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Comparing Fricatives: A Spectral Analysis of /hi/ and /ç/ in Japanese and German

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Abstract

The present study sheds light on the phonetic value of the realizations of the /h/-part in the Japanese syllable /hi/, German /h/ before /i/ and German /ç/ in its specific environment from an acoustic point of view. In phonetic descriptions of Japanese, /h/ before /i/ is often transcribed as both, [ç] and devoiced [i̥] in the same broader context. Since German treats both realizations as phonemically distinct, it seems to be a useful language to compare the Japanese data with. An acoustic analysis of Japanese and German data will be undertaken to show similarities and differences of the acoustic structure of these sounds, depending on the environment of occurrence.

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1 Introduction

In classifying Japanese consonants, there are different ways to group the so-called "h-sounds". In a /hi/-sequence the /h/-part could be realized as either [ç] or as a voiceless front high vowel [i̥], the latter being the devoiced counterpart of the following vowel. The occurence of either realization can go together with vowel devoicing in specific environments. In Japanese, high vowels are often devoiced between voiceless obstruents, which can even be deleted, either in rapid speech (Vance, 1987, p.55) or if a fricative or affricate precedes, although coarticulatory effects remain on that fricative (Kawakami, 1977). Some linguists point out that [ç] always occurs when followed by a highfront vowel. Others, on the other hand, have shown, that [i̥] can be found in the same position.

In German, the quality of the glottal fricative /h/ is dependent on the quality of the following vowel. It could also be described as the devoiced counterpart of the following vowel (Kaneko & Neyer, 1984). Therefore, in the sequence /hi/, as in the German word "hier" (meaning 'here'), the fricative is palatalized. In addition, a distinctively different fricative, the "ich-Laut", can be found in German. In syllable-initial position, it occurs before front vowels only and is transcribed as the palatal fricative [ç], as in the German word "Chirurg" (meaning 'surgeon'), realized with standard German pronounciation.

In the present study some comparisons of the acoustic structure of specific effects within and across Japanese and German are shown.

2 Segmental Context, Position in Syllable and Word

On a segmental level, each language has its own set of sounds and its own rules to combine them. The rules sometimes overlap but more often differ from those of other languages. Although the set of sounds and the phonotactic structure of Japanese and German do overlap in many aspects, there are some differences which have to be taken into account.

A brief description of the context and the placing of the sounds, which this study focusses on, will therefore follow.

2.1 /hi/ in Japanese

The syllable structure in Japanese allows only a very limited number of combinations of sounds. Roughly speaking, a Japanese syllable has the following structure:

(C) (S) V (N/Q)

"V" could be any of the five Japanese long and short vowels, "C" any Japanese consonant —including affricates—and "S" one of the Japanese semivowels (Murasaki, 1982). The syllable-final "N" refers to a nasal, which only occurs after a vowel and takes its quality from the context. One more phoneme is "Q", which is a quantity phoneme, that extends the length of the following consonant; similar to consonant gemination in Italian and Finnish.

The /hi/-syllable can be found at any position in a Japanese word, preceded by any vowel and the nasal "N", but not by the gemination phoneme "Q". "N"or "Q" may be added to the end of the syllable, and every permissible syllable may follow. In intervocalic positions or after "N", any /h/-sound may be voiced, due to voicing assimilation. However, this voicing was not found in the data, used for the following experiment.

As mentioned above, the vowel /i/ of the focus-syllable can be devoiced or even dropped in a specific context. In the data used for the acoustic analysis in this study, this was almost always the cases when /hi/ occurred before unvoiced stops. Kawakami(1977) claims that, in such a case, the phonetic value of the fricative /h/ is always [ç] and can never be replaced by a glottal fricative. Others say, that this may well appear instead of the "ich-Laut" in most environments (Sakuma; 1929). A third group claims that before a high front vowel a palatal fricative [ç] is generally found (Amanuma et al., 1985[8]).

2.2 /hi/ in German

The glottal fricative /h/ in German occurs in syllable initial position only, immediately followed by any German vowel. Its quality is very much influenced by the following vowel and acts therefore as the unvoiced counterpart of the vowel. In the case of /hi/, the phonetic value would be [i̥i]. In intervocalic position and sometimes even if placed word- or utterance-initial, /h/ is almost always voiced. Nevertheless, the probability of finding a devoiced realization is highest when /hi/ is at the beginning of an utterance, opening a stressed syllable.

At the end of a syllable introduced by /hi/, any permissible syllable-final sound combination in German may occur.

2.3 /ç/ in German

The palatal fricative [ç] in German is known as the "ich-Laut". Different phonological approaches classify it either as an allophone of /x/, in complementary distribution with the "ach-Laut"[x,χ] or as an independent phoneme, using derrivated words as basic units for a phonological analysis (Werner, 1972). In this study, the latter approach will be adopted.

This fricative is restricted in its permissible context but may occur in initial or final positions of a syllable. In initial position it be followed by any vowel. Words, in which a non-front vowel follows the palatal fricative are very often borrowings from Greek, such as "Echo" and "Eucharistie". On the other hand, a morpheme boundary between the fricative in syllable initial position and the non-front nuclear vowel of the syllable may be identified, as in "Verseuchung" (meaning 'contamination'). In other Greek borrowings, it might be followed by a /t/, as in the word "chthonisch". In final position the palatal fricative can be found immediately after front vowels, diphthongs targeting front vowels or after /l,r,n/. It may also be followed by /t/ in this position.

In some southern German dialects, word initial [ç] is unknown, although realized as such in word-intermediate but syllable initial position. In Swiss-German [ç] is always substituted by the "ach-Laut".

Rules for its distribution can be expressed as follows[1]:

/ç/ /	V[+front]	__	(t)$	
/ç/ /	V	C[l,n,r]	__	(t) $
/ç/ /	$	__	V	
/ç/ /	$	__	t	V
/ç/ /	$	__	#	V[+back]

3 Data Analysis

For the spectral analysis two sets of data were used.

3.1 Japanese Data

For Japanese, the speech data of four male and four female speakers—all professional announcers speaking standard Japanese—were used. This is part of the ATR Speech Database, which was recorded in a sound-proof recording booth. Of this set of 5240 common Japanese words, 229 words per speaker containing the syllable/hi/ were selected. They were segmented and labelled previously and the labelled /h/-portion was used for spectral analysis.

[1] $denotes a syllable boundary; # denotes a morpheme boundary

3.2 German Data

The German data was obtained from seven German speakers (three female, four male) in Japan. It consists of connected speech, a set of sentences including a set of words with /ç/ (54 words) and /hi/ (24 words) in diverse contexts, read by the subjects five times and recorded in a sound-proof recording booth. The target sounds were labelled afterwards for the analysis procedure in that way, that they also contained transient information.

3.3 Formant Analysis

Before the spectral analysis of the data was started, it was digitized at a sampling rate of 12kHz. The spectral analysis is based on an LPC analysis; formants are equivalent to the poles in the complex z-domain, their frequency corresponds to the arguments of the complex poles and their bandwidth to the inverse distance between pole location and unit circle. For root-findings a modified Newton-Raphson algorithm was used (Bairstow algorithm). Following this procedure, five formant values between 0 and 6kHz and their bandwidths were calculated in steps of 5ms from the beginning to the end of each fricative, obtaining formant values for each of these steps.

Since the use of the term "formant" varies among researchers, the following conditions were adopted: the term "formant" will be used in the sense that it denotes a peak of high occurrence in the frequency domain of calculated values by the above described method. The peak showing the lowest frequency value will be called the first formant (F1), the peak with the next higher frequency value the second formant (F2) and so forth. So it is p ossible, that for some time frame, a value of F2 can be found, but not one for F1.

Formant values with a higher bandwidth will have low amplitudes and are therefore not considered reliable. Only formant values with bandwidth below 500Hz were included in the statistical calculation.

4 Results and Discussions

Depending on the different contextual conditions, the mean and the standard deviation of each formant was calculated.

The data showed that for some formants there are two groups, aligned with high frequency of occurrence, differing strongly in their values (Fig. 1, Fig. 2, Fig. 3). In German F1 and F2 of /ç/, a second set of formant values group at the same frequency, where the next higher formant has its highest frequency of occurrence. For that reason, this data is eliminated from the statistical calculation of the formant it is analyzed with. The results of German /ç/ for F1 consists of formant values below 1.5kHz and those of F2 below 2.6 kHz only.

Although two separate groups can be discovered in the Japanese data for F1, such overlapping of the second group (the higher value group) with the formant value of the next higher formant (showing the highest frequency of occurrence), cannot be discovered. This point will be discussed later on.

4.1 General Comparison between Japanese /hi/, German /ç/, /çi/ and /hi/

First of all, the fricatives in both languages under any further context were statistically examined (Table 1; Fig. 4 , Fig. 5). This procedure was chosen to find out whether for such fricatives some unique spectral feature, similar to the locus of other consonants (Fry, 1979), can be found. The palatal fricative under the conditions syllable-initial and followed by /i/ was also chosen for this comparison, because of its phonotactical similarity with Japanese and German /hi/.

4.1.1 General Results

The results of F1 show no significant difference between German /ç/ and German /hi/($p > 0.05$), which have significantly lower values than /çi/. Much higher than all these three fricatives is the Japanese /hi/.

The second formants of German /ç/ and /çi/ are not significantly different from each other, but they are both significantly below Japanese and German /hi/. Among the /hi/-data , the Japanese fricative is higher ($p < 0.05$) than the German fricative.

In F3, German /ç/ is not different from German /hi/, whereas German /çi/ and Japanese /hi/, which are different from each other—/hi/ is higher than /çi/—show higher frequency for F3.

The relation within F4 is similar to F2, where both German palatal fricatives show no distinctive difference. Still, Japanese /hi/ is lower than in German /çi/. German /hi/ on the other hand shows cosiderably higher values than all the other categories.

The formant values of F5 differ very much between the categories, where the fricative in Japanese /hi/ is higher than German /hi/, which lies above /çi/, which again is higher than /ç/.

4.1.2 Discussion

Differences and similarities vary for each formant. Therefore, under general conditions, there is no clear one-to-one correspondence of the spectral structure observable between

Japanese /hi/ and any German fricative of this set. In addition, there is no such correspondence within the German fricatives either (i.e. between the two palatal fricatives or between the two fricatives followed by /i/). As a general tendency, one can find that the formant values of Japanese /hi/ are higher than all German fricatives in most cases, as in F1, F2, F3 and F5. On the other hand, German /ç/ tends to have lower formant values than most of the other fricatives for F1, F2, F3 and F5 and can never be found highest. German /hi/, which very often has lower value too (F1 and F3), can also be found to have higher values than the other fricatives. German /ç/ shows the same values as the fricative in /çi/,twice (F2 and F4) and this is also the case with German /hi/ (F1 and F3), whereas Japanese /hi/ is always different from any German fricative and also German /hi/ and /çi/ never overlap. Because of the general dissimilarity between the Japanese and German data, where the Japanese data show a strong tendency for almost all formants to be higher than the formants of the German data, one has to reject the idea of a possible locus these fricatives have in common and must acknowledge the effects of language variability and speaker variability for such fricatives. Therefore, for further comparisons, similarities in tendencies across the two languages will be focussed on.

4.2 Realized and Dropped /i/ in Japanese /hi/

As mentioned in the introduction, Kawakami(1977) points out that if the /hi/-syllable in Japanese does not carry a voiced vowel, the fricative has to be the palatal fricative /ç/. In the following comparison, the relationship between the Japanese realizations and between the possible Japanese and German counterparts—which is German /hi/ if the Japanese /hi/ contains a voiced vowel and /ç/ if it does not contain a voiced vowel—will be described (Table 2, Fig. 6, Fig. 7, Fig.8, Fig. 9).

4.2.1 Results

The first formant F1 shows clear differences in its values between the two sets of the Japanese data, where the formant values are much higher if the [i] is dropped, than in the case of phonetically realized [i]. There is no correspondence to the German counterparts, where the formant values of the fricative in /hi/ is similar to the formant values of /ç/.

F2 of the two Japanese realizations (Fig. 6, Fig. 7) are not different, which is the case for the formant values of the two German fricatives, where the formant values of /ç/ is lower than those of /hi/.

As with the German data, there is no difference within the Japanese data for F3.

F4 shows significantly higher values for the Japanese version without [i] ($p \prec 0.05$), which stands in contrast to the German data, where /ç/ shows much lower formant values than

the fricative in /hi/. Only in F4 are the German data formant values higher than those of the Japanese data.

In F5 of the Japanese data, it can be observed that the fricative of the syllable containing a realized [i] is significantly lower than that without [i], which is not the case for the German data, where the formant values for /ç/ and the fricative in /hi/ are the same. Here again, the formant values of the German data are lower than the Japanese data.

4.2.2 Discussion

For the Japanese data, there is a tendency for the fricative without a following voiced vowel to be higher. This stands very much in contrast to the German data, where almost always the palatal fricative is distinctively lower than the glottal fricative in /hi/. Therefore, one cannot assume a one-to-one-correspondence between the German palatal fricative /ç/ and the Japanese fricative, in case of the dropped vowel on one side and the glottal fricative in German /hi/ and the fricative followed by [i] in Japanese /hi/, on the other side. The difference of the F1-values can be connected to the two seperate peaks in the F1-histogram, introduced in 4 (Fig.3). Although not equivalent to the German data, there is strong evidence that this effect is a reliable feature of the different spectral structure under the aspect "not followed by [i]" and "followed by [i]" (Fig. 10, Fig. 11, Fig. 12).

4.3 Positions in Word and Syllable

In the following, the influence of the position of the Japanese /hi/-syllable in a word and the position of the German palatal fricative /ç/ in a syllable on the spectral structure of the fricative will be examined. Although the German /hi/ occurs in syllable initial position only, it is added to the comparison (Table 3).

In Japanese, the /hi/ may occur in three different positions in a word: initial, medial and final. In addition, it may be a word by itself.

The palatal fricative in German may occur in any syllable of a word and in the beginning and at the end of a syllable (see 2.3 for further contextual restrictions).

4.3.1 Results

Word final and word medial, a very similar formant structure can be observed, where F1 and F3-F5 show the same values between the groups. A difference can be found for F2, where the value for the word final data is considerably lower. Although most formant values are higher for /hi/ in word initial position than /hi/ in final and medial position, they are

equal to the values for F2 in word medial position. /hi/ as a word shows values between the values for initial and final position (F1 and F2) or values that do not differ from the values of other formants (F3, F4, F5) of either of them. For example, F3 for /hi/ as word equals F3 for /hi/ in initial position, which is also the case for F5. On the other hand, the value of F4 is the same for /hi/ as a word and for /hi/ in medial and final position (Fig. 13, Fig. 14, Fig. 15).

Except for F4, there is no difference in the formant values for syllable initial and syllable final /ç/. In case of F4, the value for syllable final /ç/ is slightly higher than for /ç/ in syllable initial position.

4.3.3 Discussion

There is some tendency for the fricative in Japanese /hi/ to differ in dependency on its position in a word. Although the spectral structure /hi/ in final position is very similar to /hi/ in medial position, it receives some kind of "dark-colouring" through F2, where the value differs strongly from the value in medial position, which equals the value of the fricative in initial /hi/ here. Apart from that, most of the formant values of initial /hi/ are considerably higher. The /hi/-syllable as a word seems to inherit both position properties, final and initial, because it shows intermediate formant values for the lower formants and overlapping in its values with the values of the fricative in /hi/ in both positions.

The difference of the values of F4 in German is not as strong as the differences for the Japanese data. In addition, the lower value is found in initial position and not syllable final. This stands in contrast with the Japanese data, where in initial position the values are usually higher.

4.4 Consonantal Context

Contextual effects will be examined in this section. For such an examination, a contextual situation, that is available in both languages was chosen. This is the case, when a fricative is followed by a voiceless plosive. As mentioned in 2.1, the vowel of the /hi/-syllable in Japanese is almost always dropped, when a voiceless plosive follows. Therefore, the sequences /hik/ and /hit/, containing no phonetically realized vowel were chosen. For German, the sequences /çk/ and /çt/ were used for this comparison.

4.4.1 Results

The formant values for the Japanese fricatives in both environments are the same for F1,

F3 and F5 (Table 4).They differ for F2 and F4 ($p<0.05$; F2 and F4) in that tendency, that the formant values for the fricative followed by [k] is lower than for the fricative followed by [t] in both cases.

The German data show no significant difference for all formants of the fricative in either context (i.e. F1: $p>0.05$; see also Fig. 15, Fig. 16, Fig.17, Fig. 18).

4.4.2 Discussion

The Japanese and the German data differ very much. Within the German data, no difference connected with the different consonantal context can be identified, whereas the Japanese data show context sensitivity for two formants. These attributes signify the different status of the fricative for each language.

4.5 Vocalic Context

To investigate possible overlapping of context effects through vowels of both languages, again phonotactically similar conditions in Japanese and German were chosen. The utterance initial /hi/-syllable in German and the word initial /hi/ in Japanese—which is utterance initial as well, since the Japanese data is extracted from a word database—, which contains also the vowel [i], were used for this procedure. Here, the vowel of the next syllable served as possible factor of variability. In most cases, there is at least one consonant between the [i] of the /hi/-syllable and the vowel of the next syllable.

4.5.1 Results for the Japanese Data

The Japanese data show strong differences according to the openess/closeness of the vowel for F1 (Table 5): the formant value of F1 for the fricative in the /hi/-syllable, when the next syllables nucleus is /e/,/i/ or /u/ does not differ among each other, whereas in the case of /a/ the formant value is higher, which is still lower than before /o/, the only rounded vowel in Japanese.

The formant values of F2 vary in a different way. Here, if /a/,/e/ or /u/ follows, the same formant value can be identified for the fricative. If the next syllable contains /i/, F2 is lower and in the case of /o/ it is higher.

For F3, one can observe some kind of ranking of the formant values in correspondence to the different vowels: the lowest value can be found if /u/ follows, a higher value for /i/, next comes /o/, followed by /a/ and if the next syllable contains /e/, the highest value of this formant can be identified. In the case of /u/, F3 is significantly lower than in any

other vocalic context ($p < 0.05$). For the other vowels, the value is not different from the neighbouring vowel on that scale, but differs from the next-next neighbouring vowel.

A similar kind of ranking can also be observed for F4, where the order is different. Again, in the case of following /u/, the formant value is lowest, higher comes the case of following /i/, then /a/, then /o/ and finally /e/. The neighbouring effect is the same as for F2, except for the case of following /u/, where the formant value is distinctively lower than in case of any other following vowel ($p < 0.05$).

The same ranking effect is present for F5, again in a different order. In case of /u/, a significantly lower formant value can be found ($p < 0.05$). Next higher value appears with the context /i/, followed by /e/-context, next comes /o/ and highest with /a/-context.

4.5.2 Results for the German Data

Before describing the results, a brief explanation of the symbols and their phonetic quality used in Table 5 and Fig. 19, Fig. 20 and Fig. 21 will be undertaken. What is transcribed as /A/, refers to the centralized vowel, which is the pronounciation for the syllable final "r" immediately after a vowel or the "er"-sequence in an unstressed syllable, as in the name "Peter". /e/ refers to the short front and open-mid vowel, which lies close to the third cardinal vowel, as in the word "Pech". /sw/ is used as abbreviation for the centralized vowel schwa, which is more closed than /A/.

F1 does not show different effects through /A/ and /e/, but in case of /sw/, the formant value of the fricative is noticeably lower.

/sw/ shows again very different effects for F2, where the formant value is much lower than in the case of /A/ and /e/. However, /A/ and /e/ do not evoke any differences in the F2-formant value of the fricative.

For F3, /e/ differs in its effect on the fricative from the other two vowels ($p < 0.05$), whereas those do not differ from each other and show lower values of the formant.

The same effect as for F3 can be identified for F4, where in the case of /e/ the formant value is higher than in case of /A/ and /sw/, which do not cause any differences.

The formant value is the same under all three contextual conditions for F5.

4.5.3 Discussion

For the Japanese data, there is a tendency for the following closed vowels /u/ and /i/, that all formant values of the fricative are lower than for almost all other vowels. The other vowels show no influence in any particular order for each formant, but the values are always higher than in the case of the closed vowel. Interesting is, that the only rounded vowel in Japanese, the /o/, has a reverse effect on the fricative than one would suppose: according

to Fry (1979, p. 81) lip-rounding causes a low F2 value for the vowel itself. In this case, it causes a higher F2 value than any other vowel on the fricative.

In German, the central vowel /sw/ shows influence in that way, that the formant value of the fricative is lower than for the other vowels in most cases. The more open central vowel /A/ shows similar effects on the fricative as /e/ for the lower formants (F1, F2), but for F3 and F4 it is similar to the other central vowel /sw/.

In Japanese, there seems to be a general close/open influence on the fricative, whereas in German this seems to be the case for the lower formants (F1, F2) only. For the higher formants (F3, F4), a centralizing effect seems to come in, where the central vowels /sw/ and /A/ evoke lower formant values of the fricative than /e/.

A general effect is that different formant values of the fricative under different vocalic context can be discovered. Therefore, influence of the vowel following the /hi/-syllable on its fricative in both languages can be assumed.

5 Conclusions

Three different approaches to the phonetic classification of the fricative in the Japanese /hi/-syllable were presented in 1 and 2.1. These three points of view vary from classifying it as the palatal fricative /ç/ before a high front vowel in general. Others say that the glottal fricative may appear instead in most cases, whereas a third group claims that the palatal fricative occurs in case of a devoiced vowel in a /hi/-syllable before an unvoiced stop.In German on the other hand the palatal fricative /ç/ and the glottal fricative /h/ are different phonemes.

This study showed five comparisons of the acoustic structure of the Japanese and German data under five different contextual conditions.

A general finding is that there is no direct correspondence of the fricative in Japanese /hi/ to either of the two German fricatives for any of the formants on the frequency level. In addition, the effect of the different auditory impression for the fricative in Japanese if the [i] is dropped compared to the version, when the [i] is phonetically realized is caused by a different factor than the acoustic distinction between German /hi/ and /ç/. A spectral difference in the case of the two variations of /hi/ in Japanese can be identified and this is also true for the two German fricatives. Nevertheless, the way of distinction differs between the two languages. One reason for this effect might be, that the Japanese [ç] in the /hi/-syllable lies further back than the German /ç/, as Hattori (1984,p. 88) points out from an articulatory point of view.

Positioning is another factor that shows differences between the two languages. In Japanese, the position of the syllable in the word has strong influence on the spectral structure of the fricative. German does not show such a strong effect and the spectral structure

varies only very little for the palatal fricative /ç/ in syllable initial or syllable final position.

Context effects due to neighbouring consonants show also very different results for the two languages under the same context. For German, no clear context effect is observable, but this is the case for Japanese. Vowel influence can be identified in both languages. There is also some overlapping between the two languages for the case that if a more closed vowel follows the /hi/-syllable, the middle formants (F2, F3, F4) are lower than in the context of the other vowel. For the higher formants such effect across the languages is not found.

Finally, one cannot assume a one-to-one correspondence between the fricative in the Japanese /hi/-syllable and either of the German fricatives. Context effects also differ between the two languages. However, there is different quality for the Japanese fricative observable, it shows a very different spectral structure under the same conditions as the German palatal fricative. This might arise, because of different rules of context sensitivity. The same is true for the fricative of the /hi/-syllable in both languages.

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APPENDIX

TABLES AND FIGURES

F	#	*ger* /ç/	*ger* /hi/	*ger* /çi/	*jp* /hi/
F1	$\bar{x}$	0.71	0.72	0.78	0.89
F1	sd	0.3	0.41	0.28	0.46
F1	n	1796	603	151	3971
F2	$\bar{x}$	2.2	2.34	2.21	2.37
F2	sd	0.22	0.33	0.2	0.3
F2	n	4419	1006	355	7102
F3	$\bar{x}$	3.13	3.14	3.18	3.22
F3	sd	0.32	0.27	0.29	0.3
F3	n	13758	1600	1182	12483
F4	$\bar{x}$	3.91	3.98	3.9	3.88
F4	sd	0.28	0.29	0.27	0.25
F4	n	13013	1742	1271	14185
F5	$\bar{x}$	4.64	4.66	4.59	4.74
F5	sd	0.29	0.33	0.25	0.32
F5	n	9849	1277	944	9090

Table 1: Mean ($\bar{x}$), standard deviation (sd) and number of Data (n) for the fricative in German/ç/, /hi/ and /çi/ and Japanese /hi/. $\bar{x}$ and sd values in kHz.

F	#	*ger* /ç/	*ger* /hi/	*jp* /hi/ *without* [i]	*jp* /hi/ *with* [i]
F1	$\bar{x}$	0.71	0.72	0.98	0.83
F1	sd	0.3	0.41	0.36	0.51
F1	n	1796	603	1653	2318
F2	$\bar{x}$	2.2	2.34	2.36	2.37
F2	sd	0.22	0.33	0.33	0.27
F2	n	4419	1006	3175	3927
F3	$\bar{x}$	3.13	3.14	3.22	3.22
F3	sd	0.32	0.27	0.28	0.33
F3	n	13758	1600	5512	6971
F4	$\bar{x}$	3.91	3.98	3.89	3.87
F4	sd	0.28	0.29	0.25	0.25
F4	n	13013	1742	6071	8114
F5	$\bar{x}$	4.64	4.66	4.76	4.72
F5	sd	0.29	0.33	0.3	0.34
F5	n	9849	1277	3931	5159

Table 2: Mean ($\bar{x}$), standard deviation (sd) and number of data (n) for the formants (F)of the fricatives in German /ç/and /hi/ and Japanese /hi/, when [i] is realized and when [i] is *not* phonetically realized. $\bar{x}$ and sd values in kHz.

F	#	*ger /ç/ final*	*ger /ç/ initial*	*ger /hi/*	*jp /hi/ as word*	*jp /hi/ word initial*	*jp /hi/ word final*	*jp /hi/ word medial*
F1	$\bar{x}$	0.71	0.71	0.72	0.81	0.98	0.75	0.7
F1	sd	0.29	0.32	0.41	0.37	0.38	0.53	0.56
F1	n	1299	497	603	57	2587	774	553
F2	$\bar{x}$	2.2	2.2	2.34	2.33	2.38	2.29	2.39
F2	sd	0.23	0.21	0.33	0.16	0.29	0.36	0.33
F2	n	3125	1267	1006	138	5222	933	809
F3	$\bar{x}$	3.13	3.14	3.14	3.23	3.24	3.17	3.15
F3	sd	0.32	0.34	0.27	0.24	0.29	0.36	0.31
F3	n	9623	4065	1600	191	9301	1614	1377
F4	$\bar{x}$	3.92	3.89	3.98	3.85	3.97	3.87	3.86
F4	sd	0.27	0.29	0.29	0.15	0.25	0.27	0.24
F4	n	9164	3894	1742	242	10055	2101	1787
F5	$\bar{x}$	4.64	4.63	4.66	4.77	4.74	4.71	4.72
F5	sd	0.28	0.29	0.33	0.19	0.32	0.34	0.33
F5	n	6981	2868	1277	123	6518	1299	1150

Table 3: Mean ($\bar{x}$), standard deviation (sd) and number of data (n) for the formants (F)of the fricative in German /ç/, syllable initial and syllable final, and /hi/ and Japanese /hi/ in diffrent word positions. $\bar{x}$ and sd values in kHz.

F	#	*ger* /çk/	*ger* /çt/	*jp* /hik/ *without* [i]	*jp* /hit/ *without*[i]
F1	$\bar{x}$	0.74	0.67	0.98	0.99
F1	sd	0.34	0.25	0.36	0.35
F1	n	57	303	1019	325
F2	$\bar{x}$	2.2	2.22	2.36	2.42
F2	sd	0.19	0.2	0.28	0.28
F2	n	112	706	2047	696
F3	$\bar{x}$	3.16	3.14	3.22	3.24
F3	sd	0.33	0.32	0.28	0.28
F3	n	419	1956	3552	1250
F4	$\bar{x}$	3.94	3.93	3.87	3.93
F4	sd	0.29	0.26	0.25	0.25
F4	n	417	1859	3725	1533
F5	$\bar{x}$	4.62	4.64	4.74	4.75
F5	sd	0.28	0.28	0.31	0.3
F5	n	325	1432	2439	978

Table 4: Mean ($\bar{x}$), standard deviation (sd) and number of data (n) for the formants (F) for German /ç/ before /k/ and /t/ and the fricative in Japanese /hi/, when followed by /k/ or /t/ *and* when [i] is *not* phonetically realized.
$\bar{x}$ and sd values in kHz.

F	#	*ger* /hi/ before /A/	*ger* /hi/ before /e/	*ger* /hi/ before /sw/	*jp* /hi/ before /a/	*jp* /hi/ before /e/	*jp* /hi/ before /i /	*jp* /hi/ before /o/	*jp* /hi/ before /u/
F1	$\bar{x}$	0.72	0.73	0.64	0.98	0.94	0.94	1.05	0.94
F1	sd	0.42	0.39	0.32	0.36	0.42	0.35	0.41	0.39
F1	n	92	124	37	778	171	563	659	383
F2	$\bar{x}$	2.37	2.33	2.12	2.38	2.38	2.34	2.42	2.37
F2	sd	0.36	0.3	0.31	0.29	0.29	0.27	0.31	0.28
F2	n	184	148	49	1566	352	1210	1323	723
F3	$\bar{x}$	3.12	3.18	3.09	3.26	3.27	3.24	3.25	3.2
F3	sd	0.26	0.19	0.2	0.3	0.29	0.29	0.3	0.28
F3	n	305	257	71	2746	637	2050	2329	1408
F4	$\bar{x}$	3.96	4.03	3.91	3.89	3.91	3.88	3.9	3.86
F4	sd	0.26	0.27	0.26	0.24	0.25	0.23	0.26	0.26
F4	n	397	316	60	3082	761	2092	2516	1448
F5	$\bar{x}$	4.71	4.69	4.65	4.77	4.74	4.73	4.76	4.7
F5	sd	0.29	0.38	0.26	0.3	0.32	0.32	0.33	0.32
F5	n	271	180	40	1993	445	1313	1656	1019

Table 5 : Mean ($\bar{x}$), standard deviation (sd) and number of data (n) for the formants (F) of the fricative in German /hi/ and Japanese /hi/, word initial, in dependency of the following vowel.
$\bar{x}$ and sd values in kHz.

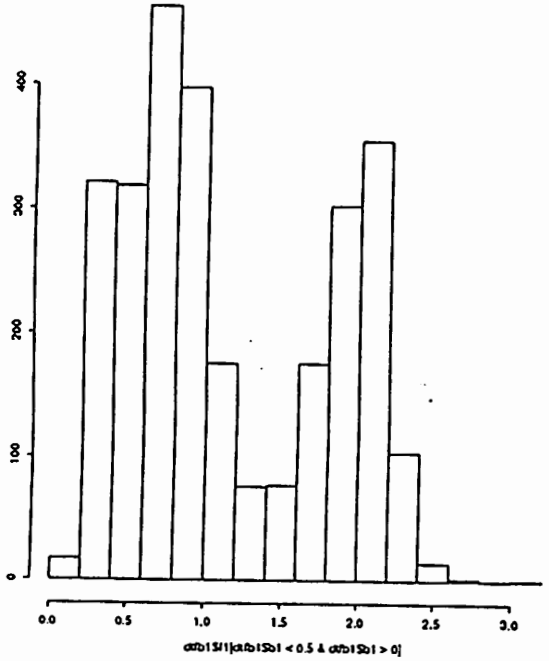


Fig. 1

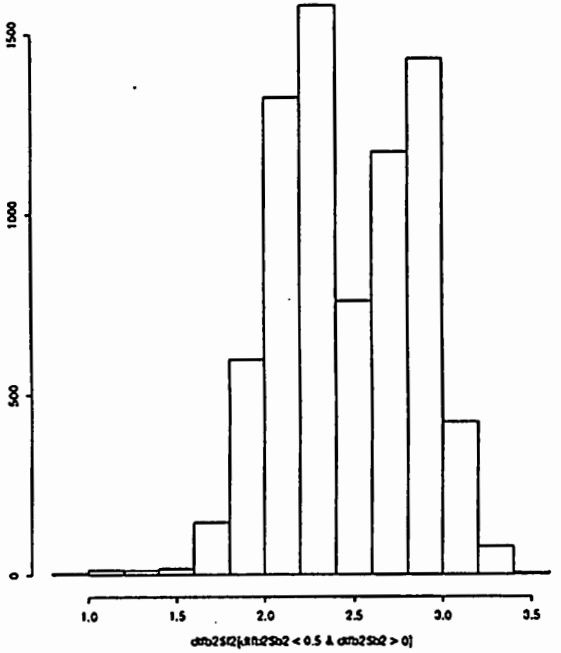


Fig. 2

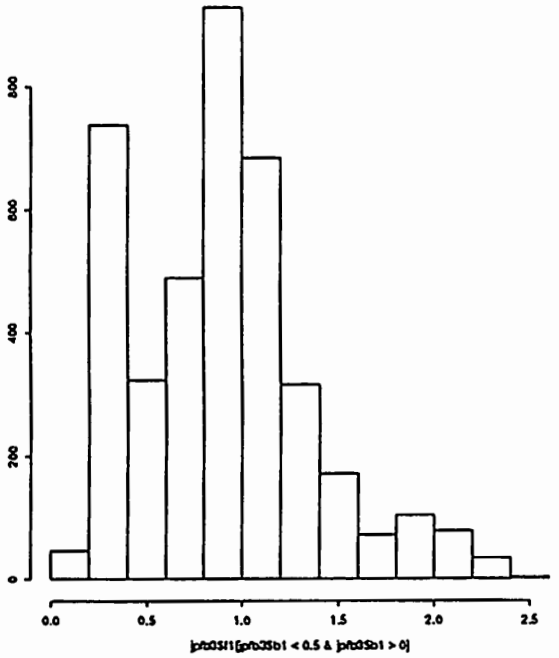
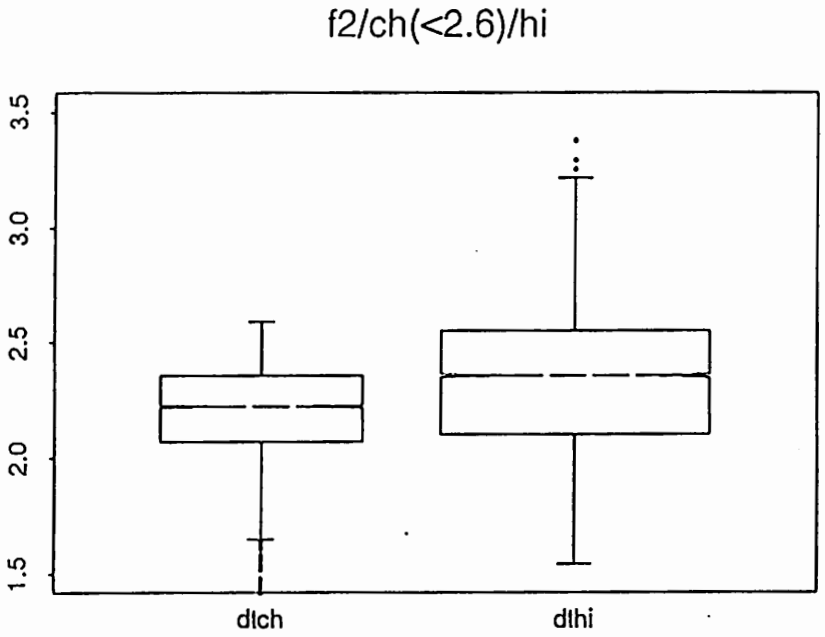


Fig. 3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3.5
3.0
2.5
2.0
1.5
dtch
dthi

Fig. 4

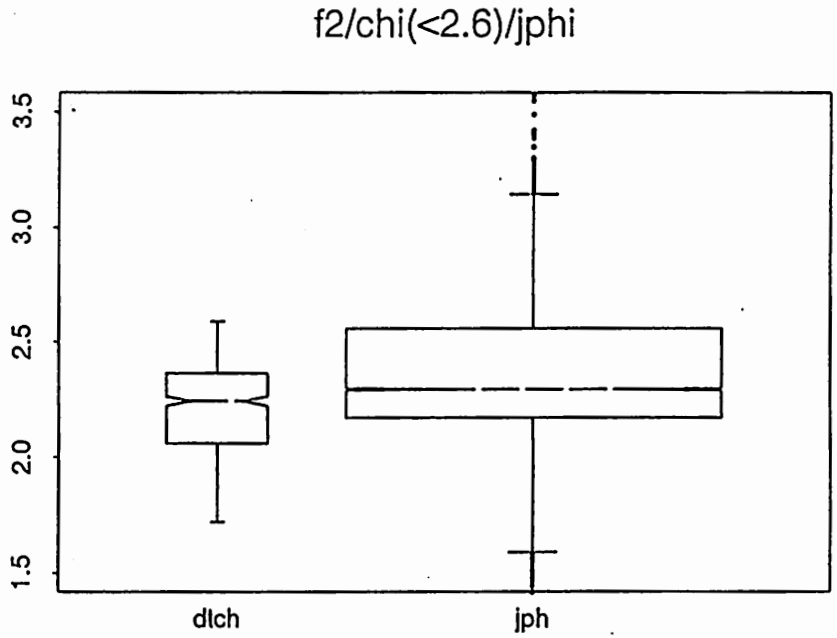

f2/chi(<2.6)/jphi
3.5
3.0
2.5
2.0
1.5
dtch
jph

Fig. 5

B

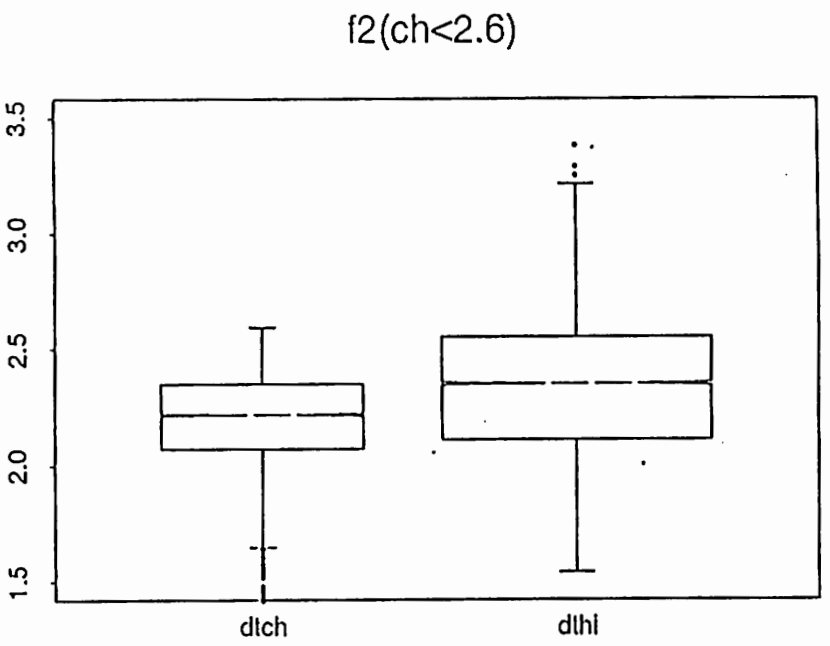


Fig. 6

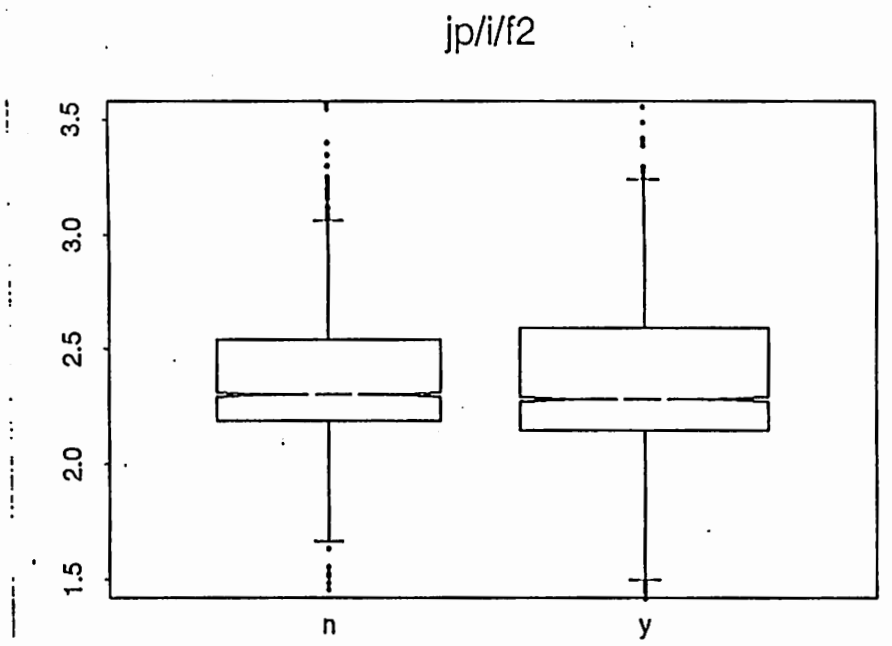


Fig. 7

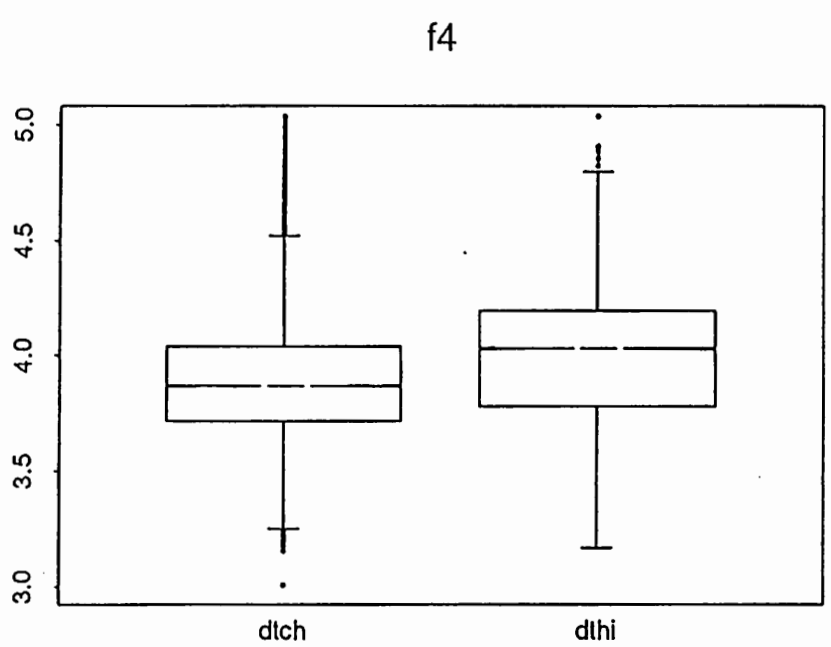


Fig. 8

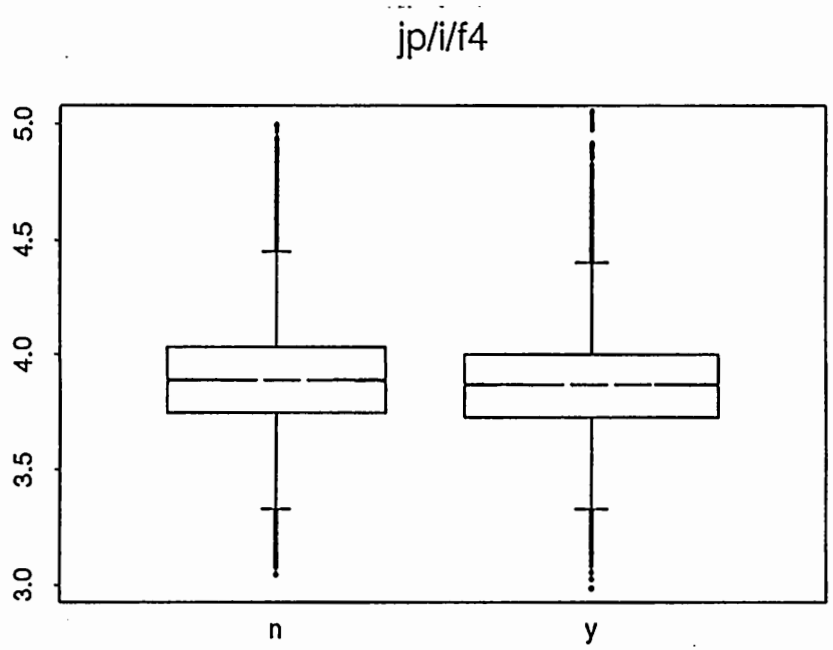


Fig. 9

Fig. 10

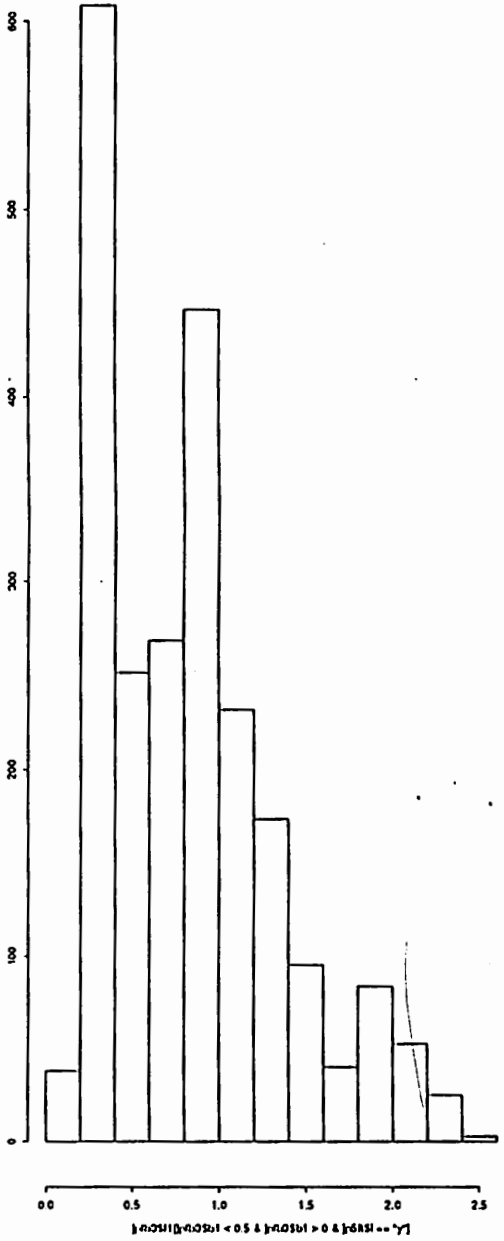


Fig. 11

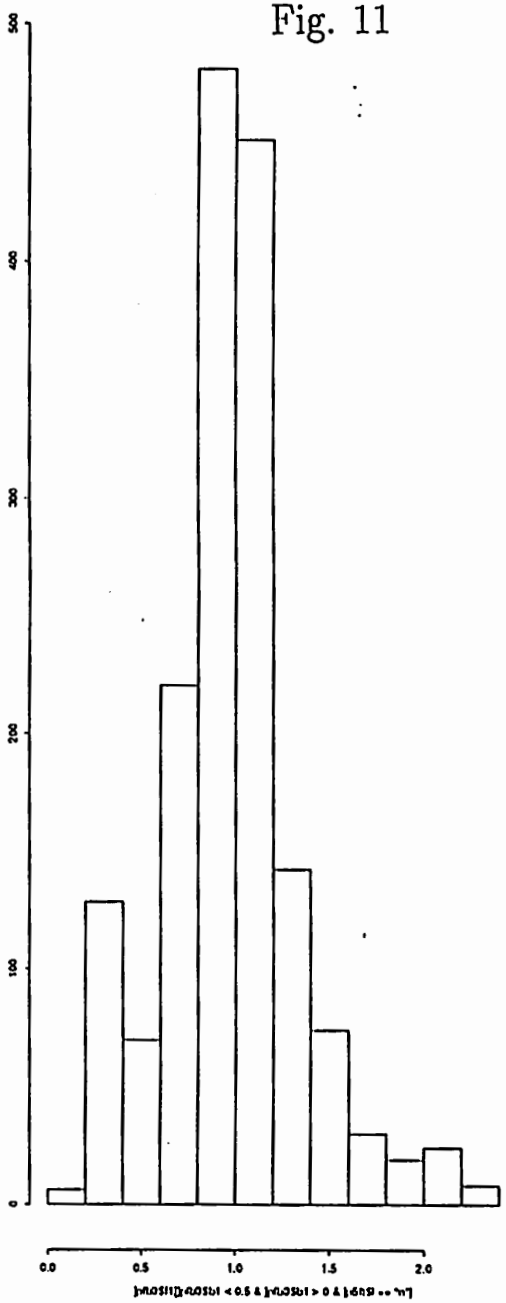
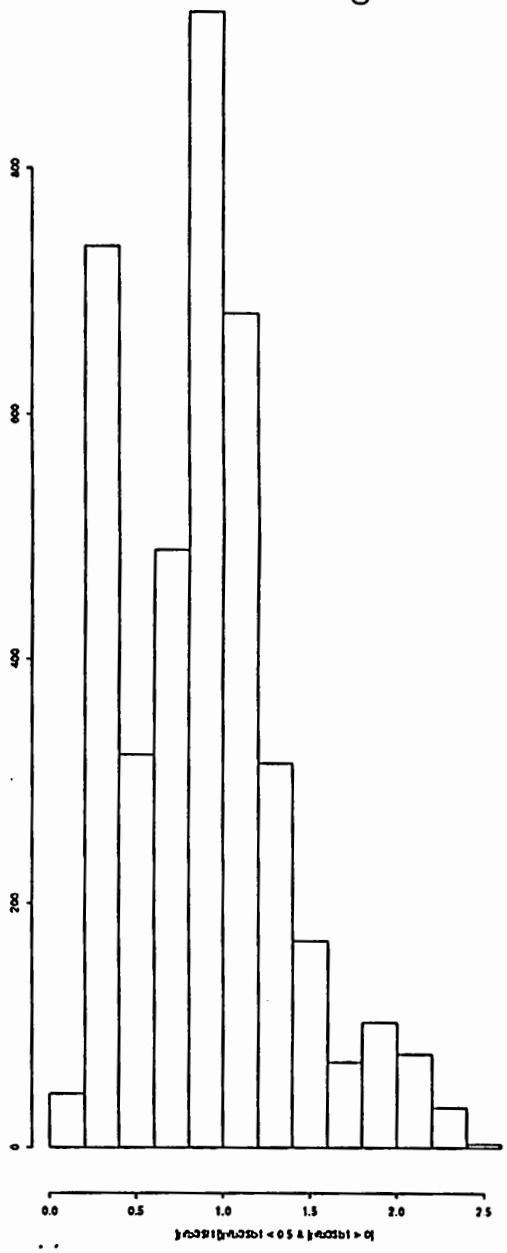


Fig. 12



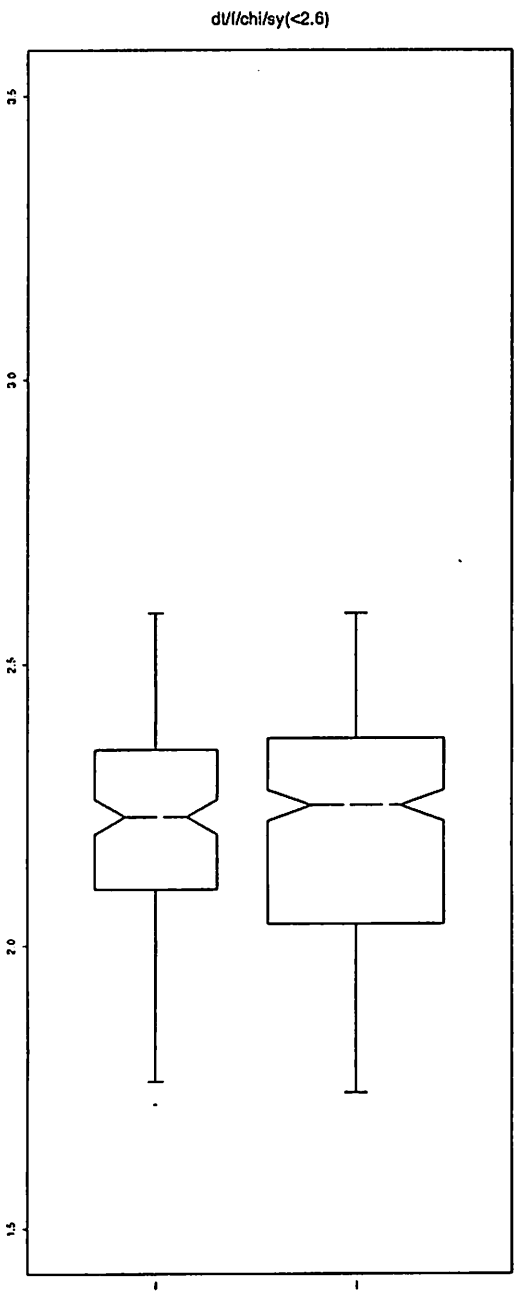


Fig. 13

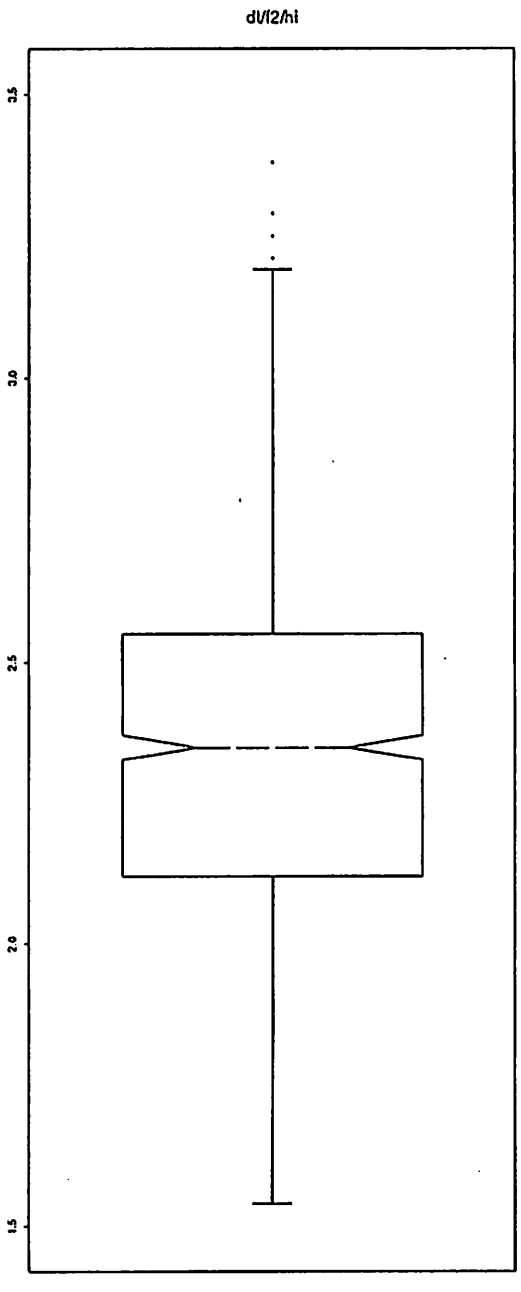


Fig. 14

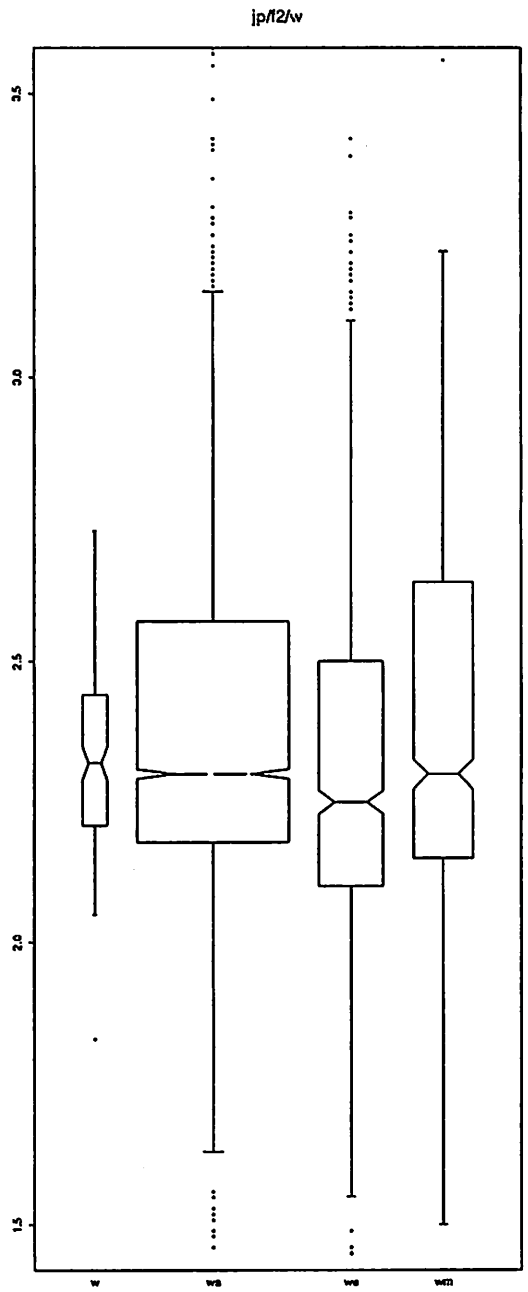


Fig. 15

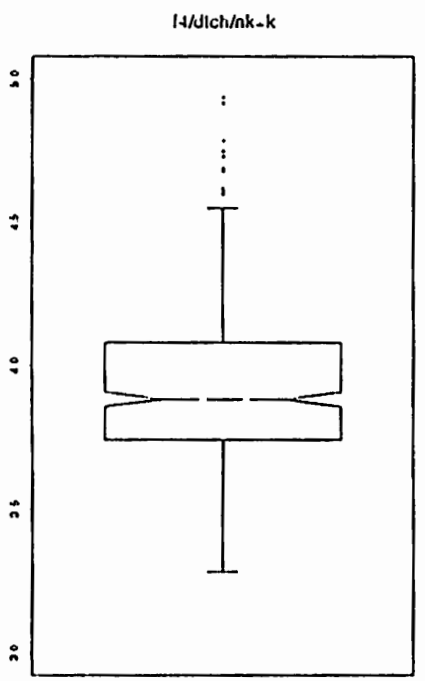


Fig. 16

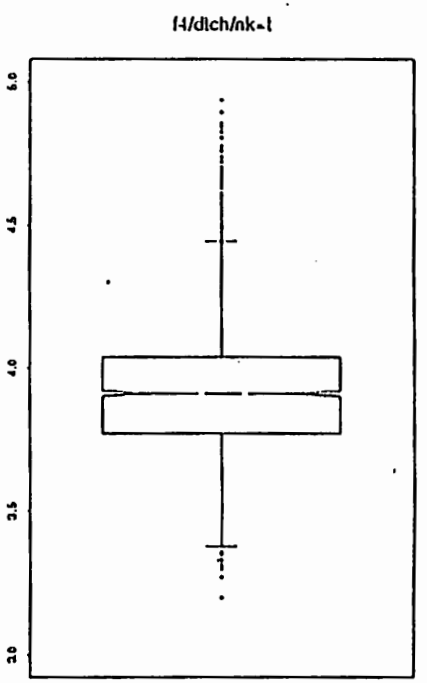


Fig. 17

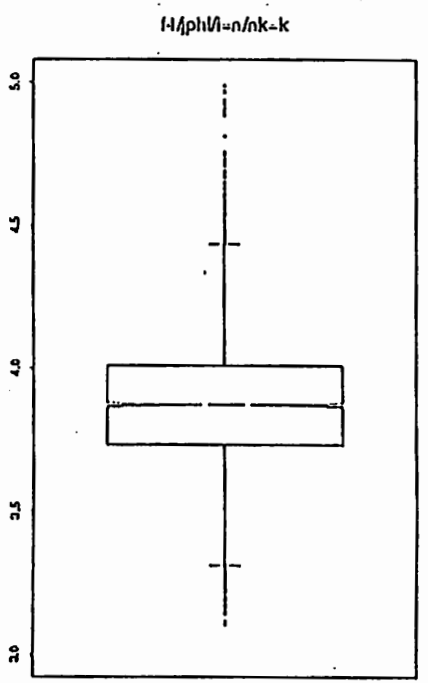


Fig. 18

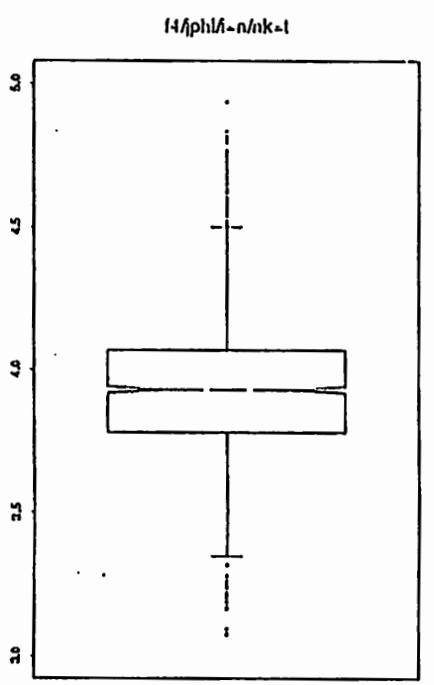


Fig. 19

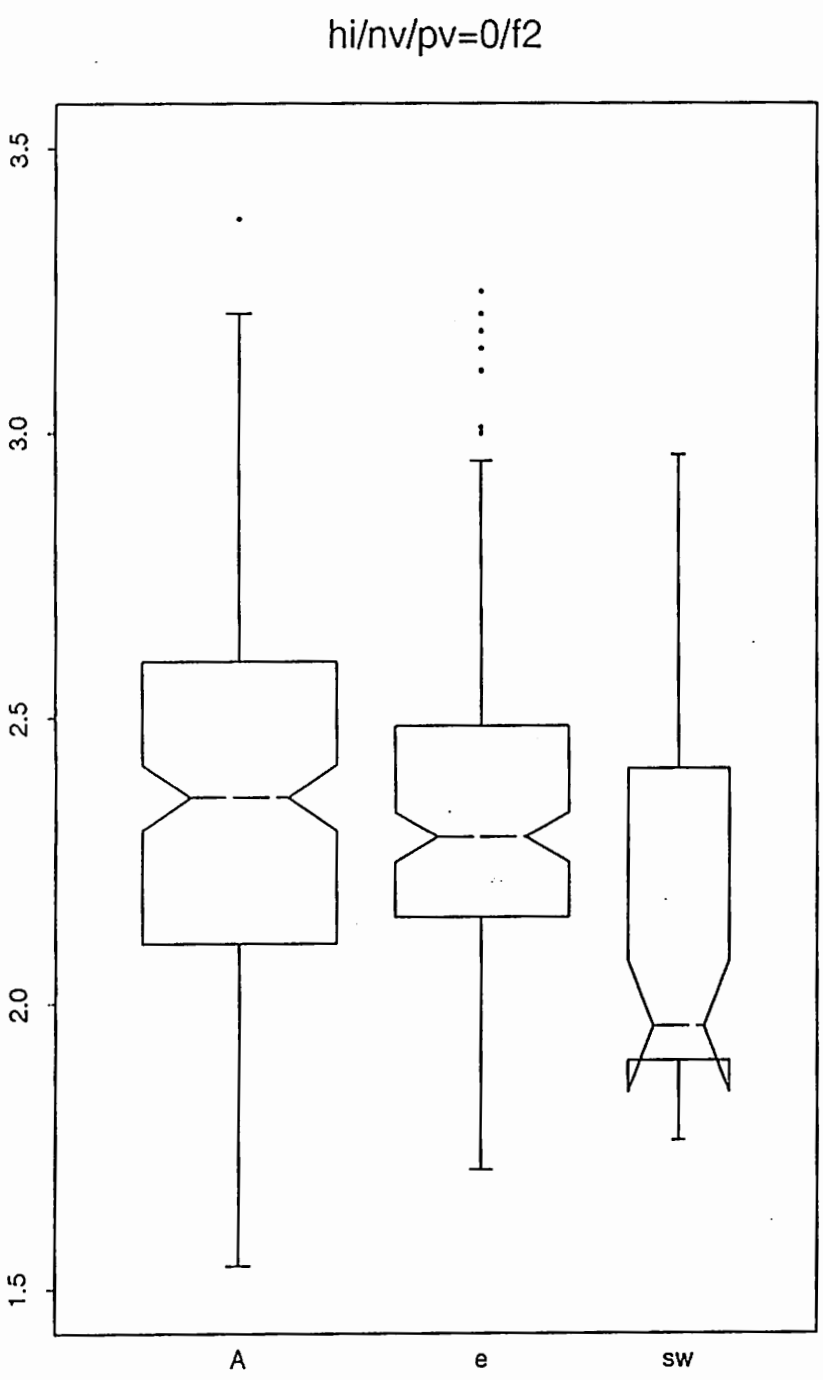


Fig. 20

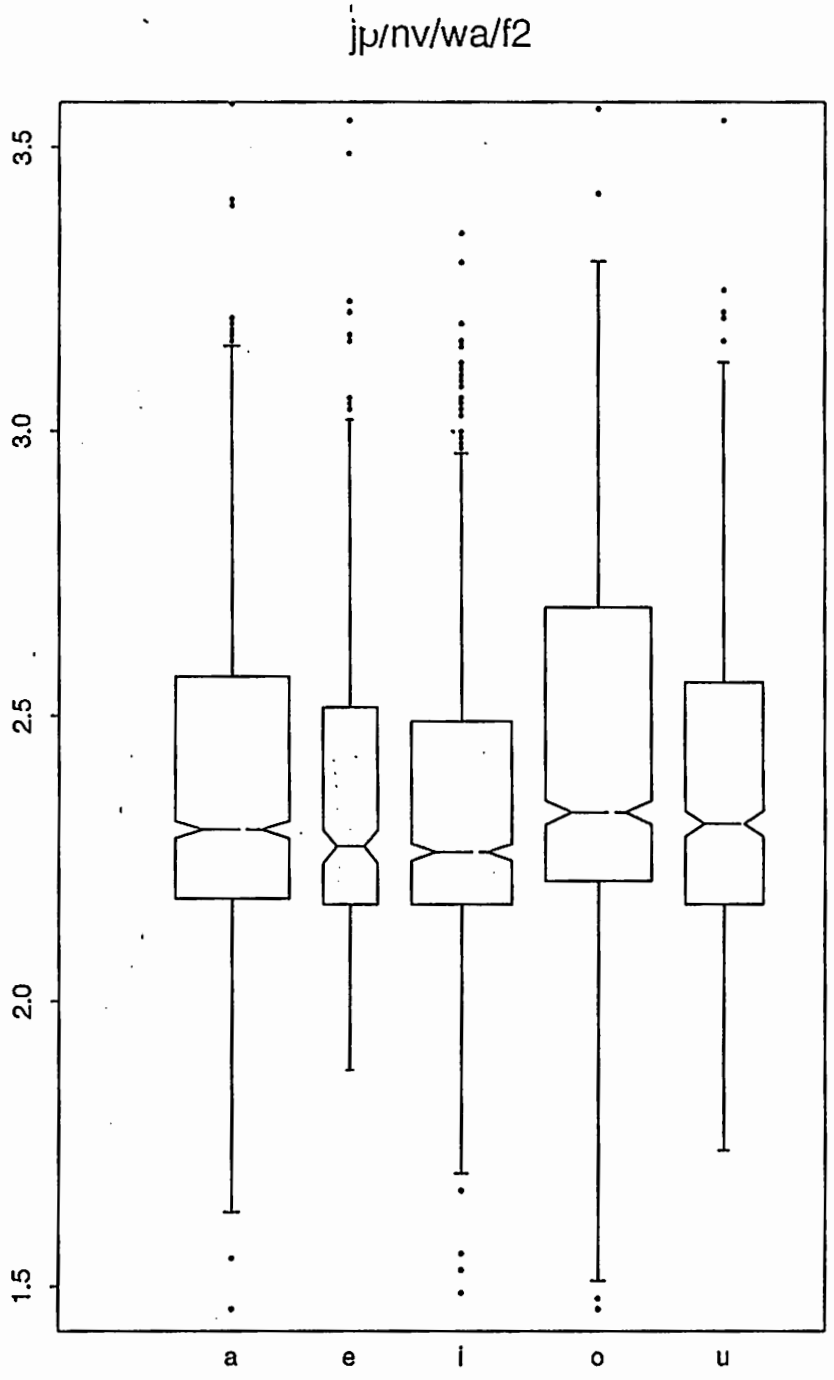


Fig. 21

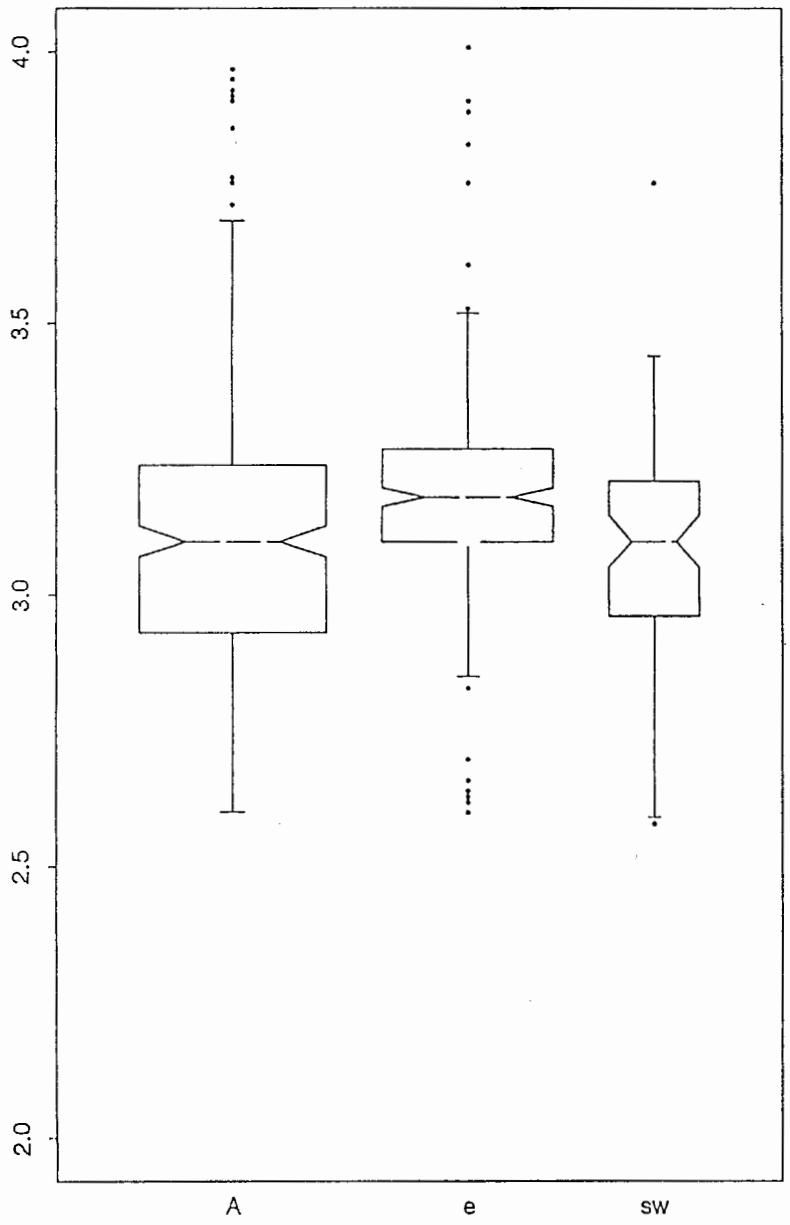


Fig. 22

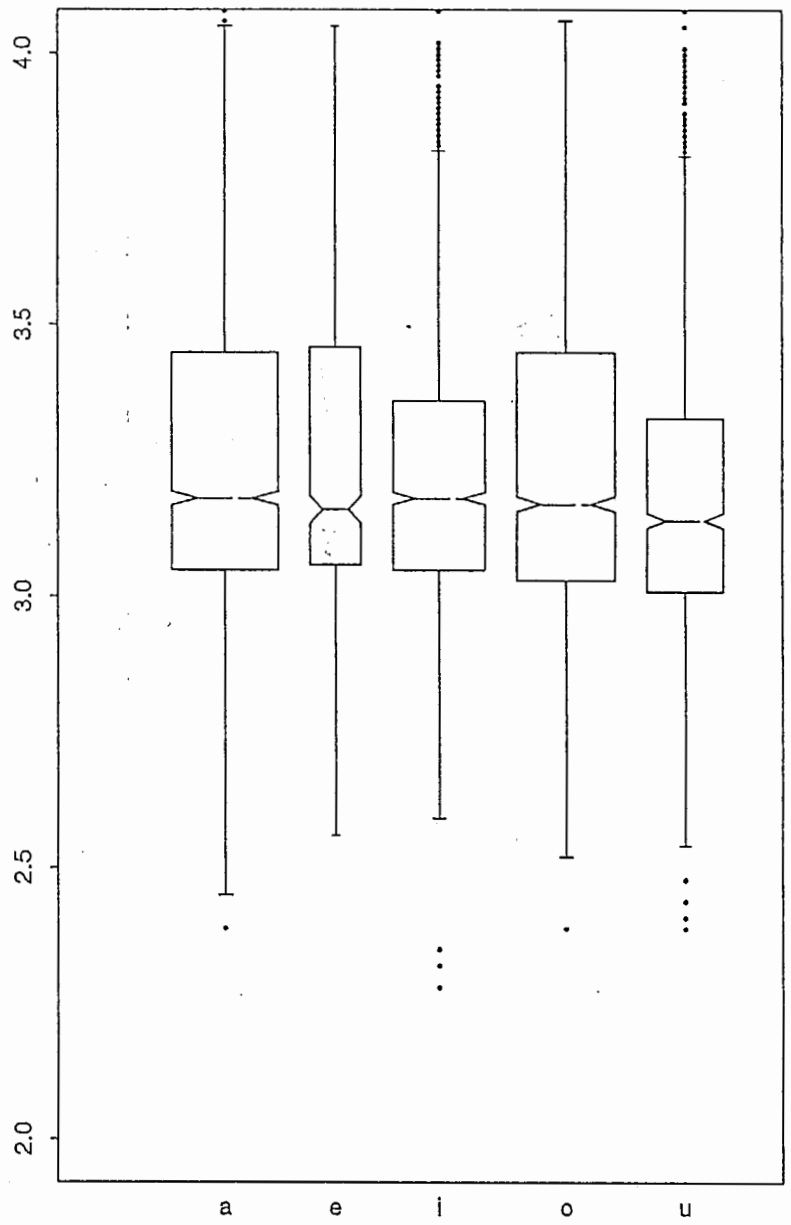


Fig. 23