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TONAL EXPERIMENTS WITH WHISPERED THAI[1]

In so-called tonal languages it is the general consensus among linguists and phoneticians that the feature used to distinguish most, if not all, of the tonal phonemes is pitch variation. The question arises as to what happens in whispered utterances of such a language, where there is no vocal fold vibration to produce a fundamental frequency that varies according to the levels or contours prescribed by the phonological system. In some languages, such as Swedish, tonal oppositions are restricted to certain points in the utterance and may in fact be conditioned syntactically to some extent; the question of the preservation of tonal oppositions is more intriguing in a language like Thai, in which every syllable has a tone as part of its phonemic make-up.

This problem has interested a number of phoneticians working on a variety of languages. In an investigation of Mandarin Chinese, Charles Boardman Miller (1934) found that its four tonal phonemes are readily identified in whispered speech. He concluded that this was done through extensive help from the context as well as changes in energy indicating variations in pitch. Miller's experimental design, however, apparently provided no tests in which tone itself was the only variable. Panconcelli-Calzia (1955) maintains that in tonal languages context makes comprehension of longer whispered utterances possible, but he just about rules out comprehension of isolated words. Where others have claimed that whispered tones are indeed audible,[2] he advances two thoughts: either they were not dealing with a genuinely voiceless whisper,[3] or the semantic function of tones has been exaggerated. In a rejoinder, Giet (1956) reaffirms his stand that tonal distinctions are maintained in

[1] This work was inspired by a long conversation with Pierre Delattre who was at the time looking at other aspects of whispered speech (Delattre, Liberman and Cooper 1959). Early versions were presented as oral papers at the Seventy-Third Annual meeting of the Modern Language Association of America, December, 1958 and the Fifty-Eighth Meeting of the Acoustical Society of America, October 1959 (Abramson, 1959).

[2] E.g. Giet, 1950: p. 95.

[3] This is indeed something to be guarded against in such discussions. In true whisper the glottis may be somewhat narrowed but the folds do not pulsate (von Essen, 1962: 35). In stage whisper, although the cartilaginous glottis is open to allow turbulent air through, the membranous folds will be sufficiently approximated to allow for the breathy phonation known as murmur (Zemlin, 1964: 165); this quasi-periodicity, albeit mixed with noise, can of course carry tonal information.

whispering and rendered perceptible, though less clearly so, through the substitution of other phonic features for pitch. The two substitutes in REAL Chinese whispering, he says, are changes in vowel color as well as increases in air flow for high tones and decreases in air flow for low tones. Addressing himself to this controversy, Meyer-Eppler (1957) supports Giet with spectrographic evidence of upward shifts in some vocalic formant frequencies for higher pitch, as well as an increase in intensity accompanied by noisy components in the gaps of the higher spectral regions for whispered German.[4]

Further work on tonal distinctions in whispered Mandarin was done by Wise and Chang (1957), who found that in tests with paired utterances minimally distinguished by tone, listeners were able to identify no more than 62% of the critical words. Kloster Jensen (1958), however, obtained somewhat higher recognition scores for Mandarin; they ranged from 73% to 85%, so he concluded that phonemic tones are reflected somehow in whispered speech.[5] Two rather recent studies show on the one hand very little tonal information transmitted for whispered Vietnamese (Miller, 1961) and, on the other hand, considerable information on the word accents of whispered Swedish (Segerbäck, 1966).

The foregoing claims and counterclaims, as well as the mixed experimental results, made it seem desirable to tackle the problem of the perception of phonemic tones in whispered speech with yet another language. The Thai language appears to be a good choice for this purpose because it has been clearly established (Abramson, 1962) that pitch movements furnish the dominant cues for the identification of the phonemic tones. Standard Thai or Siamese is the national language of Thailand and the regional dialect of the central plains including Bangkok. It is usually said to have five tones: middle, low, falling, high and rising. Spectrographic measurements of fundamental frequencies show that the mid tone starts near the middle of the speaker's voice range and remains level; if it occurs before a pause, it drops slightly at the end. The low tone starts just below the middle of the voice range, drops gradually and levels off somewhat above the bottom of the range. The falling tone starts rather high and drops rapidly to the bottom of the range. The high tone starts above the middle and rises slowly; before a pause, in certain phonetic environments, it drops slightly toward the end and shows concomitant laryngeal constriction with irregular pulsing. The rising tone starts quite low and rises rapidly to the top of the voice range.[6]

The plan of this study was to see whether in fact Thai tones could be identified in whispered speech, and then, using equipment not available to previous investigators, to see whether such information as is transmitted is also available in normally phonated speech. After all, one might argue that the mixed results from Mandarin

[4] Meyer-Eppler does not take German to be a tonal language but asserts that the prosodic distinction between a question and a statement is analogous.

[5] Kloster Jensen's study included similar experiments with Norwegian, Slovenian and Swedish.

[6] For more details see Abramson, 1962, especially Tables 3.2–3.3 and Figures 3.3–3.6. These statements are for citation forms; a full allophonic description would have to take at least tonal environment and sentence intonation into account.

suggest that some speakers go through special maneuvers to compensate for the missing pitch information, while others simply supply the usual instructions to their speech production mechanisms minus fundamental frequency control.

The most severe test of the phonological distinctiveness of tonal features would seem to be one in the context-free condition of isolated monosyllabic words. Before proceeding to whispered speech then, it was necessary to establish that the tones could be distinguished in phonated speech without any help from verbal context. Perception tests were prepared for each of four sets of tonally differentiated words in which each word was pronounced five times by a male native speaker of Thai. All the stimuli were presented in a random order to eleven native speakers, including the informant. Two tests gave five choices, one gave four, and the last gave three. Most of the subjects scored 100% on all the tests. There were a few scattered errors. Although these results indicate that all five tones are readily identified in isolation, R. B. Noss (1954, section 1.1.2) claims that the mid and low tones are not distinguishable in isolation but require an environment where relative pitch criteria are available. In a recent private communication, Noss has clarified this point by describing perception tests of his that do indeed strongly suggest that the tonal opposition in question is somewhat unstable in isolation. The informant used in the present study,[7] he goes on to say, must have produced optimal maximally differentiated contours that the listeners had no difficulty in identifying. To reconcile the apparent conflict, it may be necessary to view the distinction between the mid and low tones as an unstable one, or at least a facultative one, in isolation. This is obviously an important observation to take into account when considering the identifiability of whispered tones in isolated words.

The sets of words so well identified in phonated speech were once again recorded five times each by the same informant in a whisper. Great care was taken to insure that the speaker used true whisper. Neither auditorily nor spectrographically could any laryngeal pulses be detected. The recordings were randomized into test tapes and played to the eleven subjects used for the base line test; for two of the four tests, only eight of the subjects were available. The results are given in the form of confusion matrices in Tables 1 through 4. The words and brief glosses are given in each table. In Table 1, the words are also labelled as to tone to facilitate the reading of the tonal symbols in the rest of the tables. The convention of using double vowel symbols to represent distinctive length is followed here.

The mean recognition scores of Tables 1 through 4 show a sharp drop in identifiability of whispered isolated words as compared with normally phonated words. The individual scores ranged from 73.3% for the informant himself in Table 4 down to two instances of 5% in Table 2. Examination of the confusion matrices suggests that more information has been transmitted than indicated by the overall scores. Indeed, the pattern of responses might make one suspect the existence of a marginal tonal

[7] The informant and base line tests described here are the same as those found in Abramson, 1962: 128.

TABLE 1

Confusion of Matrix of Tones in Words

Number of subjects: 11

Percent Identification

	Whispered				
	Mid	Low	High	Falling	Rising
Heard					
Mid	*14.5*	14.5	23.6	16.4	7.3
Low	9.1	*54.5*	14.5	10.9	7.3
High	27.1	5.5	*40.0*	20.0	12.8
Falling	5.5	7.3	9.1	*52.7*	3.6
Rising	43.7	18.2	12.8	0	*69.0*
N:	55	55	55	55	55

Heard as intended: 46.2%

Words

/naa/ 'field' (Mid tone)
/nàa/ 'custard apple' (Low tone)
/náa/ 'mother's younger sibling' (High tone)
/nâa/ 'face' (Falling tone)
/nǎa/ 'thick' (Rising tone)

TABLE 2

Confusion Matrix of Tones in Words

Number of subjects: 8

Percent Identification

	Whispered				
	Mid	Low	High	Falling	Rising
Heard					
Mid	*42.5*	35.0	37.5	52.5	20.0
Low	52.5	*52.5*	60.0	35.0	67.5
High	5.0	0	*2.5*	0	0
Falling	0	12.5	0	*12.5*	7.5
Rising	0	0	0	0	*5.0*
N:	40	40	40	40	40

Heard as intended: 23%

Words

/k'aj/ 'dried sweat'
/k'àj/ 'egg'
/k'áj/ 'to scoop out'
/k'âj/ 'fever'
/k'ǎj/ 'to unlock'

TABLE 3

Confusion Matrix of Tones in Words

Number of subjects: 11
Percent Identification

	Whispered			
Heard	Mid	Low	High	Falling
Mid	*12.7*	40.0	31.0	26.4
Low	61.8	*18.2*	9.1	20.8
High	9.1	5.5	*12.7*	11.6
Falling	16.3	36.4	47.2	*41.5*
N:	55	55	55	55

Heard as intended: 21.3%

Words

/lom/ 'wind'
/lòm/ 'mud'
/lóm/ 'to fall'
/lôm/ 'shipwreck'

TABLE 4

Confusion Matrix of Tones in Words

Number of subjects: 8
Percent Identification

	Whispered		
Heard	Mid	Low	High
Mid	*57.5*	42.5	52.5
Low	37.5	*57.5*	27.5
High	5.0	0	*20.0*
N:	40	40	40

Heard as intended: 45%

Words

/p'ææ/ 'raft'
/p'æ̀æ/ 'to spread'
/p'ǽæ/ 'to be defeated'

system whose categories do not coincide exactly with those of the normal tonal system. It is however hard to see a consistent breakdown into categories. Note, for example, the rather different treatment of the rising tone in Tables 1 and 2 even though in both tests there are five response choices.[8]

[8] Chi-square tests show that the overall distribution of responses is significantly different from chance at the 1% level of confidence in Tables 1 and 3; it is barely significant at the 1% level in Table 4 and not significant in Table 2.

The data of Tables 1 through 4 hint that the context-free conditions of the first four tests may have been too severe to allow a by-system of whispered reflexes of tonal categories to emerge clearly, although such a system, without too much of a stretch of the imagination, may seem to be incipient in the matrices. Four more tests were prepared with sets of two and three tonally differentiated words embedded in sentence frames and randomized on magnetic tape. Because of grammatical and semantic constraints, we could not at that time think of any sentence that would accomodate five tonally differentiated words. The confusion matrices for these tests are displayed in Tables 5 through 8. The sentences, key words and glosses are given in the tables. The sentence environments seemed to induce a slight improvement in perception, although it is difficult to quantify the difference.[9] For three of the eight subjects there was a startling improvement. In the test underlying Table 5, one subject had 90% correct.[10] All the other subjects, however, ranged from 40% to 60%, thus accounting for the poor resolution of Table 5. The somewhat better resolution of Table 6 is accounted for by the 100%, 80% and 70% achieved by three other subjects. Once we move to a three-way choice in Tables 7 and 8, we do not find such high individual scores. In Table 7 individual scores range from 33.3% to 60%, and in Table 8 from 33.3% to 80%, the latter achieved by the informant himself. It seems reasonable to infer from these findings that, given a sufficiently long linguistic context, some Thai speakers at least are moderately successful at using phonic features other than pitch to distinguish phonemic tones perceptually.

At this point the question arose as to whether the concomitant features associated with the distinctive pitch contours were simply not as audible in whisper as in phonated speech. To test such a hypothesis it was necessary to expose the subjects to voiced speech which presumably retained the concomitant features but was neutral as to pitch. This was done by passing the sets of spoken words through an 18-channel vocoder at a constant fundamental frequency, i.e., a monotone, of 130 cps.[11] Although some of the concomitant features, e.g., the abrupt amplitude drop of the falling tone, were quite detectable by ear, the four tests yielded no discrimination at all. That is, the eleven subjects either showed chance distributions of responses or assigned nearly all the stimuli to the mid tone when it was one of the response choices. It would seem that the presence of pitch, even if it was a monotone, was too great

[9] Chi-square tests show that the overall distribution of responses is significantly different from chance at the 1% level of confidence in Tables 7 and 8; it is barely significant at the 1% level in Table 6 and not significant in Table 5.

[10] Interestingly enough, the informant correctly identified only 50% of his own productions in this test.

[11] The vocoder is a machine that processes speech, first by analyzing it and then by resynthesizing it. The analyzer separates the speech signal into information about its voiced and voiceless characteristics and its spectrum information, or roughly, into information about activity at the vocal folds versus information about articulation. The synthesizer supplies its own voiced sounds in the form of a buzz and its own voiceless sounds in the form of a hiss. These sounds are shaped by the spectrum information from the analyzer. The result is highly intelligible speech, but with a voice quality that is characteristic of the machine (Dudley, 1939).

TABLE 5

Confusion Matrix of Tones in a Sentence

Number of subjects: 8
Percent Identification

	Whispered	
	Low	Falling
Heard		
Low	*30.0*	32.5
Falling	70.0	*67.5*
N:	40	40

Heard as intended: 48.8 %

Sentence frame: /pʻǒm rúu wâa kʻun cʻɔ̌ɔp______dii/
'I know you like good______.'
Key words: /kʻàaw/ 'news'
/kʻâaw/ 'rice'

TABLE 6

Confusion Matrix of Tones in a Sentence

Number of subjects: 8
Percent Identification

	Whispered	
	High	Rising
Heard		
High	*47.5*	15.0
Rising	52.5	*85.0*
N:	40	40

Heard as intended: 67.5 %

Sentence frame: /pʻǒm mii______hòk tua/
'I have six______.'
Key words: máa 'horse(s)'
mǎa 'dog(s)'

a distraction for any kind of tonal identification based on other features. The experiment was repeated by resynthesizing phonated versions of the sentences used for Tables 5 through 8 on vocoder buzz to make sure, once again, that the lack of a carrier frame was not dulling the sensitivity of the subjects to such cues as were present in the key words. There was no sharpening of discrimination at all; the results were the same as for the isolated words. These findings are consistent with those of another experiment (Abramson, 1962:131–33 and Figure 3.11), in which the optimum contour for each of the five tones was artificially imposed on each member of a set of five

TABLE 7

Confusion Matrix of Tones in a Sentence

Number of subjects: 8

Percent Identification

	Whispered		
Heard	Low	Falling	Rising
Low	*17.5*	52.5	5.0
Falling	5.0	*30.0*	10.0
Rising	77.5	17.5	*85.0*
N:	40	40	40

Heard as intended: 44.1%

Sentence frame: /pen______/
'It is a______.'

Key words: /sìa/ 'mat'
/sîa/ 'upper garment'
/sǐa/ 'tiger'

TABLE 8

Confusion Matrix of Tones in a Sentence

Number of subjects: 8

Percent Identification

	Whispered		
Heard	Mid	High	Falling
Mid	*50.0*	27.5	40.0
High	37.5	*52.5*	10.0
Falling	12.5	20.0	*50.0*
N:	40	40	40

Heard as intended: 50.8%

Sentence frame: /raw cà paj duu______k'ɔ̌ɔŋ k'un/
'We will go look at your______.'

Key words: /naa/ 'field'
/náa/ 'mother's younger sibling'
/nâa/ 'face'

tonally differentiated words for identification by Thai listeners. This was done with the Haskins Laboratories' Intonator, a device that enables one to pass speech through the vocoder while at the same time substituting a new fundamental frequency contour for the original one. Ten Thai subjects made nearly perfect identifications of all members of the /naa/ set of words (listed in Table 1) in terms of the synthetic tones rather than the tones of the original unvocoded productions.[12] It is interesting to note that the experimenter himself, in taking this test, was able to recognize nearly all instances of syllables originally spoken on the falling and rising tones by listening for allophonic variations in duration and changes in the course of intensity; yet the native speakers of Thai apparently ignored these features and attended only to the fundamental frequency movements.

Even while providing some interesting information in their own right, the vocoder monotone experiments did not answer the questions for which they were designed. To determine whether the concomitant features of the tones might not be more audible in phonated speech than in whisper it was apparently necessary to strip away the voice and thus remove the distracting impression of pitch. This was done by passing both the isolated words and the sentences through the vocoder once again, but this time with the buzz generator turned off. The outputs of the analyzing channels were modulated instead upon hiss to produce vocoder 'whispering'. In these tests the subjects were told that someone else had done the whispering. The word data are displayed in Tables 9 through 12, and the sentence data [13] in Tables 13 through 15. As we look at the word data in Tables 9 through 12, we find that overall recognition is somewhat better than for the isolated whispered words in Tables 1 through 4.[14] The confusion matrices show that some of the tones, in particular the rising tone, are perceived rather well on vocoder hiss. Also, as before, certain subjects did much

TABLE 9

*Confusion Matrix of Tones in Words**

Number of subjects: 9
Percent Identification

	Resynthesized on Vocoder Hiss				
	Mid	Low	High	Falling	Rising
Heard					
Mid	*13.3*	20.0	0	2.2	0
Low	0	*66.7*	0	0	0
High	60.0	0	*75.5*	26.8	0
Falling	8.9	4.4	2.2	*71.0*	0
Rising	17.8	8.9	22.2	0	*100*
N:	45	45	45	45	45

Heard as intended: 71.6%

* The same as in Table 1.

[12] Each of the five words, of course, had the synthetic version of its own original tone imposed upon it as well as those of the other four tones making twenty-five stimuli in all. These were recorded four times and randomized into a test order of 100 items.

[13] The sentences of Table 7 were not used for this part of the study.

[14] Tables 9 through 12 are all significant at the 1% level.

TABLE 10

*Confusion Matrix of Tones in Words**

Number of subjects: 9
Percent Identification

	Resynthesized on Vocoder Hiss				
	Mid	Low	High	Falling	Rising
Heard					
Mid	*17.8*	15.6	22.1	24.4	6.7
Low	26.7	*82.3*	28.9	24.4	11.1
High	6.7	0	*0*	0	0
Falling	8.9	2.2	13.3	*51.2*	0
Rising	40.0	0	35.6	0	*82.3*
N:	45	45	45	45	45

Heard as intended: 46.7%

* The same as Table 2.

TABLE 11

*Confusion Matrix of Tones in Words**

Number of subjects: 9
Percent Identification

	Resynthesized on Vocoder Hiss			
	Mid	Low	High	Falling
Heard				
Mid	*35.6*	28.0	20.0	15.8
Low	28.9	*72.0*	15.6	15.8
High	24.5	0	*40.0*	9.1
Falling	11.1	0	24.5	*59.0*
N:	45	43	45	44

Heard as intended: 51%

* The same as Table 3.

better than the others. For example in Table 9, two subjects achieved identification scores of 88% and 80% respectively, while the rest ranged from 64% to 52%. In Tables 10 through 12 the individual scores ranged from 75% down to 6.6%. The sentences also show a somewhat sharper patterning of responses on vocoder hiss than do their whispered counterparts.[15] Table 13 makes it dramatically evident that at least some tonal oppositions in suitable sentence contexts can be reliably distinguished.

[15] Table 13 is significant at the 0.1% level and Table 15 at the 1% level. The distribution of responses in Table 14 is not significantly different from chance.

TABLE 12

*Confusion Matrix of Tones in Words**

Number of subjects: 9
Percent Identification

	Resynthesized on Vocoder Hiss		
	Mid	Low	High
Heard			
Mid	*33.4*	48.8	27.3
Low	4.4	*42.3*	9.1
High	62.2	8.9	*63.6*
N:	45	45	44

Heard as intended: 45.9%

* The same as Table 4.

TABLE 13

*Confusion Matrix of Tones in a Sentence**

Number of subjects: 6
Percent Identification

	Resynthesized on Vocoder Hiss	
	Low	Falling
Heard		
Low	*91.7*	2.8
Falling	8.3	*97.2*
N:	36	36

Heard as intended: 94.4%

* The same as in Table 5.

TABLE 14

*Confusion Matrix of Tones in a Sentence**

Number of subjects: 6
Percent Identification

	Resynthesized on Vocoder Hiss	
	High	Rising
Heard		
High	*58.3*	47.2
Rising	41.7	*52.8*
N:	36	36

Heard as intended: 55.7%

* The same as Table 6.

TABLE 15

*Confusion Matrix of Tones in a Sentence**

Number of subjects: 6

Percent Identification

	Resynthesized on Vocoder Hiss		
	Mid	High	Falling
Heard			
Mid	*36.2*	30.6	8.3
High	11.0	*36.2*	8.3
Falling	52.8	33.3	*83.4*
N:	36	36	36

Heard as intended: 51.8%

* The same as Table 8.

Table 14, with its chance distribution of responses, is in fact less good than its whispered counterpart in Table 6. This is more apparent in the treatment of the rising tone than in the overall scores. Pending instrumental examination of the stimuli, we can only speculate that the speaker may have considerably enhanced the concomitant features in that particular rendition of whispered /mǎa/. Table 15 indeed shows a patterning of responses — but one that is somewhat different from that of its whispered counterpart in Table 8. It is hard to decide that there is an improvement throughout the confusion matrix, even though the falling tone in particular is now identified correctly 83.4% of the time.

The results of the research presented here indicate that in the context-free setting of isolated words, whispered Thai tones cannot be well identified. As Hockett (1955:17–18) points out in discussing by-systems and marginal cases at the boundaries of language that should not be allowed to complicate one's phonologic analysis, "A whispered utterance mocks the phonologic structure of the same utterance spoken in the normal way, but almost always omits certain contrasts which are functional in normal speech." The responses to the whispered sentences, however, suggest that when the concomitant features of tonal phonemes are embedded in a sufficiently long phonic environment, at least some Thai speakers can do reasonably well at identifying certain tones. The vocoder buzz experiments, both for words and sentences, convincingly demonstrate that these concomitant features are really redundant and probably can never function distinctively in the presence of distracting pitch. This conclusion is supported by parallel work done on the tonal contours of Thai (Abramson, 1962). But the vocoder hiss experiments show that the concomitant features are indeed present in phonated speech and, once the distracting voice is stripped away, are somewhat more audible than in whispered speech.

The poor transmission of tonal features in whispered speech did not seem to warrant a detailed instrumental analysis of the concomitant features for the present study. For Thai these features appear to involve variations in vowel duration (Abramson, 1962:107–8) and changes of amplitude, especially for the falling and rising tones. In phonated speech, the whole larynx is likely to rise and fall with great changes in pitch, thus shortening and elongating the pharyngeal tube; such changes in the length of the vocal tract will of course affect formant frequencies and thus sometimes, if these formant shifts exceed the psychoacoustic thresholds, cause changes in vowel quality (Parmenter, Treviño and Bevans, 1933). Auditory phonetic analysis suggests that this happens in Thai, but no quantitative data are available. For this to have any effect in whispered speech, it is necessary to suppose that the speaker replicates 'instructions' that he sends in phonated speech to the extrinsic muscles of his larynx and, perhaps, muscles of the tongue to make adjustments in vocal tract configuration to facilitate large pitch changes.[16]

It would seem that in Thai and no doubt other tonal languages[17] whispered communication can be ambiguous in short utterances with low redundancy. In longer utterances or in short utterances embedded in a conversation or a particular situation, the high contextual redundancy plus the tonal distinctions that whispering does provide, combine to make whispered communication quite feasible.

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[16] That this kind of replication happens for voicing distinctions has been at least tentatively established by transillumination of the larynx (Malécot and Peebles, 1965; Lisker, Abramson, Cooper and Schvey, 1969).

[17] This statement may not be completely true of a language in which one or more tones are characterized by prominent non-pitch features, such as strong glottal stop. This kind of thing may at least partially explain the mixed observations of some of the sources cited.

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