1

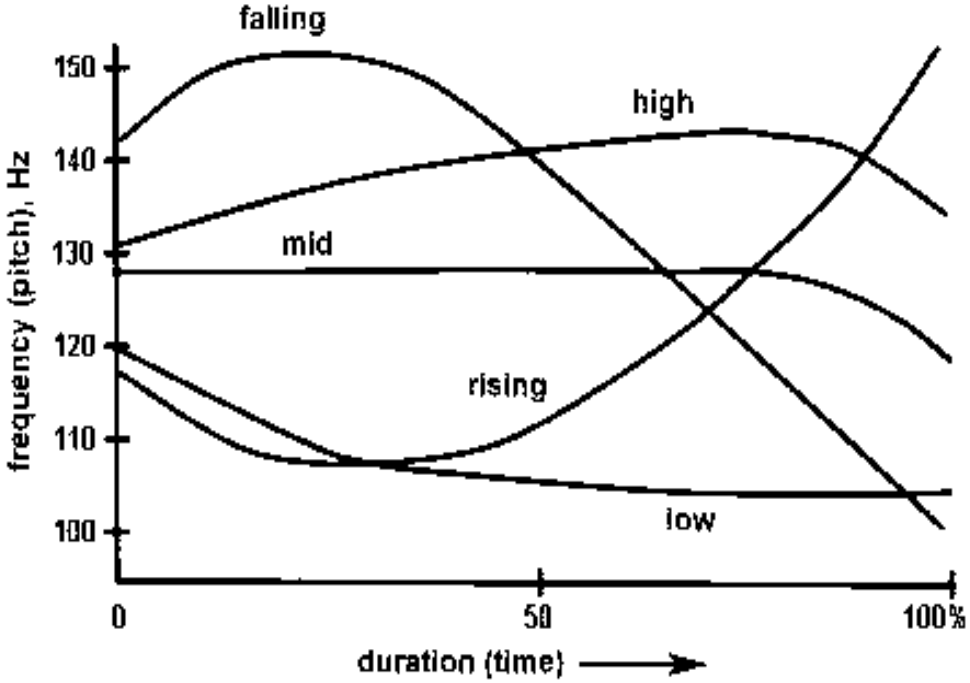
Tones in Dysarthic Speech: Thai Speaking Cases of Stroke

Vaishna Narang
Deepshikha Misra
Sulaganya Punyayodhin

Tone and Pitch in Thai Language: According to Ladefoged, (1962) it is generally assumed that the principal phonetic features of tone are found in the domain of pitch. The term "tone" refers to a particular way in which pitch is utilized in language; the term "pitch" (nonlinguistic, perceptual), on the other hand, refers to how a hearer places a sound on a scale going from low to high without considering the physical properties of the sound. Its primary acoustic correlate is fundamental frequency. The term "fundamental frequency" (acoustic) refers to the frequency of repetition of a sound wave of which, when analyzed into its component frequencies, the fundamental is highest common factor of the component frequencies (Ladefoged, 1962:176).

According to Fromkin (1978), A tone language is a language in which pitch is used to contrast individual lexical items or words. Fromkin recognizes five contrastive tones in Thai. They are "traditionally labeled mid (¯), low (˴), falling (^), high (ˊ) and rising (ˇ). The following set of words illustrates these tones: khaa 'a grass', khàa 'galangal 'a rhizome', khâa 'to kill', khǎa 'to engage in trade'." Average

fundamental frequency contours of the five Thai tones in prepausal position are represented below:



(Fromkin, 1978:43)

Abramson (1962:128) presented four sets of five tonally differentiated real-speech monosyllabic words of Thai language, produced by a single male speaker, for absolute identification judgments. Most of the subjects (11) identified the tones easily with no errors. Abramson (1975:3-4) replicated the experiment with a different set of monosyllabic words, this time produced by five male and five female speakers. The overall intelligibility score achieved by the subjects (25) was nearly perfect. Confusion between the mid and low tones accounted for most of the small number of errors; nearly half of these errors, however, were caused by the utterances of one of the ten speakers. Abramson 1976 found in a similar experiment that the confusion between the mid and low tones was virtually eliminated when the utterances of only one speaker were used for identification tests as compared to composite tests in which the utterances of all the speakers were randomized to prevent adaptation to

any one speaker. The mid and low tones, the two Thai tones most vulnerable to confusion, are typically characterized by very little movement of fundamental frequency over time, unlike the falling, high and rising tones, each of which displays considerable movement of the fundamental frequency as indicated in the above figure. The mid and low tones were not confused in most of the individual tests, which suggests that the normalization of the tones space could be effected much more easily for an individual speaker.

Lateralization of Tone Processing: In tonal language speakers' it is said that the human brain has evolved to recruit neural tissue for specialized functions. Right-handed speakers seem to have linguistic comprehension and production lateralized to the left hemisphere. On the other side of the brain, according to Liegeois-Chauvel et al, the right temporal lobe seems to handle the discrimination of aspects of music, including pitch, which leads to the understanding of tone or prosody (Liegeois-Chauvel et al., 1998). As cited in Missig 2006, the question then is, what happens in case of languages which depend on tone for lexical decisions, such as Punjabi, Thai, and Vietnamese etc. The questions raised by Missig (2006) are: "What happens in the brains of people who natively speak tonal languages? Does the brain still lateralize tone processing to the right, does it move over to the left, or are there two separate sites for tone processing?" (Missig, 2006. 85-414)

Anticipatory tonal coarticulation in Thai bisyllabic noun compounds was found to be essentially intact in LHD and RHD patients (Gandour, Ponglorpisit, et al., 1993). By using the same subjects, Gandour et al. (1996) found that anticipatory and preservative tonal coarticulation was disturbed in longer sentence contexts in both anterior and posterior aphasics. Tonal coarticulation was absent in the former, reduced in magnitude and temporal extent in the latter. Coarticulatory effects in RHD patients and were indistinguishable from those of normal controls. These findings suggest that the planning of tonal coarticulation may deteriorate in longer sentence contexts in the speech of LHD patients. More deficiencies are observed in the coarticulation of tones. (Gandour, 1998. 214-215).

The Present Study: The present study is focused on 3 male and 3 female Thai speaking cases of stroke. None of the cases under study, 4 LHD and 2 RHD had marked communication deficit and scored well on language test. All six subjects had mild dysarthria which prompted this study of production of tones in dysarthric speech**.** For the control group we selected four male and four female speakers randomly and out of the random sample we selected one, as the best recording

which was also adjudged by the native speakers of Thai as most clear articulation of words. This subject is female aged 46, whose family belongs to the Central region of Thailand, and after completing her graduation, she has been in Bangkok for more than 15 years.

Since we have three male case studies also, we had random samples of 4 normal male speakers and then on the basis of clarity and quality of recording selected one as the normal control. This male control is 57 years old, whose family belongs to the Northeast region of Thailand near the border between Thailand and Cambodia. The subject was born in Buriram but has lived in Bangkok and Pathumtani- the Central part of Thailand for more than 30 years.

Table 1: Subjects under Study

Sex	LHD	RHD	Control	Total
Female	1	2	1	4
Male	3	0	1	4
Total	4	2	2	8

As indicated in the table below, the six select cases of stroke are in the age range of 46 to 78, and include 4 LHD and 2 RHD, 3 Males and 3 Females.

Table 2: Details of six select cases and two normal controls

Subject no.	Code	Age	Handedness	Education	LHD/RHD, Dysarthria
1	VP57ML	57	Left handed	M.A.	normal
2	AJ52M	52	Left handed	M.A.	LHD,+Dys
3	CHP54M	54	Right handed	B.A.	LHD,+Dys
4	YM70M	70	Right handed	Primary P. 2	LHD,+Dys
5	SP46F	46	Right handed	M. Phil	normal
6	NR53F	53	Right handed	Primary P.4	RHD
7	CH56F	56	Right handed	Primary P.4	RHD
8	CHP78F	78	Right handed	Primary P.4	LHD,+Dys

Word List: 3 examples of each one of the five tones in contrast were selected. The vowel with the requisite tone was in the medial position. The word list is reproduced below.

Table 3: selected word list

Tone 1 Mid tone สามัญ	**1. *แกงปลากราย***	/kæŋ plākrāj/	fish curry
	2. *หัวไชเท้า*	/hŭa chāj tháo/	radish
	3. *ผงชูรส*	/ phŏŋ chū: rót/	monosodium glutamate
Tone 2 Low tone ไม้เอก	**1. *ต้มข่าไก่***	/tôm khà: kài/	chicken galanga soup
	2. *คนแปลกหน้า*	/khōn plɛ:k nâ:/	the stranger
	3. *หุ่นกระบอก*	/hùn krà bɔ:k/	the puppet
Tone 3 Falling tone ไม้โท	**1. *พริกขี้หนู***	/phrík khî: nŭ:/	chilli
	2. *ห้างหุ้นส่วน*	/hâ:ŋ hûn sùan/	Company Limited
	3. *ต้มเยื่อไผ่*	/tôm yɯ:a phài/	bamboo tissue soup
Tone 4 High tone ไม้ตรี	**1. *คันธนู***	/ khan ta nu:/	bow
	2. *คนค้าขาย*	/khōn khá: khăj/	vendor
	3. *ชุดนักเรียน*	/chút nák rī:an/	student uniform
Tone 5 Rising tone ไม้จัตวา	**1. *สแมสาร***	/sà mɛ: să:n/	a city
	2. *ข้อสัญญา*	/khɔ: săn yā:/	a contract
	3. *หอมหัวใหญ่*	/hɔ:m hŭa yàj/	

Software Used: Data was recorded in a sound proof room of JNU using PRAAT; Goldwave was used for noise reduction. While wavesurfer used for spectrograms, the analysis was mostly done by using PRAAT.

Results and Discussion: Pitch was calculated in terms of F0 variation during the articulation of the vowels. For this reason the F0 values were calculated at three points in the duration of the vowel; at the beginning, the middle and the final position. These three points gave us the contour as well as the level of the tone**.**

Control Data: Table below shows the control data obtained from the male and female, normal control subjects, case VP57ML (i.e. VP name initials, 57 years old, Male, Left handed) and SP46F (i.e. SP name initials, 46 years old, Female).

Table 4

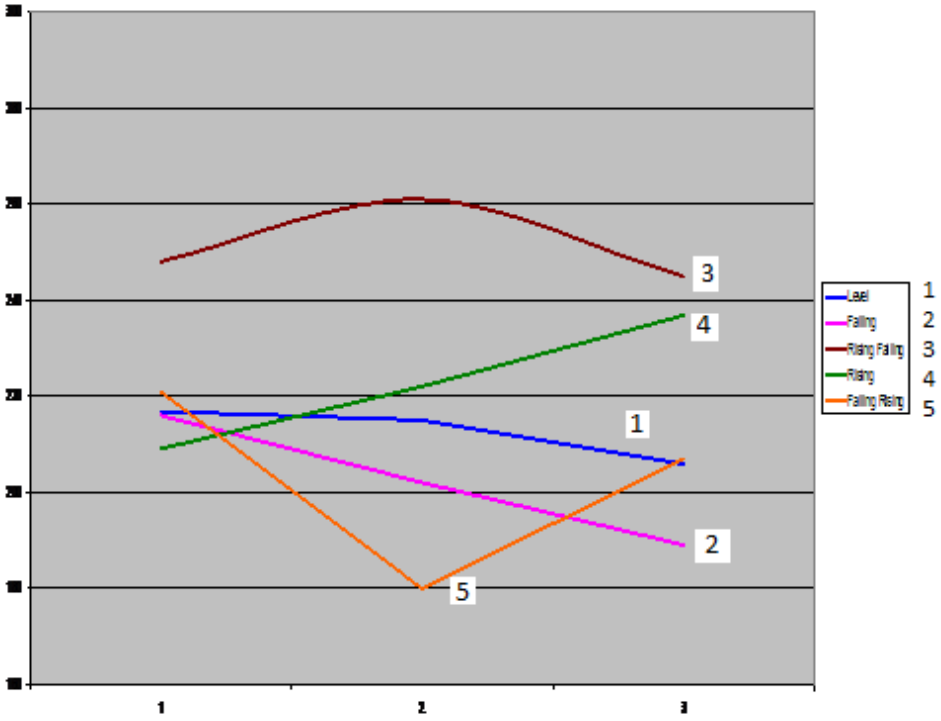
		Level			Falling			Rising-Falling			Rising			Falling-Rising			Av
Code	Case	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	
SP46F	Normal	217	215	206	216	202	189	237	261	242	209	222	237	220	179	198	218
NR53F	RHD	160	165	167	155	140	134	186	185	165	182	175	163	154	141	161	162
CH56F	RHD	198	195	199	182	175	174	221	221	199	216	210	208	161	149	187	192
CHP78F	LHD, Dys	201	195	200	182	180	178	182	193	182	187	190	193	177	177	176	184
VP57ML	Normal	106	104	102	104	91	84	137	145	122	122	117	109	100	91	104	110
AJ52M	LHD, Dys	211	205	210	204	190	178	204	213	196	207	200	198	192	178	195	198
CHP54M	LHD, Dys	126	127	128	128	120	119	153	151	132	140	139	139	127	127	132	134
YM70M	LHD, Dys	95	95	93	97	90	100	120	121	113	116	115	114	110	104	111	108

Female normal control is SP46F i.e. 46 years old female from Bangkok, whose recording of all the 15 sample words was used for comparison with female cases of stroke. Male normal control subject is case no. VP57ML i.e. 57 years old male who also comes from Bangkok and is a teacher of Thai language in a university, and seems to have a clear articulation of words, also a good, clear recording. Hence his production of the 15 sample words was also used as control for comparison with the test words of Male cases of stroke. The following table and graphic representation of the averages of the three examples of all the five tones shows a comparison of the male and female normal control productions.

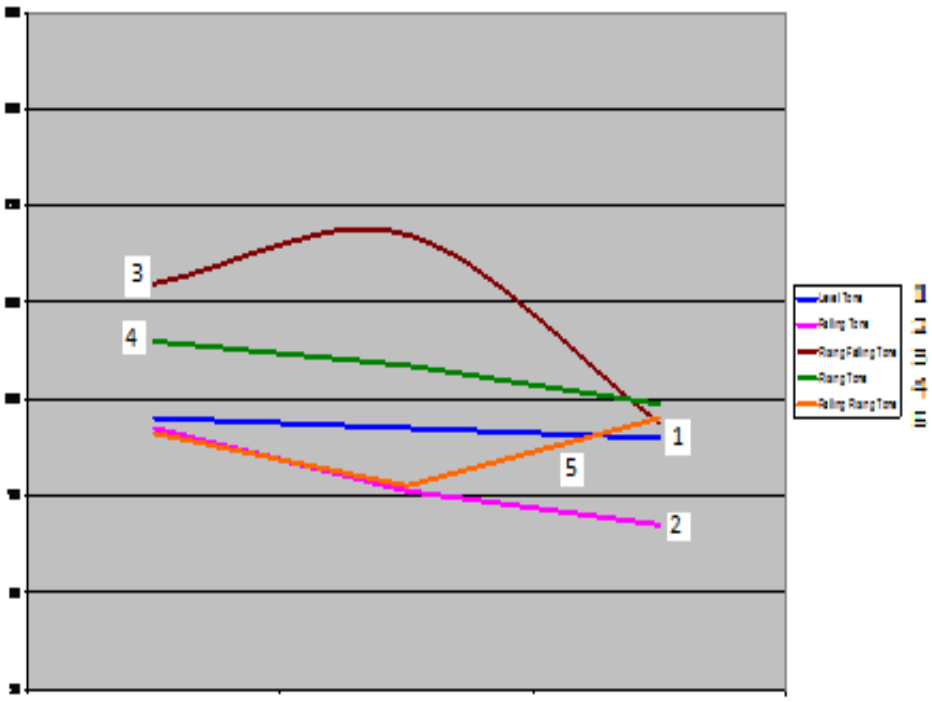
Table 5

Tones	Control Female			Control Male		
Level	217	215	206	106	104	102
Falling	216	202	189	104	91	84
Rising Falling	248	261	245	134	144	105
Rising	209	222	237	122	117	109
Falling Rising	221	180	207	103	92	106

Female Control- SP46F



Male Control- VP57M



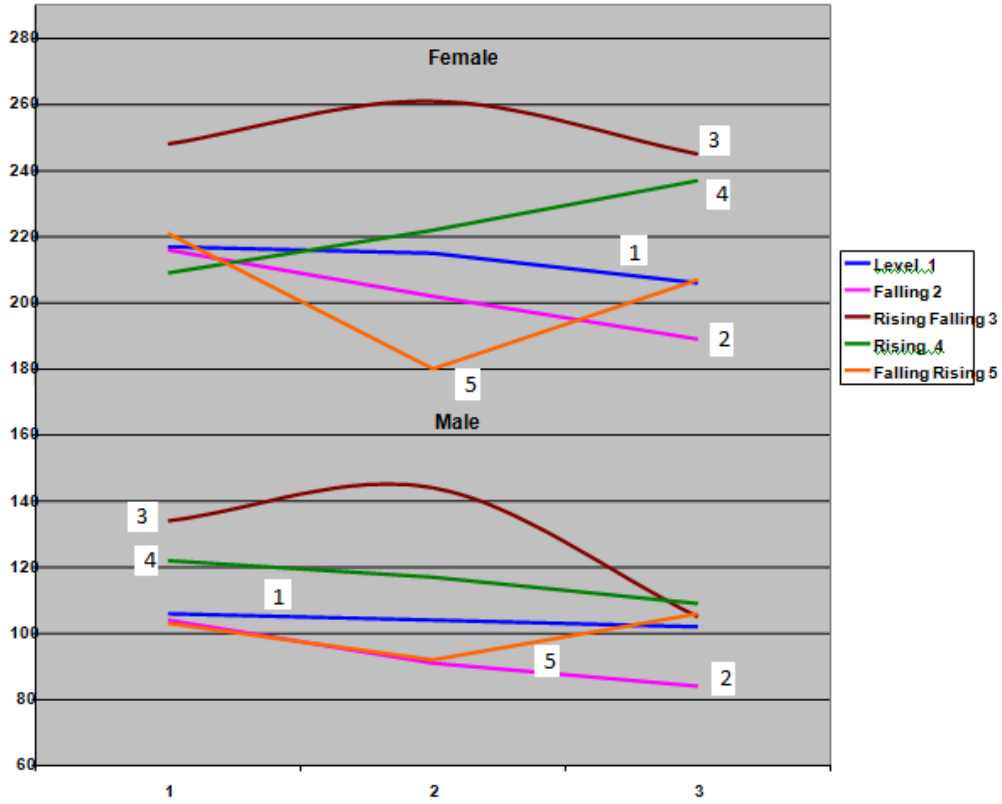
Female Control

As we can see from the table, the average pitch of SP46F as the female control case is at 218 Hz with the lowest point at 179 and the highest point at 261 i.e. in the range of -39 and + 43. Level tone is between 214 to 202 and the variation is ± 6. Falling tone starts with 211 and falls down to 187 i.e. the fall in pitch is -24Hz. Rising-Falling tone is rising up at the point 237 to the highest point about 261, and is falling down to 242. The rising and falling points are +24 and -19 respectively. In rising tone, the value starts from 212 rising to 238, and the rise in pitch is +26. Falling-Rising tone goes down from 220 to the lowest point about 179 and goes up to 198. The range of the falling and rising tones is -41 and +19.

Male Control

It is shown that the average pitch of VP57L like the control case is at 110 Hz with the lowest point at 86 and the highest point at 145 i.e. in the range of -24 and +35. Level tone points to 106 to 104-102 and the variation is ± 2. Falling tone is from 92 falling down to the point 86 i.e. the fall in pitch is -6. At Rising-Falling tone, the value is rising from 137 up to the highest point around 145 and falling down to 122 and the rising and falling points are +8 and -23 as reported in the table. Rising tone goes up from 115 to 119 and the rise in pitch is only +4. Falling-Rising tone is going down from 100 to the lowest point 91 and going up to 104. The falling and rising range is -9 and +13.

Comparison of Fundamental frequencies of vowels at the Word level between Female and Male Control cases



- The important difference between male and female control is that the male control speaker has all the five tones in a relatively smaller range of -24, +35 i.e. 59 Hz. and female has the same five phonemic tones in the range of -39, +43 i.e. 82 Hz. So, for Thai normal speakers we should have the average range from 60 to 80 Hz. Also, the male pitch range of -24 and +35 seems enough to get all the tonal contrasts, and all the levels and contours, for their phonemic function and distinctive perception.

- In case of F control all the tones except High/ Rising- Falling tone start at the same level i.e. 215, +/ - 5; the R-F tone starts at a much higher level and also has a well defined RF contour. In case of M control three tones, Level, Falling and Falling –Rising tones start around the same level, around 104, and

continue to acquire the requisite contour. The Rising- Falling tone which starts at a much higher level, at 134 and also has the right contour. The 5th tone, the Rising tone starts at a higher level but gradually goes down by about 10- 12 Hz, treating it as High tone rather than Rising tone. This is important as we shall see while comparing the cases under study with the Male control.

3.2: Six Cases of Stroke under study

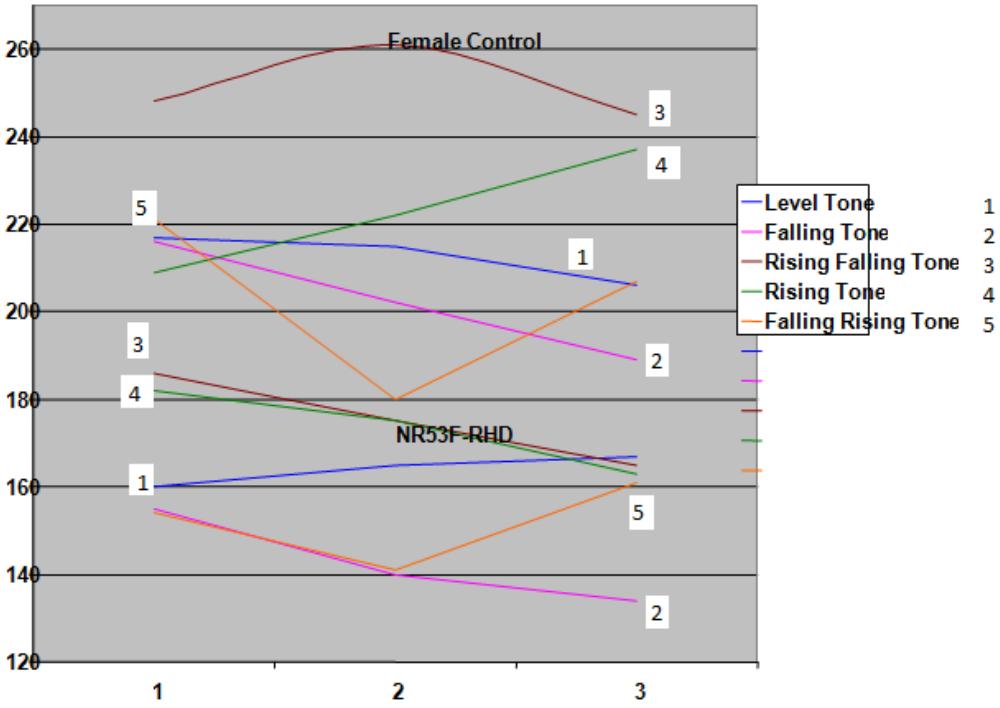
		Level			Falling			Rising-Falling			Rising			Falling-Rising			Av
Code	**Case**	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	
SP46F	**Normal**	217	215	206	216	202	189	237	261	242	209	222	237	220	179	198	218
NR53F	**RHD**	160	165	167	155	140	134	186	185	165	182	175	163	154	141	161	162
CH56F	**RHD**	198	195	199	182	175	174	221	221	199	216	210	208	161	149	187	192
CHP78F	**LHD, Dys**	201	195	200	182	180	178	182	193	182	187	190	193	177	177	176	184
VP57ML	**Normal**	106	104	102	104	91	84	137	145	122	122	117	109	100	91	104	110
AJ52M	**LHD,Dys**	211	205	210	204	190	178	204	213	196	207	200	198	192	178	195	198
CHP54M	**LHD,Dys**	126	127	128	128	120	119	153	151	132	140	139	139	127	127	132	134
YM70M	**LHD,Dys**	95	95	93	97	90	100	120	121	113	116	115	114	110	104	111	108

Comparison of Fundamental Frequencies of vowels at the Word level between Female control and all female Stroke cases compared individually.

Case: NR53F –RHD

The average pitch of NR53F is at 162 with the lowest point at 134 and the highest point at 186 i.e. in the range of -28 and +24. Level tone is at 164 and the variation is +3 and -1. Falling tone starts at 155 goes down to 134 and the fall in pitch is -21. Rising-Falling tone should be rising first, but it remains level at186 to 185 in the first half duration, and then towards the end falls down to the point 165 i.e. -20 Hz. (as this case is a RHD stroke patient). Rising tone is tone is starting at a higher level i.e. 182 and the subject is not able to maintain a high pitch or go higher; comes down instead to 163, i.e. -19 Hz. Hence there appears to be no significant difference between the 3rd and the 4th tones i.e. Rising –Falling and Rising tones, both starting around 182 to 185 going down by -20 Hz.

Falling-Rising tone is going down from 154 to 141 and rising up to 161 and the falling and rising points are -13 and +20 respectively.



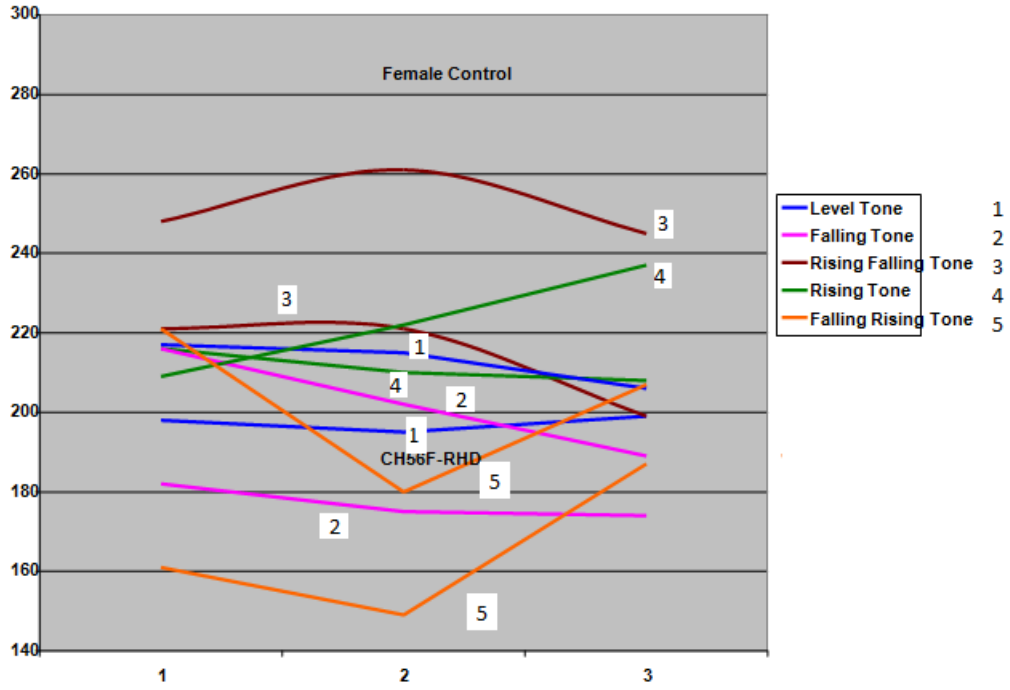
Case of NR53F in comparison with Female Control

- Except one tone i.e. rising tone which is pronounced by the RHD case as falling tone (i.e. -19Hz), all the other tones are fairly close to natural control, although this case of RHD uses a much smaller pitch range i.e. 52 Hz as compared to the 82 Hz range of the female control.
- The rising tone is pronounced as a falling tone, and yet remains distinctive because as compared to the 1st, 2nd and 5th which start at 155 +2; 4th tone i.e. rising tone starts at a much higher level at 182 going down to 163, treating this as a (High) tone and not as High-Rising tone.
- The contrast between the Rising- Falling and Rising tone is lost. Changing of contour from Rising to Falling seems to be really difficult for this person

Case: CH56F-RHD

The average pitch of CH56F is at 192 with the lowest point at 149 and the highest point at 221 i.e. in the range of -43 and +29. Level tone is at 209 to 190, and the variation is ± 9.5. Falling tone is going down from 155 to 134 i.e. the fall in pitch is -21. Rising-Falling tone starts at 221 and falls down to 199. The Level tone is -22. Rising tone starts from 216 down to 208 i.e. the fall in pitch is -8. Falling-Rising tone goes down from 161 to lowest point at 149 and goes up to 187. The falling and rising points are -12 and +38.

This is an interesting case of RHD. The speaker articulates all the tones at different levels i.e. at 160, 180, 190, 216 and 220, and except for the last one all are pronounced as level or slightly falling tones. Even level tone goes down by about -20 Hz. Contours seem to be difficult for this subject, so probably this is the strategy to maintain the phonemic contrast between tones.



Case of CH56F in comparison with Female Control

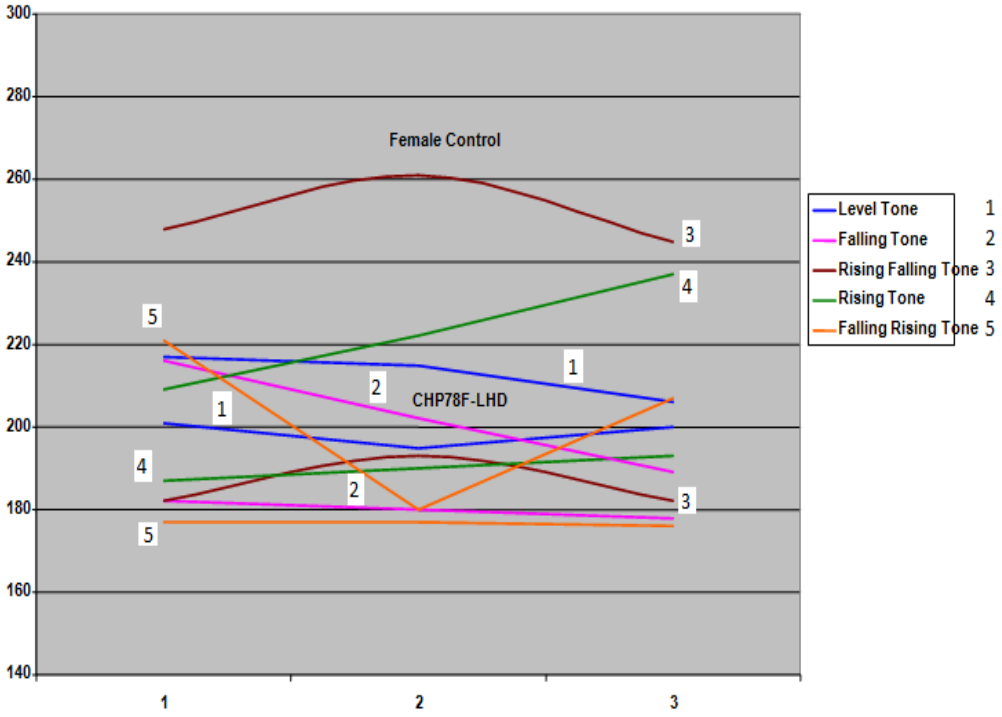
- Except one tone i.e. Falling- Rising ,which starts at a much lower level and then acquires the requisite contour, all other tones start at different levels irrespective of the contour required.

- The contrast between the five tones is maintained by varying the levels using a much bigger range across tones, rather than variations within the same tone to get the right contour.
- The range is about 72 Hz, with an average pitch of 192 Hz, -43 and + 29. Within the same tonal phoneme the range is + 10 Hz only except in case of Falling- Rising tone.
- The rising tone has actually become a falling tone in this case too, starting at a high pitch of 216 Hz.

In fact it appears that for both these cases of RHD, the rising, falling, or a combination of the two contours are hard to achieve; and phonemic contrast seems to be dependent on levels rather than contours.
For these two cases of RHD, it seems easier to maintain distinctive contrast between pitch levels rather than contours.

Case: CHP78F –LHD

The average pitch of CHP78F is at 184 with the lowest point at 176 and the highest point at 193 for 2nd to 5th tones i.e. -8, +9, in the range of 17 Hz. Level tone is at 206 to 196 and the variation is ±5. Falling tone is going down from 182 to 178 i.e. the fall in pitch is an insignificant -4 Hz only. Rising-Falling tone starts from 182 to 193 and goes down to 182 and the rising and falling points are +11 and -11 Hz which is also very small. Rising tone is going at 187 up to 193 and the rise in pitch is +6 Hz only, which is as good as level tone. Falling-Rising tone is around 177 in two points to 176 with practically no falling and rising, becoming a flat / level tone. Hence with the exception of the 3rd tone i.e. Rising- Falling contour with +11, -11, all the tones are produced like level tones with a variation of +/- 1 to +/- 6 Hz only. The contrast between the tones seems to come from the level at which the tones are starting, with 10 Hz lower for the falling-Rising and 10 Hz higher for the Level tone, and there is very little difference between the other three tones, the 2nd, 3rd and the 4th.



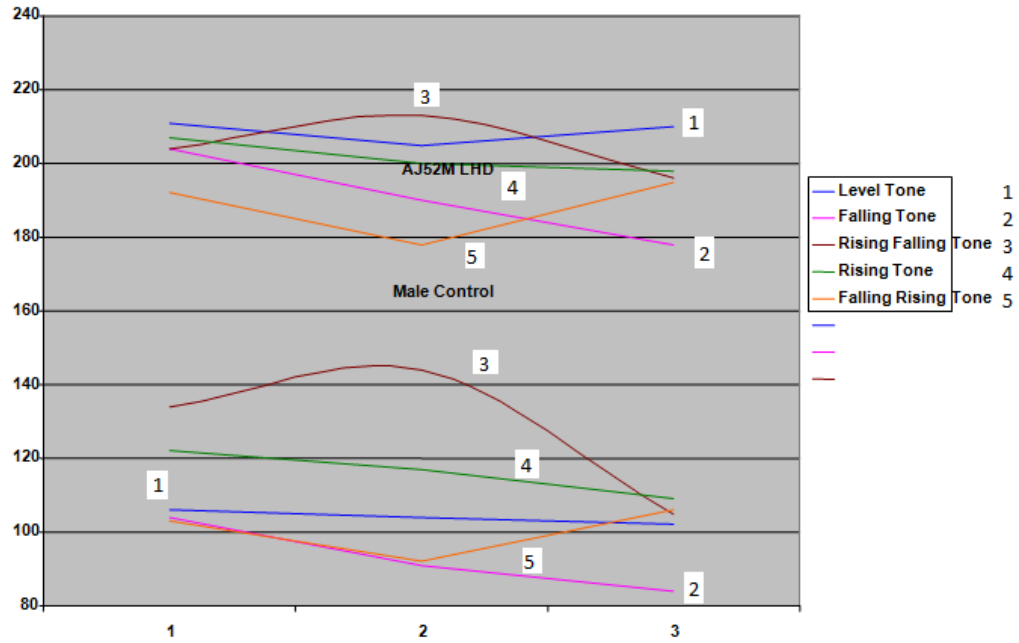
Case of CHP58F in comparison with Female Control

- In this case the first tone i.e. level tone is pronounced, as level but at a higher level than the rest of the four tones. The 2nd, 3rd, 4th, 5th tones show a range of AV 184, +9,-8, i.e. a range of only 17 Hz. This is significant because the case is LHD with a mild dysarthria.
- The 3rd tone, i.e. Rising –Falling tone has a contour of +11, -11, and the other tones are like level tones.
- The average pitch level is 182 and except the Level tone, all are starting at 182 +/-5 Hz only. The Level tone which should be in the mid zone starts at a higher pitch, 182 +20Hz, -5 in the middle and +5 at the end, like a High- Level tone.
- The impact of LHD and dysarthria on the production of tones is evident in this case. Although there is no marked aphasia with practically no language deficit with a 100% score on comprehension of language and tonal contrasts, 20 out of 30 in the production of tonal contrasts (in 15 words with different tones), the mild dysarthric condition makes it difficult for the subject to produce the tones in requisite range and contours.

Comparison of Fundamental frequencies of vowels at the Word levels between Male control and all male Stroke cases (All LHD) individually:

Case: AJ52M- LHD

This male speaker has a high pitched voice. The average pitch of AJ52M is at 198 with the lowest point at 178 and the highest point at 213 i.e. in the range of -20 and +15. Level tone is at 223 to 205 and the variation is ± 9 Hz. Falling tone is going from 204 down to 178 i.e. the fall in pitch is -26 Hz. Rising-Falling tone starts from 204 to 213 and falls down to 196. The rising and falling points are +9 and -17 which is a very small range, but acceptable, as compared to the male normal control of +8 and -15. Rising tone goes from 207 down to 198 and the fall in pitch is -9 but in fact this tone should be rising up. Falling-Rising tone goes down from 192 to the point at 178 and up to 195. The falling and rising points are -14 and +17.



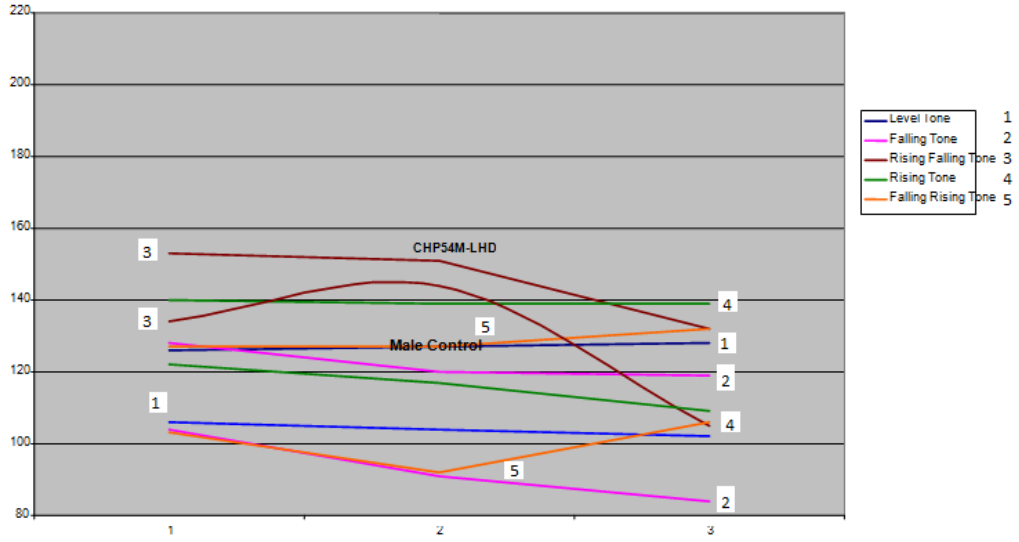
Case of AJ52M in comparison with Male Control

- Generally a small range of pitch i.e. 35 Hz is used for all tonal contrasts.
- Except one tone i.e. Rising tone which is mispronounced as Falling tone (i.e. -9 Hz), the other tones are pronounced with correct change in tonal contour, although in a smaller range.
- His tonal productions show clear dysarthric condition but perception of tonal contrasts and other comprehension test results show no aphasia.

- Except F-R tone all the other tones start at a higher level i.e. between 204-215 Hz., unlike the F/M control with all tones except Raising -Falling start around the same pitch/ Rising -Falling at a higher pitch.

Case: CHP54M-LHD

The average pitch of this case is 134 Hz. with the lowest point at 119 and the highest at 153 i.e. in the range of -15 and +19 Hz. Level tone is at 130 and the variation is ±4.5. Falling tone starts with 128 and falls down to 119 i.e. the fall in pitch is only -9 Hz. Rising – Falling tone should be like up and down in pitch but it remains around 153, 151 and in the second half goes down to 132. Rising tone is at 140 – 139 like level tone. The reason could be that this case is LHD stroke patient. In the case of Falling-Rising tone, there is no fall in pitch in the first half at 127 Hz and then the pitch level rises up to 132. We can see that the difference in value is only +5 Hz.



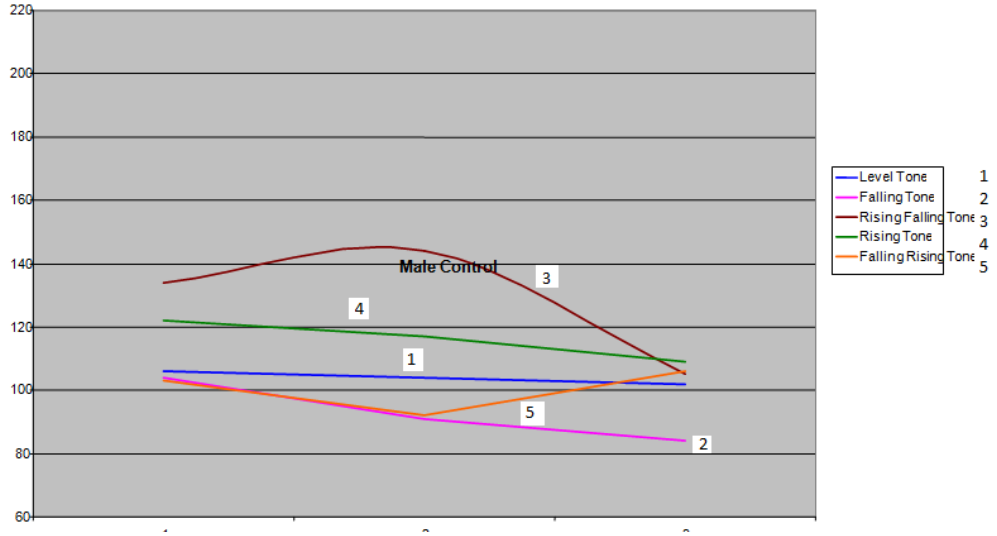
Case of CHP54M in comparison with Male Control

- Small pitch range across tones; all tones are produced with a range of 34 Hz. Only.
- Small pitch range even within tones such as Rising pronounced like Level tone, Falling, Rising-Falling tones both show a slight lowering of pitch at the end; Falling-Rising tone also, is almost like a Level tone with a slight increase an pitch towards the end, all becoming nearly flat / level tones.

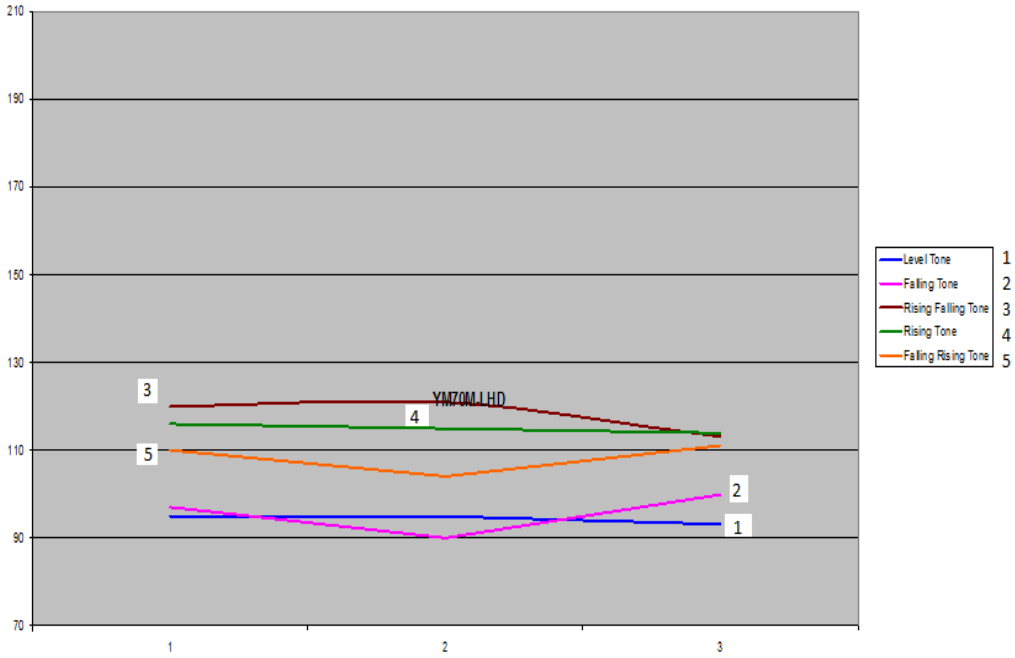
Case: YM70M-LHD

The average pitch is 108 Hz with the lowest point at 95 and the highest point at 121 i.e. in the range of -13 and +13. Level tone is at 96 and the variation is ±4. Falling tone should be falling down but the pitch goes from 97 to 100 i.e. 3 which is like a Level tone. Rising-Falling tone is at 120, 121 and falls down to 113 i.e. -8 which appears to be only a falling tone, on close to level tone. Rising tone is in the same range of from 116 to 114 and the difference is -2 Hz which is also like a level tone. Falling-Rising tone is also pronounced like a Rising tone with a rise in pitch by + 10 Hz. to 111 like the Rising tone and the different points are at +4 and +7 respectively which is a Rising tone and not a Falling-Rising tone.

Male control:



Case: YM70M-LHD



Case of YM70M in comparison with Male Control

- Small pitch range across tones; all tonal contrasts are pronounced within an average range of 26 Hz only.
- Small pitch range even within tones such as Rising, Falling, Rising-Falling or Falling-Rising tones, all become nearly flat / level tones with a variation of + 3 Hz to + 10 Hz.
- In trying to achieve the tonal contrasts the patient starts these tones at different levels; only Level and Falling tones start around the same level, at 95-97 Hz, and the other three tones start at 100, 116, and 120.
- Like other cases under study for this person also tones at different levels are easier than contours of different kinds.

Findings:

Generally speaking, all the six cases show practically no language deficit/ aphasia symptoms, and are able to communicate with fairly easy to comprehend articulation, with very mild dysarthric condition. All the subjects show the effect of stroke on their

pitch function i.e. tones to a greater or lesser extent. So, we decided to examine the two cases with RHD and four cases of LHD separately.One case who was left handed and suffered LHD separately in comparison with the other two male, right handed, LHD subjects. Comparison between male and female cases would not reveal much because we do not have an equal number of male and female LHDs or male and female RHDs, for the results to be valid.

The two cases of RHDs show that the pitch contours and changes in contours are hard to maintain, whereas levels are easier to handle; and that Rising tone becomes a high tone with a level or a slightly falling contour; both the subjects pronouncing this as a high-level or high tone with a slight fall.

All the other subjects 3F and one Male had LHD, and all these subjects show a much smaller pitch range in use for all the five tonal contrasts. The range used across the five tones as well as the range used within specific tones is rather small. The contours appear to be level tone/ flat tones within a small range which seems to be the influence of mild dysarthric condition as well as LHD. All the subjects can comprehend tonal contrasts, but are not able to produce the Rising and Rising-Falling or Falling and Falling-Rising, tones as distinct from each other.

One left handed person with LHD is behaving more like RHDs in his use of pitch levels in contrast, rather than contours
The findings are tentative in nature due to a small sample size but they are interesting and important because they do indicate the impact of LHD/ RHD on tones even if there are no clearly marked, visible signs of aphasia or dysarthria. Perhaps pitch manipulations are more vulnerable, and get affected by the injury to the brain, as in cases of stroke under study, before any other aspect of communication gets affected.

References

Abramson, Arthur S. 1962. The Vowels and Tones of Slandered Thai: Acoustical Measurements and Experiments. In *Anthropology, Folklore, and Linguistics, Publication20.* Bloomington: Indiana University Publications.

Fromkin A. V. 1978. *Tones: A Linguistic Survey*. United Kingdom Academic Press, INC (London) LTD .

Gandour, J.1987. Tone Production in Aphasia. In J. Ryalls (ed.) *Phonetic Approaches to Speech Production in Aphasia and Related Disorders.* Boston, MA: College-Hill Press.45-57.

Gandour, J., etal. 1993.Anticipatory Tonal Coarticulation in Thai Noun Compounds after Unilateral Brain Damage. *Brain Lang.* 45. 1–20.

Ladefoged, Peter. 1962. *Elements of Acoustic Phonetics*.The University of Chicago Press.

Liégeois-Chauvel, etal.1998. Contribution of Different Cortical Areas in the Temporal Lobes to Music Processing. *Brain,* 121. 1853–1867.

Missig,J.2006.Lateralization of Tone Processing in Tonal Language Speakers. *Cognitive Neuropsychology.* 85-414.

❑❑❑