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TONE PERCEPTION
OF
NONBRAIN DAMAGED AND
BRAIN DAMAGED
CANTONESE SPEAKING ADULTS

by

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ABSTRACT

A perceptual study of lexical tone was conducted to evaluate the extent and nature of tonal confusion in nonbrain damaged and brain damaged native speakers of Cantonese, a tone language which has six contrastive tones. A total of 47 subjects participated: seven aphasics, ten right brain damaged and 30 normal control subjects. Three tests were presented: tone discrimination, tone identification and lexical comprehension. The right brain damaged subjects performed similarly to the normal group whereas the aphasic group scored consistently and significantly lower than the other groups across three tests. The results suggest that tone perception deficits of left brain damaged subjects can be attributed specifically to pathology in their language dominant hemispheres rather than to a general brain damage effect. No difference in performance among the aphasic could be attributed to a specific aphasic syndrome. Besides tonal confusions, phonological segmental and semantic comprehension deficits were evident in the aphasic group.

INTRODUCTION

Tones are used to make phonemic contrasts in tone languages. Tones function similarly to both consonants and vowels in giving minimal meaningful difference. These generally are conceived to be a function of the left hemisphere. However, tones are a local modulation of fundamental frequency, such as musical notes. These are often assumed to be the domain of the right hemisphere (Ryalls and Reinvang, 1986). What kind of laterality effects would be observed for stimuli which are linguistic and tonal as well ?

Recent studies of cerebral lateralization of processing linguistic prosody have attracted extensive attention. However, inconclusive results are found. Some studies of the perception of linguistic prosody supported left hemisphere lateralization while others supported right hemisphere lateralization. Blumstein and Cooper's (1974) results from five dichotic tasks demonstrated left ear advantages (LEA) for the linguistic intonation contours presented with or without the phonetic context. Across several experimental tasks demanding the simultaneous processing of verbal and tonal (musical) material by 16 trained musicians, Goodglass and Calderon (1977) also found left ear advantages for the tonal component while independent right ear advantages for the verbal component of stimuli. Behren (1985) obtained contrastive results. When normal subjects were asked to discriminate stress contrasting real-word minimal pairs, right ear advantages (REA) occurred. Left ear advantages (LEA) were found when stimuli were filtered with phonetic and semantic content. No ear preference was detected when nonsense words were used. This showed that laterality for stress placement is influenced by the amount and types of segmental and semantic cues in the stimuli.

Besides results from experimental studies of dichotic listening in normal subjects, different impressions of hemisphere lateralization were obtained from clinical observations. Weitraub, Mesulam and Kramer (1981) found that right brain damaged subjects had significant impairment in ability to discriminate contrasting phonemic stress patterns in single words. In contrast, Emmorey (1987) discovered that left CVA aphasics performed significantly worse than both normal controls and right brain damaged nonaphasics in comprehending the stress contrast between noun compounds and noun phrases. Baum et al. (1982) demonstrated that the Broca aphasics performed worse than normal subjects in comprehending sentences that were disambiguated by stress changes. These observations suggest that a higher failure rate in stress differentiation of aphasics would be expected if stress is processed by the left hemisphere. It is because the receptive and expressive language processes of aphasics are impaired due to focal brain lesions in left hemisphere which are primarily responsible for the language function.

Literature reviewed so far on sentential intonation (right hemisphere dominant) and stress differentiation (left hemisphere dominant) mainly focuses on the cerebral lateralization of prosody processing of English speakers. English is a non-tonal language in which pitch changes do not affect semantic meaning. In Cantonese, a tonal language, pitch changes are used to signal and contrast completely different meanings for the same phoneme. Moreover, Cantonese is rich in tonal contrasts consisting of two contour and four level tones (Fok, 1974).

Tone 1: 55 / 53	(high level/ high falling)
Tone 2: 35	(high rising)
Tone 3: 33	(mid level)
Tone 4: 21	(low level)
Tone 5: 23	(low rising)
Tone 6: 22	(low mid level)

These differences suggest the value of investigating the possible cerebral dominance for prosody in Cantonese.

Generally, the results of the following few single cases and experimental studies reveal that a tone perception deficit occurred with left brain damaged patients. They suggest a left hemisphere lateralization for tones in native speakers of tone languages.

April and Han (1980) reported a case study of a right handed, non-fluent, Cantonese-English crossed aphasic. The patient scored 80% and 70% correct on Cantonese tonal identification and discrimination tasks respectively. However, no definite conclusion of tone perception deficit could be drawn since no comparison was made with nonaphasic controls. Naeser and Chan (1980) examined a right handed, monolingual Chinese aphasic. A tone perception deficit was revealed. When Mandarin tones 1 to 4 were used, the patient scored only 55% correct (compare to 100% in a non-aphasic adult Chinese control). This held even for words where the patient was 100% or nearly 100% correct in character-picture matching and tone repetition. Gandour and Dardarananda (1983) found that the performance of tone perception on Thai words of four left brain damaged aphasics differed significantly from that of a normal control subject while the performance of the right brain damaged patient did not. Hughes, Chan & Ming (1983) studied 12 Chinese right hemisphere damaged patients who performed reasonably well in identifying Mandarin tones that indicated different meanings for the same phoneme.

Van Lancker and Fromkin (1973) studied the lateralization effects in both Thai and English normal subjects. Dichotic listening tasks with contrasting tones, words of the same tone, and pitches (tone without the linguistic context, i.e. hum) were conducted. They found that both tone words (Thai words differing only in tone) and consonant words (Thai words contrasting only in initial consonant and having the same tone) showed significant left hemisphere lateralization in Thai speakers while hum showed no ear effect. The results from English speakers suggested that the consonant words gave the usual right ear effect, while the tone words and the hums did not. This showed that perception of Thai tones by Thai native speakers was lateralized to the left hemisphere to at least the same degree as consonant-vowel words. It was concluded that when pitch was processed linguistically, left hemispheric specialization occurred as for other language stimuli.

The objective of this study is to examine the tone perception of native Cantonese speakers with and without brain damage. In this study, I hope to answer the following questions:

1. Is lexical tone perception of native speakers of Cantonese associated with the left hemisphere, like other linguistic elements ?

2. Can tone perception reflect a general brain damage effect or a pathology in the language-dominant hemisphere ?

3. What will be the extent and nature of confusion of Cantonese tones by nonbrain and brain damaged native speakers of the language ?

METHOD

Subjects

A total of 47 subjects participated in the study: seven left brain damaged aphasics, ten right brain damaged nonaphasics and 30 normal control subjects. The Cantonese Aphasia Battery's scores (Yiu, 1989) determine diagnostic categories of aphasic subjects. The aphasics included three Broca's, two transcortical motor and one anomic. One of the aphasics had not completed the Battery and thus he was not classified.

All the brain damaged subjects had unilaterally cerebral vascular accident (CVA), and were at least three months post onset. Their lesion localizations were provided either by neurologists' diagnosis or CT scan.

All subjects were adults above 30 of age. They were monolingual Cantonese native speakers and right handed. Their hearing was within normal limits. The pure tone averages (0.5k, 1k, 2k Hz) of their better ears were less than 40 dBHL. Table 1 summarizes the subjects' medical histories and personal particulars.

TABLE 1. DESCRIPTIVE DATA FOR SUBJECTS

Clinical type	Ss. No.	Sex	Age (years)	Post onset time (months)	Etiology
Normal	30	F=18 M=12	Range=49-84 Mean =71.07 SD =+9.28	---	---
Right brain damaged	10	1 M	69	41	* Clinical
		2 M	76	38	Clinical
		3 F	53	4	Infarct
		4 M	68	4	Haemorrhage
		5 M	59	6	Haemorrhage
		6 F	67	3	Infarct
		7 M	59	6	Infarct
		8 M	67	6	Clinical
		9 F	74	3	Haemorrhage
		10 M	74	4	Clinical
		F=3 M=7	Range=53-76 Mean =66.60 SD =+7.5	Range=3-41 Mean =11.40 SD =+14.86	
Left brain damaged	7	1 M	61	3	Infarct
		2 M	65	6	Infarct
		3 M	62	50	Clinical
		4 M	45	16	Clinical
		5 M	69	21	Clinical
		6 F	39	4	Embolism
		7 F	66	5	Infarct
		F=2 M=5	Range=39-69 Mean =58.14 SD =+11.47	Range=3-50 Mean =15.00 SD =+16.87	

* Clinical: Diagnosis was made by neurologists. No C-T scan was done.

__Stimuli__

The present study included three sets of tonal tests: tone discrimination, identification and So & Varley Lexical Comprehension (So & Varley, 1991). All stimuli were presented by an adult female native speaker of Cantonese and were recorded on an AR-X 60 tape (Appendices 1 & 2 provide details of the stimuli).

The tone discrimination test consisted of 36 pairs of [ji] sounds which were presented in random order. Six of them were identical tone pairs and remaining 30 tone pairs had minimal contrastive tone differences.

The tone identification test included totally 30 stimuli arranged in random order. They were five repeated sets of six Cantonese tones with the same citation form:

[ji_1]	"doctor"	(醫)
[ji_2]	"chair"	(椅)
[ji_3]	"spaghetti"	(意)
[ji_4]	"child"	(兒)
[ji_5]	"ear"	(耳)
[ji_6]	"two"	(二)

The Cantonese Lexical Comprehension Test consisted of 39 stimuli. The stimuli included all possible tone pairs. Each one was presented with three distractors: tonal, segmental and semantic.

<u>Procedure</u>

Each subject was tested individually in a quiet room. The test tapes were played on a Sony TCM 5000 ev cassette player. The stimuli were presented to the subjects through KG K135 headphones connected to a portable Madsen Midi Mate 602 pure tone audiometer to monitor the output amplitude. Signal were presented unilaterally at the most comfortable listening level. The experimenter varied the interstimulus interval to ensure that each subject proceeded through the tests at a comfortable pace. One repetition was allowed for any stimulus not heard clearly. The tests were administered in a counter-balanced design.

Tone discrimination test used a "same-different" (AX) procedure. To ensure that the subjects understood the test requirements, they had to perform at least four out of five practice trials correctly before proceeding with the test proper.

In tone identification test a close set multiple choice procedure was used. The subjects were asked to select one photo out of six. The target stimulus was presented by embedding in a carrier phrase.

[tsi$_2$ ha$_5$ jix pei$_2$ ŋɔ$_5$ t^{h}ɐi$_2$]

指 吓 __ 俾 我 睇

Point to __ for me to see.

The subjects were asked to point to the referent of each stimulus presented auditorily. Prior to the actual test, the subjects were requested to point to appropriate photos for five practice trials of stimulus words to insure they could perform the test. In So & Varley Lexical Comprehension Test, the subjects were asked to select one photo out of four. As in the tone identification study the target stimulus was presented by embedding in a carrier phrase. The subjects were asked to identify each auditorily presented stimulus by pointing to the appropriate picture.

RESULTS

Tone discrimination test

In a same-different discrimination test, all subjects may make two types of incorrect responses. They may respond "dissimilar" to stimuli that are identical (false dissimilar) or they may respond "identical" to stimuli that are in fact different (false identical). The false dissimilar errors were taken as a measure of subjects' guessing rate, i.e. as an index of his ability to perform the test reliably (Blumstein, et al., 1977). Guessing errors were submitted to an Group x Sex analysis of variance. There were no significant differences in guessing rate among subject groups, $F(2;40) = 2.42$, $p = 0.1$, nor among aphasic types. Table 2 presents a summary of the performance of the three subject groups in tone discrimination test.

TABLE 2. MEAN TONE DISCRIMINATION SCORES OF THE THREE SUBJECT GROUPS

Subject	Normal	RBD	LBD
Identical (out of 6)	5.90	5.80	5.57
Percentage	98.33%	96.67%	92.83%
Range	4 - 6	4 - 6	4 - 6
SD (±)	0.40	0.63	0.79
Dissimilar (out of 30)	27.57	28.10	24.14
Percentage	91.90%	93.67%	80.47%
Range	24-30	25-30	19-27
SD (±)	1.48	1.66	2.61
Total score (out of 36)	33.47	33.90	29.71
Percentage	92.97%	94.17%	82.53%
Range	28-36	29-36	23-33
SD (±)	1.57	2.02	2.29

False identical scores were submitted to a Group x Sex analysis of variance with age as a covariate followed by Tukey group comparison tests where appropriate. Results of this analysis revealed a significant Group effect, $F(2;40)=7.81$, $p=0.001$. In tone discrimination test, age was not a significant factor as a covariate, $F(1;43)=2.32$, $p=0.13$.

The left brain damaged aphasic subjects scored significantly higher than the other groups in the mean false identical errors, $t(35)=3.01$, $p=0.005$; $t(15)=2.85$, $p=0.012$. Performance of the right brain damaged subjects did not differ significantly from the normal control subjects, $t(38)=-0.96$, $p=0.34$. No significant difference was observed among different left brain damaged aphasic types of classification, $F(2;5)=1.59$, $p=0.34$. The hypothesis that there was a direct relation between tone discrimination and auditory comprehension was tested by computing the correlation between these two variables. The Pearson Product Moment Correlation was 0.26 which meant that discrimination performance could not predict auditory comprehension at all well. The analysis of tone discrimination across the aphasic groups indicated that different aphasic types, Broca's, transcortical motor and anomic, were impaired to a similar extent on this test.

Table 3 shows the distribution of responses across the three subject groups on tone discrimination test. To test whether the number of correct discrimination responses for each tone pair was significantly higher than the chance level, binomial distribution test was employed.

TABLE 3. DISTRIBUTION OF RESPONSES ACROSS THE THREE SUBJECT GROUPS

Tone pairs	Normal correct	Normal incorrect	RBD correct	RBD incorrect	LBD correct	LBD incorrect
Identical						
1/1	30	0	10	0	7	0
2/2	29	1	9	1	7	0
3/3	29	1	10	0	7	0
4/4	29	1	10	0	7	0
5/5	30	0	10	0	* 5	2
6/6	30	0	10	0	6	1
Dissimilar						
1/2	60	0	20	0	14	0
1/3	59	1	20	0	+10	4
1/4	60	0	20	0	13	1
1/5	60	0	20	0	12	2
1/6	60	0	20	0	14	0
2/3	58	2	20	0	14	0
2/4	59	1	19	1	14	0
2/5	*35	25	*12	8	* 5	9
2/6	60	0	20	0	12	2
3/4	58	2	20	0	11	3
3/5	57	3	20	0	14	0
3/6	*34	26	14	6	* 7	7
4/5	59	1	20	0	13	1
4/6	55	5	18	2	* 9	5
5/6	52	8	18	2	* 9	5

+ means NOT statistically significant at $p < 0.05$.
* means NOT statistically significant at $p < 0.10$.
This means that the number of correct responses was not significantly higher than the chance level.

For the normal control and the right brain damaged subjects, tone pairs 2/5, 3/6 were easier in causing confusion. Besides those, the left brain damaged aphasic subjects also found 5/5, 1/3, 4/6, 5/6 difficult and responded at the chance level.

To determine whether the left brain damaged subjects responded significantly more at chance level than the other groups, Chi-square tesst was used. Statistical significance was not found, $X^2 = 3.70$, n.s.. The null hypothesis that the subjects responded by chance is independent on the brain damage effect is not rejected. Approaching significance is obtained when data were analysed by using binomial distribution test, $z = 0.71$, $p = 0.24$. This suggested that the left brain damaged aphasics operated nearly by chance in judging similarity of tone pairs.

Tone identification test

Table 4 shows the overall identifiability of Cantonese tones, measured by mean percentage of correct identification responses pooled across the six tones. The results differ greatly between aphasic and nonaphasic subjects. The mean correct response of the left brain damaged aphasic subjects, 41.43%, was nearly and less than one half of the right brain damaged, 74%, and normal control groups' scores, 84.78% respectively.

TABLE 4. THE MEAN CORRECT RESPONSES OF THE THREE SUBJECT GROUPS

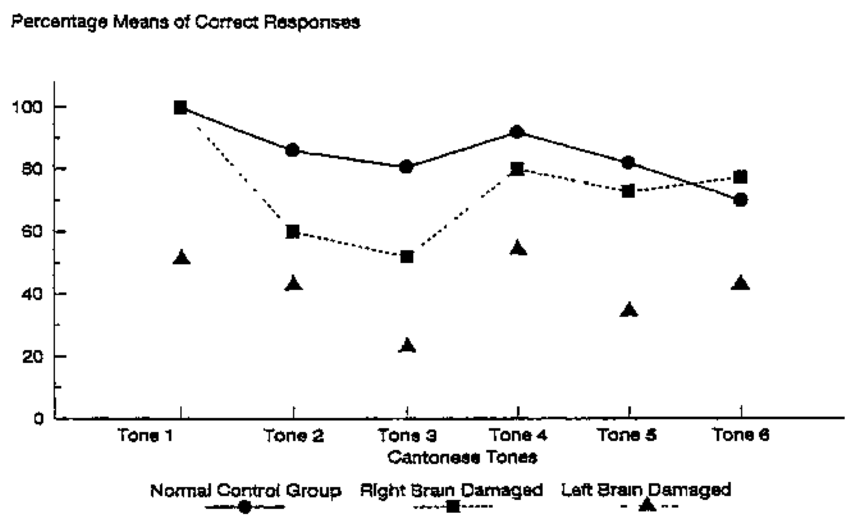
Subject	N	Mean (out of 30)	SD
Normal	30	25.77 (84.78%)	± 3.13
RBD	10	22.30 (74.00%)	± 2.00
LBD	7	12.29 (41.43%)	± 3.09

To determine whether there were significant differences in performance among the three subject groups, an analysis of variance was performed on the frequency of correct responses pooled across six Cantonese tones. Results showed that the means of correct responses both for differences in age and for brain damage contributed significantly to variances, $F(1;40) = 14.65$, $p < 0.0001$, $F(2;40) = 46.86$, $p < 0.0001$. Age and lesion site had main effects in the subjects' performance on tone identification. The left brain damaged subjects' mean score was statistically significantly lower than the nonaphasic groups. The right brain damaged subjects' mean score was marginally significantly lower than the normal control group. This suggests that brain damage to either hemisphere would cause significantly poorer performance in tone identification test, with a greater degradation of the left side.

Given the limited number of left brain damaged subjects in the present study, three Broca's, two transcortical motor and one anomic aphasics, no claim can be made regarding the relationship between diagnostic aphasia categories and deficits in the perception of Cantonese tones. However, the severity scores (taken as the aphasic quotient in the auditory comprehension of Cantonese Aphasia Battery) of the left brain damaged aphasics showed a high positive correlation, r=0.78, with their tone identification scores. No main effect could be found with the post onset time.

Figure 1 shows the identifiability of individual Cantonese tones for the three subject groups. It was measured by the percentage of correct identification responses in the cells along the diagonals of their confusion matrices. This reveals the relative ease of identifying individual tones across different subject groups.

FIGURE 1. PERFORMANCE MEANS ACROSS SUBJECT GROUPS CORRECT TONE IDENTIFICATION RESPONSES



The mean correct identification scores across the three groups followed similar trends although they differed quantitatively. Table 5 ranks the difficulty of identifying individual tones among the three subject groups. Tone 1 was the most easiest. Both the normal and the right brain damaged groups scored 100% while the aphasics scored 51.43% which was the second easiest after tone 4, 54.29%. Tone 5 was the most difficult for the normal control group, 72.7% whereas both the left and the right brain damaged groups scored the lowest in tone 3, 22.86% and 52% respectively.

TABLE 5. RANK ORDER OF INDIVIDUAL TONES FROM HIGHEST (1) TO LOWEST (6) AVERAGE PERCENTAGE OF CORRECT IDENTIFICATION RESPONSES AMONG THE THREE SUBJECT GROUPS

Subject	N	High level	High rising	mid level	Low level	Low rising	Low mid level
Normal	30	1	3	4	2	6	5
RBD	10	1	5	6	3	2	4
LBD	7	2	# 3.5	6	1	5	# 3.5

means identical scores

Table 6 shows confusion matrices of all subject groups. Both the normal control and right brain damaged subjects confused the following tone pairs in a significant level as calculated by the formula used by Fok (1974, P.61). Suppose n out of N presentations were correct, the remaining score would be evenly distributed over the remaining five cells if the confusion was made by chance.

Significant number of errors:

$$\frac{N - n}{5} + 1.96\sqrt{\frac{N - n}{5}\left(1 - \frac{N - n}{5N}\right)}$$

5 <—> 2 (high rising and low rising tones)
3 <—> 6 (mid level and low mid level tones)
6 <—> 4 (low level and low mid level tones)

TABLE 6. CONFUSION MATRICES OF IDENTIFICATION RESPONSES IN PERCENTAGE FOR THE THREE SUBJECT GROUPS

Responses	Target Stimuli						
Normal	1	2	3	4	5	6	N
1	100						30
2		63			10		30
3			60	(7)		23	30
4			(3)	80		(17)	30
5		30	(13)		90		30
6		(7)	23	13		60	30
RBD	1	2	3	4	5	6	N
1	100						10
2		60			16		10
3			52	(6)	(2)	18	10
4		(2)	(4)	80		(12)	10
5		34	(8)		82		10
6		(4)	36	14		70	10
LBD	1	2	3	4	5	6	N
1	51	(6)	(14)	(11)	(3)	(3)	7
2	(14)	43	(9)	(6)	31	(11)	7
3	23	(9)	23	(6)	(14)	(6)	7.
4	(6)	(3)	(11)	54	(3)	(17)	7
5		31	(20)	(9)	34	23	7
6	(6)	(9)	23	(14)	(14)	43	7

() means NOT significant at $p < 0.05$ calculated by the formula suggested in Fok (1974).

In addition to the above confusion, the aphasic group confused between tone 1 (high level) and 3 (mid level), tone 6 (low mid level) and 5 (low rising) with a significant degree.

Furthermore, there were other confusions of tone pairs which did not reach a significant level. This implies that left brain damage could cause an extensive disruption in tone perception.

The finding suggests that the aphasics' performance primarily distinguished from that of the normal Cantonese adults in terms of number rather than kind of errors; i.e. primarily a quantitative rather than a qualitative difference. Despite all aphasic subjects making numerous errors on mid level and low mid level, high and low rising tone words, no two aphasic groups were significantly similar in their overall rank order of the six tones from the highest to the lowest percentages of correct identification responses.

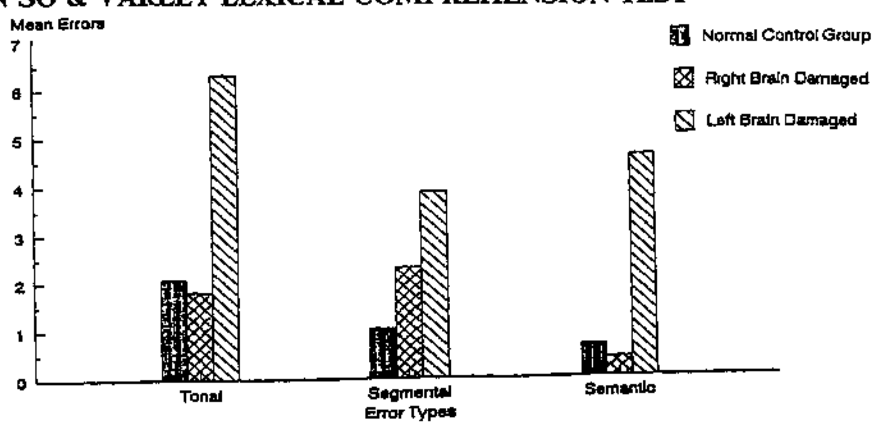
So & Varley Lexical Comprehension Test

Table 7 summarizes the performance of all subject groups in So & Varley Lexical Comprehension Test. A Group x Sex analysis of variance was conducted followed by Tukey group comparison tests. The results revealed that there was a brain damage main effect, $F(2;40) = 64.24$, $p < 0.0001$ while the mean age difference computed as a covariate among the subjects had no significant effect on the correct scores, $F(1;40) = 0.159$, $p = 0.692$. The normal control and the right brain damaged subjects made significantly more correct responses than the left brain damaged subjects, $p < 0.05$. No significant difference existed between the normal control and the right brain damaged group. In addition to correct responses three types of errors were distinguished: tonal errors, phonological segmental errors and semantic errors (Figure 2).

TABLE 7. THE PERFORMANCE MEANS ACROSS THE THREE SUBJECT GROUPS IN THE LEXICAL COMPREHENSION TEST (PERCENTAGE)

		Correct Responses	Error Types		
Subject	N	Target	Tonal	Segmental	Semantic
Normal	30	35.23 (90.34%)	2.07 (5.30%)	1.03 (2.65%)	0.67 (1.71%)
Range		31-39	0-6	0-4	0-4
SD ±		2.57	1.46	1.25	0.99
RBD	10	34.50 (88.46%)	1.80 (4.62%)	2.30 (5.90%)	0.40 (1.02%)
Range		32-37	0-5	0-6	0-1
SD ±		1.65	1.99	2.16	0.52
LBD	7	24.29 (62.27%)	6.29 (16.12%)	3.86 (9.89%)	4.57 (11.72%)
Range		15-33	2-10	0-9	2-10
SD ±		7.43	3.09	3.13	2.99

FIGURE 2. ERROR RATE PERFORMANCE OF THE THREE SUBJECT GROUPS IN SO & VARLEY LEXICAL COMPREHENSION TEST



The critical result in this test was the distribution of different kinds of errors. Selection of tonal distractors implies that the subjects could perceive tonal components of the stimuli correctly while having segmental confusions and the reversed for the choice of segmental distractors. The selection of semantic distractors indicates that the subjects knew the semantic categories that the stimuli belong to. Either the number of segmental or tonal errors can reflect disruption at phonological level while semantic errors can reflect lexical confusion while perceiving tone and phonological segment correct.

The data of error types were submitted to an one way analysis of variance followed by Tukey group comparison tests where appropriate. The left brain damaged aphasic subject group scored significantly higher than the nonaphasic groups for all error categories. The right brain damaged group scored as many segmental errors as the left brain damaged aphasic group. No age main effect was detected, $F(1;40) = 0.159$, $p = 0.7$.

To determine whether errors were distributed evenly across tonal, segmental or semantic categories, Chi-square tests were performed within groups. In both nonaphasic groups, the error scores were not evenly distributed, $X^2 = 25.2$, $p < 0.005$ for the normal control and $X^2 = 33.6$, $p < 0.005$ for the right brain damaged subjects. In contrast, the number of errors was not significantly higher in one of the error categories than the others for the left brain damaged subjects, $X^2 = 4.45$, n.s.. To determine which error type was significantly more than the others, t-test was used to compare three error types. In the normal control group, the result shows that tonal errors were significantly more than the other errors. The amount of segmental errors was similar to semantic ones.

In the right brain damaged group, no significant difference was revealed between the amount of segmental and tonal errors. Semantic errors were less than either of them.

The left brain damaged subjects performed quite differently from the other two groups. Errors were distributed similarly in three categories, $p < 0.1$. The lexical scores had a strong positive correlation with the corresponding auditory comprehension scores, $r = 0.94$, $p < 0.001$.

In short, brain damage did not necessarily result in significant tonal confusion. Rather the side of brain lesion determined the effect. In particular the left brain damaged aphasic subjects but not the right brain damaged ones had tonal confusion. In addition, the aphasic group also manifested significant segmental and semantic confusion.

DISCUSSION

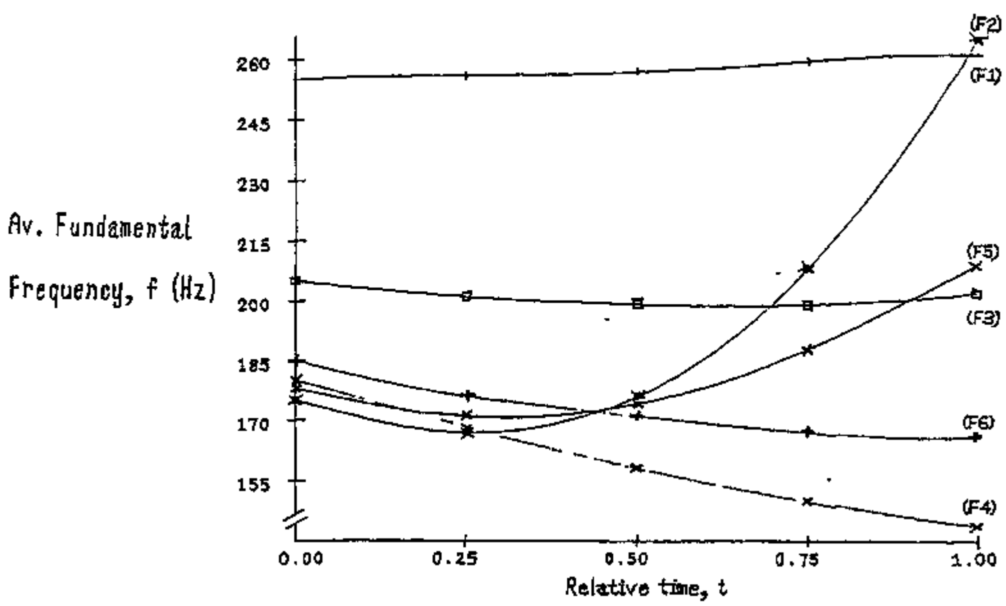
The findings of the present study demonstrate a left hemisphere dominant effect for Cantonese tone perception by native speakers of Cantonese. Tone perception appears unrelated to sex and age.

The aphasic's scores of the three tests were well above (chance level): tone discrimination was 80.47% (50%), tone identification was 41.43% (16.67%) and lexical comprehension was 62.27% (25%). The left brain damaged aphasic group scored consistently and significantly the lowest. If tones function as a part of propositional language, they are likely to be primarily served by the left hemisphere (Hughes et al., 1983). Therefore, it is expected that the left brain damaged aphasic subjects perform significantly lower than both the normal and the right brain damaged speakers of tone languages. The results of this study support that the aphasics have tone perception deficits on monosyllabic words (the Pearson moment correlation of tone identification scores with tonal errors was -0.83). Similar phenomena of aphasic's tone confusion were reported in clinical studies of tone languages, e.g. Thai (Gandour et al., 1983 & 1988), Mandarin (Naeser and Chan, 1980; Packard, 1984), and Cantonese (April and Han, 1980; Yiu, 1989).

Tone confusion and phonetic features of Cantonese tones

A similar pattern of significant tone pair confusions in both tone discrimination and identification tests across the three subject groups suggests that aphasics' tone perception deficit differs quantitatively rather than qualitatively from normal control and the right brain damaged subjects. Besides those tone pairs that are particularly confused in tone discrimination, errors involved appear to be extensive and scattered in tone identification test. Almost every tone pair was involved. Confusion was observed between maximally contrastive tones, which enclose the frequency range of other Cantonese tones, e.g. tone 1 and 4 (17%). Nevertheless, the confusion patterns pooled across the six tones of the aphasic group follow a similar trend demonstrated by the normal control and the right brain damaged groups'. Figure 3 helps one suggest how tone confusions might be explained by phonetic features of Cantonese tones. Fok (1974) proposed that the fundamental frequency (Fo) appears to be the main factor responsible for keeping tones distinct. The closer were the tones, the easier it was to confuse them. The comparatively high identifiability of tone 1 (high level) can be attributed to its phonetic distinctiveness. The Fo of tone 1 is relatively high in the frequency range of Cantonese tones. Thus it has the maximum perceptual separation from the other five tones. Vance (1977) reported that more tones crowd together in the lower end of the frequency range of Cantonese tones. This agrees with the present observations of more tone confusions between tone 3 and tone 6, and a slightly better discrimination between tone 1 and tone 3 (10/14) over tone 3 and tone 6 (7/14) of the aphasic group. However, unexpectedly tone 4 has high identifiability even though it falls in the lower end of the frequency range. A plausible explanation was provided by Vance (1977) who argued that tone 4 was often accompanied by creaky voice and showed a slight falling in tone shape. That is, additional features besides the difference in Fo are employed for identification.

FIGURE 3. SIX CANTONESE TONES



It is interesting to note that tone pairs which cause confusion differ mostly in height dimension, e.g. tone 2 and tone 5, tone 3 and tone 6 for all groups. In addition, the aphasic group has difficulty in discriminating tone 1 from tone 3, tone 4 from tone 6 to a significant degree. Given our limited numbers of subjects and intersubject variability, we can only speculate that slope dimension was found a more salient contrastive feature. No confusion was observed between contour and level tones of similar heights except for confusions between tone 5 and tone 6 in the aphasic group. This shows that perception of pitch gliding was relatively resistant to brain damage while the sensitivity to perceptual difference of tone height had decreased.

Tone confusion in relation to Cantonese tone sandhi rule, phonemic inventory and tone acquisition

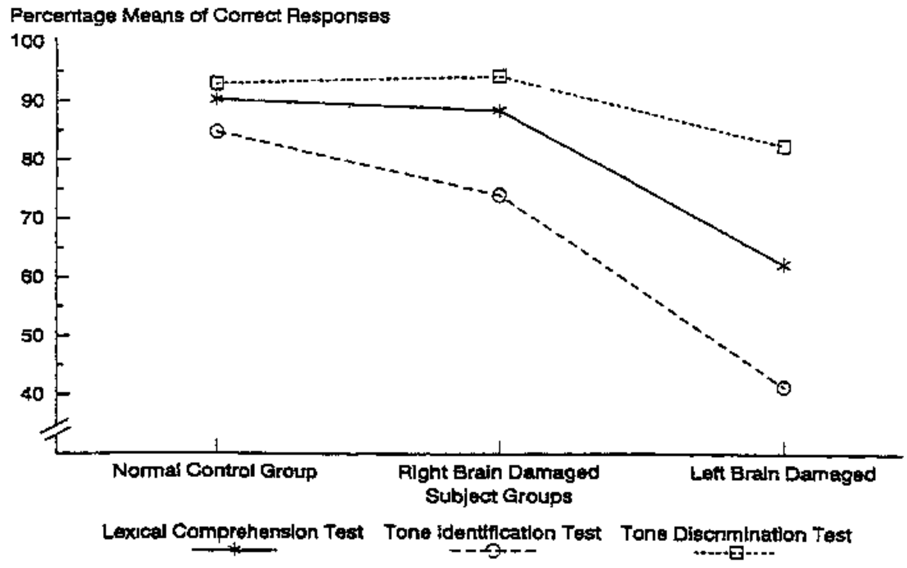
Gandour, Petty and Dardarananda (1988) have found several factors account for the differential resistance of tones. The factors are the distribution of language specific Fo trajectories in the tone space, the number of tones in the phonemic inventory and the kinds of phonological processes that particular tones undergo. Since Cantonese has few tone sandhi rules (Hashimoto, 1972), the influence of these phonological processes on it should be minimal. Our results agree that predictions about confusion are mostly based on Fo. On the other hand, the results of our study do not show that the number of tones in the phonemic inventory has any parallel relation with differential identifiability of tones. Fok (1974) ranked the frequency of occurrence of individual tones in descending order as tone 2 (high rising), tone 1 (high level), tone 6 (low mid level), tone 3 (mid level), tone 4 (low level), and tone 5 (low rising) from data samples of conversation and radio broadcasts. This sequence did not correlate with the identifiability of tones as shown in Table 7. Monrad-Krohn (1947) suggested tones which were acquired earliest would be more resistant to confusion. Concerning the tone acquisition order in relation to the comparative resistance of tones to confusion, no definite conclusion could be drawn. The present results were compared to ~~those from~~ a longitudinal study of Cantonese tone acquisition (Tse's, 1977). The patterns matched overall. Tone 1 and tone 4 were acquired first which agrees with their higher identifiability here. Tone 5 was acquired relatively late and was correspondingly more susceptible to tone confusion. Tone 2 was located in the middle. Confusions of tone 3 and tone 6 do not follow their order of tone acquisition. Since the data of the tone acquisition sequence was derived from a single case study, individual difference should be considered. More research would help elucidate the relationship between tone acquisition and the differential identifiability of tones.

Nevertheless, our results supported Edmondson, Ross, Chan and Seibert (1987)'s study. They proposed that the brain's ability to react to the acoustical properties was peculiar to a language, i.e., tone vs. nontone, during the experience of language acquisition.

Brain damage effects

Unexpectedly the right brain damaged subjects scored significantly lower than the normal group in tone identification test, $p = 0.04$. In contrast, the right brain damaged subjects performed within the normal range in tone discrimination and in So & Varley Lexical Comprehension Test. The significant difference between performance on the two tests may be explained by the nature of the test response and the brain damage effect other than tone perception deficit. Van Rooij and Plomp (1990) investigated speech perception of elderly listeners. Their results showed that a general performance decrement in speech perception was due to reduced mental efficiency. It is indicated by a general slowing of performance and a reduced memory capacity. Figure 4 shows the three tests are of different difficulty. Although subject groups differ in their order of performance, each group responded in a similar pattern across the three tests.

FIGURE 4. MEAN PERCENTAGE SCORES ACROSS THE THREE TESTS INDICATING VARIED DIFFICULTY LEVEL



Tone identification requires subjects to choose a correct response out of five distractors. It is plausible that the auditory processing is more demanding than in both lexical comprehension test in which three distractors were presented or in tone discrimination test in which a "same-different" judgment response was required. Blumstein and Cooper (1972) and Lanzetta, Dember, Warm and Berch (1987) pointed out that identification task demands more information processing. This is because a subject must analyse the auditory information into its linguistic components and hold it in short-term memory long enough to be able to encode his response.

The brain damaged subjects appeared more susceptible to the demands for processing more information. Kent and Rosenbek (1982) suggested that right hemisphere may be involved in attention mechanism. They compared the acoustic description of the prosodic disturbances associated with different neurological disorders and found out that similar prosodic disturbance in patients with right hemisphere dysarthria and subcortical disorders. The same authors speculated that cortical functions may be replicated or complemented subcortically. Thus they suggested that the attentional functions subserved by the right hemisphere are linked to similar functions in the thalamus.

Tomkins and Flowers (1985) observed that the performance of the left hemisphere damaged subjects fell with increasingly demanding task. However, in our nonaphasic groups, we could not separate the brain damage effects by the hemispheric locus of damage.

The decrement in percentage mean scores from tone discrimination test to tone identification test was twenty percent (93.67% - 74%) in the right brain damaged group but forty percent (80.47% - 41.43%) in the left brain damaged aphasic group. Hence, the brain damage effects could not account for all the decrement in percentage mean scores of the aphasic group.

The nearer to normal performance of the right brain damaged subjects allows the conjecture that the larger deficits in the perception of tone exhibited by left brain damaged aphasic subjects can be attributed specifically to pathology in the language dominant hemisphere rather than to a general brain damage effect.

Deficits besides the tonal perception deficit

Besides tonal errors, a similar degree of phonological segmental and semantic deficits were evident in the left brain damaged aphasic group. This indicates that tonal confusion is related to language dominant hemisphere as other linguistic elements, such as consonants and vowels.

It was unexpected that the right brain damaged made significant more segmental errors than the normal control group. Since our audiometric constraint for listening to tones was limited to the pure tone average, high frequency hearing loss was possibly interferring. Orlebeke (1986) and Van Rooij et al. (1990) suggested that speech perception in the elderly seemed to be largely determined by hearing loss at the higher frequencies and the performance in the elderly was found partly correlated with age. This would cause more consonant confusion at high frequency range, especially beyond 2k Hz. This view is supported by 13 of 21 segmental confusions between either fricative /s/ or affricate /ts/, /ts^h/ and consonants at lower frequencies such as plosives.

Tone confusions for different aphasias

Although Blumstein, Baker and Goodglass (1977) suggested that subtle differences in phonological processing might exist among the aphasic groups, there were no differences among the mean percentage of correct identifications across different aphasic classifications. This precludes attributing a selective deficit in tone perception to any of Broca's, transcortical motor or anomic aphasias. Accordingly the results were not interpreted for each clinical types of aphasia.

Language specificity and tone perception

This finding of impairment in tone perception in Cantonese aphasics with unilateral left hemisphere damage is compatible with the results of the Van Lancker and Fromkin (1973, 1978). In their dichotic listening studies on the perception of Thai tones, they found (1973) that normal Thai speakers show a right ear advantage when the pitch configurations of the Thai tones are part of speech but an absence of ear preference when the same pitch configurations occur nonlinguistically in hums. In a follow-up, Van Lancker and Fromkin (1978) further found that neither musically trained nor musically untrained English speakers show a right ear advantage for the tone words. These results like those of the present study indicate that the native speakers perceive phonemic pitch contrasts through mechanisms lateralized in their left hemispheres.

The finding of a tone perception deficit in left brain damaged Cantonese aphasics is also consistent with the hypothesis of left hemisphere processing (Bever, 1980). He assumed that linguistic processing is an analytic mental activity. Following him we may suggest that in this experiment Cantonese subjects with left hemisphere brain damage in this experiment exhibited deficits in the perception of linguistic tones.

It has been suggested that for tone, hemispheric lateralization is determined by the extent to which tone is linguistic. Tonal stimuli are ranged on a continuum from "most systematically linguistic" to "least systematically linguistic" pitch contrasts. Pitch contrasts, say Thai tone or Mandarin tone and emotional tone or personal voice quality are associated respectively with left and right hemispheres (Van Lancker, 1980). As predicted by this scale for hemispheric specialization of pitch processing in speech and language, our findings show that tonal abilities are, indeed, impaired following left hemisphere injuries to speakers of a tone language.

APPLICATION

Performance of the same subject can be different when information processing demand of tasks varies. This indicates that one need great caution to interprete test results or to design clinical therapy tasks. Factors such as the information processing demand of task, age and brain damage effects should be taken into account.

Aphasics' tone perception deficit is evident and correlates highly with auditory comprehension. Tones deserve assessment. On one hand, tone perception deficit can reflect the overall auditory comprehension problem. On the other hand, assessment of it offers a deeper understanding of how factors causing comprehension problem interact with each other. Aphasia battery for speakers of tone languages may need modification to include tone perception.

Predominantly tone perception has been studied by focusing on single words. I hope that the results of this study prompt further research on how aphasia involves the perception of affective intonation and its possible interaction with lexical tones in Cantonese.

LIMITATION

The small sample and the varied nature of aphasic syndromes mean that findings from these analyses cannot confidently be generalized beyond the 47 subjects who participated in the study. Moreover, the inclusion of Broca's, transcortical motor and anomic aphasic subjects who had relatively better comprehension may have biased the results as would concentrating on Wernicke's, transcortical sensory and global aphasic subjects. No definite answer could be drawn on whether the performance of all types of aphasic significantly differs from each other in the perception of Cantonese tones.

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CONCLUSION

The left brain damaged group but not the right brain damaged group scored consistently and significantly the lowest support our hypothesis that tone perception deficit of the aphasics reflect a pathology in the language-dominant hemisphere. With similar degrees of phonological segmental and semantic deficits, tone perception deficits was associated with the left hemisphere. Brain damage would cause a general decrement in information processing. Tone confusions of the aphasics were similar to other groups but an extensive pattern was revealed. Confusions were found to be related to the similarity between tone pairs. No strong relationship was revealed between confusions and Cantonese phonemic inventory or sequence of Cantonese tone acquisition. Although different aphasic groups performed similarly, involving more subjects were suggested to confirm the results of our results.

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Data Record Sheet
[illegible]: ______________
[illegible]: ______________
Sex ______________
Neurological State ______________

Tone Identification
Trials: [illegible] ______
______
______
______
______
______

Tone Discrimination
2× [illegible] ______
[illegible] ______
4/2 ______
3/3 ______

Stimuli		Response		Stimuli	Response	
Tones value	Gloss	Correct	Wrong	Tone pair	Same	Dissimilar
1. 6	二			1. 3/2		
2. 5	耳			2. 5/2		
3. 2	椅			3. 6/1		
4. 3	意			4. 2/6		
5. 4	兒			5. 3/1		
6. 5	耳			6. 2/2		
7. 2	椅			7. 5/1		
8. 3	意			8. 3/3		
9. 1	医			9. 6/6		
10. 6	二			10. 5/6		
11. 6	二			11. 2/1		
12. 5	耳			12. 4/6		
13. 1	医			13. 1/3		
14. 2	椅			14. 4/3		
15. 5	耳			15. 2/4		
16. 3	意			16. 5/5		
17. 4	兒			18. 4/5		
18. 1	医			17. 6/4		
19. 5	耳			19. 2/3		
20. 6	二			20. 5/4		
21. 4	兒			21. 3/4		
22. 1	医			22. 1/4		
23. 2	椅			23. 6/6		
24. 6	二			24. 6/2		
25. 2	椅			25. 5/3		
26. 4	兒			26. 1/5		
27. 3	意			27. 4/1		
28. 1	医			28. 1/6		
29. 3	意			29. 4/2		
30. 4	兒			30. 6/3		
Total				31. 1/1		
				32. 1/2		
				33. 6/5		
				34. 2/5		
				35. 3/6		
				36. 3/5		
				Total		

[illegible]

NAME ____________

Target	Response Choice: Target	Tonal	Segmental	Semantic
BOAT	船			
GIVE	俾			
1. SOUP	湯	糖	燈	奶
2. CRAB	蟹	鞋	奶	虫
3. GUN	槍	牆	箱	刀
4. TREE	樹	試	射	花
5. FIELD	田	天	停	池
6. CRAWL	爬	怕	牙	[illegible]
7 PEAR	梨	脷	俾	蕉
8 EAR	耳	椅	雨	鼻
9. WRITE	寫	蛇	鼠	讀書
10. RUN	跑	拋	飽	跳
11. WALL	牆	唱	床	門
12. BOX	箱	上	驗	罐頭
13 HURT	損	船	鼠	傷心
14. SMILE	笑	小	跳	錫
15. FISH	魚	雨	鼠	龜
16. DOOR	門	滿	盆	窗
17 TREE	樹	壽	射	花
18. BOX	箱	相	槍	罐頭
19 BLOW	吹	槌	追	紙
20. TUMMY	肚	吐	抱	手
21. BISCUIT	餅	病	頸	飽
22. OLD	老	路	肚	年青
23. STAND	企	碟	被	坐
24. PHOTO	相	上	水	相機
25. NECK	頸	鏡	餅	膊頭
26. BREAD	包	肚飽	貓	餅
27 WINDOW	窗	唱	箱	門
28 HOSE	喉	口	牛	桶
29. COW	牛	狗	頭	豬
30 MOUTH	嘴	追	水	眼
31. CHAIR	凳	燈	唱	枱
32. DIG	鋤	坐	茶	切
33 SHOOT	射	蛇	石	拋
34 WET	濕	汁	十	乾
35 EAR	耳	醫	雨	鼻
36. LOO	百	白	鈪	十
37 CLOTH	布	煲	吐	紙巾
38 HOSE	喉	后	牛	水喉
39 SHOOT	射	寫	樹	打
TOTAL				

UNIVERSITY OF HONG KONG
DEPARTMENT OF SPEECH AND HEARING SCIENCES

CONSENT FORM

I consent to participate in a study of the tone perception in Cantonese speakers aged 50 to 75 years old. I understand that the purpose of this study is to find out how the Contonese tones are perceived by Cantonese speakers including some who have had strokes.

I understand that my hearing will by screened to make sure I can hear tones adequately. I will then be asked to listen to about 100 different tones and point to corresponding pictures. I know that these procedures will last approximately 30 minutes.

Any personal information for identification will be kept confidential and will be disclosed only with my written consent.

本人同意參與一項名為"五十至七十五歲的廣東人，聽廣東音調的能力"之研究。

本人明白劉小姐之研究目的。本人知悉此研究的參與者包括有中風病者。

本人明白為肯定本人有足夠之聽力，本人之聽力會被測試。本人會聽到大約一百個不同的音調，然後指出相應的圖片。我知道全部過程需要接近三十分鐘。

任何個人資料將會絕對保密，除事前得我同意外，將不會對外公開。

____
Signature of participant

____
Signature of witnesses

____
Signature of investigator