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BILINGUAL ACOUSTIC VOICE VARIATION: THE CASE OF SORANI KURDISH-PERSIAN SPEAKERS

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ABSTRACT

Many individuals around the world speak two or more than two languages. This phenomenon adds a fascinating dimension of variability to speech, both in perception and production. But do bilinguals change their voice when they switch from one language to the other? It is typically assumed that while some aspects of the speech signal vary for linguistic reasons, some indexical features remain unchanged across languages. Yet little is known about the influence of language on within- and between-speaker vocal variability. The present study investigated how acoustic parameters of voice quality are structured in two languages of a bilingual speaker and to what extent such features may vary between bilingual speakers. For this purpose, speech samples of 10 simultaneous Sorani Kurdish-Persian bilingual speakers were acoustically analyzed. Following a psychoacoustic model proposed by Kreiman (2014) and using a series of principal component analyses, we found that Sorani Kurdish-Persian bilingual speakers followed a similar acoustic pattern in their two different languages, suggesting that each speaker has a unique voice but uses the same voice parameters when switching from one language to the other.

Keywords: voice quality, bilingual speakers, Persian, Sorani Kurdish, principal component analysis

1. Introduction

Laver (1980) described voice quality as the "characteristic auditory coloring of an individual speaker's voice". Abercrombie (1967: 91) defined voice quality as "those characteristics which are present more or less all the time that a person is talking: it is a quasi-permanent quality running through all the sound that issues from his mouth".

While the anatomical and physiological characteristics of an individual's vocal apparatus play a role in the quality of the voice, some characteristics are shared amongst the members of the same linguistic community, i.e., speakers of a certain community have acquired the shared features to mark their social or regional membership in a group (Esling et al., 2019). This includes speakers of the same language, whose articulators, Esling (2000) believes, are physiologically trained to operate based on the phonetic constituents of that particular language. Honikman (1964) as cited in Esling (2000) proposed that activation of articulatory postures and patterns is a function of the language being

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spoken. Thus, one may assume that a switch from one language to another by bilinguals entails a variation in voice quality. Therefore, the present study seeks to find out whether the voice quality of the bilinguals varies across the two languages they speak.

Some researchers have investigated, with inconclusive results, what aspects of voice change and what aspects are robust against change across different languages. Amongst these surveys, F0 was the most studied voice quality feature. In the case of Cantonese-English bilinguals, Altenberg and Ferrand (2006) found no significant difference in F0 while the subjects were speaking either English or Cantonese. However, Ng et al. (2010) reported a correlation between F0 and the language being spoken, and higher F0 values were reported by Ng et al. (2012)including fundamental frequency (F0 when women were speaking English. Engelbert (2014) compared bilingual Brazilian's production of English and Portuguese. She found a significant difference in LTAS, F0, H1-H2, and harmonics-to-noise ratio (HNR) in the two languages. Lee and Sidtis (2017) did research on Korean-English and Mandarin-English speakers. Their results indicated that bilingual speakers in both language groups exhibited different voice patterns depending on the language. Johnson et al. (2020) investigated the degree to which the voice quality of bilingual speakers changes across two languages, namely Cantonese and English. They extracted and measured F0, F1-F4, the corrected versions of harmonic spectral slopes (i.e., H1*–H2*, H2*–H4* respectively), the corrected version of amplitude difference between the fourth harmonic and the harmonic closest to 2000 Hz (i.e., H4*–H2kHz*), the corrected amplitude difference between the harmonics closest to 2000 Hz and 5000 Hz (i.e., H2kHz*–H5kHz*), cepstral peak prominence (CPP), energy, and subharmonics-harmonics amplitude ratio (SHR), using VoiceSauce (Shue et al., 2009). They found that the majority of speakers have the same voice across the two languages. In a study done by Cheng (2020). The f0 level was higher for Korean\nthan English, regardless of gender, age, or generational status (early\nand late bilinguals did not differ, F0 was found to change in Korean-English bilinguals across the two languages.

As noted above, no consensus was achieved on whether bilinguals use the same voice in the two languages. For some speakers, no change was observed in their voice, while others change their voice quite substantially across the languages. Therefore, the main goal of the present research is to investigate if the voice quality changes in the case of Kurdish-Persian bilinguals.

2. Method

The present study is a pilot study of a project which is going to be done on a larger corpus of bilinguals, speaking different languages.

2.1 Data

Speech samples from 10 simultaneous male bilinguals of Kurdish-Persian were recorded. All participants were educated and spoke a Sorani variety of Kurdish. Their age range was between 25–39 (Mean= 34, SD= ±4.02). All speakers were asked to read "the North Wind and the Sun" once in Persian and once in Kurdish at their comfortable pitch and loudness and with their normal speaking rate in two different recording sessions.

The audio recordings were compiled using ZOOM H5 hand-held recorder that was set on 44.1 kHz and 16-bit resolution. The recorder was held 20 cm away from the speaker's mouth at a 45˚ angle. All recordings were done in a quiet room with no background noise.

2.1.1 Persian and Sorani Kurdish speech sounds

Both Persian and Kurdish belong to the Iranian branch of Indo-Iranian languages which itself is a branch of the Indo-European language family.

Persian is an aspiration language with 6 monophthongs (/i, e, a, ɑ, o, u/) and 23 consonants. While some scholars argue that Persian has six diphthongs (/ei/,/ai/, /ɑi/, /ui/,/oi/, /ou/), others believe that these are sequences of a vowel and a semi vowel. The syllable structure in Persian is CV(C)(C).

Kurdish belongs to the northern branch of western Iranian languages. The language itself is stratified into 3 different categories: Northern, Central, and Southern. Sorani is one of the central Kurdish varieties. It has 8 monophthongs /i, e, æ, ə, u, ʊ, o, ɑ/, 7 diphthongs, and 29 consonants. The syllable structure in Sorani Kurdish is considered to be the same as Persian, i.e., CV(C)(C).

2.2 Pre-processing the speech samples

Before carrying out the acoustic measurements of voice quality parameters, all voiced segments (vowels and consonants) of the signals were extracted using the command (Extract voiced and unvoiced) in Praat Vocal Toolkit (Corretge, 2022) which is a free plugin for Praat (Boersma & Weenink, 2022) with automated scripts for voice processing. Only the voiced parts were saved and used for further analysis. All voice quality measurements were done using the VoiceSauce (Shue et al., 2009) however, the default was changed to 5 ms intervals.

2.3 Acoustic parameters

Voice-quality-related acoustic parameters were selected based on the "psychoacoustic model of voice quality" proposed by Kreiman et al. (2014). According to Kreiman et al. (2014), only the "necessary" and "sufficient" parameters to model the voice quality are included in the model. The model components were originally stratified into four different categories, including "time-varying source characteristics", "vocal tract transfer function", "harmonic source spectral shape" and "inharmonic source excitation".

The parameters used in the present study and the original model are presented based on the category they belonged to.

F0: a parameter that depicts "the time-varying source characteristic" (Kreiman et al., 2014) and is a perceptual correlate of the pitch.

The first four formant frequencies (F1, F2, F3, F4): the first four formant frequencies are associated with the transfer function of the vocal tract (Kreiman et al., 2014). The first three formants are commonly employed when discussing the linguistic variations in different languages and the fourth formant is mostly referred to as a speaker-specific parameter (Johnson et al., 2020)

H1-H2**[1]*, H2*-H4*, H4*–H2kHz*, and H2kHz*–H5kHz:* all these parameters are associated with the spectral shape of the harmonic source. H1*-H2* denotes the difference between the amplitude of the first and the second harmonics and gauges the harmonic slope which is indicative of the phonation type. H2*-H4* is the relative amplitude of the second and the fourth harmonic in a higher frequency band. H4*–H2kHz*is the difference between the amplitude of the fourth harmonic and the harmonic nearest to the 2000 Hz in frequency. This parameter measures the spectral slope of the harmonic in a higher frequency band. H2kHz*–H5kHz is the amplitude difference between the closest harmonics to the 2000 Hz and 5000 Hz. This parameter is related to the spectral slope of harmonic independent of F0 (Johnson et al., 2020).

Cepstral peak prominence (CPP): corresponds to the ratio of harmonic energy to spectral noise. It is correlated with the degree of the regularity and periodicity of the voice signal (Hillenbrand, 2011)

Apart from the parameters in the original model, several other parameters were added to it including formant dispersion (FD), energy, and subharmonics-harmonics ration (SHR) (Y. Lee et al., 2019). FD is the "averaged distance between successive formant frequencies" and is believed to be associated with vocal tract length (Fitch, Energy refers to "the Root Mean Square (RMS) energy, calculated at every frame over a variable window equal to five-pitch pulses"(Shue et al., 2009). SHR quantifies the amplitude ratio of subharmonics to harmonics and is related to period-doubling. The spectral noise is characterized by these two parameters in addition to the CPP. The last acoustic measure that was added to the original model was the *moving coefficients of variations* (moving $\text{CoV}=\frac{\textit{moving standard deviation } (\sigma)}{\textit{moving mean } (\mu)}$) to capture the dynamic variations of voice quality since it is believed that listeners do not only rely on the absolute values of different measures to discriminate between speakers (Y. Lee & Kreiman, 2019). Table 1 represents the parameters and their corresponding categories.

Table 1. Acoustic measures with their corresponding categories

Category	Parameter
F0	F0
Formants	F1, F2, F3, F4, FD
Harmonic source spectral shape	H1*–H2*, H2*–H4*,H4*–H2kHz*, H2kHz*–H5kHz
Inharmonic source/spectral noise	CPP, Energy, SHR
Variability	Coefficients of variation for all acoustic measures

[1] The asterisk sign(*) accompanying the harmonics signifies that the parameters are corrected for the effect of formants on harmonic amplitudes (Iseli & Alwan, 2004; Lee et al., 2019)

2.4 Post-processing the acoustic parameters

After running the VoiceSauce, observations with erroneous values (e.g, impossible 0 value for F0) were removed from the data set. Per speakers, values of each parameter were then normalized regarding the minimum and maximum value of that parameter in the whole data set in each language. The final values of each parameter ranged from 0 to 1 after normalization. The moving coefficient of variation for each parameter was calculated using a 50 ms window (10 observations). In total, 102114 data frames from Kurdish samples and 104608 data frames from Persian samples were obtained.

2.5 Statistical analysis

The method used in this survey is adapted from the works of Johnson et al. (2020), Lee et al. (2019), and Lee & Kreiman (2022) on analyzing the voice-quality-related parameters. All analyses were carried out using R version 4.0.4 (R Core Team, 2021)

An independent sample t-test was conducted to find out whether acoustic measurements remain stable or vary across the languages in general and in each individual in particular.

Then, to extract the internal structure of the data in the present study we performed Principal component analysis (PCA). PCA is a method used to reduce the dimensionality of large data sets while at the same time making the interpretation of the results easier. In PCA variables that are on the one hand correlated with one another and on the other hand independent of other groups of variables, are categorized into one component. Breaking down the data sets into different components enables the researcher to better identify and explain the internal structure of the data- and thus find the similarities and differences in the voices of bilinguals. In PCA, since some correlation was expected between the measured parameters, oblique rotation was implemented to simplify the structure of the data (Johnson et al., 2020; Y. Lee et al., 2019; Y. Lee & Kreiman, 2022). Only components with eigenvalues greater than 1 were included to ensure the interpretability of variances in the data (Kaiser, 1960). The loadings (weight) threshold for the parameters to be included in a component is equal to or higher than 0.32.

First, the common voice space for each language was designated by performing PCA in the whole Persian and Sorani Kurdish data sets. By doing so, the difference between the internal structure of both languages was captured.

Second, PCA was separately conducted for each speaker in each language using all 26 acoustic measurements obtained from the speech samples of that individual (13 variables + 13 CoVs for each variable), i.e., we had two PCAs per speaker (one in Persian, one in Sorani Kurdish). Then, the cumulative number of times each parameter appeared in each component was calculated by counting the times a particular parameter (e.g., F0) appeared in each component (the data is comprised of speech samples from 10 speakers in each language, therefore, no matter which component a particular parameter appears in, the cumulative number, in the end, would be 10). In this way, differences between the individuals in each language will be accounted for (individual voice space). Then the most prominent parameter in each category was determined. This was done in order to extract the general voice space within the individuals.

3. Results and Discussion

Results from t-test analysis showed that while all F0, formants, source spectral shape, and spectral noise parameters remained stable across Persian and Sorani Kurdish, almost all CoVs (except CoV F1 and CoV SHR) varied significantly. The effect size of the difference between the parameters across languages, however, was trivial. Detailed results for each variable parameter are presented in Table 2.

Table 2. Results obtained from independent sample t-test run on the whole Persian and Sorani Kurdish data set

Parameter	Results	Cohen's d	Median	
			Persian	Kurdish
CoV F0	$t(206719) = -70.240, p < 0.05$	0.309	0.088	0.076
CoV F2	$t(206719) = 2.906, p < 0.05$	0.013	0.199	0.204
CoV F3	$t(206719) = -4.00, p < 0.05$	0.018	0.132	0.126
CoV F4	$t(206719) = 14.150, p < 0.05$	0.062	0.219	0.224
CoV FD	$t(206719) = 14.178, p < 0.05$	0.062	0.219	0.224
CoV H1*–H2*	$t(206719) = -2.833, p < 0.05$	0.012	0.128	0.125
CoV H2*–H4*	$t(206719) = 8.320, p < 0.05$	0.037	0.185	0.187
CoV H4*–H2kHz*	$t(206719) = 11.069, p < 0.05$	0.049	0.186	0.183
CoV H2kHz*–H5kHz	$t(206719) = -3.539, p < 0.05$	0.011	0.149	0.146
CoV CPP	$t(206719) = 14.703, p < 0.05$	0.065	0.231	0.233
CoV Energy	$t(206719) = -34.257, p < 0.05$	0.151	0.057	0.054

Since some differences were observed between the acoustic parameters of voice, PCA was conducted to extract the common voice space of each language and find out how similar and/or different acoustic voice spaces are structured across Persian and Sorani Kurdish.

PCA resulted in 11 components for each language which cumulatively accounted for 68.9% and 70.5% of variances in Persian and Sorani Kurdish respectively. Analyzing the parameters in each component revealed that there is a similarity in the occurrence of the parameters in each component, specifically those parameters that did not exhibit significant variation in the t-test analysis. The internal structure of each component is represented in Figure 1.

As can be observed in Fig. 1, those parameters that did not vary across the languages either appear in the same components (PC01, PC02, PC05, PC11) in both languages or they appear in combination with the same other parameters (F0 and Energy in PC09 and PC06, F1 and CoV F1 in PC10 and PC09 in Persian and Sorani Kurdish respectively). The four components that were completely similar across the languages, accounted for 32.1% of the variability in Persian and 32.9% in Kurdish. The difference between the two

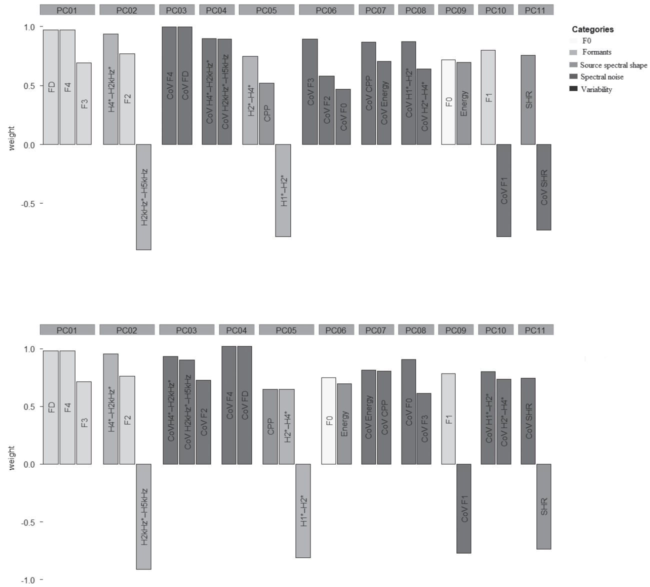

Figure 1. Bar plots of acoustic parameters in all PCs for Persian speakers (Top panel) and Sorani Kurdish speakers (bottom panel). Parameters in each PC are ordered from the highest absolute value of rotated component loading (weight) to the lowest. The hue of each bar delineates the category of the parameter.

languages is mostly observed where coefficients of variations (CoVs) emerged in the components. These parameters are the ones that differed significantly across the languages, therefore, variation in them was expected.

Based on the results obtained, acoustic measures of formant frequencies (FD, F4, F3) were dominant in the first component for both languages, accounting for 10.9% of the variance in the Persian data set and 11.7% in Sorani Kurdish. The second component was predominantly occupied by spectral shape measures (H4*–H2kHz* and H2kHz*–H5kHz) and formant frequency measures (F2), representing 10.2% of the variance in Persian and 11% in Sorani Kurdish.

The third component in Persian consists of coefficients of variation for F4 and FD, while these measures appear in the fourth component for Sorani Kurdish. The third component in Sorani Kurdish was strongly based on the coefficient of variation for the spectral shape measures and CoV F2.

Since some differences were observed between the acoustic parameters of voice across languages, a student's t-test was employed to find out how variable these parameters were across each individual's voice. The same results as the cross-language analysis were obtained for the variation of the acoustic parameters in each individual albeit with a difference in their effect size and inclusion of CoV F1 and CoV SHR in the results. The number of speakers whose acoustic voice quality parameters vary significantly is reported in Table 3.

Table 3. Number of Cohen's d for cross-linguistic comparisons in parameters that differed significantly in each individual

Parameter	Number	Cohen's d			
		Trivial 0–0.2	**Small 0.2–0.5**	**Medium 0.5–0.8**	**Large > 0.8**
CoV F0	9/10	5	2	1	1
CoV F1	1/10	1	–	–	–
CoV F2	10/10	5	5	–	–
CoV F3	8/10	3	4	1	–
CoV F4	10/10	4	3	3	–
CoV FD	10/10	4	3	3	–
CoV H1*–H2*	10/10	4	4	2	–
CoV H2*–H4*	8/10	4	4	–	–
CoV H4*–H2kHz*	10/10	4	6	–	–
CoV H2kHz*–H5kHz	8/10	3	5	–	–
CoV CPP	9/10	3	5	–	1
CoV Energy	10/10	5	3	2	–
CoV SHR	*5/10*	5	–	–	–

Observing the difference in some parameters in each individual, we performed separate PCAs for all the speakers and then determined the most prominent parameter in each component based on the results obtained from each speaker. In this way, while a common pattern amongst speakers was identified, the speaker-specific patterns were considered as well (see 2.5 for a detailed explanation of the method). Figure 2 delineates the internal structure of PCA results.

Since Figure 2 represents the general voice space within the individuals, variations in the occurrence of parameters in the components were expected. As is evident from Fig. 2, the most prominent category of parameters in components 1 to 3 are the formants and their CoVs counterparts in both Persian and Sorai Kurdish with the addition of source spectral shape parameters in the Persian data set. This is the same pattern that has emerged as the common voice space in Persian and Sorani Kurdish, albeit with different ordering and weight of the parameters in each component. Spectral slope in the higher frequencies (H4*–H2kHz* and H2kHz*–H5kHz) appeared along with F2 in Persian which is similar to their occurrence in the common voice space of Persian and Sorani Kurdish. The first three components in Persian and Kurdish accounted for 28.39% and 28.47% of variances respectively.

Like the common voice in Persian and Sorani Kurdish, F0 did not emerge in lower-order components, but when it did, it was accompanied by Energy. F1 and SHR with their CoV counterparts emerged in the same components in both languages.

Overall, the results obtained here were consistent with the results in Johnson et al. (2020) which showed that the acoustic patterns of voice were similarly structured across

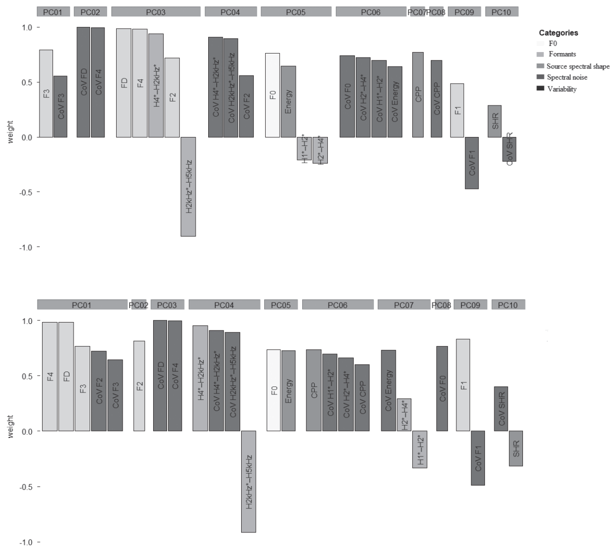

Figure 2. Bar plots of acoustic parameters emerging in 10 PCs for Persian speakers (Top panel) and Sorani Kurdish speakers (bottom panel), depicting the general voice space within the individuals. Parameters in each PC are ordered from the highest absolute value of rotated component loading (weight) to the lowest. The hue of each bar delineates the category of the parameter

the two languages of bilingual speakers. This delineates that bilingual speakers have the same voice when they switch from one language to another.

3. Conclusion

The present research studied how acoustic voice spaces vary individually and commonly across two languages of bilingual speakers. Results revealed that acoustic voice variations are similarly structured in the different languages of the speakers. While some acoustic voice space is shared amongst speakers across their two languages, there are also speaker-specific patterns within individual speakers, suggesting that each speaker has his/her own unique pattern as well. This means that speakers vary in the extent of acoustic voice quality structures between themselves. However, they showed a substantial similarity toward themselves. Despite the phonetic differences in the speech sound patterns of Sorani Kurdish and Persian, the variation in acoustic voice quality revealed a similar pattern in the lower dimensional structures.

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