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A Study on the Perception of /r/ and /l/ in Natural and Synthetic Speech Sounds

Katsumasa SHIMIZU and Masatake DANTSUJI

O. Introduction

The study on the perception of /r/ and /l/, mainly in English, has been of considerable interest among researchers since the /r/–/l/ contrast has often been a choice to study the effect of linguistic experience, and /r/ and /l/ have unique articulatory and acoustic characteristics which can be defined as an intermediate between stop consonants and vowels. There have been a number of reports on the experiments of the perception of /r/ and /l/ using natural and synthetic speech sounds. Especially, the cross-linguistic studies reveal that the speakers of different languages, e. g., Japanese and English speakers, have different degree of performance in the perception of these sounds, since the /r/–/l/ contrast is functionally different in the two languages. Miyawaki et al. (1975) studied the effect of linguistic experience of American English and Japanese in synthetic speech sounds and mentioned that the difference of linguistic experience is specific to perception of speech mode. Furthermore, Gillette (1980) examined the contextual effects on the perception of /r/ and /l/ in natural speech sounds by Japanese and Korean speakers and reported that there are some differences in the perception of these sounds between the two language groups.[1)] Similarly, Mochizuki (1981) made a cross-linguistic study of /r/ and /l/ using natural and synthetic speech sounds and reported that position of the two sounds within a word has large effects on the perception of these sounds. As has been mentioned above, the study on the perception of /r/ and /l/ has attracted the attention of several people and some significant remarks have so far been made. However, the studies on the contextual effects on the perception of these sounds are still scarce, and the relation between acoustic characteristics and the perception of /r/ and /l/ has not yet been fully clarified. Therefore,

Katsumasa SHIMIZU (清水克正) : Instructor, Dept. of Linguistics, Kyoto University, and also faculty member of Nagoya Gakuin University.
Masatake DANTSUJI (壇辻正剛) : Graduate Student, Dept. of Linguistics, Kyoto University.
The authors conduct research under the direction of Dr. Tatsuo Nishida, Professor of Linguistics, Kyoto University. Parts of this article were presented at the XIIIth International Congress of Linguists, Tokyo, Japan, August 29–September 4, 1982.

1) Gillette (1980) carried out the listening experiments using natural sounds to Japanese and Korean speakers, and mentioned that, though there are similarities in the perception of /r/ and /l/ in the two groups of subjects, main differences are found in the perception of these sounds in word-initial and word-final positions, i.e., both positions are more difficult for the Koreans than for the Japanese.

the present study aims at examining how contextual differences in natural sounds affect the perception, what acoustic parameters are responsible for the /r/–/l/ contrast, and how Japanese and American English speakers perceive synthetic continuum of /ra–la/.

1. EXPERIMENTS ON THE PERCEPTION OF /r/ AND /l/ IN NATURAL SPEECH SOUNDS

The distinction between /r/ and /l/ in perception has been considered to be one of the trouble spots in teaching English for Japanese students, since the two sounds are not phonemically distinctive in Japanese and Japanese /r/ does not articulatorily correspond to them in English. In a survey recently carried out for Japanese learners of English, it is reported that the two sounds are often confused to each other by learners of English and belong to phonetically difficult category for them (Koike (ed.), 1978). Although there are several cross-language studies on the perception of the /r/–/l/ contrast from a point of teaching English as a foreign language, several questions arise on the contextual effects on the perception of the two sounds and on their acoustic characteristics. Therefore, the present experiments using natural sounds are designed to examine how contextual differences affect the perception of /r/ and /l/ by Japanese speakers. The experiments consist of (1) identification test of the /r/–/l/ contrast in 50 minimal pairs (Type 1), (2) identification test of the /r/–/l/ contrast in 40 words embedded in a carrier sentence "I said the word ____." (Type 2), and (3) identification test of the /r/–/l/ contrast in 40 words embedded in a carrier sentence "____ is my favorite word." (Type 3).

1.1 Test Materials

The test materials in natural speech sounds consist of three types of environment, as mentioned above. One male native speaker of American English, instructor of English teaching, read and recorded all test materials in three types. Minimal pairs and words in carrier sentences include occurring and non-occurring words of English. The recording was made at the sound-proofed recording facility of Nagoya Gakuin University.

1.2 Subjects

Subjects in the experiments were 32 undergraduate students, freshmen at the Department of English Literature, Kooka Women's College. All of them were naive to the experiments. They were native speakers of Japanese and have studied English as a foreign language for at least six years in their high school days.

1.3 Results

All subjects listened to the three types of listening materials and were instruc-

ted to identify the word containing either /r/ or /l/. For the identification of minimal pairs, they were instructed to indicate which word of the presented pair occurred first. For the identification of word embedded in carrier sentences, subjects were asked to identify which word containing either /r/ or /l/ was presented. Results of the listening tests of the minimal pairs are shown in Table 1 and the figures indicate the percentage of the pair correctly identified by 32 Japanese subjects. Results on Type 2 and Type 3 materials are not fully presented here, but are shown in reanalyzed form in Tables 2 to 4.

Table 1. Results of the Listening Test.
The figures indicate the percentage of the given minimal pair correctly identified by 32 Japanese subjects

1.	lead	— read	84.4%	26.	literary	— literally	68.8%
2.	ul	— ur	100.0	27.	porter	— portal	90.6
3.	il	— ir	81.3	28.	law	— raw	84.4
4.	oro	— olo	84.4	29.	ara	— ala	78.1
5.	allay	— array	90.6	30.	bleach	— breach	65.6
6.	ulu	— uru	81.3	31.	anger	— angle	96.9
7.	play	— pray	75.0	32.	ere	— ele	93.8
8.	pore	— pole	93.8	33.	sprinter	— splinter	53.1
9.	teller	— terror	81.3	34.	loom	— room	75.0
10.	rend	— lend	93.8	35.	pier	— pill	100.0
11.	right	— light	87.5	36.	ili	— iri	59.4
12.	hearer	— healer	81.3	37.	secular	— secure	78.1
13.	ro	— lo	93.8	38.	led	— red	90.6
14.	lay	— ray	96.9	39.	wrong	— long	90.6
15.	secretly	— secretary	87.5	40.	poor	— pool	96.9
16.	pilot	— pirate	59.4	41.	stir	— still	100.0
17.	ar	— al	81.3	42.	healing	— hearing	65.6
18.	till	— tear(N)	96.9	43.	el	— er	90.6
19.	ru	— lu	96.9	44.	la	— ra	84.4
20.	li	— ri	93.8	45.	brink	— blink	78.1
21.	towel	— tower	93.8	46.	collar	— core	100.0
22.	rock	— lock	81.3	47.	a roan	— alone	93.8
23.	holler	— horror	75.0	48.	solo	— sorrow	78.1
24.	peer	— peel	90.6	49.	lice	— rice	84.4
25.	le	— re	87.5	50.	or	— ol	81.3

As shown in Table 1, 32 Japanese subjects identified the minimal pairs of /r/ and /l/ fairly well, i. e., they identified the sequence of the minimal pairs at the average identification rate of 84.9%. Among 50 pairs, 22 pairs were correctly identified at the rate of more than 90%, while 13 pairs were less correctly identified at the rate of less than 80%. It can be said that the Japanese subjects can identify the phonetic cues for distinction of these contrastive pairs considerably well.

Table 2 indicates the overall performance for three types of listening materials.

Table 2. Percentage of Correct Identification in Three Types of Listening Materials.

Type of Listening Materials	Percentage Correctly Identified
Type 1	85.0%
Type 2	72.6
Type 3	70.7

From Table 2, it can be said that the /r/–/l/ in minimal pairs are more correctly identified than the words embedded in carrier sentences. There is no noticeable difference in the performance whether a key–word was placed in sentence–initial position or sentence–final position. This may be attributed to a more complete articulatory configuration of the contrast in minimal pairs than in carrier sentences.

Next, the data was reanalyzed to examine the effects of position in a word. Within a word, as is well–known, English liquids occur in word–initial, intervocalic, word–final–positions, and in the form of consonant clusters. They are said to have either a vocalic or consonantal nature depending on the position in a word, more specifically in a syllable; /r/ has phonetically a consonantal nature in a syllable–initial position, while it has a vocalic nature in a syllable–final position. On the other hand, /l/ has two allophonic variants; clear l [l] and dark l [ɫ], and dark l which is a velarized [ɫ] has vocalic characteristics, closer to the vowel [u].[2] Based on the results in the minimal pairs, the effect of position within a word can be shown in Table 3.

Table 3. Percentage of Correct Identification According to Positions in a Word.

Position within a word	Percentage Correctly Identified
Word–final	92.2%
Word–initial	88.4
Intervocalic	77.9
Consonant clusters	68.0

N.B. Consonant clusters were placed in a word–initial position

Table 3 indicates that the /r/–/l/ contrast in the word–final and word–initial positions are better perceived than in intervocalic position and in consonant clusters. This may mean that the contrast in the former positions is phonetically more distinctive than in the latter positions. These results agree with Gillette (1980) and partly with Mochizuki (1981). The weak performance in the intervocalic position

2) It is understood that dark l [ɫ] is acoustically similar to vowel [u] or [ʊ], in spite of the articulatory differences between them, and there is a fairly common change from [l] to [ʊ] in such examples as [mɪʊk] for milk and [fɪʊm] for film in American English.

and in consonant clusters may be attributed to the coarticulatory effects of the neighboring segments.

It is known that the performance in the listening tests is influenced by neighboring phonetic segments. We examined the effects of vowel environments, and the vowels examined were [i, ɪ, ɛ, ɔ, u]. They can be specified in such phonetic features as back, round, low, etc. Table 4 shows the effects of vowel environments.

Table 4. Percentage of Correct Identification in Neighboring Vowel Environments.

		Type 1	Type 2	Type 3
Word-initial	#___[−back, −low]	94.8%	92.6%	78.1%
	#___[+back, +round, −low]	87.0	82.8	67.7
Word-final	[−back, −low]___#	94.5%	84.4%	95.4%
	[+back, +round, −low]___#	89.1	61.0	92.2

For Type 1 materials, when a front, non-low vowel follows in the word-initial position, the percentage of the correctly identified pairs was 94.8%, but when a back, rounded vowel follows, the one was 87.0%. From Table 4, it can be said that the /r/-/l/ contrast is better perceived in the environments of non-low, front vowels than those of back rounded vowels in word-initial and -final positions. That is, the environments of non-low front vowels facilitate the perception of the contrast, while the ones of back rounded vowels may inhibit it. It can be said that the anticipatory rounding caused by roundness of back vowels may inhibit the perception of the contrast.

1.4 Spectrographic Analysis

As has been pointed out in several literatures, /r/ and /l/ in English show a considerable allophonic variation in phonetic quality depending on the phonetic environments. Several studies have been made on the acoustic characteristics of these segments in various environments, and allophonic details have been acoustically analyzed (Lehiste, 1964). In the present study, however, instead of examining such details themselves, spectrographic analysis was made for the pairs with a higher percentage of identification and the ones with a lower percentage to examine the acoustic cues for the distinction between the two segments.

Upon examining the spectrographic analysis in Type 1 materials, several noticeable differences between the two segments were observed in the transitions of the second formant (F2) and the third formant (F3). The pairs like ul-ur, allay-array, and li-ri, etc. which were more correctly identified showed some differences in these

transitions. In the word-initial position, /r/ showed a tendency of rising transition of both F2 and F3 to the following vowel, while /l/ showed the rising or level transition of F2 and the falling one of F3. In the word-final position, the transition of F3 appears to be the main cue for distinguishing the two sounds; /r/ showed the rising transition, while /l/ showed the falling one. Furthermore, in the intervocalic position, F3 pattern in VCV sequence seems to contribute to the distinction; /r/ showed the fall-rise transition, while /l/ showed the rise-fall one. In the pairs mentioned above, these characteristics in the formant transitions were clearly manifested, but in such pairs as pilot-pirate which were less correctly identified they were not distinctly shown. From these, it can be said that the transitions of F2 and F3 are the main cues to the distinction between /r/ and /l/.

2. EXPERIMENTS ON THE PERCEPTION OF /r/ AND /l/ IN SYNTHETIC SPEECH SOUNDS

A cross-language study using synthetic speech continuum /r-l/ has attracted the attention of several people in terms of examining the acoustic features in the synthesis of English liquids and the effects of linguistic experience on the perception of these sounds, and several studies have so far been reported. What is relevant to the present study are Miyawaki et al. (1975) and Mochizuki (1981). Miyawaki et al. carried out the experiments using synthetic speech and non-speech continuum of /r-l/ for both English and Japanese speakers. They reported that a significant difference between the two groups of speakers was found in the pattern of discrimination of speech continuum; categorical perception by American English speakers and continuous perception by Japanese speakers, but both subject groups showed the identical pattern in discrimination of non-speech continuum of /r-l/. From these results, they suggested that the effect of linguistic experience is specific to the perception of these sounds. The difference in the pattern of discrimination can be attributed to the one in the phonemic function of these sounds in the two languages. Furthermore, Mochizuki carried out the experiments on perception of synthetic continuum of /r-l/ for both groups of subjects and reported that there exists a difference in the identification of these sounds, especially /r/, between the two groups of subjects.

In the synthesis of /r-l/ continuum for the experiments, it is generally understood that the starting frequency of F3 has an important role to make a distinction between /r/ and /l/, and previous studies which have so far been done used the synthetic continuum in which the starting frequency of F3 was systematically varied in equal step. A number of spectrographic analyses have shown that the initial transition of F3 is one of the most relevant features for the /r/-/l/ distinction, and it is observed that in the word-initial position the transition on /r/ is rising after a brief steady state, while the one on /l/ is falling. As shown in our spectrographic

analysis, the transition of F2 also changes in almost the same direction with F3, and is one of the relevant features for the distinction. In our present study, therefore, the stimuli were prepared in which both starting frequencies of F2 and F3 were varied in almost equal steps.

2.1 Stimulus Materials

The stimuli were prepared on the OVE III synthesizer at Haskins Laboratories. The 10-step /ra-la/ stimuli differed in the frequency values of F2 and F3 within the initial steady-state portions and the transition portions. F2 values varied in almost equal step from 951 to 1404 Hz and F3 values from 1488 to 3246 Hz. F1 values were kept constant for 10 stimuli. The stimulus with 1404 Hz of F2 and 3246 Hz of F3 was a good /la/, while the one with 951 Hz of F2 and 1488 Hz of F3 was a good /ra/. The total duration was 377 msec. The schematic formant pattern and the duration can be shown in Figure 1.

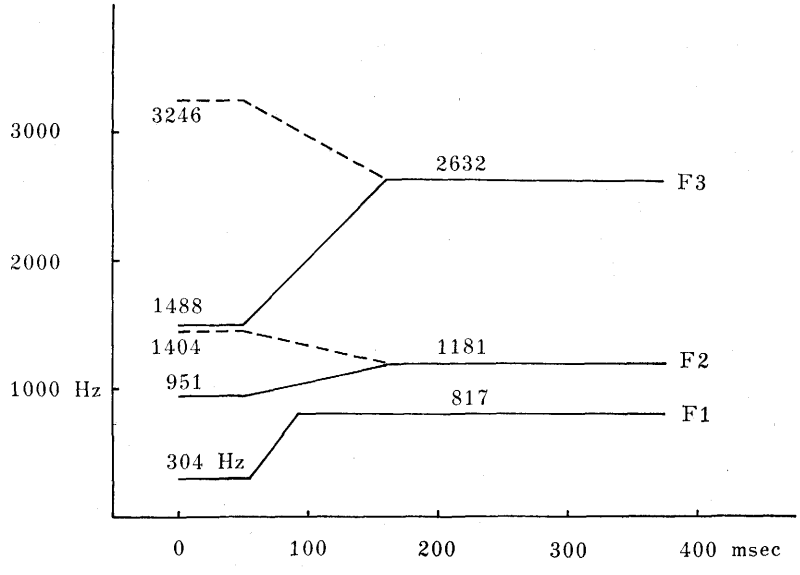

Fig. 1. Schematic formant pattern of synthetic stimuli.

Two types of test were prepared; an identification test and an oddity discrimination test. In the former test, each stimulus was repeated 10 times, making the total presentation 100, and the stimuli were randomly arranged. The interstimulus interval was 1 sec. and the block interval was 10 sec. The oddity discrimination test consisted of 18 repetitions of each of 7 stimulus pairs (1-4, 2-5, 3-6, 4-7, 5-8, 6-9, and 7-10), totalling 126 triads in all. Stimulus pairs were arranged such that members were three steps apart along the 10-step stimuli. For each pair, triads were constructed by duplicating one member of the pair, and six permutations of each companion was included; i.e., for 1-4 pair, 1-4-4, 1-1-4, 4-1-1, 1-4-1, 4-1-4, and 4-4-1. All test materials were recorded on audio tape for presentation to

subjects.

2.2 Subjects

Subjects were 7 native speakers of American English and 23 native speakers of Japanese. American English subjects had lived in Japan for a certain period, ranging from three months to 3 years. Japanese subjects were undergraduate students who had studied English as a foreign language in their high school days. All subjects reported having no hearing impairment by self-judgement.

2.3 Procedure

The subjects of both language groups were tested at ordinary language laboratory facilities. Stimuli were presented binaurally at a comfortable listening level. About ten stimuli were presented for familiarization with the stimuli.

2.4 Results

Results of the identification and discrimination tests can be shown in Figures 2 and 3.

Figure 2 shows the results of the pooled identification for Japanese and American English subjects. Japanese subjects identified stimuli 1, 2, and 3 as /ra/ and stimuli 8, 9, and 10 as /la/ with 60—70% of identification rate. American English subjects, on the other hand, identified stimuli 1 to 5 as /ra/ and stimuli 9 and 10 as /la/ with an almost 100% of identification rate. The two subjects groups showed

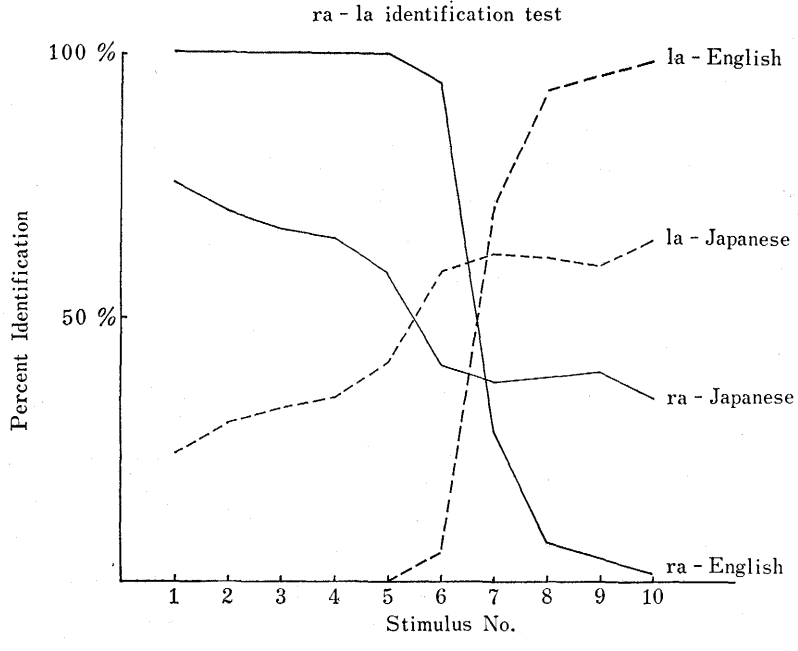

Fig. 2. Pooled identification of Japanese- and English-speaking subjects.

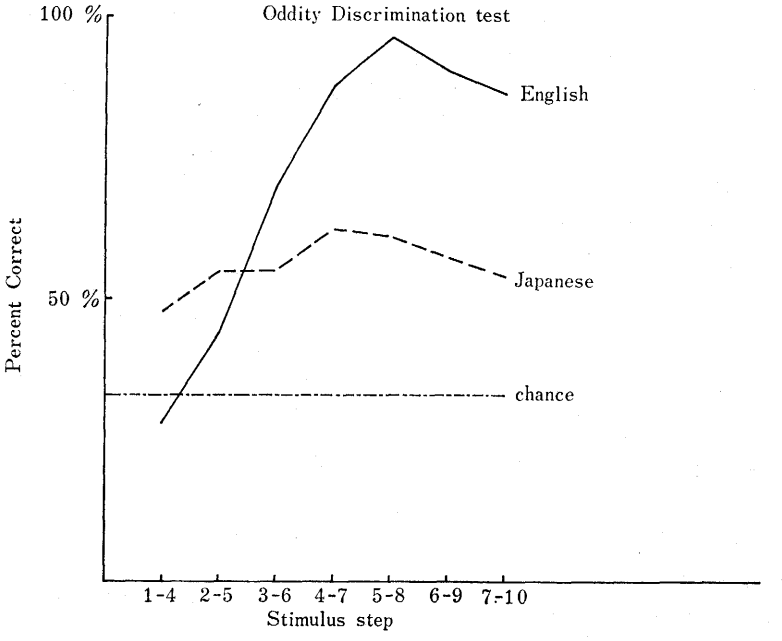

Fig. 3. Pooled discrimination of Japanese- and English-speaking subjects.

completely different patterns in the identification of /r-l/ continuum. It can be found that Japanese subjects showed a gradual shift of identification curve as the stimulus shifts from 3 to 7, while American English subjects showed an abrupt shift of the curve in the stimulus range from 5 to 8. Furthermore, the boundary between /r/ and /l/ lies between stimuli 5 and 6 for Japanese subjects and between 6 and 7 for American English subjects.

The difference between the two groups in the identification test can be substantiated in the discrimination test. Figure 3 shows a pooled discrimination for both groups of subjects. Examining the results of discrimination function in Figure 3, the two groups of subjects demonstrated a completely different pattern of performance. Japanese subjects discriminated the stimuli with an accuracy rate ranging from 50 to 65% across the continuum of stimulus set. They showed a moderate increase in discrimination of stimulus pairs 4–7 and 5–8 which are considered to be in the boundary in the identification test, but there is no remarkable change in the accuracy percentage in both within and between categories. On the other hand, in case of American English subjects, the accuracy was below the chance at 1–4 pair but sharply rose to near perfect accuracy at 5–8 pair which is in the phonetic boundary between /r/ and /l/. That is, American English subjects discriminated very well between stimuli drawn from different phonetic categories but very poorly between stimuli drawn from the same phonetic category.[3] The discrimination peak occurred

3) The term "phonetic" may be replaced by "phonemic". It is used here in the dichotomy of auditory-phonetic distinction.

at the stimuli which corresponded to their identification boundary. Examination of the discrimination function of the two groups reveals that Japanese subjects perceive the synthetic /r–l/ continuum continuously, while American English subjects perceive it categorically.

3. EXPERIMENT ON THE DISCRIMINATION OF /r/ AND /l/ BY JAPANESE PRESCHOOL CHILDREN

In order to examine how Japanese preschool children perceive the synthetic /r–l/ continuum, an oddity discrimination was carried out with six children whose age was around 5 years old. In the previous study Eimas (1975) examined the discrimination of the synthetic /r/ and /l/ by American infants (2 and 3 months old) and reported that they can discriminate stimuli along the acoustic continuum related to /r/ and /l/ in a nearly categorical manner. This implies that the very young children may have mechanisms for the phonetic processing of speech and they are part of innate endowment for the human infants. There has been no report on the perception by Japanese infants. In relation to this kind of consideration, it will be of interest to examine how Japanese preschool children discriminate the /r–l/ continuum and how their discrimination differs from the one by adult Japanese subjects.

3.1 Experimental Procedure

Six Japanese preschool children took part in the discrimination test as subjects. All of them were five years old and had normal hearing ability. They have never been exposed to English before. An oddity discrimination test was carried out one at a time and they were instructed to indicate verbally which one of the three stimuli differs from the other two stimuli. This kind of instruction caused no trouble to the subjects. The synthetic stimuli were exactly the same with the ones described in 2.1.

3.2 Results

Results of the oddity discrimination test were examined in individual and pooled ones. In examining the data, two subjects were eliminated because of erroneous patterns in responses. Pooled discrimination curve of four subjects can be shown in Figure 4.

The level of discrimination was rather low. The accuracy rate was near or below the chance at 1–4 and 2–5 pairs, and moderately rose to about 60% at 5–8 and 6–9 pairs. There is a peak at 5–8 pair. From this level and pattern of discrimination, it is difficult to speculate whether Japanese preschool children discriminate the synthetic /r–l/ continuum, but the overall pattern of accuracy seems to be categorical, since they can discriminate the stimuli which are considered to be drawn

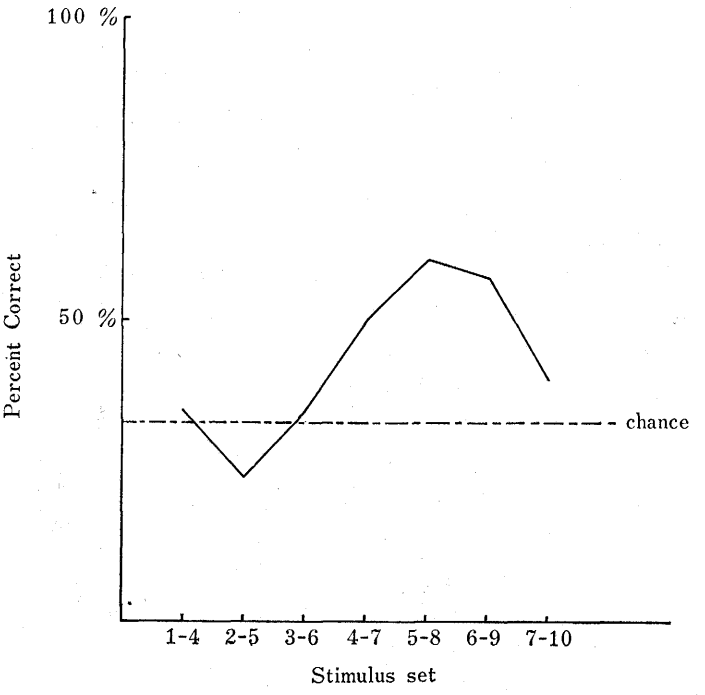

Fig. 4. Pooled oddity discrimination of 4 Japanese Preschool Children.

from different categories relatively well. This may imply that Japanese children have an access to some mechanisms, maybe auditory ones, to discriminate stimuli ranging from 4 to 9 with the accuracy rate of about 60%. Although the data is still less convincing, this means that Japanese preschool children, being independent of linguistic experience to the /r/–/l/ contrast, have the ability to perceive the contrast. This has a significant implication in examining the speech processing mechanisms of the children.

4. Discussion

In the foregoing sections, we have examined how Japanese subjects perceive the /r/–/l/ contrast, how two groups of subjects perceive the synthetic continuum of /r–l/, and how Japanese preschool children discriminate the continuum. In examining the results in natural speech sounds, it has become clear that Japanese subjects can discriminate the contrast in minimal pairs, pronounced by an American speaker, fairly well, and the identification can be affected by neighboring phonetic circumstances. As seen in Tables 3 and 4, the contrast is better perceived in word–initial and word–final positions than in intervocalic position and in the form of consonant clusters, and /r/ and /l/ preceding or following non–low front vowels are better perceived than those in the environments of non–low back vowels. These results conform in whole or in part to the previous findings on the cross–language

studies on the perception of natural /r/ and /l/ sounds. That the performance in discrimination is influenced by phonetic contexts can be attributed to coarticulatory and/or anticipatory effects by neighboring segments, especially the anticipatory rounding caused by the following back round vowels weakened the discrimination of the contrast.

In the identification and discrimination tests of the synthetic /r-l/ continuum conducted with Japanese and American English subjects, the two groups showed a markedly different pattern of performance. Stimuli 1 to 5 which were identified by American English subjects as /ra/ with 100% were identified by Japanese subjects with 50—75% rate. Stimuli 9 and 10 which were identified by American English subjects as /la/ with 95—100% rate were identified by Japanese subjects with around 60% rate. Moreover, patterns in the identification and discrimination curves are different in the two groups; American English subjects abruptly change the identification from /ra/ to /la/ at stimuli 6 and 7, while Japanese subjects gradually change the identification as stimulus shifts from one another. The difference in the identification can be reflected in the presence or absence of a peak in discrimination; American English subjects were very accurate in the pairs drawn from different categories of /r/ and /l/ and the peak was situated in the region of phonetic boundary, but Japanese subjects were rather less accurate throughout the continuum. From these patterns in both tests, it can be said that Japanese subjects perceive the /r-l/ continuum continuously, while American English subjects do it categorically. The findings that the two groups of subjects have a considerably different pattern of identification and discrimination in the synthetic sounds are in agreement with the previous studies (Miyawaki et al., 1975; Mochizuki, 1981). As has been claimed, it can be said that the difference can be attributed to the one of linguistic experience of the two groups of subjects.

Moreover, in the synthesis of the stimuli, the starting frequencies of both F2 and F3 were systematically varied in almost equal step, and the stimuli prepared in this way could draw a difference in the patterns of identification and discrimination between the two groups. It can be said, therefore, that the variation of the initial transition of F2 is also perceptually responsible for the distinction between /r/ and /l/.

In examining the results in natural and synthetic speech sounds, Japanese subjects discriminated the minimal pairs of natural /r/ and /l/ with around 85% accuracy, though the level of accuracy is dependent on the neighboring phonetic circumstances. Japanese subjects who were able to identify the natural /r/ and /l/ sounds fairly well showed a rather depressed performance in the identification of the synthetic stimuli. There seem to be two reasons for the different level of performance between natural and synthetic speech sounds. The one is that the Japanese subjects have been accustomed to the natural /r/ and /l/ sounds in English in their process of learning English and some other acoustic factors than F2 and F3 transitions may

contribute to a fairly good performance in natural sounds. The other is that they may use different auditory processes from the one used for natural sounds when the synthetic /r–l/ continuum is presented and is characterized as linguistically non–significant segment.

The performance in the discrimination by Japanese preschool children reveals an interesting phenomenon. It is generally considered that the very young children are unable to discriminate the stimuli when their native language does not have the phonemic contrast. Since /r/ and /l/ are not phonemically distinct in Japanese, it can be predicted that preschool children cannot discriminate the synthetic /r–l/ continuum. However, in our experiment on children, they showed a tendency to discriminate the synthetic continuum, though the data is less convincing. Although further elaboration is needed on the experiments, the discriminability by children has a significant implication. All children in the experiment were five years old and have never been exposed to English before. It is considered that they might have already passed the critical period of learning a mother language, but they may still have sensitivity to discriminate the /r–l/ continuum. This indicates that preschool children who are still immature in language learning may have the mechanisms to discriminate the acoustic dimension into functionally distinct classes. This mechanism may lose the sensitivity in the development of language learning unless they are exposed to the specific linguistic experience in their environments.

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