# THE EFFECT OF MOUTH OPENING LEVELS ON ACOUSTIC PARAMETERS OF VOICE SIGNAL

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## Résumé

Cette étude examine l'effet de trois niveaux différents d'ouverture de la bouche sur : la fréquence fondamentale, le « jitter », le « shimmer », le rapport harmoniques/bruit, la fréquence du premier formant, la fréquence du second formant et le rapport des deux premiers formants lors de la production de la voyelle /a/. Une stratégie d'échantillonnage aléatoire simple a été utilisée pour recruter 36 participants. Au total, 18 femmes et 18 hommes âgés de 18 à 29 ans ont été recrutés. Les participants ont soutenu la voyelle /a/ pendant 7 secondes. La première et la dernière seconde de la voyelle ont été omises afin d'éliminer du signal audio l'effet d'initiation et de terminaison de la voyelle, et les 5 secondes du milieu ont donc été analysées pour en déduire les paramètres acoustiques. Sept caméras infrarouges ont enregistré l'ouverture de la bouche et les mouvements de la tête. Les résultats ont montré que le niveau d'ouverture de la bouche n'a d'effet que sur la fréquence fondamentale (p=0,009<0,05), le shimmer (p=0,033<0,05) et la fréquence du premier formant (p=0,004<0,05). Une posture de mâchoire ouverte place le larynx dans une position plus basse, ce qui entraîne une phonation plus détendue qui réduit la fréquence fondamentale et augmente le shimmer. Le niveau d'ouverture de la bouche a une relation inverse avec la fréquence du premier formant.

**Mots clefs :** niveaux d'ouverture de la bouche, fréquence fondamentale, fréquences des formants, jitter, shimmer, rapport harmoniques/bruit, voyelle /a/.

## Abstract

This study examined the effect of three different mouth opening levels on fundamental frequency, jitter, shimmer, harmonic to noise ratio, first formant frequency, second formant frequency and first two formants ratio in Producing vowel /a/.simple random sampling strategy was used to recruit 36 participants. 18 females and 18 males between age 18 to 29 years were recruited. the participants sustained vowel /a/ 7 seconds. The first 1 second and the last 1 second of the vowel were omitted in order to eliminate the vowel initiation and termination effect from the audio signal and, thereby, the middle 5 seconds were analyzed to derive acoustic parameters. Seven infrared cameras recorded mouth opening and head movements. The results showed that mouth opening level is only effective on fundamental frequency (p=0.009<0.05), shimmer (p=0.033<0.05) and first formant frequency (p=0.004<0.05).An open jaw posture places the larynx in a lower position which causes a more relaxed phonation that reduce fundamental frequency and increase shimmer. Mouth opening level has an inverse relationship with first formant frequency.

**Keywords:** mouth opening levels, fundamental frequency, formant frequencies, jitter, shimmer, harmonic to noise ratio, vowel /a/.

## 1 Introduction

The speech production system, according to the source-filter theory, is composed of two main parts, the source (larynx) and the filter (articulators). Based on this theory, features of the vocal tract can be inferred from its acoustic output. In other words, different postures in the articulators produce different sounds. If the Supraglottic part of the vocal tract (supraglottis) is assumed as the acoustic resonator, different postures will change the shape of this acoustic resonator and, subsequently, the acoustic features of the produced signal will change as well. While producing the speech, the source or the larynx produces the harmonics and then the filter selectively enhances or attenuates the amplitude of harmonics [1]. The shape of the filter is influenced by the changes in the postures of the articulators. One of these articulators is the lower jaw. By changing its posture, the length and width of the vocal tract changes and, thereby, affects the signal produced by the larynx.

The larynx has a cartilage-muscular structure suspended from the hyoid bone. When the jaw is lowered (i.e. the open jaw posture), the hyoid bone is placed in the lower position too and, subsequently, the larynx is placed at a lower position as well. The placement of the jaw in the lower position reduces the muscular tension, improves approximation of the

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vocal folds [2], and increases the vocal folds adduction [3] which causes a more relaxed voicing pattern [4]. On the contrary, the tense phonation is associated with the higher position of the hyoid bone and, subsequently, the placement of the larynx in the higher position.

### 1.1 Mouth opening as a voice therapy technique

Mouth opening is also used as a voice therapy technique to reduce muscular tension. The yawn-sigh technique and Froeschels' chewing method are two treatment methods that are used by opera singers [5]. The treatment methods focusing on the reduction of muscular tension, which have been used for singers, have improved the phonation among this group of patients [6]. The use of the Lee Silverman Voice Training (LSVT) method among patients with Parkinson's disease reduced the vocal cord bowing and increased vocal loudness. In this therapeutic method, the increase in the vocal effort is followed by an increase in the mouth opening [7]. Using LSVT method in dysarthria group changes formant frequencies of vowels and improves vowel goodness which is checked through perceptual vowel ratings [8].

### 1.2 Mouth opening and acoustic parameters

Studies have been conducted aiming to investigate the effect of the posture of the lower jaw on fundamental frequency. Lim et al. showed that the amount of mouth opening is inversely related with fundamental frequency [9]. Zawadzki & Gilbert showed that the fundamental frequency is related to the position of the lower jaw but the exact relationship was not reported [10]. Other studies have been conducted on the effect of the posture of the lower jaw on the filter-related parameters. Tasko et al. showed that as the mouth opening increases and the jaw is in a lower position, the first and second formant of the diphthongs are increased [11]. In another study, Mercer et al. investigated the effect of the lower mandible maneuver on the aerodynamic and acoustic parameters. They showed that the lower mandible maneuver results in a higher aerodynamic efficiency, higher SPL and also lower values of the first and second formants [12]. The effect of mouth opening on the parameters related to the source and filter were studied simultaneously by Mautner. In this study, it was shown that the mouth opening helps to increase the fundamental frequency, first formant, and the vowel space area and to reduce the jitter and the difference between the amplitude of first tow harmonics [13].

Science findings about mouth opening and frequency, first formant and second formant are in contrast in previous studies and mouth opening amount is mostly reported in a qulititative manner, the aim of this study was to investigate the effect of mouth opening in a quantitative and normalized manner on acoustic parameters of voice signal. The studied acoustic parameters included the fundamental frequency, jitter, shimmer, harmonic-to-noise ratio, the first formant, the second formant, and the first two formants ratio.

The hypothesis of the current study is that acoustic parameters of voice will be different in three mouth opening levels.

## 2 Method

The present study has been approved by the Isfahan University of Medical Sciences under the Ethical Code IR.MUI.RESEARCH.REC.1399.509.

### 2.1 Participants

The study participants included 18 males and 18 females aged between 18-29 years old. All participants met the inclusion criteria for this study: The mother tongue of the participants was Persian (Farsi). None of the participants had a history of smoking, drinking alcohol, gastrointestinal disease and voice disorder based on their own report and also didn't have temporomandibular joint problems. Based on diagnostic criteria of temporomandibular joint problems [14] if the researcher doubted the existence of signs or reported symptoms of the temporomandibular joint problems, the participant was eliminated from the study. On the sampling day none of the samples showed signs of allergy and cold.

### 2.2 Materials

To investigate the acoustic parameters of interest in the present study, the production of the vowel /a/ was used. For this purpose, the samples were asked to produce the vowel /a/ for 7 seconds. The first 1 second and the last 1 second of the pronunciation of the vowel were omitted in order to eliminate the vowel initiation and termination effect from the audio signal and, thereby, the middle 5 seconds were examined.

### 2.3 Procedures

Once the necessary permits were obtained from the Isfahan University of Medical Sciences, in order to invite people to participate in this study, an invitation was published on the relevant pages of the journals of the colleges of the Isfahan University of Medical Sciences. In these pages, the research objectives were described. Then, the applicant entered the sampling process. When the number of applicants from each gender reached 36, a number was assigned to each of them based on the table of random numbers. Next, using The Hat software, 18 participants were selected from each group. Again, the research objectives were explained to the selected participants. Then, they filled in the ethical consent form of the Isfahan University of Medical Sciences. These participants were examined in terms of the inclusion criteria and if qualified, they entered the next stage. In the next stage perceptual and acoustic voice assessment was done. The voice perceptual assessments were performed using the GRBAS scale. For this purpose, the participants read the rainbow text [15]. Also, they were asked to produce the vowel /a/ for 7 seconds and, then, scoring was done based on these two speech tasks. The cut of point was 0. To perform the voice acoustic assessment, which was done using the PRAAT (V.6.1.08), the samples were asked to produce the vowel /a/ for 7 seconds. Then, the middle 5 seconds were selected to perform the voice acoustic analyses. jitter, shimmer, and harmonic-to-noise ratio were analyzed. The cut off point for shimmer was less than 2/6, for jitter was less than 1 and for harmonic-to-noise ratio was greater than 12Db. The participants who had all inclusion criteria and proved healthy in the perceptual and acoustic assessments entered the sampling process. If each of the participants couldn't achieve the intended score in acoustic or perceptual assessment they were excluded from the study and another participant substituted the eliminated one. Accordingly, two participants were eliminated from the study at this stage.

In order for sampling, the participants were asked to open their mouth as wide as possible without feeling pain. Then, their mouth opening amount was measured by a caliper in mm and the 1/3 and 2/3 values of the measurements were calculated and recorded. Then, 4 markers were placed on the bone landmarks nasion, pogonion and porion according to the Fig. 1 with double sided glue. The participants sat in front of the cameras of the Qualisys system equipped with 7 infrared cameras. These cameras and QTM software (version 7.5; the Qualisys, Göteborg, Sweden) recorded the data of the mouth opening fixedness and head fixedness through the markers placed on the bone landmarks.

To collect the acoustic signal sample, a Zoom H1 recorder (Model 2016 made by ZOOM Company, Japan) was used. The microphone was connected to a headset and then the headset was placed at a distance of 5cm from the mouth and at a 45o angle at the right side of the mouth. The participants were asked to open their mouth as wide as possible. Then their mouth opening was measured again by a caliper to make sure that it is equal to the first amount. Afterward, the participants were asked to keep their mouth opening fixed and produce the vowel /a/ with a loudness of 75dB for 7 seconds while they had to avoid moving their head during sampling process. The voice loudness was examined using Sound Level Meters. Meanwhile, the cameras and QTM software recorded the data of the mouth opening fixedness and head fixedness through the markers placed on the bone landmarks. Camera data for each marker was reported in three-dimension x, y and z. the difference between the position of the nasion and pogonion markers was used to check mouth opening movements and the difference between the positon of left and right porion markers was used to check head movement. In the case that, considering the data obtained from the cameras, the mouth openness had changed or the participant had moved his/her head, the sample taken from that participant was eliminated and another sample from another participant was replaced. This process was repeated for the 1/3 and 2/3 values of the mouth opening. Once the process was finished, the data collected from the cameras was examined and the outlier was calculated. The audio signals were checked before data analysis and if any sample had abrupt loudness changes, the sample was eliminated.

The data obtained from the analysis of the audio signal of the participants were imported into the SPSS-25 software. The analysis of the collected data was performed using the ANOVA test and Bonferroni post hoc test. Also, the data obtained from the cameras were imported into the SPSS-25 software. Then, the outlier data were calculated and, accordingly, the samples with excessive head or mouth movement were eliminated from the sampling process.

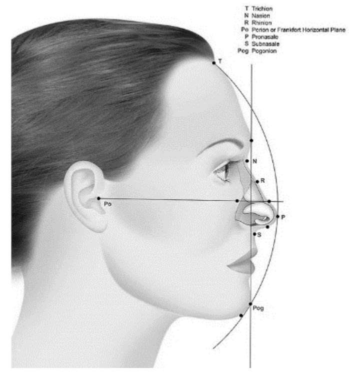


**Figure 1:** Bone landmarks, where markers are placed.

## 3 Results

The result obtained from descriptive statistics of marker's position at each level of the mouth opening are presented in-Tab. 1.

**Table 1:** Descriptive Statistics of difference in position of nasion-pogonion markers and left and right porion markers.

| | N | Mean | SD | Max | Min |
|---|---|---|---|---|---|
| **Nasion-pogonionx1/3** | 36 | -10.05 | 5.00 | 0.00 | -22.00 |
| **Nasion-pogo-niony1/3** | 36 | -5.00 | 4.00 | 7.00 | -16.00 |
| **Nasion-pogo-nionz1/3** | 36 | -134.09 | 11.00 | 118.00 | -161.00 |
| **Porionx1/3** | 36 | -6.00 | 4.00 | 0.03 | -14.00 |
| **Poriony1/3** | 36 | -145.00 | 49.00 | 137.00 | -188.00 |
| **Porionz1/3** | 36 | -6.00 | 4.00 | 0.08 | -16.00 |
| **Nasion-pogo-nionx2/3** | 36 | -10.00 | 5.00 | 1.00 | -22.00 |
| **Nasion-pogo-niony2/3** | 36 | -7.09 | 4.00 | 0.06 | -17.00 |
| **Nasion-pogo-nionz2/3** | 36 | -164.00 | 234.0 | 143.00 | 147.00 |
| **Porionx2/3** | 36 | -5.00 | 3.00 | 0.09 | 19.00 |
| **Poriony2/3** | 36 | -141.00 | 51.00 | 156.00 | -163.00 |
| **Porionz2/3** | 36 | -6.00 | 3.00 | 2.00 | -14.04 |
| **Nasion-pogo-nionx3/3** | 36 | -8.00 | 6.00 | 12.00 | -20.00 |
| **Nasion-pogo-niony3/3** | 36 | -6.00 | 4.00 | 2.09 | -16.00 |
| **Nasion-pogo-nionz3/3** | 36 | -182.00 | 170.0 | 133.00 | -147.00 |
| **Porionx3/3** | 36 | -4.00 | 2.00 | 0.00 | -9.00 |
| **Poriony3/3** | 36 | -142.00 | 52.00 | 162.00 | -165.00 |
| **Porionz3/3** | 36 | -6.08 | 3.00 | 1.00 | -13.00 |

N: Number SD: Standard Deviation Max: Maximum Min: Minimum

The results obtained from descriptive statistics, including the mean and the standard deviation, at each level of the mouth opening are presented in Tab. 2

**Table 2:** Mean and standard deviation for each of the seven experimental measures in three different mouth opening levels.

| Measures | | 1/3 Mouth opening | | 2/3 Mouth opening | | 3/3 Mouth opening | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| F0 | male | 127.98 | 16.44 | 124.08 | 14.09 | 125.75 | 21.57 |
| | Female | 250.10 | 32.97 | 245.40 | 30.35 | 243.19 | 34.59 |
| Jitr | | .271 | .142 | .266 | .125 | .276 | .097 |
| Shimer | | 2.076 | .914 | 2.039 | .746 | 2.550 | 1.156 |
| HNR | | 23.76 | 2.83 | 24.30 | 3.16 | 23.10 | 2.85 |
| F1 | | 758.95 | 104.09 | 778.61 | 100.79 | 795.43 | 114.37 |
| F2 | | 1164.05 | 139.43 | 1174.76 | 129.65 | 1197.67 | 117.96 |
| F1/F2 | | .648 | .046 | .658 | .056 | .659 | .058 |

Also, the ANOVA test results concerning the effect of the mouth opening level on the fundamental frequency, separated based on the gender, jitter, shimmer, harmonic-to-noise ratio, the first formant, the second formant, and the first two formant ratio, are presented in Tab. 4.

**Table 3:** Results of Anova test performed on the seven experimental measures in three different mouth opening levels.

| Agent | Measure | | F | df1 | df2 | sig | 2 η |
|---|---|---|---|---|---|---|---|
| Mouth opening | F0 | male | 2.884 | 2 | 16 | .085 | .265 |
| | | Female | 6.360 | 2 | 16 | .009* | .443 |
| | % Jit | | .113 | 2 | 34 | .893 | .007 |
| | % Shim | | 3.791 | 2 | 34 | .033* | .182 |
| | HNR | | 2.628 | 2 | 34 | .087 | .134 |
| | F1 | | 6.647 | 2 | 34 | .004* | .281 |
| | F2 | | 1.911 | 2 | 34 | .164 | .101 |
| | F1/F2 | | .939 | 2 | 34 | .401 | .052 |

As indicated by the results in Tab. 3, the mouth opening level has a significant effect on the fundamental frequency in the women's group. According to the results of Bonferroni post hoc test (Tab. 4).

**Table 4:** Results of Bonferroni test performed on F0, % Shim and F1.

| Measure | Mouth opening level | Mouth opening level | Mean difference | P value |
|---|---|---|---|---|
| F0 | 1/3 | 2/3 | 4.704 | .018* |
| | 1/3 | 3/3 | 6.914 | .021* |
| | 2/3 | 3/3 | 2.210 | .933 |
| Shim | 1/3 | 2/3 | .037 | .99 |
| | 1/3 | 3/3 | -.474 | .029* |
| | 2/3 | 3/3 | -.511 | .038* |
| F1 | 1/3 | 2/3 | -19.66 | .02* |
| | 1/3 | 3/3 | -36.478 | .004* |
| | 2/3 | 3/3 | -16.819 | .231 |

In the 1/3 mode of mouth opening, the average fundamental frequency is significantly higher than that in the 2/3 and 3/3 modes of mouth opening. Since the eta-squared in women's group is 0.443, 44.3% of the fundamental frequency variations in the women's group at these three levels is due to the mouth opening level. The mouth opening level also affects the shimmer ($p=0.033<0.05$). According to the results of the Bonferroni post hoc test (Tab. 4), the shimmer in the 1/3 mode of mouth opening is significantly lower than the shimmer in the 2/3 mode of mouth opening. Also, the shimmer in the 2/3 mode of mouth opening is significantly lower than that I the 3/3 mode of mouth opening. Considering the fact that the obtained eta-squared value is 0.182, 18.2% of the shimmer percentage variations at these three levels is due to the mouth opening level. The mouth opening level also affects the value of the first formant ($p=0.004<0.05$). The Bonferroni post hoc test (Tab. 4) shows that the average first formant in the 1/3 mode is significantly lower than that in the 2/3 mode and significantly lower than that in the 3/3 mode. Since the eta-squared value of 0.281, 28.1% of the first formant variations at these three levels is due to the mouth opening size. As for the jitter ($p=0.893>0.05$), the harmonic-to-noise ratio ($p=0.078>0.05$), the second formant ($p=0.146>0.05$), and the first two formant ratio ($p=0.401>0.05$) don't affect the mouth opening level. As shown in Tab. 2, the jitter has the highest average in the 3/3 mode of mouth opening and the lowest average in the 2/3 mode of mouth opening, but such a difference is not significant according to Tab. 3. According to Tab. 2 the harmonic-to-noise ratio has the lowest value in the 2/3 mode of mouth opening and the highest value in the 3/3 mode of mouth opening. However, such a difference is not significant (Tab. 3). As shown in Tab. 2, the average second formant has the highest average value in the 3/3 mode of mouth opening and the lowest average value in the 1/3 mode of mouth opening, but this difference is not significant (Tab. 4). The first two formant ratio has the highest average value in the 3/3 mode of mouth opening and the lowest average value in the 1/3 mode of mouth opening (Tab. 2), but such a difference is not significant according to Tab. 4.

## 4 Discussion

### 4.1 Mouth opening and fundamental frequency

The present study aimed to investigate the effect of the mouth opening level on the parameters of the produced acoustic signal. According to the findings, with an increase in the mouth opening level, the fundamental frequency reduced in both groups of men and women. This difference was insignificant in men's group so that the statistical tests exhibited no significant difference while this difference was significant in women's group. In women's group, the average fundamental frequency in the 1/3 mode of mouth opening was higher than that in the 2/3 and 3/3 modes. The increased mouth opening causes the larynx to be placed in a lower position [4]. Furthermore, the vertical movements of the larynx are directly related to the control of the fundamental frequency [16]. The placement of the larynx in a higher position results in a higher fundamental frequency and a lower position of the larynx leads to a lower fundamental frequency. with an increase in the mouth opening level and, subsequently, placement of the larynx in a lower position, the fundamental frequency is reduced. This phenomenon, which is well known, has no clear cause-and-effect explanation. In a study in this regard, Kakita & Hiki investigated the vertical movements of larynx and electromyography of the infrahyoid muscles (sternohyoid, sternothyroid, thyrohyoid, and omohyoid) and found a strong relationship between the fundamental frequency, the vertical movements of larynx, and contraction of the infrahyoid muscles. Based on these findings, they designed an anatomical model in which the thyrohyoid and sternothyroid muscles controlled the vertical position of larynx. In this model, the effect of the larynx's vertical position on the fundamental frequency was attributed to the vertical movements of the cricothyroid joint [17]. With the rotation of the cricothyroid joint, the cricothyroid muscle is stretched and changes the vocal cord's tension, in this way affects the fundamental frequency. In the following studies, as for the probable cause of the effect of the larynx's vertical movements on the fundamental frequency, Hirai et al. explained that the larynx's movements in vertical direction result in the rotation of the cricoid cartilage. The rotation of this cartilage affects the length of the vocal cords and controls the voice fundamental frequency [18]. As such, the position of the larynx in the neck affects the fundamental frequency.

Studies have reported that the thickness of the vocal cords in men in 20% more than that in women. Such a difference in thickness affects the voice frequency so that in the individuals undergoing SRS surgery (sex reassignment surgery), the thickness of vocal cords must be changed by 20% in order that the fundamental frequency of voice can be changed from a male voice into a female voice [19]. As mentioned above, the rotation of the cricoid cartilage following the change in the vertical position of the larynx results in the stretch of the vocal cords and also the increase in the muscular tension leads to the increased fundamental frequency. In men who have thicker vocal cords, probably the force imposed on the vocal cords following the placement of the larynx in a higher position will be slighter and will result in a slighter stretch of the vocal cords. Accordingly, the increase in the produced frequency will be slighter in the men's group.

In a study on patients with mutational falsetto, Salturk et al. showed that in the case of using lower mandible maneuver and, subsequently, the placement of the larynx in a lower position, the fundamental frequency decreased significantly [20]. Findings of this study were consistent with those of the study conducted by Lim et al. [9]. Also, Gilbert and Zawadzki obtained similar results [10]. However, findings of Mautner et al.'s study [13] were not consistent with results of the present work since in their study, the fundamental frequency increased with an increase in the mouth opening level. Regarding the fact that the mouth opening level in this study was qualitative and it was not exactly known how wide the subjects had opened their mouth when producing the vowel, the results of these two studies cannot be compared appropriately.

### 4.2 Mouth opening and jitter, shimmer and harmonic to noise ratio

In this study, the average shimmer in the 1/3 mode of mouth opening was significantly lower than that in the 3/3 and in 2/3 was lower than 3/3 mode of mouth opening. Nevertheless, the increase in the mouth opening level didn't cause the shimmer to exceed its normal value, which was 2.6 [2]. As the mouth opening level increases, the larynx is placed in a lower position and its normal state, which is followed by a reduced glottal tension and, thus, the voice is heard a bit breathy. The voice breathiness degree is correlated with the closeness of the vocal cords. The endoscopic studies on the yawn-sigh method have shown that with the placement of the larynx in a lower position and the expansion of the pharyngeal space, the degree of the vocal folds adduction is reduced so that in the closed phase, in which the vocal cords must be completely closed, there will be a small gap between two vocal cords resulting in an increased perturbation level, an increased shimmer, and a breathy voice quality [4]. Shimmer findings of the present study are consistent with those of the above-mentioned study. Also, other studies in this regard have shown that an increase in the fundamental frequency would lead to a reduction in the average shimmer. In fact, with an increase in the fundamental frequency, the vibrational regularity of the vocal cords is increased and the average shimmer is reduced [21, 22]. Therefore, the reduction in the shimmer observed in the 1/3 mode of mouth opening can be due to the increased frequency observed at this mouth opening level. In the study conducted by Mautner, the increase in the mouth opening was associated with a reduced average shimmer [13]. In 2007, in a study conducted on the effect of mouth opening on the speech production and voice characteristics of children with hearing loss and healthy children, Lee showed that the exaggerative mouth opening would result in a lower shimmer percentage and an increased voice stability [23]. In both of these two studies, the mouth opening level has not been examined quantitatively and since the subjects' mouth opening level is not clearly known, the obtained results cannot be compared to the findings of the present work. Furthermore, studies have shown that the voice loudness is a confounder variable for the parameters related to the acoustic signal disturbances (i.e. jitter, shimmer, and harmonic-to-noise ratio). This means that an increased voice loudness would improve these parameters even in individuals with voice disorders. Therefore, when these parameters are used to investigate the quality of the acoustic signals, the voice loudness must be controlled as a confounding variable [24]. Thus, the improvement in the shimmer observed in these studies might be due to the increased voice loudness since in both of these studies, the voice loudness has not been controlled and merely the subjects have been asked to produce the given vowels and syllables with their habitual voice loudness. In the present study, the jitter and the harmonic-to-noise ratio exhibited no significant relationship with the mouth opening level. On the other hand, in Mautner's study on the effect of mouth opening level on the above-mentioned parameters, it was shown that the increased mouth opening would reduce these two parameters. As mentioned earlier, such an improvement might be due to the increased voice loudness and the effect of the increased SPL (sound pressure level) on these parameters, not due to the direct effect of the increased mouth opening.

## 4.3 Mouth opening first formant, second formant and first two formants

Results of the present study showed that the first formant is significantly related to mouth opening level while the second formant and the first tow formant ratio don't have a significant relationship with mouth opening. In this study, with an increase in the mouth opening, the frequency of the first formant increased. The first formant has a reverse relationship with the tongue height so with a reduction in the tongue height, the value of the first formant increases. Since the tongue and the lower jaw mainly move together, it is expected that the movements of the lower jaw affect the frequency of the formants because the lowering of the jaw results in the lowering of the tongue and elongation of the oral cavity. As the mouth opening increases, the tongue is placed in a lower position and the frequency of the first formant increases. In Mautner's study, the frequency of the first formant increased with an increase in the mouth opening [13]. Lee et al. obtained the same findings. They studied the relationship between the position of the tongue on the X-Y axis and the values of the first and the second formants and found a very strong reverse relationship between the tongue's position on the Y-axis and the value of the first formant. Accordingly, the highest the position of the tongue on the Y-axis, the lower the frequency of the first formant [25]. Results of this study confirm the results of the previous works.

The theory states that the value of the second formant is related to the tongue's posterior and anterior position in the mouth so the more posterior the position of the tongue, the smaller the value of the second formant. Furthermore, studies have shown that as the mouth is opened wider, the tongue moves backward and the vowel constriction finds a more posterior position [26]. Based on the findings, it is expected that with an increase in the mouth opening, the value of the second formant decreases. There are studies with findings that confirm the above claim [12, 13]; whereas, in the present work, no significant relationship was found between the frequency of the second formant and the mouth opening level. This can be probably attributed to the relationship between the frequency of the second formant and the height and forward movement of the tongue at the same time. Findings of a new study show that the second formant is identically related to the tongue's position on the X-axis and the Y-axis. In this study, it has been shown that the frequency of the first formant is clearly related to the height of the tongue or, in other words, the tongue's position on the Y-axis. On the other hand, for the second formant, the relationship between the tongue's position on the X-axis and the Y-axis and is a bit more complex. This study showed that the second formant is dependent not only on the tongue's position on the X-axis or the posterior and anterior position of the tongue but also on the tongue's position on the Y-axis or, in other words, the tongue's height [25].

The first tow formants ratio determines the quality of the vowel. Accordingly, the longer the distance of the first and second formants of a vowel, the higher the quality of that vowel. Also, as the anterior part of the oral cavity gets smaller and the posterior part of the oral cavity expands, the first and second formants of the vowel get farther and, thereby, the quality of the vowel increases [1]. However, as the mouth opening level increases, the case gets reversed. Accordingly, with an increase in the mouth opening level, the anterior part of the oral cavity expands while with the backward movement of the tongue, the posterior part of the oral cavity gets smaller.

Findings of the present study about fundamental frequency and shimmer shows that with opening the mouth in 3.3 level, which is the maximum mouth opening level without pain, fundamental frequency decreases the most. In treatment of voice disorders such as mutational falsetto and muscle tension dysphonia increasing mouth opening level in maximum amount (3/3) can be helpful in frequency decrease without exceeding the shimmer from its normal value. First formant frequency also increases as the mouth opening increase. Studies have shown first formant frequency in people with dysarthria decreases [27, 28]. Findings of the present study shows that first formant frequency has its normal value in 1/3 of maximum mouth opening. Therefore, it seems exaggerated amounts of mouth opening doesn’t improve vowel quality in people with dysarthria. Further studies are needed to determine which level of mouth opening can improve vowel quality in people with dysarthria.

# 5 Conclusion

The results in this study show that by increasing the amount of mouth opening level, fundamental frequency decrease, while shimmer and the first formant frequency increase. Other acoustic parameters didn’t have significant relationship with mouth opening level.


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