Perception of Central Thai Tones and Segments by Thai and Australian Adults

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<u>Introduction</u> Thai and Australian adults were tested for their ability to discriminate pairs of bilabial stop consonant plus /a:/ vowel syllables spoken by a Thai speaker. Three different speech contrasts were incorporated into the design of the experiment: (i) prevoiced bilabial stops vs voiceless aspirated bilabial stops - /b/ vs /p^h/; (ii) prevoiced bilabial stops vs voiced unaspirated bilabial stops - /b/ vs /p/; and (iii) tonal contrasts incorporating all possible combinations of the five Central Thai tones. The three main purposes of the study were (a) to investigate the relative salience of Thai phonological distinctions, (b) to study the effects of linguistic experience on speech perception, and (c) to investigate hemispheric specialization in speech perception. Details of these are set out below.

<u>(a) Relative Salience of Thai Contrasts</u>
(i) Tonal Contrasts: Central Thai has five tones (mid, high, low, rising, and falling). Many studies have investigated the relative perceptual salience of these for Thais. For example, Gandour (1979) conducted a multidimensional scaling analysis on Thais' discrimination of various pitch contours and found three tone-related dimensions. The relatively low-level auditory dimension of average pitch was the most important factor in subjects' perceptual judgements, and is also an important cue for speakers of non-tonal languages and for speakers of tonal languages other than Thai (Gandour, 1983). The other two dimensions were the direction dimension, which served to distinguish between rising and falling contours on the basis of pitch movement rather than absolute start and end points, and the slope dimension, which served to distinguish between what Abramson (1978) has called static (mid, low, high) and

Direction distinguishes between L/M and M/A!

dynamic (rising, falling) tones. These results agree to some extent with Abramson's (1978, 1986) studies with Thais in which he found that differences in pitch levels are sufficient for the identification of static tones, although this is enhanced by slow f_0 movement.

(ii) Consonantal Contrasts: The bilabial stop voiced-voiceless contrast is phonologically relevant in English and understandably this is discriminated more easily by English speakers than the irrelevant prevoiced-voiced contrast. However, there is some indication that this is not just a function of linguistic experience. It has been found that 6- and 10-month-old infants also have greater difficulty perceiving the prevoiced-voiced contrast (Aslin, et al., 1981; Burnham, et al., 1991), even though at this age this bias is unlikely to be linguistically based (Burnham, 1986). Results of a study by Pisoni (1977) suggest that there may be a psychoacoustic element to this bias. Investigation of the perception of these two contrasts by Thai and English speakers in this study will provide a good test of this hypothesis.

(iii) Consonantal vs Tonal Contrasts: Some information about the relative salience of Thai consonantal and tonal contrasts may be gleaned from developmental studies. Clumeck (1980) reports that the onset of the lexical use of tonal and segmental distinctions coincide, each of these first emerging around 11 months. However, acquisition of tonal distinctions appears to be easier, because these are completely acquired by around 23 months before the acquisition of segments is completed (Tuaycharoen, 1977; Luksaneeyanawin, 1976; Clumeck, 1980). There is also evidence from a 10- to 11-month-old child that tones are more perceptually salient than segments (Li & Thompson, 1977). These data suggest that tone differences are more basic than segmental differences and should be more easily discriminated by English speakers when phonological relevance is equated.

<u>(b) The Effects of Linguistic Experience</u> Many studies have shown that linguistic experience systematically biases speech perception abilities towards the phonological distinctions present in the ambient language (Aslin et al., 1981; Burnham et al., 1991; Werker & Tees, 1983, 1984), such that adults have more restricted perceptual abilities than infants in the same linguistic environment. Werker concludes

that this shift from infancy to adulthood does not entail sensori-neural loss because under certain conditions adults can still discriminate phonologically-irrelevant contrasts (Werker & Logan, 1985; Werker & Tees, 1984). There also seems to be an attentional shift associated with the onset of reading which biases children towards the perception of phonemes which are relevant in the ambient language (Burnham, 1986). The effects of linguistic experience were studied in the current study by the comparison of Thai and English speakers' perception of relevant and irrelevant distinctions in a 500msec interstimulus interval (ISI) condition and a 1500msec ISI condition. These two intervals have been shown by Werker & Logan (1985) to induce a language-general phonetic mode of perception and a language-specific phonological mode of perception, respectively. It was expected that native English speakers' performance on the irrelevant consonantal contrast and the tonal contrasts should be better at 500 than at 1500 msec.

<u>(c) Hemispheric Specialization for Speech</u> The left hemisphere of the human brain is said to be specialized for language processing with between 93% and 100% of right-handers being left hemisphere dominant for language (Hiscock & Kinsbourne, 1980; Kolb & Whishaw, 1990). Behavioural studies of this specialization have used the dichotic task, in which different auditory inputs are delivered to each ear and the subject is required to identify input to one particular ear. Using this procedure Haggard and Parkinson (1971) found stronger right ear advantages (REAs) for place than voicing contrasts, and Studdert-Kennedy and Shankweiler (1967) found stronger REAs for voiceless place contrasts than for voiced place contrasts. Thus phonetic cues seem to vary in their potency in the production of ear advantages.

With regard to tone, speakers of languages which do not use tone at a lexical level either show a left ear advantage (LEA) or no ear advantage for tonal identifications and discriminations . For example, Murray (1986) found a significant REA for speech syllables and an LEA for simple tones of different frequencies. On the other hand, speakers of tonal languages show REAs for tonal contrasts. Van Lancker and Fromkin (1973) found an REA for Thai speakers' identification of dichotically presented consonantal and tonal contrasts but no ear advantage for hummed versions of the five Thai tones, while English speakers showed an REA for consonant differences but no ear advantage with tonal contrasts or hums.

From this behavioural evidence it appears that speakers of tonal languages process tone in the left hemisphere along with consonantal distinctions. In this study it was expected that Thai speakers should show REAs for all three contrasts while English speakers should show an REA for the /b/-/p^h/ contrast, possibly for the /b/-/p/ contrast, but certainly not for the tonal contrasts.

Method

Subjects 48 right-handed adult subjects were tested. Of these 24 were native Australian English speakers with little or no experience with other languages. The other 24 were native Thai speakers, who could also speak English with varying degrees of proficiency.

Design A native language (Thai/English) x ISI (500msec/1500msec) x Contrast (/b/-/p^h/, /b/-/p/, tonal contrasts) x Ear of Presentation (Left/Right) design was employed. All subjects were tested on all three contrasts with both ears of presentation. Half of the subjects in each language group were tested with an ISI of 500msec between the two stimuli to be discriminated and half were tested with the 1500msec ISI condition. In each language by ISI subgroup half the subjects were males and half were females. Presentation order of the three blocks of contrasts was balanced between subjects.

Stimulus Materials Speech tokens were all produced by a native Thai female (S.L. in the author list). Bilabial stop consonant plus /a:/ vowel tokens, /ba:/, /pa:/ and /p^{h}a:/, were used . For the consonantal contrasts these were all presented with mid tone. For the tone contrasts the prevoiced syllable, /ba:/, was used to carry the five tones. For each of the seven different consonant-vowel pairs, five exemplars were produced by the speaker. These were digitized and stored on disk of the laboratory computer.

Three different Thai contrasts were tested in the experiment: /ba:/ vs /p^{h}a:/, which is phonologically relevant in English; /ba:/ vs /pa:/, which is phonologically irrelevant in English; and tone contrasts, e.g., /bǎ:/ vs /bá:/ which again are irrelevant in English. All possible pairings of the five tones were used, a total of 10 possible tone contrasts. The computer was programmed to chose at random any one of the five exemplars for each of the sounds in any particular contrast on each trial. This exemplar variation over trials was employed to encourage phonetic processing, in which the phonetic features are important for perceptual discrimination, as opposed to acoustic processing, in which idiosyncratic features of particular tokens may become important cues for discrimination.

Apparatus Two sets of apparatus were used: a laboratory-based version at the University of NSW, and a portable version for use at Chulalongkorn University. The laboratory version was based on an IBM 386 type computer, while the portable version was based on a Toshiba 3100e laptop AT type computer fitted with a false bottom in order to house D-A, digital I/O, and filter boards. The computer was the only difference between the laboratory and portable systems so only the latter is described here.

The main features of the apparatus were the computer, a set of headphones, and a response panel. The computer stored the sounds on disk, controlled presentation and timing of the sounds, and recorded subjects' responses and reaction times for each trial. The response panel contained a "same" key and a "different" key for subjects' responses, and a set of coloured lights, which flashed on and off as feedback whenever subjects made a correct response.

Procedure An AX procedure was employed in which either same phone pairs (AA) or different phone pairs (AB) were played to the listener, whose task it was to respond as quickly as possible by pressing either the "same" or "different" key. The first sound was always presented binaurally and the second sound monaurally, with 50% of trials being presented to each ear.

There were four phases in the experiment. The first was a task competence phase in which subjects were required to respond correctly on seven out of the eight trials on a simple /dʒo:n/ vs /lə:/ distinction. Four of these were same (AA) trials, and the other four were different (AB) trials. This phase was included to ensure that each subject could in fact, make simple auditory discriminations.

The three test phases (/b/-/p/, /b/-/p^h/, tones) then followed with order counterbalanced between subjects. In each phase there were 48 trials in three blocks of 16. In each block there were 8 AA and 8 AB trials. On 4 of each of these 8 the second sound was presented to the left ear and on the other 4 the sound was presented to the right ear. In each such block of 4 in the tone phase there was one "static-static" trial (mid/high, mid/low, or low/high), two "static-dynamic" trials (mid/rising, mid/falling, low/rising, low/falling, high/rising, or high/falling), and one "dynamic-dynamic" trial (rising/falling).

Dependent Variables The number of correct and incorrect responses and the accompanying reaction times were recorded by the computer. From these three dependent variables were derived. The first was a discrimination index (DI) given by [number of correct responses on different trials minus number of *incorrect responses on same trials]/number of trials.* The resulting score, between -1 and 1, serves to indicate how well subjects were able to discriminate speech sounds on AB trials. Two reaction time (RT) measures were recorded, one for correct responses on AA trials and one for correct responses on AB trials. There were six average DIs, six average AA RTs, and six average AB RTs for each subject, one average for left and right ear on each of the three contrasts.

Results

Contrast Comparisons Each of the dependent variables was subjected to Language x ISI x Contrast x Ear analysis of variance. A Bonferonni adjustment was made *for having* three dependent variables ($F_{critical\ .05} = 6.20$). Mean DIs (max=1.0) and RTs (in msec)are shown in Table 1. Analysis of DIs revealed that Thais were better at discriminating the three contrasts than the English speakers ($\bar{X}_{Thai} = .95$, $\bar{X}_{English} = .79$), $F(1,44) = 62.91$. Both English and Thai speakers discriminated /b/-/p^h/ better than /b/-/p/, $F(1,44) = 58.21$, *though this was more pronounced for the English speakers,* $F(1,44) = 25.15$.

Table 1: Contrast Types - DIs and RTs (in msec)

Contrast	Thai Speakers			English Speakers		
	DI	RTAA	RTAB	DI	RTAA	RTAB
/b/-/p^h/	.972	1085	1103	.939	948	951
/b/-/p/	.887	1136	1119	.649	1021	1105
Tones	.983	1155	1166	.769	1113	1120

Comparison of the two consonant contrasts and the tone contrasts revealed an interaction with language and ISI, $F(1,44) = 5.78$, significant only at the nominal level of alpha ($F_{critical} = 4.06$). As can be seen in Table 2, English speakers performed better on both consonant contrasts at 1500msec ISI than 500msec ISI, while for the tone contrasts they performed better at 500msec. The opposite was the case for Thais though to a lesser degree: consonant discrimination was attenuated by the longer ISI while tone discrimination improved slightly.

Table 2: DIs for Contrast x ISI x Language

Contrast	Thai Speakers ISI		English Speakers ISI	
	500	1500	500	1500
/b/-/pʰ/	.976	.969	.924	.954
/b/-/p/	.935	.840	.455	.601
Tones	.979	.986	.820	.719

There were no overall RT differences between English and Thai speakers. However, there were effects due to type of contrast. RTs were longer for the tone contrasts than the two consonant contrasts both for AA, $F(1,44) = 18.97$ and AB trials, $F(1,44) = 12.43$, presumably because the tone is carried on the vowel of these consonant-vowel pairs, while the consonant contrasts are carried on the initial phoneme. With regard to the two consonant contrasts, RTs for the /b/-/p/ contrast were longer both on AA trials, $F(1,44) = 18.31$ and AB trials $F(1,44) = 12.00$, suggesting along with the DI data that /b/-/p/ is more difficult to discriminate than /b/-/pʰ/. This difficulty was similar for Thai and English speakers, though the effect on AA trials was somewhat larger for the English speakers, $F(1,44) = 25.15$.

Table 3: RT_{AA} for Contrast x Ear (msec)

Contrast	Thai Speakers		English Speakers		All Speakers	
	Left	Right	Left	Right	Left	Right
/b/-/pʰ/	1089	1117	945	956	972	991
/b/-/p/	1131	1107	1103	1107	1118	1106
Tones	1152	1181	1097	1144	1124	1163

Finally, there were ear advantages found for RTs on AA trials. As shown in Table 3, these differed according to contrast type - consonant contrasts vs tones, $F(1,44) = 6.31$, and /b/-/p^h/ vs /b/-/p/, $F(1,44) = 4.30$ - not according to native language. In Table 3 it can be seen that there is a strong LEA for tone contrasts and this is true for both English and Thai speakers. On the other hand there is a slight LEA for /b/-/p^h/ and a slight REA for /b/-/p/ which tends to be carried by the Thai speakers more than by the English speakers, though not significantly so.

<u>Tone Comparisons</u> Tone contrast types were analysed in terms of the Abramson categories of static and dynamic in Language x ISI x (Tone Contrast x Ear) analyses of variance. Mean DIs and RTs are shown in Table 4. Dynamic/dynamic contrasts were discriminated more easily than static/dynamic contrasts, $F(1,44) = 7.65$, an effect more pronounced for English speakers $F(1,44) = 4.08$, with static/static contrasts falling somewhere between the two. This comparative ease with dynamic/dynamic over static/dynamic contrasts was reflected in RT advantages both on AA $F(1,44) = 7.87$ and on AB trials, $F(1,44) = 15.72$.

Table 4: Tone Types - DIs and RTs (in msec)

Contrast	Thai Speakers			English Speakers		
	DI	RT_{AA}	RT_{AB}	DI	RT_{AA}	RT_{AB}
Stat/Stat	.987	1165	1199	.793	1099	1174
Stat/Dyn	.968	1168	1170	.716	1120	1177
Dyn/Dyn	.993	1133	1074	.876	1082	997

There were also ear advantages. AB trial RTs were slower for static/static contrasts than the other two types $F(1,44) = 14.18$, and this interacted with ear of presentation, $F(1,44) = 5.90$, but not with native language. As shown in Table 5 there is an REA for static/static contrasts but an LEA for those contrasts involving dynamic tones. Even though this effect is somewhat reduced for Thais, it is still present and there was no interaction with language group.

Table 5: RT_{AB} for Tone Type x Ear (msec)

Contrast	Thai Speakers		English Speakers		All Speakers	
	Left	Right	Left	Right	Left	Right
Stat/Stat	1228	1170	1222	1125	1225	1148
Stat/Dyn +) Dyn/Dyn)	1119	1126	1047	1127	1048	1126

Finally, each individual tone comparison was investigated to determine the degree of difficulty of each comparison. In Table 6(a) the mean percent correct for Thai and English speakers at 500 and 1500 ISIs are shown for the five same tone pairs and the ten different tone pairs. For the five same pairs a Language x ISI analysis of variance revealed a significant effect of ISI, $F(1,16) = 15.41$ and a language by ISI interaction, $F(1,16) = 7.43$. This shows that consistently across all tone pairs Thai speakers improved from 500 to 1500 msec ISI, while English speakers' ability deteriorated between 500 and 1500 msec ISI. A similar pattern is evident for the ten different pairs: the ISI comparison was significant, $F(1,16) = 40.28$, though the interaction with language failed to reach significance, presumably due to Thais scoring very high at both ISIs.

Table 6(a) Percent Accuracy over Tones

ISI	Five Same Pairs		Ten Different Pairs	
	Thai	English	Thai	English
500msec	97.2	95.5	99.2	84.1
1500msec	98.8	89.7	100	80.0

The orders of difficulty given in Table 6(b) show some interesting effects, especially for the English different pairs. The order of difficulty appears to be determined by the nominal starting pitch of the tones. If the initial pitches are quite different, e.g., in low/falling, then accuracy is good (94%). On the other hand if initial pitches are nominally similar, e.g., low/rising, then accuracy is quite poor (54%). For the Thais on the ten different pairs, the two with accuracy less than 100%, mid/low and low/rising, are contrasts which have similar initial pitches and which provide some difficulty for the English speakers. In addition, mid/low has been identified by Abramson (1976) as a particularly difficult contrast in Thai.

Table 6(b) Order of Difficulty for each Tone Contrast

Thai Speakers		English Speakers	
Contrast	X% Correct	Contrast	X% Correct
	Same Pairs		
F-F	96	M-M	87.5
M-M	96.9	R-R	92
R-R	97	H-H	94
H-H; L-L	100	F-F; L-L	95
	Different Pairs		
M-L; L-R	98	L-R	54
M-H; H-L;)		H-F	75
R-F;M-R;)	100	M-L; M-R	79
M-F; H-R;)		M-H	81
H-F; L-F		H-R	88
		M-F	90
		R-F	91
		H-L; L-F	94

Discussion

(a) Relative Salience of Thai Contrasts

(i) Tonal Contrasts: The dynamic/dynamic tone contrasts were most easily discriminated followed by static/static, and then static/dynamic contrasts. Thais were significantly better than English speakers but nevertheless the same pattern of results occurred for both language groups. This suggests that the relative difficulty of tonal contrasts is based on acoustic rather than phonological factors. Comparison of individual tone contrasts (see Table 6b) shows that difficulty of discrimination seems to be based on absolute initial pitch of the component tones. This supports Gandour's (1979, 1983) suggestion that general pitch or height is the most important dimension for tone discrimination and Abramson's (1978, 1986) finding of the sufficiency of pitch level for the discrimination of static tones.

(ii) Consonantal Contrasts: English listeners discriminated the phonologically-relevant /b/-/p^h/ contrast more easily and more quickly than the irrelevant /b/-/p/ contrast. However, a similar finding for Thai speakers suggests that part of the difficulty with the /b/-/p/ contrast is due to acoustic factors. This is in accord with developmental data showing that even linguistically-inexperienced infants have greater difficulty with the prevoiced-vciced contrast (Aslin et al., 1981; Burnham et al. 1991). Pisoni (1977) suggests such results can be explained if one considers the release in a stop consonant as a high frequency component and voicing onset as a low frequency component. Masking appears to be more effective when a high frequency component follows a low frequency component (as in /b/) than the other way around (as in /p^h/). In accord with this hypothesis, the supremacy of /b/-/p^h/ over /b/-/p/ occurs even for mature Thai adults, who have extensive phonological experience with each contrast.

(iii) Consonantal vs Tonal Contrasts: For Thai speakers tone contrasts were slightly more easily discriminated than both consonantal contrasts. For English speakers the tonal contrasts were more easily discriminated than the other irrelevant contrast, /b/-/p/. These results support evidence from children (Tuaychareon, 1977; Luksaneeyanawin, 1976; Li & Thompson, 1977), for whom it has been found that tonal contrasts have developmental primacy over consonantal contrasts in both production and perception. One cause of this may be that tonal contrasts have greater psychoacoustic salience than consonantal contrasts.

Burnham (1986) has put forward a theory of speech perception development in which he claims that all speech contrasts can be placed on a continuum from robust to fragile. Robust contrasts (a) have a strong psychoacoustic basis (e.g., temporal order variables such as voice onset time) and (b) tend to have their contrasting sounds represented as allophones even in languages in which the contrast is irrelevant. In addition, perception of phonologically irrelevant robust contrasts is relatively resistant to the otherwise debilitating effects of exposure to an unsupportive linguistic environment. Although Burnham (1986) did not consider tonal contrasts, it would seem that tonal contrasts would satisfy the criteria of robust contrasts. We are currently investigating the development of the perception of tone by children in a study using the same method as that set out here. The results of this study will be important in order that current knowledge about speech perception development may be extended to tonal contrasts.

(b) The Effects of Linguistic Experience Above it was shown that certain effects (tonal vs consonantal contrasts and /b/-/p^h/ vs /b/-/p/) occur despite differences in linguistic experience. In this section the effects due to differential linguistic experience are the focus. A consistent interaction of contrast type, ISI, and linguistic experience was found. For tonal contrasts the phonological level of perception (ISI = 1500msec) facilitated discrimination for Thai speakers over and above the phonetic level (ISI = 500msec). Presumably, at the phonetic level phonologically irrelevant differences between tone pairs may have attenuated Thai subjects' performance, whereas the phonological level would facilitate placement into phonological categories because irrelevant differences would be disregarded. For the English speakers the opposite occurred: perception of tonal contrasts was better at the phonetic level. Presumably, this level allowed English speakers to *retain in memory phonetic information about different* tones which would facilitate discrimination. Memory for such differences would be lost at the longer ISI because this would force subjects to code information in a more long-term store involving (non-tonal) phonological categories. The phonetic/phonological effects found for the consonantal contrasts are not so understandable: for the consonantal contrasts performance by Thai speakers was attenuated by the 1500msec level, while performance for English speakers was facilitated. The elucidation of this issue must await further research.

(c) Lateralization of Brain Function Table 3 shows that there was a small LEA for the /b/-/p^h/ contrast and a small REA for the /b/-/p/ contrast. This is consistent with the general finding that ear advantages can differ as a function of such dimensions as voicing (Studdert-Kennedy & Shankweiler, 1967), though the actual direction of this difference does not concur with their observed results.

Of greater magnitude than the ear advantages for consonantal contrasts, is the LEA for the tonal contrasts, suggesting that tonal contrasts are more quickly processed in the right (non-language) hemisphere. Such a finding is understandable for English speakers, for whom the tonal contrasts are not linguistically relevant. However, as the effect consistently occurs for both Thai and English speakers, its origin is less clear. Consideration of the results in Table 5 may help to resolve the issue. There it can be seen that the direction of the ear difference depends upon whether dynamic tones are involved. When dynamic tonal contours are involved, RTs on AB trials show an LEA for both Thai and English subjects. However, when only static tones are involved both Thai and English speakers show an REA. Thus the effect in Table 3 may be seen to result from the fact that in this experiment there were more contrasts involving dynamic tones than static tones (in a 3 to 1 ratio) thus causing an overall LEA.

Thus is appears that the <u>type</u> of tonal contrast determines the hemispheric advantage for RT, just as differences in voicing of consonantal contrasts lead to variations in the degree of REA (Studdert-Kennedy & Shankweiler 1967) . This is consistent with the notion that the right hemisphere processes more "musical" information. However, the consonantal differences which have been found here and elsewhere (Studdert-Kennedy & Shankweiler 1967) suggest that the underlying distinction between processing in the two hemispheres is far from clear. The results reported here do not support a simple language/non-language hemisphere distinction because both Thai and English speakers show similar ear advantages. This may have been a product of the test situation, three aspects of which are worth noting. Firstly, a binaural procedure was used here and this may not involve the same perceptual processes as those involved in the dichotic listening procedure. Secondly, all contrasts, even those which were irrelevant for English speakers, were presented in a speech context, which may have contributed towards making English speakers' performance more similar to that of Thai speakers. Thirdly, a large number of trials (48) on each contrast type was provided, and this practice may have biased the English speakers towards a speech mode of processing. These issues could be further investigated in future studies. Despite these problems, the overriding finding here was that type of contrast rather than linguistic experience was the main determinant of ear advantages.

__Conclusions__ It was found that, despite differences due to linguistic experience, both Thai and English subjects had greater difficulty discriminating /b/-/p/ than /b/-/p^h/. It was also found that tone appears to be a generally salient feature for the discrimination of speech. It will be of great interest to investigate whether such effects also occur for young children and how linguistic experience may modify these differences.

The finding of phonological processing of tones by Thais and phonetic processing of tones by English speakers is of particular interest. As it was suggested earlier that tone has primacy in phonological development, it will be of interest to find whether the increase in phonological bias which occurs when English speaking children begin to read (Burnham, 1986) results in increased insensitivity to the phonologically-irrelevant tonal distinctions.

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