs are longer than what I ordered.'

   b) เสื้อผ้าที่เราสั่งมาขายเพิ่งมาถึง รู้สึกจะไม่ครบ ขาทั้นน้อยกว่าที่สั่ง

   / kʰâasân nɔ́ɔj kwàa tʰîi sàŋ /

   ' Those clothes we ordered have just arrived. Something is missing. The number of shorts is less than we ordered.'

24. a) เพิ่งนึกได้เมื่อเช้านี้เอง ของค้างอยู่ที่ห้องเขา

   / kʰɔ́ɔŋ # kʰáaŋ jùu tʰîi hɔ̂ŋ pʰǒm /

   ' I've just realized it this morning. I left my stuff in his room.'

   b) กับข้าวเหลือจากเมื่อวานตั้งเยอะ ไปเอามาหน่อย ของค้างอยู่ที่ห้องเขา

   / kʰɔ́ɔŋkʰáaŋ jùu tʰîi hɔ̂ŋ pʰǒm /

   ' There was plenty of food left from yesterday. Go get it. The leftovers are in his room.'

25. a) วันนี้ไปเที่ยวสวนสัตว์มา ยังประหลาดใจไม่หายเลย เสือขาวผิดปกติ

   / sǔa # kʰǎaw pʰìt pòkatì? /

   ' I went to the zoo today. I'm still amazed at one of the tigers which has unusual white skin.'

   b) ตำรวจจับเสือขาวได้แล้ว ทุกคนประหลาดใจเมื่อเห็นสภาพของเขา
   เสือขาวผิดปกติ

   / sǔakʰǎaw pʰìt pòkatì? /

   ' Police has successfully arrested notorious Khao. People were amazed when they saw him. That notorious Khao is deformed.'

Potisuk, S., Gandour, J.T. and Mary, P.H. 1994, "F0 correlates of stress in Thai", in *Linguistics of the Tibeto-Burman Area*, vol. 17, no. 2, pp. 1-27. (purl.org/sealang/potisuk1994f0.pdf)

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