Towards a Characterization of the Berber Vowel System

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***Abstract*—The aim of this work is to characterize the Berber vowel system in acoustics domain. We characterize these vowels in isolated context, using Pseudo Random Excitation Method of the vocal tract for the direct measuring of the vocal tract transfer function. This method provides real values of frequency formants and the fundamental relationship between the articulatory posture and formant frequencies. Berber vowel system is basically ternary /a,u, i/. We compared our results with those obtained for the French and Arabic language, knowing that the Berber, Arabic and French are the three main languages spoken in Algeria and North Africa. So in this study we obtained the real values of the three formants F1, F2 and F3 of Berber vowel system.**

Keywords-The Berber vowel; vocal tract transfer function; acoustic characterization; formants frequency; speech processing.

I. Introduction

Vowels are different when pronounced by speakers of different languages. The traditional boundary between phonetics and phonology is framed by previous studies whose intentions were to determine how the vowels vary according to the languages speakers (phonetic), and also to determine all relevant sound contrasts in a language (phonology) [1]. The three main articulatory parameters that distinguish the vowels in many languages of the world are: the degree of jaw opening, the relative position of the tongue in the vocal tract suprapharyngual part, and the lips configuration. Changes in these three articulatory parameters in different languages cause variations in the acoustic field, in particular the values of the first and second formant F1 and F2 of the vocal tract. They mainly provide the fundamental relationship between the articulatory posture and formant frequencies. Our study is intended to characterize the Berber language vowels by measuring the formants frequencies with Pseudo Random Excitation (PRE) method.

Our paper is structured as follows: In Section II, we present the previous studies. The Pseudo Random Excitation method is presented in Section III and the corpus with the phonation conditions are discussed. Results are given in Section IV, followed by the conclusion and the future work in Section V.

II. HISTORY

The differences in the vowels production based on the comparison of vowels production by speakers of different languages are framed by previous studies; Delattre [2] studied how the vowels of four languages (English, French, Spanish, German) vary, in the case of stressed or unstressed vowels. He noted that the effect of stress vowels vary with the language.

In 1972, Liljencrants et al. [3] explained a universal models vowel system by calling the principle of perceptual contrast. The authors stated that within a language community, listeners tend to have more success differentiating between vowels that are more acoustically different rather than those with fewer differences. So, the speakers, in order to avoid being misunderstood, adopt articulatory patters that maximize the acoustic contrast. Lindblom et al. [4] mentioned that the number of contrasting vowels in a language can explain some aspects of vowels production mechanism by a speaker for a given language.

Keating et al. [5] in a study of Japanese, focused on acoustic variability over repeated productions of a vowel; speakers of Japanese differentiate among five vowels transcribed /a, i, e, a, o, w/. They predict that /i/ and /e/ show a little variation in F2, and this is due to the fact that they are very close in the acoustic space, while unrounded back vowel /w/ and the low vowel /a/ that have no close acoustic neighbors would vary more.

Manuel et al. [6] compared the formant frequencies of two speakers; one was an English speaker (in English 11-12 vowels are typically differentiated depending on dialect) and the other was a speaker of Swahili (Swahili is spoken in Kenya and Tanzania, five vowels are typically differentiated). They hypothesized that the English speakers, with more vowel distinctions to make, show relatively less variability for a given vowel sound than the Swahili speakers.

Jougman et al. [7] measured the formant frequencies of the Greek vowel system (five vowels) and the German one (fourteen vowels). The results indicated that Greek speakers produced a narrower range of both formant frequency values F1 and F2 than the German speakers.

Bradlow [8] compared the formants of vowels produced by English speakers and Spanish speakers (five vowels). The results show that the frequency range in Hertz is 13% larger for English speaker than the Spanish. Bradlow [8] found also that the value of F2 for English tend to be higher than the Spanish, suggesting that English speakers use more anterior tongue positions. In this context we try to characterize the Berber vowel system [9] and make comparison between Berber, French and Arabic vowel systems.

A Berber is an Afro- Asian language spoken in the North African territory. It currently stands as a high number of dialects, the best known being: Kabyle, tachelhit, Tamashek, jerba, Chaouia, the Rif and Judeo-Berber. Current studies aim to achieve uniqueness of the Berber language. For this, researchers are in the process of characterizing each of these languages, highlighting all that is common to all of these dialects. Our approach is the measurement of the vocal tract transfer function by PRE method, to characterize the Berber vowel system in acoustic field. This method allows us direct measurements during phonation. In Section III, we present mainly the theoretical aspect of PRE method.

III. METHOD

To characterize a Berber vowel, we carried out the direct measurement of the vocal tract transfer function using the method of external excitation of the vocal tract by a pseudo random binary sequence PRE [10]. This method allows us to measure directly the vocal tract transfer function with and without phonation. a measurement time is about 100ms.

A. Theory of the PRE Method

The vocal tract is considered as an acoustic filter of impulse response *h (n)* excited by a source *x (n)* with added noise *b (n)*. Therefore *y(n)* is given by the following convolution product:

$$y (n) = [b (n) + x(n)] * h(n) \qquad (1)$$

The cross-correlation function between the excitation *x (n)* and the output *y (n)* is given by:

$$R_{XY} (n) = \sum x (k) .y (k+n) \qquad (2)$$

If we consider φxx and φxb are the autocorrelation of *x(n)* and the cross correlation of *x(n)* and *b(n)*, respectively, we can write:

$$Rxy (n) = h (n) * \varphi_{xx} (n) + h(n) * \varphi_{xb}(n) \qquad (3)$$

If we consider that the signals *x(n)* and *b(n)* are uncorrelated, we get:

$$R_{xy} (n) = h (n) * \varphi_{xx}(n). \qquad (4)$$

Therefore, we approach *h(n)* by *Rxy* if $\varphi_{xx} (n)$ is close to a Dirac peak. This implies that *x (n)* has the characteristics of white noise, which is approached in a given frequency band by a digital technique the pseudo-random binary sequence, whose autocorrelation function is close to the unit impulse. This method is implemented and measurements are performed [11].

B. Corpus and Phonation Conditions

The recordings were made in an ambient environment at the laboratory of speech communication. Isolated vowels /a, i, u/ were made by a female (KF) and male (SM) speakers of Berber language. The signal is digitized at a sampling frequency of 16 kHz. The measurement time is about 100 ms, corresponding to a pseudo random sequence of 1024 samples. Each phoneme is recorded eight times. The results are given in Section IV.

IV. RESULTS

For each speaker formant values were calculated and shown in the following figures. Formant mean values and standard deviations are given in Table I. Note that formant frequencies values are in kHz.

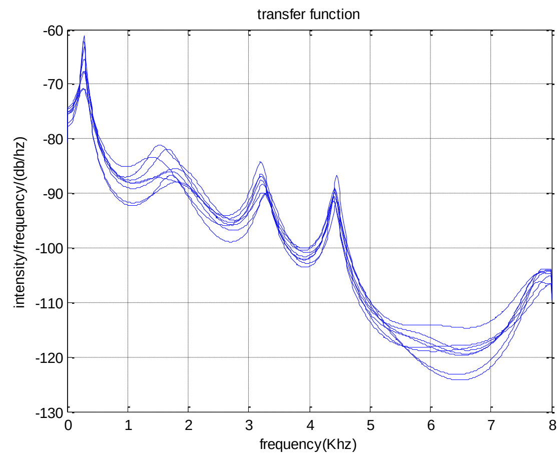

Figure 1. Transfer functions for the vowel /a/ pronounced by the male subject SM.

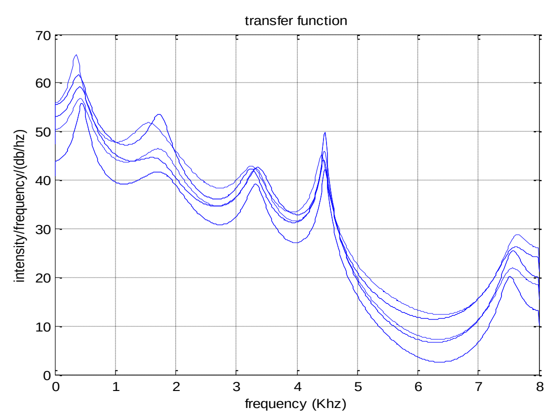

Figure 2. Transfer functions for the vowel /a/ pronounced by the female subject KF.

Figures 1 and 2 show the spectra obtained for the vowel /a/ pronounced respectively by a male and female speakers. The curves are superimposed well and the peaks are conspicuous for the eight repetitions. So, we can conclude that there is no large distortion in the spectra and the peaks frequencies are relatively steady.

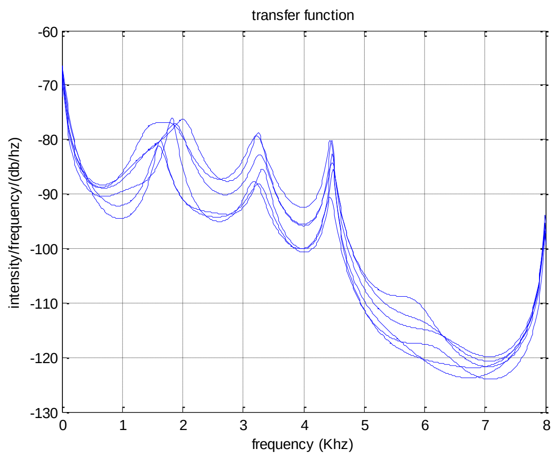

Figure 3. Transfer functions for the vowel /i/ pronounced by the male subject SM.

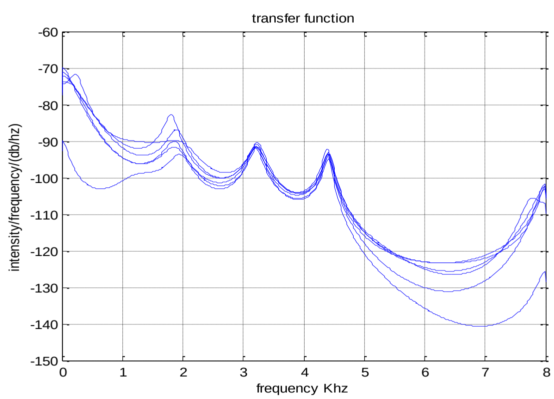

Figure 4. Transfer functions for the vowel /u/ pronounced by the male subject SM.

We find that the curves are superimposed well for eight repetitions, for the vowel /i/ as shown in Figure 3. The peak frequencies of F1, F2 and F3 are apparent. The spectra of the vowel /u/ are shown in Figure 4. To visualize the variations of the formants, we plotted the shape of these formants in the figures below.

A. *Formants Graphic Representation of Berber vowels*

The following figures show a graphic representation of the formants for all repetitions. The formant F1 is represented by a red asterisk, F2 is represented by a green circle and F3 is represented by a blue square (see Figure 6, 7 and 8).

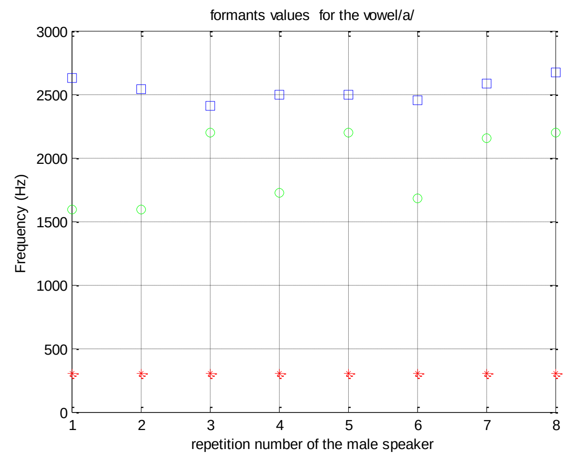

Figure 5. Formants representation for /a/ pronounced by male subject SM.

The formant F1 is highly stable for the three vowels /a, i, u/ compared to F2 having a considerable variability as shown in Figures 5 and 6. F3 has a greater variability than F1 and smaller variability than F2 (see Figure 7 and 8).

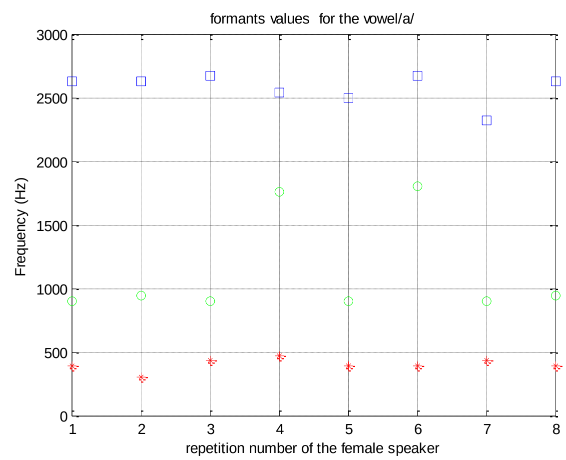

Figure 6. Formants representation for /a/ pronounced by female subject KF.

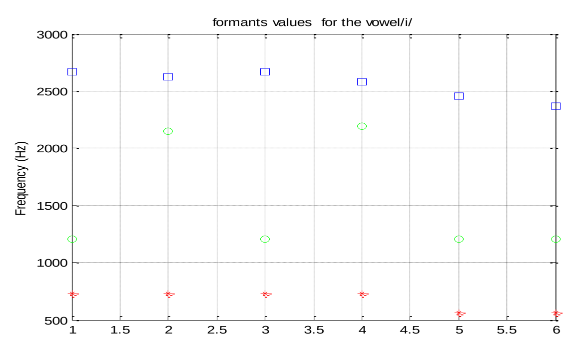

Figure 7. Formants representation for /i/ pronounced by male subject SM.

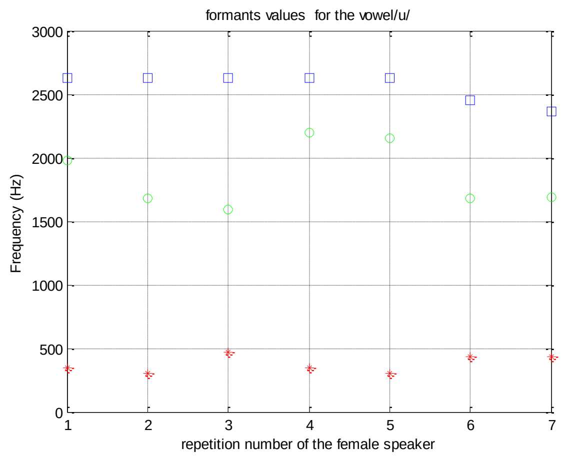

Figure 8. Formants representation for /u/ pronounced by female subject KF.

To better illustrate these variations we calculate the average values of the three formants and the standard deviation for each formant, the results are given in the Table I. It is found that F2 exhibits the greatest changes for the female speaker, compared to the male speaker. F1 exhibits the smallest variations for the both speakers.

TABLE I. AVERAGE VALUES OF F1, F2 AND F3 FOR BERBER VOWEL, STANDARD DEVIATION ARE IN PARENTHESES

Vowels	**Female speaker**			**Male speaker**		
	F1	***F2***	***F3***	*F1*	*F2*	*F3*
a	397,75 (50)	1290 (450)	2532,62 (215)	301 (0)	1914 (291)	2532,62 (87)
i	552,85 (130)	1161 (310)	2624 (24)	559 (88,8)	1476,66 (155)	2559,5 (123,8)
u	485 (70)	1640 (273)	2624 (107,8)	413,87 (100)	1997 (82,9)	2559,5 (137,9)

PRE method that we used in our study to measure the vocal tract transfer function, allows us to deduce the frequency of the excitation source. In the next section, we will present the excitation source spectrum that we obtained for each speaker.

B. Obtained Source Spectrum

To deduce the fundamental frequency spectrum F0 of the two speakers KF and MS, we applied the Fourier transform of the convolution product (given by (2)) which gives us a simple product of the excitation source with the vocal tract response; we deduce the source frequency which is a fundamental frequency of each speaker by a simple division of the vocal tract response to vocal tract transfer function; it is a deconvolution operation. The source spectrum is represented by Figures 9 and 10.

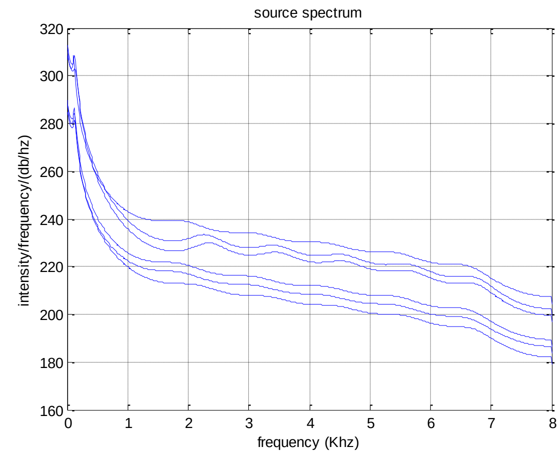

Figure 9. Source spectrum for the male subject SM.

We have two peaks frequency, one at about 100 Hz, corresponding to the fundamental frequency of the male speaker (see Figure 9), and the second at about 250 Hz for the female speaker (see Figure 10), which evenly corresponds to its fundamental frequency. These results are consistent with those given in the literature.

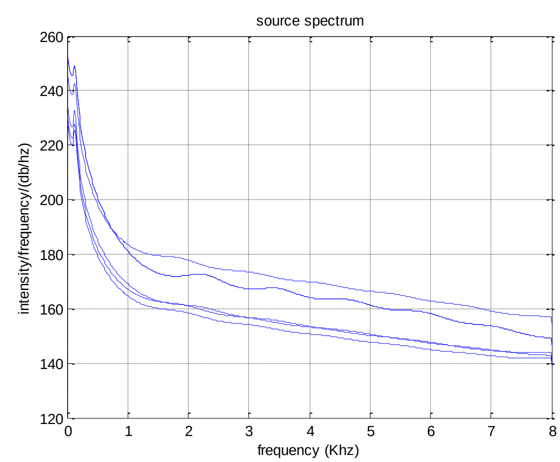

Figure 10. Source spectrum for the female subject KF

C. Analyze and Interpretation of Results

In Berber language, the vowel /a/ has a lower value for F1 (301 Hz for the male speaker, 397.75 Hz for the female speaker) compared to the F1 value of /a/of French and Arabic language [12][13]. These can be seen in Figures 1 and 2. That is due to the difference of the articulatory configuration during production of this vowel. The position of the jaw during the production of /a/ in Berber language is higher and the Pharyngeal cavity is larger compared to the production of a French vowel /a/. Perceptually, the /a/ Berber is less open, between /a / and / æ / of French language.

The /a/ delivered by a bilingual speaker (French-Berber, such as a Berber is a mother tongue) has a value of F1superior than F1 of Berber language and lower than that of the French language (376 Hz) and F2: 1838 Hz, F3: 2581 Hz. F2 is higher for the Berber (1914H z) for the male speaker and 1290 Hz for the female speaker. F3, 2532.62 Hz for the male speaker and female speaker is low compared to the value of F3 for the French vowel. These results for the vowel /a/ indicate the dependence formant values with the language of the speaker.

The vowel /i/, presents a higher F1: 559 Hz for the male speaker and 552.85 Hz for the female speaker. F2 and F3 are low compared to the value of F1, F2 and F3 for the French vowel (Figure 3). F2 is 1476.66 Hz for the male speaker and 1161 Hz for the female speaker and F3 is 2559.5 Hz for the male speaker and 2624 Hz for the female speaker.

Perceptually the Berber vowel /i/ is pronounced between the "i" /i/ and the "é" /e/ of French language where oral cavity is wider and the pharyngeal cavity is narrower compared to the production of a French vowel /i/.

The Berber vowel /u/, see Figure 4, presents values of formants F1 and F3 close to that of French and Arabic language and a higher F2; (F1: 413.87 Hz for the male speaker and 485 Hz for the female speaker. F2: 1997Hz for the male speaker and 1640 Hz for the female speaker. F3: 2559.5 Hz for the male speaker and 2624 Hz for the female speaker). The lip rounding in the production of French vowel /u/ and Arabic ones is more important compared to the production of Berber vowel /u/, which may explain the high values of F2 for /u/ of the Berber.

V. CONCLUSION

In this study, we obtained the real values of the first three formants F1, F2 and F3 of Berber vowels, by direct measurement of the vocal tract transfer function using the PRE method. This method allows us to have the source spectrum. We obtained a peak at about the fundamental frequency F0 of the speakers. We calculated a standard deviation of measurement for the eight repetitions of each speaker; the mean values of formants with the standard deviation were measured. For future work, we will study these vowels in different contexts and examine the influence of different Berber consonants on the vowels spectral shape.

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