Journal of Phonetics (1973) **1**, 101–109

Hemispheric specialization for pitch and "tone": Evidence from Thai

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Received 30th January 1973

Abstract: In past dichotic listening studies, linguistic stimuli have shown a right ear advantage, implying left hemisphere dominance for language processing, while other stimuli incorporating pitch distinctions have shown no ear preference or a left ear (right hemisphere) advantage. An experiment was devized to compare ear preferences in tone language speakers for three sets of stimuli: pitch differences within language stimuli (tone-words in the tone language, Thai); language stimuli without pitch differences (consonant-vowel words on mid-tone); and pitch differences alone (hums). Results from 22 native Thai speakers demonstrate that tone-words and consonant-words are better heard at the right ear, while the hums show no ear effect. Preliminary results on English-speaking subjects suggest that the consonant-words give the usual right ear effect, while the tone-words and the hums do not. This study leads to the conclusion that pitch discrimination is lateralized to the left hemisphere when the pitch differences are linguistically processed.

Introduction

Since the discovery by Broca more than a century ago (1861 and Bonin, 1960) that lesions in the left hemisphere produce language deficits while lesions in the right do not, lateralization of language processing has been investigated in patients and in normal subjects by a variety of means. It has been repeatedly demonstrated that for most normal, right handed people, the left hemisphere is the dominant language hemisphere. One research technique used is dichotic listening, in which two different stimuli are presented simultaneously to the right and left ears of a subject wearing stereo headphones. Data accumulated over the past decade in this experimental paradigm confirm the belief that language is lateralized to the left cerebral hemisphere; these data include a consistent right ear preference for language stimuli. Investigators have demonstrated a right ear superiority for dichotically presented digits (Broadbent, 1954; Kimura, 1961), nonsense words (Curry, 1967), nouns (Borkowsky, Spreen & Stutz, 1965; Pettit & Noll, 1972), consonant-vowel syllables (Studdert-Kennedy & Shankweiler, 1970; Berlin *et al.*, 1972), backwards speech (Kimura & Folb, 1968), Morse Code signals (Papçun *et al.*, 1971; 1972) and sentences (Zurif & Sait, 1969).

It has also been shown that when simultaneous visual stimuli are presented tachistoscopically, the right visual field (left hemisphere) is superior for verbal stimuli, suggesting that it is language, rather than the acoustic stimulus alone, that is lateralized (Faglioni, Scotti & Spinnler, 1969). This conclusion is further supported by the fact that evoked potential responses are different over the left and right hemispheres when verbal vs. nonverbal stimuli are presented (Buchsbaum & Fedio, 1970). The hemispheric difference for visual stimuli has been amply demonstrated in split-brain subjects (Gazzaniga & Sperry, 1967).

The specialization of the left hemisphere is not just for sounds, nor is it specialized for all sounds, as the right ear superiority is not observed for all acoustic stimuli. Neither ear was preferred in the processing of clicks (Schulhoff & Goodglass, 1970) or steady-state vowels (Shankweiler & Studdert-Kennedy, 1967). Other sounds have produced a left ear (right hemisphere) superiority, especially various kinds of musical stimuli such as baroque melodies (Kimura, 1964) and chords (Gordon, 1970). A right hemisphere superiority for perceiving music has been demonstrated in lobectomized patients. Subjects of listening tasks who previously had their right temporal lobes removed did worse than left lobectomized patients on the Timbre and Tonal Memory subtest of the Seashore Test of Musical Abilities (Milner, 1962), and on recognizing orchestrated melodies (Shankweiler, 1966). Left ear advantage also resulted for environmental sounds (Curry, 1967), sonar signals, (Chaney & Webster, 1966), non-language vocalizations (Carmon, 1972), hummed melodies (King & Kimura, 1972), and the "emotional tone" of sentences (Haggard & Parkinson, 1971). Studies by Day, Cutting & Copeland (1971) have demonstrated that dichotic stimuli processed in terms of their linguistic dimension are better heard at the right ear, although the same stimuli processed according to their non-linguistic dimension (such as pitch) are preferred by the left ear. The verbal-nonverbal dichotomy for acoustic processing in the left versus the right hemispheres has been further confirmed by evoked cortical response studies (Cohn, 1971; Wood, Goff & Day, 1971).

The question of hemispheric specialization for pitch has not yet been clarified. The left ear advantage (right hemisphere superiority) for certain musical stimuli is briefly reviewed above. A right hemisphere involvement in pitch-related functions is also evident in the observation that expressive aphasics (sustaining left hemisphere damage) rarely lose control of pitch in normal linguistic intonation, although other aspects of language production are severely impaired. Moreover, aphasics and left hemispherectomies can sing (Smith, 1966; Bogen, 1973; Gordon, 1973). But it is compatible with these facts to say that pitch is bilaterally or subcortically processed. In the Wada test for cerebral dominance, Bogen & Gordon (1971) observed a strong left-brain dominance for language production, but suggest that "tonal abilities" are either a right hemisphere or a bilateral function in the brain. Milner (1962) found no significant change in pitch perception after unilateral lobectomy of either side. Zurif & Mendelsohn (1972), in their dichotic listening tests for sentences, are led to suggest the possibility that "a preliminary and partial analysis of prosodic contours can be carried out in both hemispheres". Similarly, Curry (1968) found no difference in performances for the dichotic pitch discrimination test in normals and a right hemispherectomized patient. On the basis of the patient's high scores, and previous findings that cats could make pitch discriminations after bilateral ablations of the cortex (Katsuki, 1961, 1962), Curry suggests that pitch is subcortically processed.

It is possible that pitch-processing is set-influenced, and shows laterality effects according to task. This set-influence is exemplified by Spellacy & Blumstein (1970), where vowels in a linguistic context were better recognized by the right ear, while the same stimuli in a non-language context (embedded in music and environmental sounds) were preferred by the left ear. Similarly, when pitch was used linguistically to distinguish voiceless from voiced consonants, a right ear advantage resulted (Haggard & Parkinson, 1971).

In all of the experiments involving pitch reported on in the literature, the subjects were speakers of English, a language which utilizes pitch intonational contours, but which does not use pitch distinctively to contrast individual words. That is, in English, the word *cat* means "cat" whatever the fundamental frequency of the acoustic signal happens to be. In the majority of the world's languages, however, the pitch of individual syllables is as significant as, say, the voicing contrast of the initial consonant in English, which distinguishes "pit" from "bit". Such languages are known as "tone" languages.

The experiment reported on in this paper was conducted to determine whether speakers of a tone language—in this case, Thai—would show a right ear advantage when the dichotic stimuli represented contrasting tones. Secondly, we wished to compare the degree of lateralization for tone stimuli with the degree of lateralization for words, where the contrast depended on consonant substitution. Thirdly, we asked whether the task of pitch discrimination would yield a different result if the same pitches were not in a linguistic context; that is, when the same pitch configurations as are found on the Thai tones were hummed. Furthermore, we wanted to compare speakers of a tone language with those of a non-tone language for this type of task; and to compare these results with speakers of other tone languages, such as Mandarin and Yoruba.

Methods and Procedures

From a total of 24 Thai speakers, one was eliminated from analysis because he was reportedly left-handed, and another because of abnormally high errors throughout the testing. The results reported on here come from a population of 22 native Thai-speaking subjects, students and residents of Los Angeles. The English-speaking group, not yet complete, is made up of 14 students varying in musical talents, knowledge of tone languages and handedness. We are reporting mainly in the Thai subjects' data at this time.

Three sets of stimuli were used: (1) five Thai words differing only in tone (pitch), the "tone-word" stimuli; (2) five Thai words contrasting only in initial consonant, and having

Table I 3 sets of stimuli used

(1) Tone-words			
Stimulus	Tone	Length (ms)	English gloss
nāā	mid tone	625	"field"
nàa	low tone	650	(a nickname)
nâa	falling	575	"face"
náa	high tone	625	"aunt"
nǎa	rising	650	"thick"
(2) Consonant-words			
daa	mid tone	700	(a nickname)
nāā	mid tone	650	"field"
sāā	mid tone	700	"diminish"
čāā	mid tone	650	"tea"
lāā	mid tone	600	"goodbye"
(3) Hums			
	mid tone	650	
`	low tone	550	
^	falling	550	
	high tone	575	
ˇ	rising	525	

Table II Answer sheet format

First set: tone-words

	นา nāā	หน่า nàà	หน้า nââ	น้า náá	หนา nǎǎ
1.					
2.					
3.					
⋮					
10.					

Second set: consonant-words

	sāā ซา	lāā ลา	nāā นา	čāā จา	dāā ดา
1.					
2.					
3.					
⋮					
10.					

Third set: hums

	¯	` ่	^ ้	´ ๊	ˇ ๋
1.					
2.					
3.					
⋮					
10.					

Instructions to subjects: "Listen to both ears. Mark *L* for what you hear in your left ear, and *R* for the right ear."

In ε

the same tone; all five words occur on mid tone. These are the "consonant-word" stimuli; (3) for this third set of stimuli, the five Thai tones were hummed, to produce the pitches alone, without segmental information. These are referred to as "hums". For each of the three sets, every stimulus was paired with every other stimulus, producing 20 pairs. These were presented twice, with channels reversed the second time through; then the earphones were shifted and the forty pairs (2 × 20) were presented again. Thus there were 80 stimulus pairs for each set. For all subjects, the three stimulus sets were presented in the order: 80 tone-word pairs, 80 consonant-word pairs, 80 hum pairs. The pairs were presented with a 6 s interstimulus interval, with the exception of a block of 40 pairs in set I (tone-words) to be described below.

The subjects were provided with eight answer sheets with five columns, 10 rows per page (for a total of 80 pairs for each of the three sets). Each column was headed by the appropriate "tone-word" or "consonant-word", designated in both Thai and English orthography and by iconic diacritics to represent the tones. These diacritics plus the Thai word for the tones headed the "hum" column. The subjects were directed to respond by marking an "L" under the appropriate column to indicate the stimulus heard in the left ear, and an "R" under the column that specified the stimulus heard in the right ear. The order of reporting left-ear-right-ear, or right-ear-left-ear was reversed every 10 pairs. There were 10 rows per page, of eight pages for each stimulus set.

Before each of the three stimulus sets, practice sessions were conducted for all subjects using binaurally presented stimuli. The actual testing did not begin until the subjects in the recognition test showed perfect identification of each stimulus. The non-Thai speakers usually required more practice.

The responses of the first two Thai speakers showed few or no errors in reporting the "tone-words". Therefore, to induce errors, for half (40 pairs) of these stimuli, the interval between every other stimulus-pair was shortened, so that two pairs were presented in rapid succession. Thus for the first set of stimuli (only), the tone words, the subjects heard the second 40 presentations as two pairs one right after the other, then a 6 s pause, then two more pairs, etc. This task was more difficult for most subjects, but not impossible.

Results

The data were analysed as follows: the number of errors for each ear was totaled for each set of stimuli. We noted intrusions, in which one stimulus was correctly identified but located at the wrong ear, and inversions, where both stimuli were correctly identified but ear locations exactly reversed. Inversions were excluded from the error analysis. Intrusions were counted as a single error. Table III reports the results for the Thai speakers.

Thai subjects were found to be significantly left hemisphere lateralized for both Thai "tone-words" and Thai "consonant-words", i.e. they showed a significant right ear advantage (REA) for both. For "hums" there was no significant difference between the two ears.

In a Wilcox matched pairs T-test for "tone-words" $T = 24$. $P < 0{\cdot}01$
for "consonant-words" $T = 45{\cdot}5$ $P < 0{\cdot}05$
for "hums" $T = 102{\cdot}5$ not sig. $P > 0{\cdot}4$.

Since both "tone-words" and "consonant-words" gave a REA, the degree of lateralization of the two was compared. Using the Percentage of Errors method (Harshman & Krashen, 1972) each subject's score was converted to a POE score. POE score for tones

Table III Errors for Thai subjects

	Left ear errors			Right ear errors				
	X	I	Total	X	I	Total	Inv.	POE
1. naa "tone-words"	559	125	684 X̄:31	402	107	509 X̄:23	64	57·3
2. CVV "consonant-words"	522	157	679 X̄:31	428	96	524 X̄:24	185	56·4
3. "hums"	311	55	366 X̄:17	314	41	355 X̄:16	75	50·8

X = non-intrusion errors, I = intrusion errors; Inv. = inversions; POE = percentage of total errors made by the left ear.

was 58·7 [the left ear made 58·7% of the total errors]. For consonant words, the mean POE score was 58·5. A matched-pairs *T*-test showed no significant difference in the degree of lateralization between the two sets (matched $T = 0{\cdot}576$).

For "tone-words", 16 out of 21 Thai subjects showed a right ear advantage, four showed a left ear advantage, and one showed no ear difference. This is also significant, $\chi^2 = 6{\cdot}05, P < 0{\cdot}02$.

For "consonant words", 14 out of the 21 Thai subjects showed a right ear advantage, five a left ear advantage, and two showed no ear preference. This result tends to be significant, $\chi^2 = 3{\cdot}36, P < 0{\cdot}10$.

There is further support for the claim that the Thai subjects processed the "tone-words" and "consonant-words" similarly. The results show that 13 subjects had a REA for both stimulus sets, and three subjects had a left ear effect (LEA) for both sets. All subjects described themselves as right-handed, but one of these three with left ear advantage said he was also "somewhat ambidextrous". Thai children are encouraged to use their right hands even if they would have preferred the left, and therefore it is possible that the reported handedness for these three subjects is not correlated with their hemispheric dominance for language.

As stated above, 40 of the "tone-word" pairs were presented in 20 sets of two-pairs in order to induce more errors. To determine whether the result of the double items was due to a short term memory effect we analysed the data of the first 40 single pairs of "tone-words" separately. The results are given in Table IV.

Table IV Total errors for left/right ears of 40 "tone-word" pairs presented with 6 s intervals between them. Thai subjects

	Left ear errors			Right ear errors			
	X	I	Total	X	I	Total	POE
"tone words"	127	28	155 X̄:7	92	15	107 X̄:4·8	58

The Wilcox test showed a REA significant right ear advantage: $T = 35$, $P = 0{\cdot}05$.

It should also be noted that the right ear "intruded" on the left ear more for "tone-words" and "consonant-words" (see Table 1) suggesting influence or strength of the right ear stimuli.

Preliminary report on non-Thai speakers

At first analysis of the English-speaking subjects, there appears to be no significant ear difference for the "tone-words"; the "consonant-words" showed a right ear superiority; the hums showed no ear preference, although the trend toward better left ear performance for pitch processing is suggestive.

Table V Errors for American subjects

Tone-words errors L –ear– R		Consonant-words errors L –ear– R		Hums errors L –ear– R	
625	627	505	453	472	495

Discussion

The data from this study show that for a group of tone-language speakers, when pitch contrasts occurred on words in dichotic listening, a right ear effect resulted. No ear preference was observed when the same pitches occurred as hums. Perception of tones by tone language speakers was lateralized to the left hemisphere to at least the same degree as consonant-vowel words. We conclude that when pitch is processed linguistically, left hemispheric specialization occurs as for other language stimuli.

The study brings us back to the notion that the left hemisphere is specialized for language. Further research is needed to establish the attributes of language which are unique left hemisphere functions. A promising direction for research is the attempt to define "possible human language" within the context of human brain capability. We feel that lateralization research can tell us a great deal about language *and* hemispheric functions. There is evidence, for example, that some aspects of language are less lateralized than others (Abbs & Smith, 1970; Berlin *et al.*, 1972; Day & Vigorito, 1972), and that some language processing is not lateralized (Jackson, 1958; Espir & Rose, 1970; Van Lancker, 1972). It is likely that pitch perception also involves degrees or differences in lateralization within the complex phenomenon of language behavior. The Thai results indicate that the "most linguistic" function of pitch discriminations in language, the use of pitch for phonological distinctions in a tone language, is lateralized to the left hemisphere. We intend to investigate syntactic and emphatic use of pitch differences (such as white hoûse vs. white hoûse; and yes? vs. yes!) and further, to test "less linguistic" uses of pitch in language, use for attitudinal and emotional signalling. We believe that such language-oriented work in cerebral dominance will help define and refine our notions of possible human language. It is in this context that correlated studies of language and brain function have much promise.

We would like to thank Joseph Bogen, Harold Gordon, Richard Harshman, Rasami Karnchanachari, Steven Krashen, Peter Ladefoged, and George Papçun for their help and interest in this study.

This research was supported in part by USPHS Grant NS 09780, NSF Grant GS 2859, and a UCLA Academic Research Grant.

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