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# Evaluating Normalization Procedures on Reducing the Effect of Gender in Persian Vowel Space

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**Abstract**

This study is to evaluate vowel normalization procedures in Persian continuous speech, from IRIB broadcasters, on the basis of their effectiveness in neutralizing differences in vowel formant data due to inter-speaker physiological and anatomical-gender- differences. The selection among various normalization technique depends on their significance in the previous literature and the kind of measurement involved in the provided database. The assessment is mainly performed following Watt & Fabricious method [31] in evaluation a technique for improving the mapping of multiple speakers vowel spaces in $F_1 \sim F_2$plane. That is done on the basis of increasing in mapping between speaker‘s vowel triangles along two continuous parameters: (a) the ratio of the area of the female speakers‘ s vowel triangle to that of male speakers triangle and (b) the degree of overlap between the two triangle, expressed in terms of that percentage of the male speakers‘ s triangle which overlaps with the female speaker‘s triangle and vice versa. We creatively add the third parameter called intersection/union area in which ($\Delta M \cap \Delta F$) is the combination of the two triangles and is named union area while ($\Delta M U \Delta F$) is the common area between the two vowel spaces, referred to as intersection area.

***Keywords:*** vowel space; normalization procedures; vocal tract length; Persian vowel system.

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## 1. Introduction

There has been extensive evidence in phonetic and sociolinguistic research since nineteenth century representing spoken vowels by means of the frequencies of their first two resonances of the vocal tract. The resonances of vocal tract which are called formants are decisive means of determining the qualities of vowels [13,28,15,17,11). Specifically, the center frequency of the lowest resonance of the vocal tract ($F_1$) corresponds closely to the articulatory and perceptual dimension of vowel height (high vs. low or close vs. open vowels), and the second formant($F_2$) reflects the place of maximal constriction during the production of the vowel, i.e. the front vs. back dimension. The relationship between the first and the second formant is mainly summarized in a vowel space plot. It plots the lower formant of each vowel as the ordinate (on the y-axis) and the upper formant as abscissa (on the x-axis), a configuration results which suggests a correlation between these acoustic data and observations which have been made of the positions of the vocal organs, notably of the tongue, when these vowels are produced.

A major problem faced in investigating a language vowel space, as Flynn [10] mentioned, is that no two speaker's vowel tract share the same dimension. As a consequence, the same phonological vowel uttered by different speakers will show formants at different frequencies due to to the sizes of the speaker's vocal tract. For example, female speakers tend to display higher formant frequencies than male speaker, as their vocal tracts are shorter and thus their resonance frequencies are higher. Dominic Watt & Anne fabricious [31] refer to this problem as the effect of VTL (Vocal Tract Length). Ladefoged & Broadbent [14] classified anatomical and physiological variation as personal variation while Pols, Tromp and Plomp [24] as speaker-related variance. Regardless of whatever it is named or classified in, it can be difficult when comparing the positioning of vowels within speaker's vowel spaces, to identify whether differences in formant values are due to a linguistic change in the vowel system or are merely due to the anatomical and physiological difference between speakers. Therefore, a central concern in the acoustic analysis of vowels has been to attempt to eliminate the effect of VTL on the relative frequencies of the lower formants for multiple speakers.

So as to minimize the potentially problematic influence of VTL-related variation among speakers of different sexes, it can be useful to apply normalization procedures [3,21,1,11,4,9,18,20, 31,30,7]. Traditionally, vowel normalization procedures are classified according to the type of information they employ. The procedures are defined as either vowel-intrinsic(speaker-independent) or vowel-extrinsic (speaker-dependent). Vowel-intrinsic procedures use only information contained within a vowel itself, i.e, intrinsic to the vowel. These procedures typically consist of a nonlinear transformation of the frequency scale including the mel scale obtained via Stevens & Volkmann 1940, Equivalent Rectangular Bandwidth (ERB) obtained via Glasberg & Moore and Bark obtained using Traunmüller. This kind of transformation often copy some aspects of the auditory transformation to acoustic data that are known to take place in the ear. These types of speaker- independent auditory transformation are based on the idea that two equivalent vowels, even if produced by different speakers, result in a similar pattern of motion along the basilar membrane [25; 6; 11]. On the other hand, in vowel-extrinsic (speaker-dependent) procedures normalization is carried out using statistical data from the speaker beyond the vowel that is to be normalized. The information required for this kind of normalization is distributed across more than one vowel of a talker. These procedures can be found in Gerstman [9, 18, 20 and 31].

As it is implied, there are a number of differing formulae which have been put forward as normalizing algorithms, although there is a distinct lack of consensus about which normalize best. Researchers, who pursuing the matter of evaluation of different methods, [12,8,29,16,30,31,7,10] have collectively identified a number of goals of normalization in evaluating a method:

- . To minimize or “eliminate” inter- speaker variation due to inherent physiological or anatomical differences
- . To preserve inter-speaker variation due to social category differences including age, gender and dialect or due to sound change
- . To maintain vowel category and phonemic differences
- To model the cognitive processes that allow human listeners to normalize vowels uttered by different speakers;

Of course, fulfilling all the above criteria is somehow unlikely. So, intending greater importance on one criterion over the others largely depend on the nature of the study.

The purpose of the present study is to compare a number of the normalization procedures mentioned and evaluate their effectiveness in Persian based on their neutralization in vowel formant data due to inter-speaker physiological and anatomical differences which derives from measurement in Hz of F1 and F2 at the midpoints of stressed spoken vowels. Our focus will be on an assessment at the extent of reduction of speaker sex-related differences in vowel formant frequencies for 10 Persian news-broadcasters (five male, five female) on the following scales:(a) linear Hz ; (b) nonlinear intrinsic rate Z (in BARKs) and (c) extrinsic LOBANOV (d) extrinsic NEARY (e) extrinsic GERSTMANN (f) extrinsic WATT& FABRICIOUS.

Although all techniques have been devised in attempt to reduce the discrepancies between the speech of men and women, which perform best in neutralizing gender in continuous speech in Persian has not been studied yet.

## 2.Methodology

### *2.1.Speech Material*

This paper is to investigate the acoustic vowel space in continuous speech in standard Persian. Since Peterson and Barney’s classic [23] article on vowel formant patterns, the acoustic space of vowels has been studied for many languages. In most, if not all of them, the formant frequencies were extracted from specified points, in specified vowels, in specified phonetic and prosodic contexts. In contrast, we are interested in the shape of vowel space determined by extremely large collections of vowel tokens, with whatever distribution of categories and context they may have in the read text.

The speech material consists of recordings of IRIB Broadcasts of 10 news reporter of Persian who were stratified for their gender(5 male, 5 female). The broadcaster, aged 35-50 years, were born and raised in Tehran, Iran. They can be regarded as professional language users in standard version of Persian as they have all passed successfully many courses and examination in being expertized to speak well to be understood by Iranian population who are interested in following news. The news in question were broadcast and recorded in August and September, 2013.

The set of monophthongal vowels in Persian consist of 6 vowels /i, e, æ, u, o, a/. The vowels selected in the database for calculation of area of vowel space are the stressed ones since they tend to be the loudest, the largest in duration and best articulated parts of speech over time. Tokens of the vowels were identified from simultaneous inspection of three displays (raw wave-form, spectrum, and spectrogram). Formant values calculated by the program's LPC algorithm, using a window of 20ms and a band of 300Hz, were read off the spectrum display at a point which was judged as indicating the main tendency of the vowel without consonantal interference, following a procedure described by [11,33].

### *2.2. Selection of Normalization Procedures*

As mentioned before, Normalization procedures have traditionally been categorized according to whether they are vowel intrinsic or extrinsic, speaker dependent or independent. The acoustic researchers [8, 20,26,1,18,31] showed that differences between speakers were reduced to a greater extent by extrinsic rather than intrinsic normalization techniques in different languages.

The selection among various normalization technique either intrinsic, which most involve a rescaling of format frequencies, or extrinsic depend wholly on their effectiveness confirmed in the previous literature and the kind of data and measurement involved in the database. To make it clear we briefly mention some reasons intervening in the selection of procedures. It has been shown that BARK has functioned much better in adaptive dispersion theory for perceptional contrast between vowels than other intrinsic transformations [32; 19; 5] or LOBANOV, NEARY and GERSTMANN were reported to effectively reduce the scatter while preserving phonetic differences [1, 11]. So, BARK,LOBANOV, NEARY and GERSTMANN are included or Nordström was excluded from further analysis in Persian because the formula required third formant frequency measurement which is not included in the database.

In sum, since this article by comparing between various kind of formant-based speaker normalization intend to factor out the variation that is due to anatomical differences between speaker, we decide resorting more to speaker-dependant extrinsic normalization procedures (LOBANOV, NEARY and GERSTMANN, WATT&FABRICIUS) than speaker independent intrinsic normalization procedures(in this paper only BARK).

### *2.3. Normalization Formulae*

Each procedure was implemented as follows. Hz, or the baseline condition, refers to the frequencies for the formant frequencies $F_1$ and $F_2$. BARK, the bark- transformation of the baseline, was implemented with Tranunmüller [27] in (1):

$$F_i^{Bark} = 26.81 \times \left(\frac{Fi}{1960 + Fi}\right) - 0.53 \qquad (1)$$

Gerstman's [9] normalization (GERSTMAN) was calculated for F0 through F3 as in (2):

$$F_i^{Gerstman} = 999 \times \frac{F_i - F_i^{min}}{F_i^{max} - F_i^{min}} \quad (2)$$

Where $F_i^{min}$ is the minimum value of $F_i$ for all 6 vowels token and $F_i^{max}$ is the maximum of $F_i$ for the six monophthongal vowels for all talker.

Lobanov's [18] Z-Score transformation was calculated as in (3):

$$F_i^{Lobanov} = \frac{F_i - \mu_i}{\delta_i} \quad (3)$$

Where$\mu_i$ is the average formant frequency across the six monophthongal vowels for talkers and $\delta_i$ refers to the standard deviation for average$\mu_i$ .

Nearey's [20] single log-mean (NEAREY) was calculated as in (4)

$$F_i^{Nearey} = F_i^L - \mu D_i^L \quad (4)$$

Where$F_i^L$is the log-transformed value of $F_i$ for a talker and $\mu D_i^L$ is the average across log-transformed formant frequencies across the six vowels for that talker.

Watt & Fabricious [31] formula based on the centroid of the coordinates was calculated as in (5)

$$F_i^N = \frac{F_i}{S(F_i)} \quad (5)$$

$$S(F_i) = \begin{cases} \frac{F_i(i) + F_i(\alpha) + F_i(u)}{3} & i = 1 \\ \frac{F[i] + F_i[u]}{2} & i = 2 \end{cases}$$

Where $S(F_i)$ is the centroid or the grand mean of point vowels [i] , [æ] and [u].So, S is calculated as a central gravity in the $F_1$~ $F_2$ plane for each speaker. Then it divide all the observed measurements of $F_n$ by the S value for that formant and express all resulting figures as values on scales $F_n/S(F_n)$ , i.e. as ratios of S.

***2.4.Procedures***

A central concern in the acoustic analysis of vowel has been therefore to attempt to eliminate the effect at VTL on the relative frequencies of the lower formants for multiple speakers [31].Procedures were evaluated depending on their effectiveness at neutralizing the variation in formant data due to inter-speaker physiological and anatomical differences. This was measured through the assessment of the ability of method to equalize the vowel space areas of different speakers [10]. In performing this, although we have reported the acoustic space of whole vowel categories of Persian shown in figure (1), we have followed what Dominic Watt & Anne Fabricious [31] have done in evaluating normalization techniques.

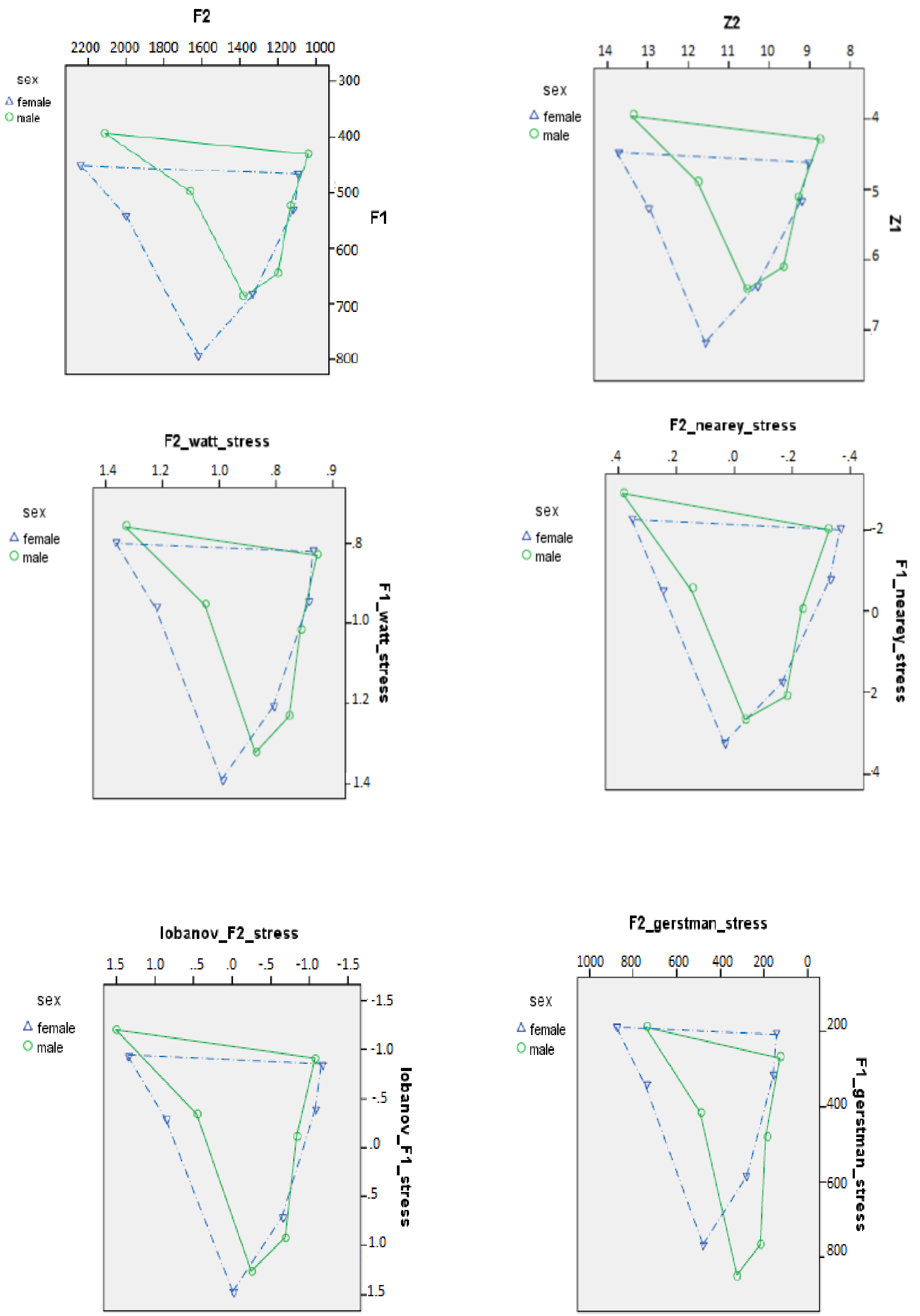


Fig. 1. The acoustic space of whole vowel categories of Persian in different scales

They calculated and draw the vowel spaces on the basis of formant frequency measurement taken for the so-called point vowels [i], the average $F_1$& $F_2$ for the vowel category with the highest average $F_1$, [æ], with the minimal $F_1$ value and [u] ,minimal $F_2$ value. So, the vowel spaces are appeared as a triangular plane with three apices occupied by three vowel points assumed to represent F1 and F2 maxima and minima for the speakers. As watt & Fabricious [31] state our estimate of the improvement in comparability between speakers is based on the increase in mapping between speaker‘s vowel triangles along two continuous parameters: (a) the ratio of the area of the female speakers' vowel triangle to that of male speakers triangle and (b) the degree of overlap between the two triangle, expressed in terms of that percentage of the male speakers' triangle which overlaps with the female speakers' triangle and vice versa. We creatively add the third parameter called intersection/union area calculated through (6):

$$\text{intersection/union area} = (\Delta M \cap \Delta F)/ (\Delta M U \Delta F) \quad (6)$$

Where(ΔM∩ΔF)is the combination of the two triangles and is named union area while (ΔMUΔF) is the common area between the two vowel spaces, referred to as intersection area. For the first two parameters, the proportion is calculated based on either female vowel space(ΔF) or male vowel space(ΔM). For the third parameter, the comparison is done on the basis of the combination of both female and male vowel spaces.

## 3. Results

### *3.1. Triangle Plotted Using Hz Scale*

The relative triangles of male and female generated from the raw Hz data are shown in figure (2):

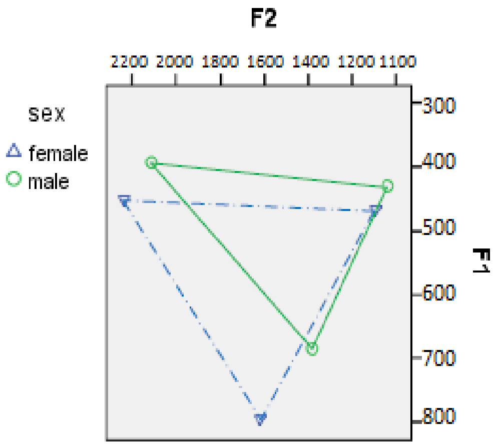


Fig. 2. triangles using HZ

In Analyzing Hz scale across three mentioned parameters we can claim (a) considering area Ratio(ΔM : ΔF), for female speakers F (ΔF) is almost 0.34% larger than that for the male speakers M (ΔM) at a ΔM : ΔFratio of 1: 1.34 (see table … for the full results in tabular form). (b) Considering overlapping, the proportion of ΔM overlapping ΔF is 62.05. In this mapping, 38% of ΔM lies in an area of the vowel plane which is unoccupied by ΔF and the proportion of the vowel space occupied byΔF which lies outsideΔM approaches 54%. We can therefore say that although the mapping of gender scale is not very poor, it is not what we wish since all Hz measurements are around the half. And(c) considering intersection/union area ,it is calculated 35.99 which is undesirable too.

### *3.2. Triangle Plotted Using Z (Bark) Scale*

Triangles using Z-transformed data by Traunmüller equation is shown in figure(3):

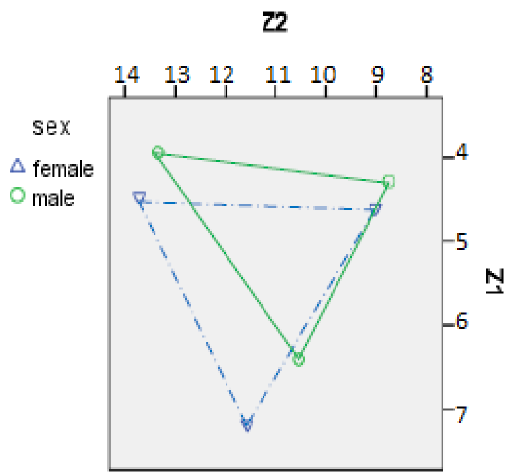


Fig. 3.triangles using BARK

Visually, it seems no improvement in Bark nonlinear scale in both area ration & degree of overlap, which statistically verified approximately. Considering area ratio, there is an improvement since the ratio of ΔM to ΔF is now 1: 1.19. Compared with the ratio 1:1.34 of raw Hz, although the changes in the amounts of overlap (ΔM : ΔF ) (62.05 compared with 60.26 of raw Hz) and overlap (ΔF : ΔM) (46.25 compared with 50.55 of raw Hz) is not only unconsiderablebut italso scores negatively (-2.9) in one respect (overlap (ΔM : ΔF) ). In addition, the amount of intersection/union area has not improved significantly (37.92 compared with 35.92 in HZ) .

### *3.3.Triangle Plotted Using Watt & Fabricius*

Triangle plotted using S units triangles using Watt & Fabricius formula are shown in figure (4):

Considering overlapping, overlap (ΔM : ΔF ) is now 79.14 (compared with 62.05 of Hz) and overlap (ΔF : ΔM) is 68.05 (compared with 46.25 of Raw Hz) which both seem salient which means there is an improvement in the match between the areas for the two triangles. Based on the factors Area ratio and intersection/union area, it is improvement too since the ratio decreases from 1:1.34 (Raw Hz) to 1:1.16 and from 35.99 to 57.63.

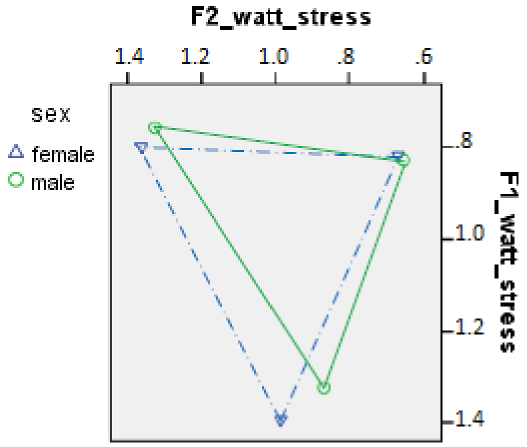


Fig. 4.triangle using WATT & FABRICIUS

### *3.4.Triangle Plotted Using Gerstmann*

Triangle plotted using Gerstmann formulaare shown in figure (5):

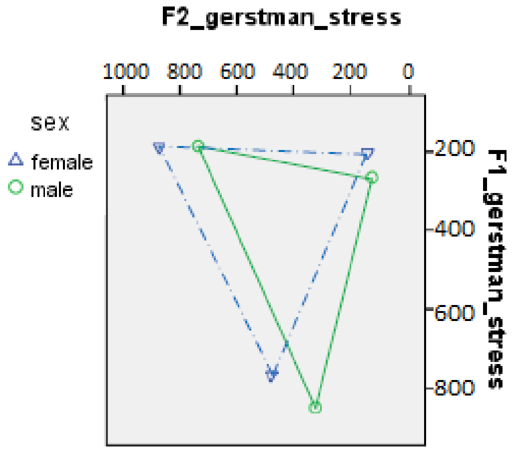


Fig. 5. triangle using Gerstmann

In this section , the triangle for female speakers F(ΔF) is just 0.16% larger than that for female speaker which show an improvement not only in comparison with Hz (1:34) but with bark (1.19) and watt (1.16) also. Evaluating the degree of overlapping and intersection/union area , there is an improvement over Hz and bark although it is scored negatively including Watt. The degree of overlap (ΔM : ΔF ) is now 67.56 (compared with 79.14 in Watt) and overlap (ΔF : ΔM) is 60.40 (compared with 68.05 in Watt). The amount of (ΔM∩ΔF)/(ΔMUΔF) is now 46.71 (compared with 57.63 in watt).

### *3.5.Triangles Plotted Using Neary*

Figure(6) shows triangles using Neary's equation:

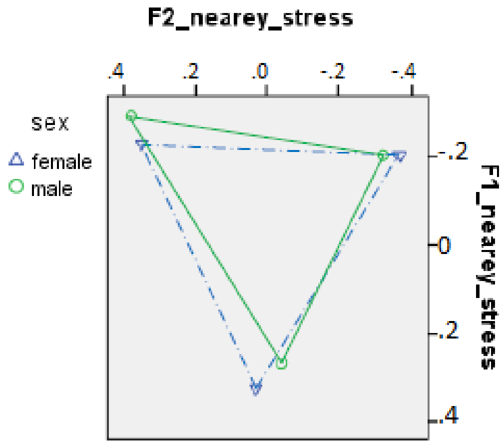


Fig. 6.triangles using NEARY

Neary's triangle ratioalso have shown increased improvement in matching male & female vowel spaces. The area ratio, here, is calculated 1:1.09 which has improved 18.7% in comparison with Hz. In Neary, we are confronted with the most amount of overlapping in ΔM : ΔF(89.96), that is, there is just 0.1% at ΔM lies in an area at the vowel plane which is unoccupied by ΔF .The degree of overlap (ΔF : ΔM) in Neary is 79.71 which is taken to be a dramatic improvement in comparison with Hz, Bark, Watt and Gerstmann. Furthermore, (ΔM∩ΔF) / (ΔMUΔF) is calculated77.78 which isthe most, too.

### *3.6.Triangles Plotted Using Lobanov*

Figure(7)shows the same data using Lobanov equation.

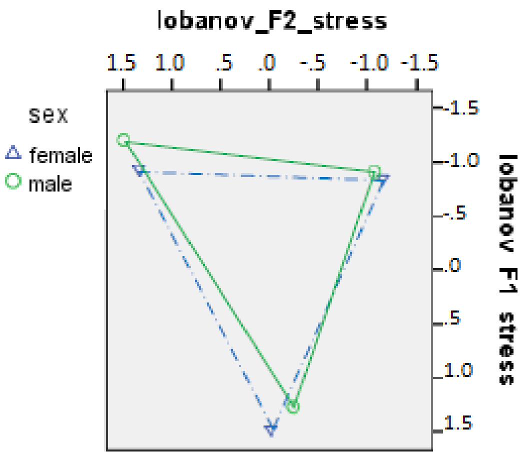


Fig. 7. triangles using LOBANOV

In Lobanov, Changes have done in area ratio is extremely interesting since agreement at the areas at two triangle is very intense. That is the triangle for the female speaker F ∆(∆F) is merely 0.02 larger than that for the male speaker M∆(AM). As a consequence, intersection/union area is improved largely (now 69.54 compared with 35.99 in HZ). The degree of overlap is also very high: the proportion of ∆M overlapping ∆A is 3.20 and the proportion at ∆F ovcerlapping ∆M is 81.44 which is the most amount across the techniques evaluated.

## 4. Conclusion

This paper is aimed to establish a method which can dramatically improve the area ratio and degree of overlap of vowel spaces from the speakers with different gender in continuous speech in Persian. These improvements are summarized in a tabular form in table(1):

Table 1.Improvement in different scale across different parameter

| | HZ | BARK | Watt | Gerstmann | Nearey | Lobanov |
|---|---|---|---|---|---|---|
| Area ratio (∆M:∆F) | 1:1.34 | 1:1.19 | 1:1.16 | 1:1.12 | 1:1.09 | 1:1.02 |
| % improvement over HZ | - | 11.2 | 13.4 | 16.4 | 18.7 | 23.9 |
| % improvement over BARK | | - | 2.5 | 5.9 | 8.4 | 14.3 |
| | | | | | | |
| % overlap (∆M : ∆F) | 62.05 | 60.26 | 79.14 | 67.56 | 86.96 | 83.20 |
| % improvement over Hz | - | -2.9 | 27.5 | 8.9 | 40.1 | 34.1 |
| % improvement over BARK | - | - | 31.3 | 12.1 | 44.3 | 38.1 |
| | | | | | | |
| % overlap (∆F : ∆M) | 46.25 | 50.55 | 68.05 | 60.40 | 79.71 | 81.44 |
| % improvement over Hz | | 9.3 | 47.1 | 30.6 | 72.3 | 76.1 |
| % improvement over BARK | - | - | 34.2 | 19.2 | 56.6 | 61.1 |
| | | | | | | |
| % Intersection/union area | 35.99 | 37.92 | 57.63 | 46.71 | 77.78 | 69.54 |

We observe from table(14) that Neary and Lobanov permit much closer mapping of triangles than do other techniques such as Hz, Bark, Watt & Gerstmann. Statistically, for evaluating different method to achieve which one normalize best, that is reducing the effect at VTL more, We reduce the four criterions (Area ration, overlap (∆M : ∆F ) overlap (∆F : ∆M) and intension/union area) to one factor in order to be able to compare the methods. It can be done by factor analysis. The principle component analysis is selected for extraction method and the regression method is used to calculate the factor score. The result is shown in the table(2):

Table 2. Factor score results

| | HZ | BARK | Watt | gerstmann | Nearey | Lobanov |
|---|---|---|---|---|---|---|
| factor scores | -1.29 | -.89 | .24 | -.24 | 1.11 | 1.08 |

We may see from the table that Neary has normalized the continuous speech in Persian better, although the differences existed between Neary and Lobanov is not significant.

Finally, We should mention that the above evaluation is not intended as a criticism of other scale (Bark, Watt, Gerstmann). However, we propose Neary "only as a means at allowing enhanced visual and statistical comparisons between vowel formant data set collected for different speakers and do not claim it has any psycho perceptual validity (e.g that it mimics the normalization process assumed to exist for the auditory processing of speech signals"[31].

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