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PHYSIOLOGICAL AND ACOUSTIC STUDY OF MUGHAM THROUGH THE PRISM OF WESTERN VOICE STUDIES: USING INSIGHTS FROM OPERA AND BELTING

Abstract: *This study investigates the physiological and acoustic characteristics of Azerbaijani mugham singing through the application of Western voice science methodologies. Mugham, an ancient and highly improvisational vocal-instrumental tradition, has been inscribed by UNESCO as part of the Intangible Cultural Heritage of Humanity. Despite its rich history, the vocal production techniques used by mugham singers remain largely unexplored in a systematic, scientific manner. The research utilizes acoustic analysis, including Long-Term Average Spectrum (LTAS), to examine the presence of the singer's formant in mugham performance. Additionally, comparisons are made with operatic and belting vocal techniques to identify potential similarities and differences in resonance strategies. Preliminary findings suggest that mugham singers employ distinct vocal mechanisms, possibly involving a specific "mugham formant" or alternative formant tuning strategies beyond those traditionally associated with opera. Furthermore, physiological investigations using high-speed video endoscopy, real-time dynamic MRI, and flexible fiberoptic laryngoscopy have provided insights into the biomechanics of mugham vocal production. Findings indicate that mugham singers engage in register transition often maintaining a chest-dominant vocal mode even in the high-pitched zil range, in contrast to the classical operatic technique. Additionally, the study identifies parallels between mugham singing and belting, particularly in the use of laryngeal positioning and megaphone-shaped vocal tract adjustments to enhance resonance and projection. The research underscores the necessity of integrating voice science into mugham pedagogy to ensure vocal health and longevity for singers. By combining traditional oral transmission methods with evidence-based pedagogical*

approaches, the study aims to bridge the gap between historical performance practice and modern vocal science. Future investigations will expand upon this work to enhance teaching methodologies and contribute to the preservation of the vocal mugham tradition.

Keywords: *mugham singing, acoustic analysis, singer's formant, resonance strategies, laryngeal biomechanics, formant tuning, vocal mugham pedagogy, belting technique*

Introduction

Vocal musical genres manifest unique aesthetic, cultural, and structural features that forge not just differences in sound but also images of ideal performance embedded in cultural paradigms and practices. Azerbaijani vocal-instrumental mugham, one of the genres of world vocal heritage, is an ancient traditional form of modally-based music with a high degree of improvisation which was 'inscribed in 2008 (3.COM) on the Representative List of the Intangible Cultural Heritage of Humanity (originally proclaimed in 2003)' by UNESCO [27]. In spite of the large amount of literature and research concerning mugham, there still remains a serious deficiency in the music science of Azerbaijan regarding the research of acoustic and physiological characteristics of Azerbaijani mugham singers' voice apparatus.

In this paper, the author intends to overview the existing approaches and methodologies applied in acoustic and physiological studies of the singing voice in classical operatic and belting genres to reveal the most relevant and effective techniques and methods that can be adapted and employed in the research of mugham singers' voices. Analysis of the acoustic and physiological characteristics of vocal mugham will enable to objectively explain the peculiarities of its vocal production.

Mugham

The art of vocal mugham necessitates mugham singers, known as *khanende*, to master exceptional singing skills, a wide vocal range, and the ability to recite comprehensive poetry known as *ghazal* [28]. They produce unique melodic "filigree," with "endless ornament," and "intonational and rhythmic gestures" [18, p.35]. During the vocal performance mugham singers start from the low range defined as *bam* in Azerbaijani vocal mugham terminology and gradually shift to the high range, defined as *zil*. The starting point of the mugham, the *bam* range, requires the ability to produce an eloquent, soft chant-like sound. In contrast, while singing in the *zil*, singers produce a loud emotionally-charged sound that demands remarkable power [18, p.178]. The vocal craftsmanship of mugham singers and the ability to achieve high tessitura is considered to be one of the outstanding and impressive moments in the performance of vocal-instrumental mugham. This loud

sound that mugham singers produce in *zil* is traditionally performed without a microphone, however, in recent years, due to the concert-like format and broader array of instruments that require a bigger stage and performing halls some young mugham singers began to utilize the microphone. Despite that fact, the professional mugham singers who are devoted to the traditional performing setting prefer not to use the microphone producing notes in high range *zil* with effortlessness that creates unforgettable experiences for the listener. However, the secrets of achieving such a mastery remain mostly uninvestigated as the mugham art has been traditionally transmitted orally from master to apprentice. This ancient teaching method assumes the lack of written materials or systemised theory. Therefore, it remains unknown which mechanisms and techniques allow mugham singers to create such spectacular vocal effects.

The study of laryngeal biomechanics contributes to a better understanding of the physiological processes underlying sound production [6, p. 1189; 4, p. 113], as well as to the development of methods that help maintain the vocal health of mugham singers, which is especially important in the context of long and intense performances typical of mugham.

Owing to the significant progress of modern acoustic computer programming, and medical technologies over the past decades, applying advanced research methodologies on the vocal apparatus became possible [8, p. 155]. This is true not only for classical but also for non-classical singing. A wealth of scholarly material has been published on the research of the vocal apparatus of many singers including operatic singers and belters [18, p.263].

Singer’s formant

Understanding the importance of filling this gap and the necessity of an academic approach to the study of mugham's vocal nature, the author began her research in this field in 2009. In the first stage of the research work the author employed acoustic analysis of the mugham singers’ voices with the use of the Long-Term Average Spectrum (LTAS) analysis method looking for common factors in the distribution of the energy across frequency spectrums to identify the absence or presence of singer’s formants [28].

Singer’s formant is a well-known phenomenon pertinent to classical singing. It was observed by Bartholomew [1, p. 27] mostly in male operatic singers and further investigated by Sundberg [33, p. 838], who interpreted it first as a “singing formant” or high spectrum envelope peak near 2.8 kHz. This phenomenon later came to be known as “singer’s formant” defined by Sundberg [34, p. 117] as the amplification of energy near 3.0 kHz (clustering of 3^{rd}, 4^{th}, and 5^{th} formants) characterised by lowering the larynx and lengthening the vocal tract that allows the voice to be heard over the orchestra.

According to Sundberg [33, p. 840], during high-pitched singing, the resonance frequency of the larynx tube rises with the increase of the area of the larynx tube opening. Sundberg [33, p. 840] points out that if the ratio between the "pharyngeal cross-sectional area of at least 9 cm^2" and the opening area of the larynx tube of 1.5 cm^2 exceeds 6:1, the larynx tube acts as a separate resonator which is possible if the larynx is lowered. So, according to Sundberg [33, p. 840], a lowered larynx widens the pharynx cavity which is important while singing at higher pitches.

The postulations of Sundberg about articulatory interpretation and centre frequency of the singer's formant were supported by Titze and Story [39, p. 2243] who indicated that a bell-like vocal ring present in operatic singing is produced as a result of narrow epilarynx and wide pharynx and according to many early studies [1, 33, 39] can be seen in the spectral envelope as a clustering of the 3^{rd}, 4^{th}, and 5^{th} formants in the range of 2500-3500 Hz.

On the other hand, McCoy [12, p. 48] in his book *'Your Voice, an Inside View'* points out that his "experience, however, refutes this." He states an interesting point that in his classroom some of his students "usually young tenors - who have not yet learned to sing without raising their larynx" were singing with a strong singer's formant [12, p. 48]. He observed that once their larynx stabilizes in the lowered position, they can acquire more refined tonal qualities [12, p. 48]. So, according to McCoy [12, p. 48], the ringing quality which is called the singer's formant can be produced only when proper sound is sent into the vocal tract by the vibrating vocal folds.

A 'ring' quality perceived in Azerbaijani mugham singing, especially in a high-ranged zil, encouraged the author to analyse Azerbaijani mugham singers' voices to find acoustic properties that contribute to this ring production. In the author's preliminary research published in conference proceedings, she carried out the acoustic measurements of the singing voices of 5 Azerbaijani female mugham singers aged 30 to 50, who performed the pieces of *Mirza Huseyn Segahi* mugham in both *bam* and *zil* ranges [28]. Applying the LTAS analysis method it was possible to reveal prominent peaks in five samples of *bam* and *zil* for all five singers within the range of 2.8-3.5 kHz, which was indicative of the presence of the singer's formant [28].

In 2022, the author conducted a similar investigation on the singing voices of prominent Azerbaijani male mugham singers by conducting LTAS analysis (Fig. 1) using Sopran software [30, p. 16-19]. Male mugham singers' acoustic data were compared to that of Azerbaijani operatic tenor.

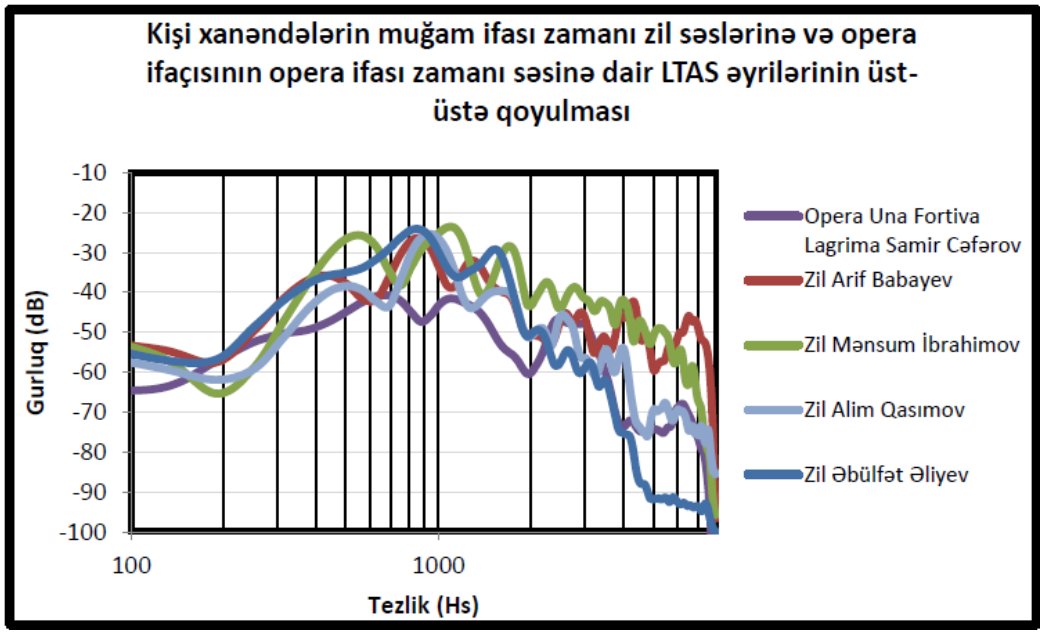
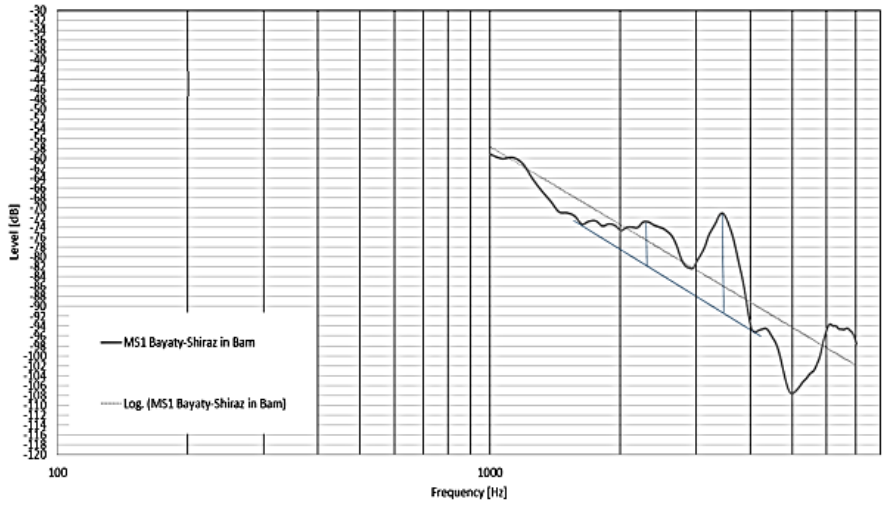
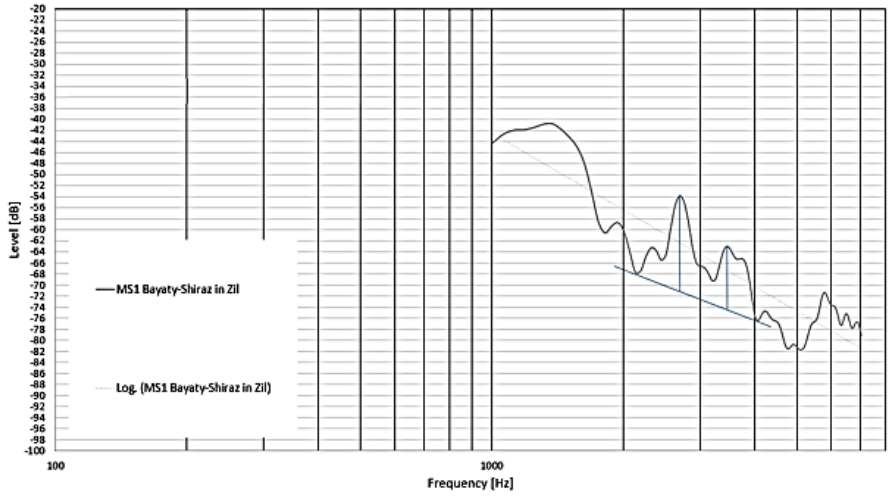
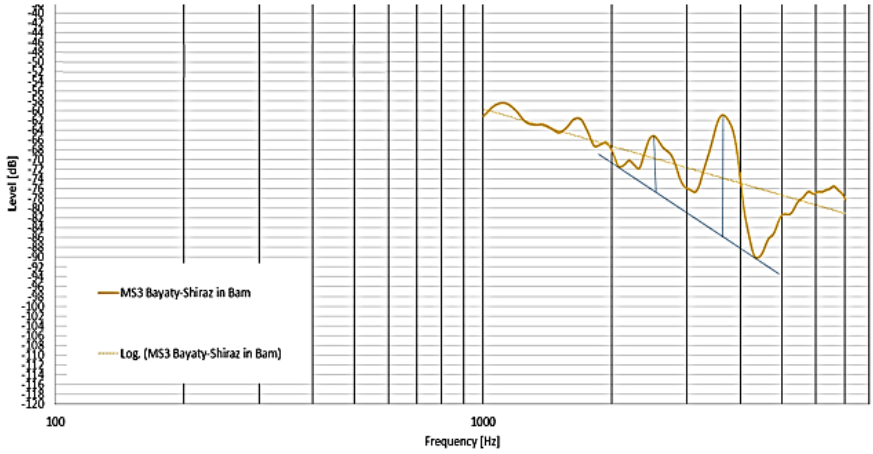


Figure 1. *Superimposition of LTAS curves of the voices of khanende singing mugham in high-range zil and operatic tenor singing opera [30, p. 24]*

The acoustic analysis led to the conclusion that, affected by the tonality, tessitura, and lyrics of the vocal mugham material, some musical excerpts showed the presence of the singer’s formant in both ranges, low (*bam*) and high (*zil*), and some excerpts didn’t demonstrate singer’s formant [30, p. 25]. In contrast to the male mugham singers, the singer’s formant was found in the sample of the operatic tenor singing operatic aria as shown in *Figure 1* [30, p. 25]. Since the abovementioned study served as a preliminary investigation, it didn’t allow for definitive conclusions. In this article, the author examined LTAS curves within the 2,000-4,500 Hz range to assess the presence or absence of the singer’s formant. The results indicate a consistent pattern in both *bam* and *zil* vocal samples, demonstrating two distinct prominent peaks, as illustrated in *Figure 2*. Visually, in *bam*, the second spectral peak was notably more pronounced than the first spectral peak. In contrast, *zil* samples showed the first peak with a higher amplitude than the second peak. Compared to the singer’s formant, which appears near 3 kHz in operatic singing [35, p. 176], these peaks most of the time were not merged into a cluster of F3, F4, and F5 formants as in operatic singing voices but rather appeared as two separate distinct peaks, resembling double-humped curves, probably clustering only F3 and F4 formants. Moreover, these peaks mostly appeared within the 2500-4200Hz range which is beyond the usual range of the singer’s formant “2500-3500 Hz” [39, p. 2234].


Level [dB]
MS1 Bayaty-Shiraz in Bam
Log. (MS1 Bayaty-Shiraz in Bam)
100
1000
Frequency [Hz]


Level [dB]
MS1 Bayaty-Shiraz in Zil
Log. (MS1 Bayaty-Shiraz in Zil)
100
1000
Frequency [Hz]


Level [dB]
MS3 Bayaty-Shiraz in Bam
Log. (MS3 Bayaty-Shiraz in Bam)
100
1000
Frequency [Hz]

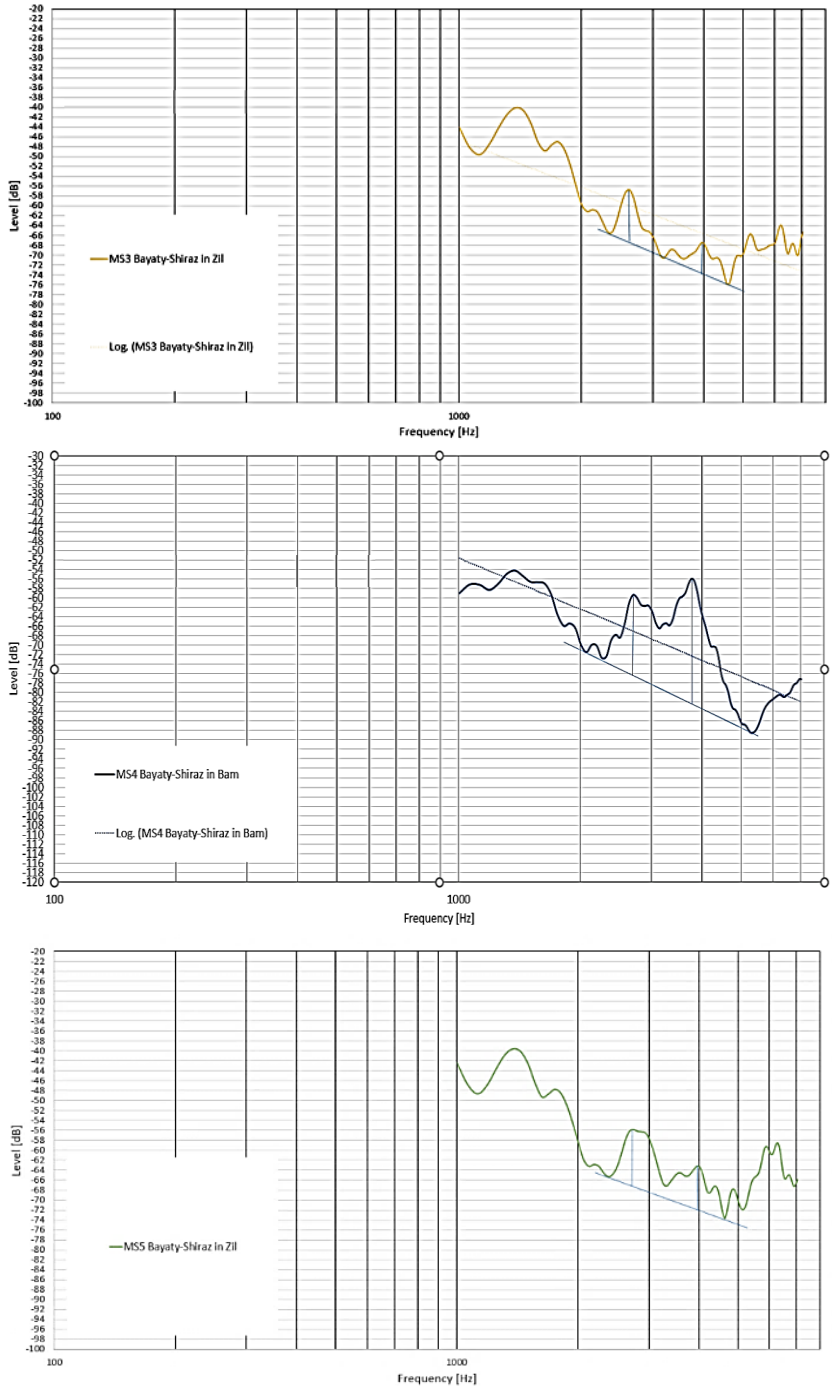


Figure 2. *LTAS curves with two distinct prominent peaks in the range of 2000-4500 Hz in bam (three graphs on the left) and zil (three graphs on the right) samples of mugham singing*

These observations gave rise to another question: providing that revealed prominent peaks were not in the expected range of the singer's formant but still existent presumably as a cluster of F3 and F4 formants can we conclude that mugham singers lower their larynx or not? McCoy's [12, p. 48] postulation, that it is not necessarily the lowered larynx that makes it possible to produce a singer's formant or ringing sound, gives reason to hypothesize that mugham singers may produce a ringing sound in a high-range *zil* using resonance strategies other than singer's formant.

Formant tuning strategies: belting and operatic singing

Vocal tract shape is demonstrative of the placement of formants which are resonances of the vocal tract that allow singers to produce various timbres and voice qualities as a result of raising or lowering the larynx, and changes in jaw opening or closing, lip position, and tongue position [9]. F1 and F2 enable vowel identification [9], while the rest formants play a role in timbre formation and amplification which is possible only with vibrating folds otherwise, there is no amplification until vocal folds are activated [12, p. 41]. Vocal amplification comes out when formants match or are very close to harmonics [9] which are integer multiples of F0 (fundamental frequency or the lowest frequency unit of a sound) involved in the formation of "'colour' or the 'quality' of the tone" [3, p.3].

To study the tuning strategies for ringing sound in vocal mugham performance, the author decided to first take insights from the studies of resonant techniques in opera and belting singing. Leborgne and Rosenberg [9] observed various studies on formants and harmonics of belting looking for tuning strategies. Bestebreurtje and Schutte revealed different tuning strategies including formant tuning of F1 and F2 to the second and fourth harmonics resulting in vocal amplification [9]. Sundberg, Gramming, and LoVetri [36, p. 303, 307] reported a raised larynx and higher F1 and F2 in belting compared to operatic singing. The investigation of Bourne and Garnier showed the tuning of F1 to H2 in belting and the absence of tuning of F1 to H2 in classical singing [9]. Lebowitz и Baken researched 20 professional singers and found out that in belting the amplitude of the first harmonic was, in most cases, higher than that of the second harmonic and vice versa in a few cases [9]. According to LeBorgne elite belters produce F1 frequency higher than expected and the first peak in the spectrum significantly interacts with H2 and H3 confirming the possibility of formant tuning [9]. In multiple studies, the brightness in the belting production is interpreted as a result of formant tuning, jaw lowering, and raised larynx [9]. If we turn our attention to the spectrogram of the vocal excerpt of a mugham singer singing the vowel [a] in *Figure 4*, it can be seen that the first formant matches the second harmonic, and the alignment of the second formant with the third harmonic appears even bolder and more pronounced which similarly allows for the possibility of formant tuning.

The author found the interesting study of tuning strategies observed in classical operatic singing. Miller [15, p. 2] investigated power spectra in over 80 recordings of *B4*-flat, out of which Luciano Pavarotti and Placido Domingo’s results are widely discussed. Luciano Pavarotti and Placido Domingo sang the vowel [o] on *B4*-flat, a final note from "Celeste Aida" [15, p. 2]. The power spectra (Fig. 3) showed that Domingo employs the singer’s formant strategy near 2.8 kHz with the amplification of H6 [15, p. 2]. Whereas, Pavarotti intentionally utilizes tuning of F2 to H3, producing H3 at 1.4 kHz which is 500 Hz above the normal speech value of 900 Hz [15, p. 3].

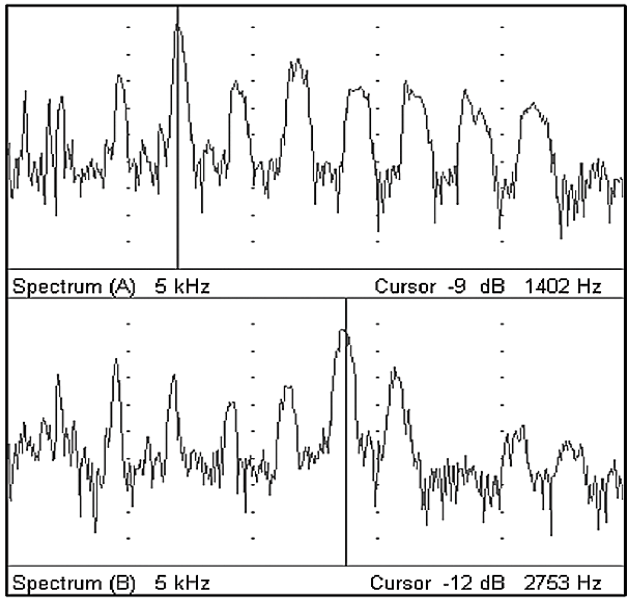


Figure 3. *Power spectra of B4-flat, the final note of “Celeste Aida” from recordings of L. Pavarotti (above) and P. Domingo (below) reflecting dominant harmonics [15, p. 2]*

To determine tuning strategies in mugham singing, the author chose the mugham recording of the singer of the beginning of the 20th century who was a prominent *khanende* who later became a cross singer after studying the *bel canto* style of singing in Italy and continued singing both mugham and operatic repertoire. The author used the spectrogram function of the Praat software to look into the recordings of mugham singing in high-range *zil*. The spectrogram of the vocal excerpt of a *khanende* singing the vowel [a] on a *B4*-flat note while performing high-ranged (*zil*) mugham (Fig. 4) shows the match of the first formant with the second harmonic, of the second formant with the third harmonic, and a closer location of the third formant to the sixth harmonic. The strong amplification of the third harmonic by the second formant indicates similarity with Luciano Pavarotti’s tuning strategy.

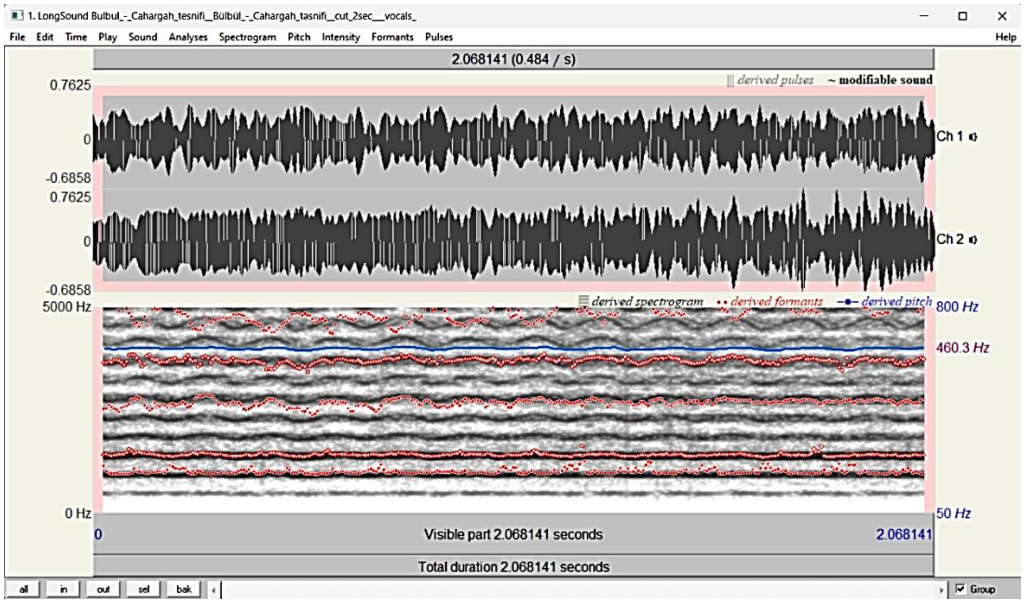


Figure 4. *Spectrogram of the vocal excerpt of a mugham singer singing the vowel [a] while performing high-ranged (zil) mugham*

For the vowel [i] (Fig. 5) sung in high-range *zil*, the tuning of F1 to H2, F2 to H4, F3 to H6, and F4 to H8 is observed. The alignment of the second formant with the fourth harmonic is indicative of the formant tuning strategy applied in classical opera and belting styles.

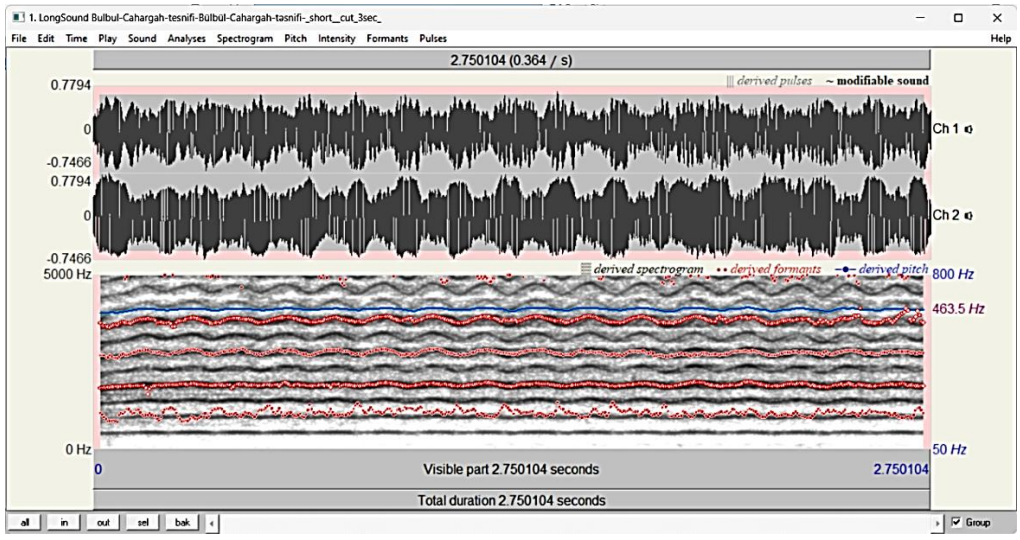


Figure 5. *Spectrogram of the vocal excerpt of a mugham singer singing the vowel [i] while performing high-ranged (zil) mugham*

It is possible to hypothesize that mugham singers use resonance strategies utilized in both these styles including the singer’s formant and other formant tuning strategies. To answer more precisely the question – which factors lie under mugham singers’ choice to apply this or that strategy – acoustical and physiological research requires a wider range of analyses to postulate accurate results and conclusions.

Physiological studies

Acoustical analysis fostered a need for physiological research to look into the laryngeal biomechanics of mugham singers while singing. Thus, the author explored the physiological characteristics of the vocal apparatus of *khanende* with the application of high-speed video endoscopy (laryngoscopy) of the respiratory tract, real-time dynamic magnetic resonance imaging (MRI), and high-speed flexible fiberoptic nasopharyngolaryngoscopy conducted by ENT specialists and radiologists. The analysis results were presented by the author at several conferences [29, 31, 32].

Based on physiological investigations on mugham voices the author made assumptions that while singing mugham professional *khanende* use the chest register with the thyroarytenoid (TA) muscle in the low-pitched *bam* range. As they ascend into the head voice range, they decide whether to continue with the TA-dominant approach or transition to male falsetto using the cricothyroid (CT) muscle or to combine both registers (TA and CT muscles) [23, p. 52], which refers to ‘mixing’ according to Miller [16, p. 50].

To understand this fully it is more to the point to refer to ‘*Resonance in singing: voice building through acoustic feedback’* by Miller [16, p. 50], where he interprets how the chest and head registers function. The chest register is thyroarytenoid muscle (TA) dominant vocal production with vocal folds shortened and thickened [16, p. 50]. Head register on the other hand is described as cricothyroid muscle (CT) dominant mode with vocal folds stretched and stiffened [16, p. 50]. To achieve legato, beauty, and evenness of the vocal line classical singers try to moderate the transition between chest and head registers. Singers performing in other styles while aiming to align the registers produce sounds with either the thyroarytenoid muscle (TA) dominant or the cricothyroid muscle (CT) dominant mode. According to Miller [16, p. 50], muscular adjustments during the transition from one mode to another are important for the balance and unification of the abovementioned registration modes. Moreover, the unification of the modes, as well as, the transition through the *passagio* area of the voice is also influenced by acoustic factors [16, p. 50]. While professionally trained singers smoothly navigate between two modes, novice singers can hardly balance the transition between two modes without an obvious notable break in the sound [2]. To ensure vocal stability singers often make a choice, whether to produce more of a TA-dominant or CT-dominant voice. This preference for one mode over another is

called mixing in vocal pedagogical terminology. In some cases, it is also affected by the vocal repertoire, the tessitura, and the lyrics of the vocal material [29, p. 121]. Singers have to be trained to employ the chest voice in the relatively high range of the vocal tessitura, without raising the larynx, resulting in the 'chesty' ringing sound that is heard over the orchestra. Unlike typical vocal transitions, *khanende* maintain a chest-dominant vocal production in the *zil* range, continuing to deploy a TA-dominant muscle position even in the high range with an extremely high larynx position [32, p. 52]. Singing with an extremely high larynx can encourage and/or be a sign of excessive vocal muscle tension and over time can lead to fatigue, pain, and vocal fold damage [5, 9].

Moreover, based on the observations of the vocal tract changes the author presumes that in the low-ranged *bam*, chest resonance is enhanced by slight constriction of the pharynx and shortening of the vocal fold, creating a "speech-like" quality, while the vocal folds are stretched and stiffened during the transition to the head voice. In the high-ranged *zil*, mugham singers exert maximum muscular effort in the head and neck for heightened emotions, involving intense constriction of vocal muscles, including the ventricular folds [32, p. 52]. While switching back and forth rapidly between two adjacent notes using the technique of "zengule," the ventricular (or false) vocal folds are actively moving, showing noticeable dynamism and even some aggressiveness in their movements, but at the same time never touching each other [32, p. 52]. Mugham singing predicts some parallels with the belting style. Belting is defined as follows:

A manner of loud singing that is characterized by consistent use of "chest" register (>50% closed phase of glottis) in a range in which larynx elevation is necessary to match the first formant with the second harmonic on open (high F 1) vowels, that is, -G4-D 5 in female voices. [26, p. 147]

It may not be the most contemporary or the most complete definition of belting, but it's one of the most frequently cited definitions of belting in recent articles. Belting is characterized as a "yell-like, or shouting voice production" [37, p. 44] involving a raised larynx, a high position of the tongue base, and a narrow pharyngeal lumen as discussed by many notable scholars and pedagogues such as Doscher, Lawrence, McChesney, McKinney, Meyers, Titze, Wilkie [13, p. 68], and Bozeman [3]. Attempt for the most pronounced sound on high notes by raising the larynx and increasing the tension in the vocal apparatus is also evident in mugham singing.

In their article Titze and Worley [40] using MRI investigated the vocal tract shape of a lyric baritone who wasn't a belter or an operatic singer but a classically trained German lieder and early music performer. The subject pronounced and sang various vowel and consonant sounds, with a wider opening of the mouth and throat when singing the vowel /a/. The subject didn't demonstrate a pronounced vocal ring which may indicate a "relatively wide epilarynx tube (0.8–1.0 cm^2)," especially

pronounced in singing compared to normal speech [40, p. 1536]. Titze and Worley [40, p. 1536] aimed to determine whether the vocal tract of this subject was similar to that of opera singers. For this, they compared the mouth shapes of this baritone with the mouth shapes of male operatic singers Luciano Pavarotti and Roberto Alagna, jazz singer Cab Calloway, and musical theatre singer Tony Vincent. Titze and Worley [40, p. 1537] analysed pitch A4 which was taken from the repertoire of the singers according to their style. The authors used MATLAB script to determine ‘the ratio of mouth area to frontally-projected head area’[40, p. 1536]. The authors assume that Pavarotti as a large man with a wide neck possesses a wide pharynx and narrowed epilarynx tube which contributes to the ring in his voice [40, p. 1537]. Pavarotti’s supraglottal vocal tract length was similar to that of the baritone’s which can be seen from “the approximate 10 cm^2 mouth area” taken from the MRI shape of the lyric baritone [40, p. 1537]. Titze and Worley [40, p. 1537] postulate that classical male operatic singing shape refers to the inverted megaphone mouth shape and the vocal tract modification typical for classically trained operatic singers involves slight larynx lowering ‘by shortening the trachea by 1.5 cm’. In the case of Calloway on the same pitch and vowel, the shape of the mouth is nearly three times larger than Pavarotti’s [40, p. 1537]. According to Titze and Worley [40, p. 1537], the slightly raised larynx is a part of belt phonation which is “simulated by lengthening the trachea by 1.2 cm and shortening the supraglottal tract proportionately.” The authors conclude that the shortening of the supraglottal tract is caused by “mouth-corner retraction” which is also part of belting [40, p. 1537]. Calloway’s spectrum indicated strong second harmonic as a result of the high larynx and megaphone-like mouth shape [40, p. 1537].

In this respect, when observing mugham singers who possess unique ring in their voices, especially in the *zil* range, it was obvious that they also maintain a megaphone mouth shape, mouth-corner retraction, and wide opening of the mouth typical to belters. However, it is important to note that this mouth shape can be noticed only during singing in high-range *zil* never in low-range *bam*. In terms of voice production strategy, it is important to study the transitions between registers, especially when singing in the high range, to avoid over-opening the mouth and to maintain the authenticity of the sound. To train mugham singers, exercises should be developed that will help balance the work of the resonators, minimise air loss, and prevent vocal folds from overstraining. This will also allow to avoid the formation of yelling in less experienced singers while preserving the characteristic style and phonation of mugham.

Conclusion

In this paper, the author reviewed the studies and methods in voice science that can be useful for investigating the physiological and acoustic properties of the voice apparatus of Azerbaijani mugham singers, particularly for researching a

unique "ring" quality in mugham singing. Accordingly, the author referred to previously developed and established Western voice analysis methods such as LTAS, spectral analysis, spectrogram, high-speed video endoscopy, real-time dynamic MRI, and high-speed flexible fiberoptic nasopharyngolaryngoscopy.

As of now, the author can only assume that the source of this unique acoustic phenomenon could be either a specific *"mugham formant"* which is manifested in mugham singing only, or be associated with formant tuning strategies or other particular characteristics related to physiology or acoustics of the voice apparatus. However, it cannot also be conclusively claimed that the formant *("mugham formant")* observed in most of the mugham spectral data is unique only for mugham vocal performance. This formant is placed in a bit higher frequency range than that of the singer's formant which requires further investigation.

The author presumes that a specific "ring" in the voice could be due to the vocal tract shape involving a raised larynx, and a megaphone-like mouth which is observed in both mugham singers and belters. The megaphone-like mouth shape can be regarded as an articulation with a particular acoustic factor not dependent on genre. Classical singers, in contrast, use an inverted megaphone-like mouth shape which creates another acoustic effect.

Thus, to achieve reliable results, a deeper analysis and a complex approach including both acoustic and physiological investigations on a larger number of mugham singers (more than 500) are of high significance. The application of Western studies and methods in the studies of vocal mugham within a complex approach combining acoustic programs and medical technologies along with traditional methods will be fundamental for the research of unique vocal characteristics in traditional mugham performing art. This knowledge can be integrated into mugham pedagogy to improve pedagogical approaches in teaching mugham. Particularly, providing that young mugham singers mostly wear and tear their voices due to the intense performance schedule, lack of proper voice care, relevant warm-up exercises, and awareness of their voice apparatus it is important and urgent to develop theoretical and practical aids that will ensure correct mastering of vocal skills for the sake of voice health and wellbeing of young generations of mugham singers and preservation of this traditional musical art.

Towards a Scientific Approach to Vocal Mugham

The study of mugham singing requires an interdisciplinary approach, necessitating collaboration with specialists in acoustics, radiology, and otolaryngology. The integration of modern acoustic technologies, including high-speed video, fiberoptic laryngoscopy, and real-time dynamic MRI, plays a crucial role in advancing this research. To facilitate the application of these technologies, in 2019, the author organized a scientific expedition to the University of Freiburg Clinic in Germany, where dynamic real-time MRI techniques were employed under the

supervision of German radiologists and ENT specialists. This investigation focused on analyzing the *khanende* voice apparatus, providing valuable MRI videos and images that enabled the measurement and observation of articulatory structures such as the tongue, lips, jaw, palate, and larynx. These observations were further refined through consultation with an Azerbaijani radiologist.

Further efforts to institutionalize voice research led to the establishment of the Voice Research Scientific Laboratory at the Azerbaijan National Conservatory in 2022. This laboratory serves as an academic platform for the systematic study of voice parameters while introducing faculty and students to contemporary voice science, vocal health, and modern pedagogical approaches. Its mission aligns with the Evidence-Based Voice Pedagogy model proposed by Kari Ragan and her colleagues [20, 21, 22, 23], which combines scientific research, pedagogical experience, and student-centred learning strategies.

Workshops and conferences organized by the author within the framework of World Voice Day and other significant events have provided opportunities to educate students and young mugham performers on the anatomy, physiology, and acoustics of the voice apparatus. Moving forward, further acoustic investigations will be conducted to deepen the understanding of phonation and respiration mechanisms, leading to the development of innovative teaching tools that integrate traditional mugham vocal techniques with contemporary scientific methodologies. Such an approach will not only enhance vocal hygiene and health but also contribute to the refinement of vocal techniques, ultimately supporting the preservation of mugham singing while expanding its theoretical and pedagogical foundations. This synthesis of tradition and science will ensure the longevity and sustainability of mugham as a vocal art form while minimizing the risk of vocal strain and damage during both learning and performance [4, 5].

The ultimate objective remains the preservation of the authenticity of mugham singing while simultaneously enriching its pedagogical, theoretical, and practical framework. By bridging traditional vocal artistry with scientific advancements, this research establishes a foundation for a more structured and sustainable approach to mugham vocal training.

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OPERA VƏ BELTİNQ ÜZRƏ QƏRB VOKAL TƏDQİQATLAR PRİZMASINDAN MUĞAMIN FİZİOLOJİ VƏ AKUSTİK TƏDQİQATI

Xülasə: *Bu tədqiqat Qərb vokal elmi metodlarından istifadə edərək Azərbaycan muğamının fizioloji və akustik xüsusiyyətlərini araşdırır. Muğam, yüksək dərəcədə improvizasiyaya malik qədim və ənənəvi vokal-instrumental musiqidir və UNESCO tərəfindən bəşəriyyətin qeyri-maddi mədəni irsi kimi tanınmışdır. Bütün tarixi əhəmiyyətinə baxmayaraq, muğam ifaçılarının vokal texnikaları elmi və sistemli şəkildə hələ də yetərincə tədqiq olunmamışdır. Tədqiqat çərçivəsində muğam ifası zamanı səs formantının mövcudluğunu araşdırmaq üçün uzunmüddətli orta spektr (LTAS) analizi tətbiq edilir. Bundan əlavə, opera və beltinq vokal texnikaları ilə müqayisə aparılaraq rezonans strategiyalarında oxşarlıqlar və fərqlər müəyyənləşdirilir. İlkin nəticələr onu göstərir ki, muğam ifaçıları çox güman ki “muğam formantı” adlandırıla biləcək xüsusi vokal mexanizmlərindən və ya operaya xas olan formant tənzimlənməsindən fərqli olan səs formalaşdırma strategiyalarından istifadə edirlər. Bundan başqa, yüksək sürətli video-endoskopiya, real zaman rejimində dinamik MRT və çevik fiberoptik laringoskopiya vasitəsilə muğam ifaçılarının vokal aparatının biomexaniki xüsusiyyətləri araşdırılıb. Nəticələrə görə, muğam ifaçıları registr keçidləri zamanı, klassik opera texnikasından fərqli olaraq, yüksək zil diapazonunda belə, əsasən döş (sinə) registrindən istifadə etməyə davam edirlər. Bundan əlavə, rezonansın artırılması və səsin proyeksiyasını gücləndirmək üçün qırtlaq mövqeyi və meqafonşəkilli vokal traktının istifadəsi baxımından muğam ifaçılığı ilə beltinq texnikası arasında müəyyən paralellər müəyyən edilmişdir. Bu araşdırma muğam pedaqogikasında vokal elminin inteqrasiyasının vacibliyini vurğulayır ki, bu da xanəndələrin səs sağlamlığının və səs uzunömürlülüyünün qorunması üçün mühüm əhəmiyyət kəsb edir. Ənənəvi şifahi ötürmə metodlarını elmi əsaslı pedaqoji yanaşmalarla birləşdirməklə, bu tədqiqat muğamın tarixi ifa praktikasını müasir vokal elmi ilə uzlaşdırmağı hədəfləyir. Bu istiqamətdə aparılan araşdırmalar davam etdirilərək tədris metodlarının təkmilləşdirilməsi, vokal muğam ənənəsinin qorunub saxlanmasına töhfə verməyi nəzərdə tutur.*

Açar sözlər: *muğam ifaçılığı, akustik analiz, səs formantı, rezonans strategiyaları, qırtlaq biomexanikası, formant tənzimlənməsi, vokal muğam pedaqogikası, beltinq texnikası*

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ФИЗИОЛОГИЧЕСКОЕ И АКУСТИЧЕСКОЕ ИССЛЕДОВАНИЕ МУГАМА ЧЕРЕЗ ПРИЗМУ ЗАПАДНЫХ ВОКАЛЬНЫХ ИССЛЕДОВАНИЙ ОПЕРЫ И БЕЛЬТИНГА

Аннотация: *Данное исследование изучает физиологические и акустические характеристики азербайджанского мугама с применением методологий западной вокальной науки. Мугам – древняя вокально-инструментальная традиция с высокой степенью импровизации, которая была включена ЮНЕСКО в список нематериального культурного наследия человечества. Несмотря на его богатую историю, вокальные техники, используемые исполнителями мугама, остаются в значительной степени неизученными в систематическом научном контексте. В рамках настоящего исследования применяется акустический анализ, в частности метод долгосрочного среднего спектра (LTAS), для выявления наличия певческого форманта в исполнении мугама. Также проводится сравнение вокальных техник оперы и бельтинга с целью выявления возможных сходств и различий в резонансных стратегиях. Предварительные результаты свидетельствуют о том, что исполнители мугама используют особые вокальные механизмы, возможно, включающие специфический «мугамный формант» или альтернативные стратегии настройки формант, отличные от традиционных оперных. Кроме того, физиологические исследования с использованием высокоскоростной видеоэндоскопии, динамической МРТ в режиме реального времени и гибкой фиброоптической ларингоскопии позволили получить данные о биомеханике вокального аппарата исполнителей мугама. Результаты показывают, что мугамные певцы во время перехода между регистрами часто сохраняют грудной регистр даже в высокочастотном диапазоне зиле, что контрастирует с классической оперной техникой. Также выявлены параллели между мугамным пением и бельтингом, в частности, в использовании положения гортани и мегафонообразной формы вокального тракта для усиления резонанса и проекции звука. Исследование подчеркивает необходимость интеграции вокальной науки в педагогические методы преподавания мугама для обеспечения вокального здоровья и долговечности голосов исполнителей. Объединяя традиционные методы устной передачи знаний с доказательной педагогикой, данное исследование стремится преодолеть разрыв между исторической исполнительской практикой и современными научными подходами к вокалу. В дальнейшем планируется расширить исследования, чтобы усовершенствовать методики обучения и внести вклад в сохранение традиции вокального мугама.*

Ключевые слова: *мугамное пение, акустический анализ, певческая форманта, стратегии резонанса, биомеханика гортани, формантная настройка, педагогика вокального мугама, техника бельтинга*

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