F1 and F2 Correlation with F0: A Study of Vowels of Hindi, Punjabi, Korean and Thai

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ABSTRACT

This is an empirical study of the peripheral vowels of four languages, Hindi, Punjabi, Thai and Korean in terms of two parameters, namely F0 variation, and acoustic space calculated by using two lower formants, F1 and F2. We examine all peripheral vowels (with level tone in case of Thai and Punjabi) to find out the correlation between the pitch of voice, a laryngeal phenomenon and the resonance phenomenon/acoustic space. The results based on four different languages including two tonal languages, Punjabi and Thai give us some interesting hypotheses to be explored further with data from more languages. The correlations are studied using SPSS. The results are interesting, the formants F1 and F2 show a statistically significant correlation with F0/Pitch of voice. F0 and F1 correlation and F0 and F2 correlation have significant implications for comparison across speakers for speaker characterization and forensic applications. These results also have significant application in speech pathology, for developing tools and instruments for assessment and therapeutic speech procedures in speech pathology.

Key words

Pitch, Tone, Formant Frequencies, Acoustic space, Resonance

1 Introduction

A general rule in acoustic–articulatory relationship is that F1 frequency varies inversely with tongue height and F2 frequency or the difference between F2 &F1, varies inversely with tongue advancement. In 1986, Syrdal & Gopal also propose an alternative interpretation that the F1-F0 difference varies inversely with tongue height. Most of the later studies seem to prefer plotting F2-F1 against F1 to arrive at the vowel space. We decided to explore the relationship between F0 and F1, F2 in Hindi, Punjabi, Korean and Thai languages.

This is an empirical study of vowels of four languages as Hindi, Punjabi, Thai and Korean in terms of two parameters, namely - tones, levels and contours as reflected in F0 variations, and lower formant, F1 which is high for open/ low vowels and low for close/ high vowels. We examine all peripheral vowels with level tone to find out the correlation between the pitch of voice, a laryngeal phenomenon and the first formant which is part of the resonance phenomenon. Correlation of F0 with the second formant F2 and F3 is also

studied. F2 variation generally corresponds to the front/back position of the tongue in articulatory terms. The results give us some interesting hypotheses to be explored further with data from different tonal and non-tonal languages.

2 Methodology

2.1 Data Elicitation Procedures

Subjects: For the present study we have 15 male native speakers of Hindi, 5 male native speakers of Punjabi, 5 male native speakers of Korean and 2 male native speakers of Thai. So altogether there were 27 male speakers. The age of the subjects range between 20-30 years.

Data Sample: Words chosen were such that the vowel phonemes occur in all the positions i.e. initial, medial and final. The speakers were asked to pronounce each word thrice. Thus there are 21 (7 vowels *3 words) stimuli and 1701 sample. Thus a random sample of 1701 words was recorded. Out of this sample of 1701 words, we selected words having vowels at the medial position and only the middle articulation of the three repetitions. This gave us a selected sample of 189 words.

Data Recording: Data was recorded in a sound proof room of Jawaharlal Nehru University New Delhi using PRAAT; Goldwave was used for noise reduction, while wavesurfer was used for spectrograms. The analysis was mostly done by using PRAAT. The voice files were converted into WAV file in order to save them for future use. WAV is the short form of Audio Format.

Pitch was calculated in terms of F0 variation. Average of the middle, steady state values was plotted as F0 against F1, (in case of level tone, in tonal languages), and f0 is also plotted against F2.

2.2 Analytical Procedures

Study of Correlation

Bivariate correlation is a tool in SPSS which is used to determine if two variables are linearly related to each other. The Descriptive Statistics section gives the mean, standard deviation, and number of observations (N) for each of the variables that are specified. For example, the mean of the F0 variable is 128.0747 (in TABLE 1), the standard deviation is 6.14283, and there were 124 observations (N) for this variable.

The section on Correlations gives the values of the specified correlation tests, in this case, Pearson's r. Each row of the table corresponds to one of the variables. Each column also corresponds to one of the variables. Likewise the cell at the middle row of the middle column represents the correlation F0 with F0. It is always 1.0. The cell at middle row and right column (or equivalently, the bottom row at the middle column) represents the correlation of F0 and F1 (or F1 with F0). There are three numbers in these cells. The top number is the correlation coefficient. The correlation coefficient in this example is -0.392. The middle number is the significance of this correlation; in this case, it is .000. (The significance basically tells us whether we would expect a correlation that was this large purely due to chance factors and not due to an actual relation.) The bottom number, 124 in this example, is the number of observations that were used to calculate the correlation coefficient. The size of correlation can be interpreted using the given table.

Correlation	Negative	Positive
None	−0.09 to 0.0	0.0 to 0.09
Small	−0.3 to −0.1	0.1 to 0.3
Medium	−0.5 to −0.3	0.3 to 0.5
Strong	−1.0 to −0.5	0.5 to 1.0

A statistically *significant* finding is one that is determined (statistically) to be very unlikely to happen by chance. Statisticians are able to calculate the likelihood that any observed relationship between two variables (as indicated by any number of cases) could have happened by chance (or random variation). If it is calculated that there is less than a one in twenty chance (0.05 or 5%) that the observed relationship could have happened by chance, the findings are designated as significant. If there is less than a one in one hundred chance (0.01 or 1%), they are designated as highly significant. Significance is influenced by the number of cases in your sample, and the observed range (difference) of the sample

3. Data Analysis

The three parameters, F0, F1 and F2 are analysed separately in all the four sections 3.1, 3.2, 3.3, 3.4 for Hindi, Punjabi, Korean and Thai respectively. In each section the data tables and graphs showing F0 plotted against F1 and F2 separately are followed by statistical analysis presented in two tables for F0 & F1, F0 & F2 for every language.
Section 3.5 is devoted to consolidated results of all the languages.

3.1 Hindi

Table-1 below followed by the two figures 1 and 2 give us the values of F0, F1 and F2 in case of Hindi vowels, plotted with F1 on x axis and F0 on y axis in Figure-1, and with F2 on x axis and F0 on y axis in Figure- 2 for the peripheral vowels of Hindi.

Vowels	/i/	/e/	/ɛ /	/a/	/ɔ /	/o/	/u/
F0	128.21	131	127	126	128	135	133
F1	268	379	645	737	593	383	265
F2	2488	2400	1819	1205	969	977	755

Table-1 F0, F1, F2 for Hindi Vowels

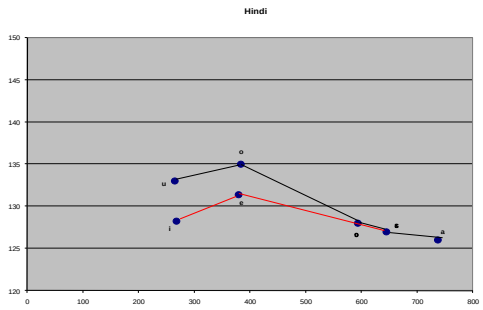


Figure-1

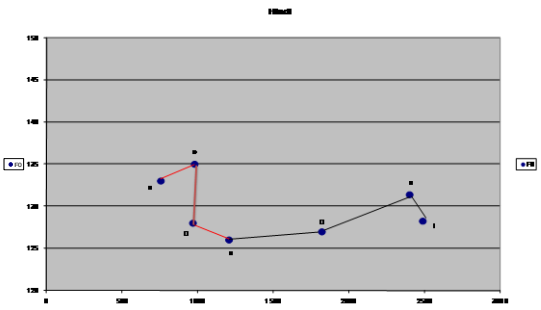


Figure- 2

The figure 1 & 2 above show that open vowel 'a' has a lower pitch as compared to high vowels. Also the front vowel has a lower pitch as compared to back vowels. The second figure shows, that high F2 values in case of i, e also corresponds to a relatively, lower pitch, as compared to u & o, back vowels with lower F2.

Correlation (Hindi)

The Pearson's coefficient for F0-F1 correlation is -0.392 (given in table 3, which is SPSS output table). Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F1. The value -0.392 also suggests a small correlation or we can say that the correlation is not very strong. Value of significance suggests that the correlation is significant at the 0.01 level.

	Mean	Std. Deviation	N
F0	129.2909	6.27005	124
F1	442.0759	157.84927	124
F2	1667.4311	704.38764	124

Table- 2 Descriptive Statistics

		F0	F1	F2
F0	Pearson Correlation	1	-.136	-.292(**)
	Sig. (2-tailed)		.132	.001
	N	124	124	124
F1	Pearson Correlation	-.136	1	-.482(**)
	Sig. (2-tailed)	.132		.000
	N	124	124	124
F2	Pearson Correlation	-.292(**)	-.482(**)	1
	Sig. (2-tailed)	.001	.000	
	N	124	124	124

** Correlation is significant at the 0.01 level (2-tailed).

Table-3 Correlations

The Pearson's coefficient for F0-F2 correlation is -0.216. Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F2. The value -0.216 also suggests that the correlation is not very strong. Value of significance suggests that the correlation is significant at the 0.01 level.

3.2 Punjabi

The Pearson's coefficient for F0-F1 correlation is -0.630 (given in table 6, which is SPSS output table). Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F1. The value -0.630 also suggests a strong correlation. Value of significance suggests that the correlation is significant at the0 .01 level. We may remember at this point that Punjabi is a tone language and high/rising tone is phonemic in this language.

Vowels	/i/	/e/	/ɛ /	/a/	/ɔ /	/o/	/u/
F0	145	139	137	139	141	139	142
F1	277.98	544	636	490	388	554	312
F2	2423	2348	1791	1143	728	910	728

Table-4: F0, F1, F2 for Punjabi Vowels

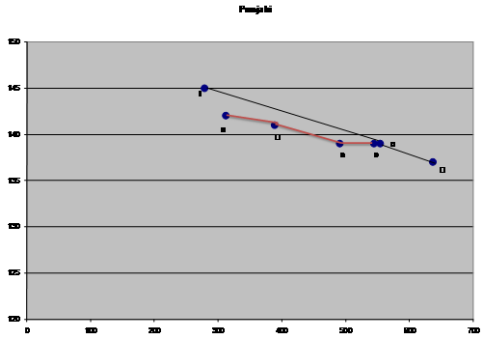


Figure 3

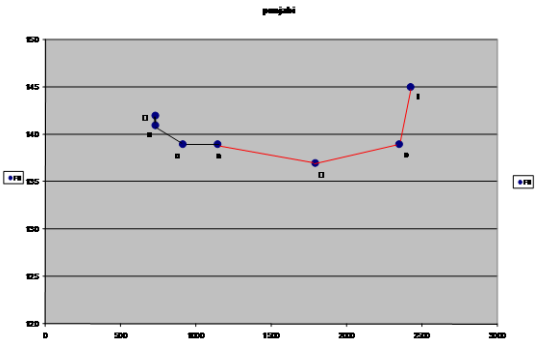


Figure 4

Correlation: (Punjabi)

	Mean	Std. Deviation	N
F0	139.66	4.075	181
F1	455.3243	127.88728	181
F2	1414.42	688.025	181

Table-5 Descriptive Statistics

		F0	F1	F2
F0	Pearson Correlation	1	-.630(**)	-.383(**)
	Sig. (2-tailed)		.000	.000
	N	181	181	181
F1	Pearson Correlation	-.630(**)	1	.156(*)
	Sig. (2-tailed)	.000		.036
	N	181	181	181
F2	Pearson Correlation	-.383(**)	.156(*)	1
	Sig. (2-tailed)	.000	.036	
	N	181	181	181

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table-6 Correlations

The Pearson's coefficient for F0-F2 correlation is -0.383. Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F2. The value -0.383 also suggests a small correlation. Value of significance suggests that the correlation is significant at the0 .01 level.

3.3 Korean

Vowel	/i/	/e/	/a/	/o/	/u/
Fo	137	132	130	133	136
F1	290	479	789	470	332
F2	2553	2274	1234	1077	976

Table-7 F0, F1, F2 for Korean Vowels

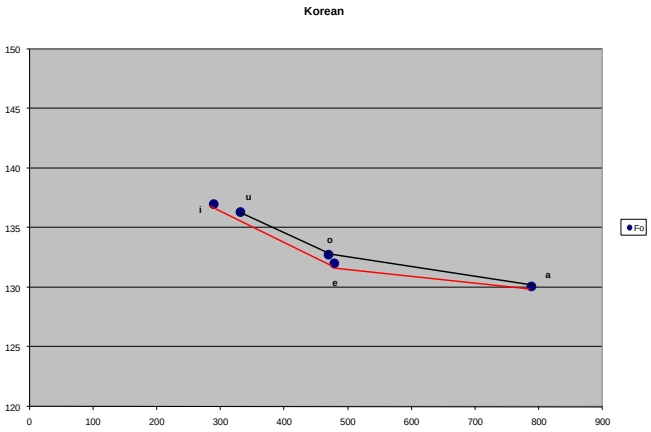


Figure 6

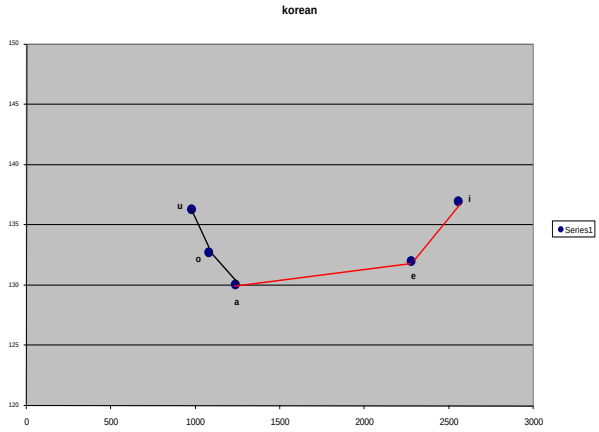


figure 7

Correlation (Korean)

The Pearson's coefficient for F0-F1 correlation is -0.344 (given in table 9, which is SPSS output table). Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F1. The value -0.344 also suggests a small correlation or we can say that the correlation is not very strong. Value of significance suggests that the correlation is significant at the 0.01 level. The Pearson's coefficient for F0-F2 correlation is 0.435. Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F2. The value 0.435 also suggests a small correlation or we can say that the correlation is not very strong. Value of significance suggests that the correlation is significant at the 0.01 level.

	Mean	Std. Deviation	N
F0	135.80	1.758	128
F1	455.17	157.872	128
F2	1619.37	661.977	128

Table- 8 Descriptive Statistics

		F0	F1	F2
F0	Pearson Correlation	1	-.344(**)	.435(**)
	Sig. (2-tailed)		.000	.000
	N	128	128	128
F1	Pearson Correlation	-.344(**)	1	-.311(**)
	Sig. (2-tailed)	.000		.000
	N	128	128	128
F2	Pearson Correlation	.435(**)	-.311(**)	1
	Sig. (2-tailed)	.000	.000	
	N	128	128	128

** Correlation is significant at the 0.01 level (2-tailed).

Table- 9 Correlations

3.4 Thai

Vowels	/i/	/e/	/ɛ /	/a/	/ɔ /	/o/	/u/
F0	127.42	130.72	132.21	139	132.92	127.92	125.21
F1	424.98	587.98	860.43	932.65	872.02	516.01	478.01
F2	2237	2087	1921	1453	1204	980	668

Table-10 F0, F1, F2 for Thai Vowels

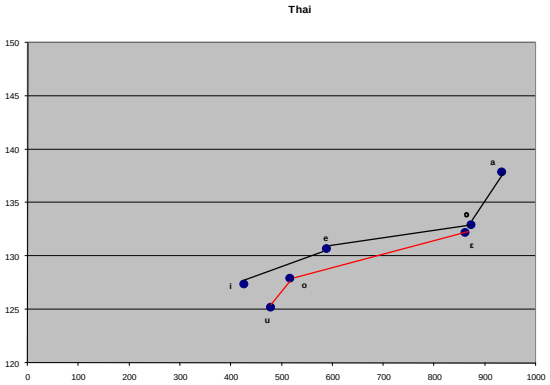


Figure 7

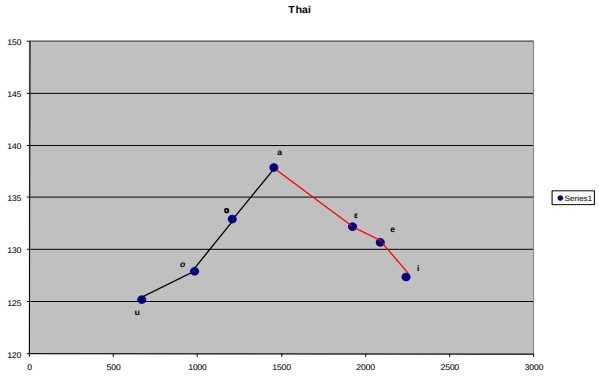


Figure 8

The two figures below (7&8) for Thai language show a reverse trend as compared to the languages, especially Hindi and Korean. Please see correlation below for details.

Correlation (Thai):

	Mean	Std. Deviation	N
F0	130.1981	4.20213	140
F1	665.9631	200.40460	140
F2	1511.5932	558.13638	140

Table- 11 Descriptive Statistics

The Pearson's coefficient for F0-F1 correlation is .0915 in case of Thai. Positive value of Pearson's coefficient suggests that F0 and F1 are directly related, if one increases the other one also increases. The value 0.914 also suggests a very strong correlation. The correlation is significant at the 0.01 level. At this point we may recall that Thai is a tone language with high tone as one of the five phonemic tones. The Pearson's coefficient for F0-F2 correlation is 0.312 in case of Thai. Positive value of Pearson's coefficient suggests that F0 and F2 are directly related, if one increases the other one also increases. The value 0.312 suggests a weak correlation. The correlation is again significant at the 0.01 level.

			F0	F1	F2
F0	Pearson Correlation		1	.915(**)	.312(**)
	Sig. (2-tailed)			.000	.000
	N		140	140	140
F1	Pearson Correlation		.915(**)	1	.034
	Sig. (2-tailed)		.000		.689
	N		140	140	140
F2	Pearson Correlation		.312(**)	.034	1
	Sig. (2-tailed)		.000	.689	
	N		140	140	140

** Correlation is significant at the 0.01 level (2-tailed).

Table 12- Correlations

We performed bivariate correlation test on the combined values (F0, F1 and F2) of all the four languages. The test again gave similar correlation for F0-F1 and F0-F2, which is inversely proportional relation. The table below is an SPSS output table for the combined data of the four languages.

SPSS analysis for all the four languages, Hindi, Punjabi, Thai and Korean.

	Mean	Std. Deviation	N
F0	134.2424	6.14952	573
F1	503.8875	185.29169	573
F2	1538.6967	662.39716	573

Table- 13 Descriptive Statistics

			F0	F1	F2
F0	Pearson Correlation		1	-.141(**)	-.153(**)
	Sig. (2-tailed)			.001	.000
	N		573	573	573
F1	Pearson Correlation		-.141(**)	1	-.124(**)
	Sig. (2-tailed)		.001		.003
	N		573	573	573
F2	Pearson Correlation		-.153(**)	-.124(**)	1
	Sig. (2-tailed)		.000	.003	
	N		573	573	573

** Correlation is significant at the 0.01 level (2-tailed).

Table- 14 Correlations

The Pearson's coefficient for F0-F1 correlation in case of is -0.141. Negative value of Pearson's coefficient suggests an inversely proportional relationship between F0 and F1. Value of significance suggests that the correlation is significant at the 0.01 level. The Pearson's coefficient for F0-F2 correlation is -0.153. Negative value of Pearson's coefficient suggests that F0 and F2 are inversely related. The correlation is significant at the 0.01 level. The values -0.141 -0.153 also suggest a weak correlation. Weak correlation is

primarily due to the fact that one of four languages, Thai a tone language shows a positive correlation especially in case of F0F1 correlation.

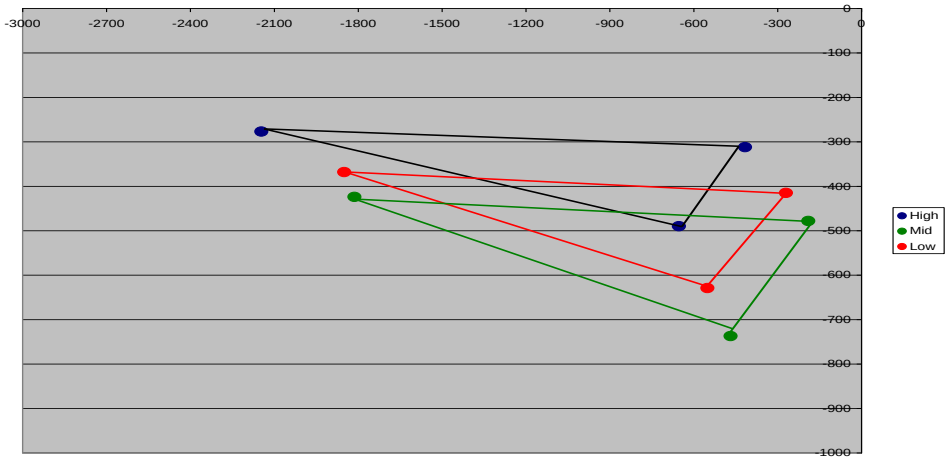
Acoustic Space of High- Mid-Low Pitch Vowels

Combined values of all the four languages: Formant values (F0, F1 and F2) for all the languages were put together and average values for the three vowels. (i, u, a) vowels of maximal contrast were calculated. The average values of the three vowels for these four languages are taken along with the F0 values of all of these vowels. Arranging the data table in the order of descending pitch from the highest F0 to the lowest F0 the average values of the high pitch vowels and mid pitch vowels and low pitch vowels were calculated separately. Depending on high, mid and low pitch values of each one of the three vowels (i, u, a) three sets of F2 & F1 and pitch values were obtained, as indicated in the table below.

	High			**Mid**			**Low**		
Vowel	**-(F2-F1)**	**-(F1)**	**F0**	**-(F2-F1)**	**-(F1)**	**F0**	**-(F2-F1)**	**-(F1)**	**F0**
/i/	-2146	-277	124	-1850	-424	118	-1813	-424	107
/u/	-416	-312	126	-270	-368	121	-190	-478	110
/a/	-653	-490	132	-551	-629	122	-468	-737	108

Table 15

These values were plotted so that we get acoustic space of high pitch vowels i, u, a as compared to the acoustic space of the mid pitch and low pitch vowels. The three triangles showing the acoustic space of the vowels with high, mid and low pitch are as given below.



As seen in the triangles, above the high, mid and low pitch vowels, i, u, a for high pitch are placed higher in the acoustic space as compared to mid pitch vowels and low pitch vowels which are placed at the lowest end of the acoustic space. Since the values of F2, F1for high pitch vowels are plotted highest in this graph it only shows that high pitch vowels have lesser F1 values as compared to mid pitch and low pitch vowels. Hence F0 is

inversely proportional to the first formant which indicates the high- low position of vowels in the articulatory/ acoustic space. Combining the three graphs we also find that the high pitch vowels are more in front as compared to mid pitch and low pitch vowels. Once again the F0 seems to be inversely proportional to the second formant as well. The correlation may not be so strong because only the high pitch vowels show relatively higher F2 values and therefore relatively more front position, in the vowel space. The F2 difference between mid pitch and low pitch vowels is much less as compared to those of the high pitch vowels.

These three triangles correlate well with the rest of the statistical analysis given in the previous section.

Hence the general conclusion is that F0 does have a significant correlation with the first formant and therefore the tongue height in articulatory terms for all the languages studied. F0 also correlates with F2 as explained above, although the correlation is not as strong.

The differences between the four languages under consideration is also important.

Another study on acoustic space in a tone language, Thai by the authors (Narang et al. 2010) empirically showed that vowels with the Rising and Falling –Rising tones seem to have a larger acoustic space by 39 to 41 % while the other three tones Falling and Rising – falling and Level tone have comparable acoustic space with only 1 to 10 % variation. This study shows, the F0 impact on the first two formant values of the vowels, in case of Thai in comparison with three other languages.

Thai and Punjabi are two tone languages, while Korean and Hindi are non-tonal languages. Both the languages show a strong correlation between F0 and F1 as compared to the other two languages. Punjabi also shows strong correlation between F1 and F0 as compared to the non tonal languages Hindi and Korean. Also the correlation is significant at 0.01 level.

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