RAST MUSICOLOGY JOURNAL | AUTUMN 2024, 12(3) 245-276
Research Article

Effects of hollowed neck designs on sound radiation and loudness of baglama

Yunis Şahinkayası
Corresponding author, Assist.Prof.Dr., Department of Computer Education and Instructional Technology, Hatay Mustafa Kemal University, Hatay, Turkiye. **Email:** ysahinkayasi@gmail.com **ORCID:** 0000-0002-1355-5369

Emir Değirmenli
Assist.Prof.Dr., Department of Instrument Training, Ankara Hacı Bayram Veli University, Ankara, 06500, Turkiye. **Email:** emir.degirmenli@hbv.edu.tr **ORCID:** 0000-0001-8164-1448

Hamide Şahinkayası
Assist.Prof.Dr., Department of Computer Education and Instructional Technology, Hatay Mustafa Kemal University, Hatay, Turkiye. **Email:** hsahinkayasi@gmail.com **ORCID:** 0000-0001-8787-8163

Ünal Öztorun
Music Teacher, Hatay Bedii Sabuncu Fine Arts High School, Hatay, Turkiye.
Email: unaloztorun@hotmail.com **ORCID:** 0000-0001-9960-3925

DOI 10.12975/rastmd.20241231 Submitted May 30, 2024 Accepted August 13, 2024

Abstract

A limited number of studies investigate the effects of the neck design on the loudness and radiation of string instruments. In the related literature, it is assumed that the neck serves as a fingerboard and has little or no impact on sound production and radiation for string instruments, although there is no scientific evidence. By redesigning the neck of string instruments, we increased the air volume of the soundbox and vibrating surface area of string instruments. This study investigated the effects of two experimental (patented) neck designs on sound radiation and the perceived loudness of the baglama, a stringed instrument. The primary hypothesis of this research is that compared to traditional neck, the experimental neck designs increase the stringed instrument's air volume and vibrating surface area, thereby contributing to sound production and radiation efficiency, and perceived loudness. Sound radiation analysis based on acoustic modal analysis and psychoacoustic analysis were conducted. First, sound radiation measurements were made in an experimental setup. The data were then examined using the Frequency Response Function (FRF). The results revealed that the experimental necked baglamas' sound produced and radiated better than the traditional one. Second, listening (N=38) and playability (N=26) tests were conducted in focus group interviews. The participants listened to or played traditional and experimental necked baglamas and rated their loudness. The Friedman and Wilcoxon signed-rank test on the scores indicated that the participants perceived the experimental necked baglamas as significantly louder than the traditional one. Most participants stated that the experimental necked baglamas sounded higher and had better quality than the traditional one. Psychoacoustic findings corroborated the results of sound radiation analysis.

Keywords

baglama, guitar, loudness, psychoacoustics, sound radiation analysis, stringed instruments

Introduction

The low intensity of the sound in the open field performance of stringed instruments with neck and body is an important issue that attracts the attention of performers and researchers (e.g. Marshall, 1985; French & Lewis, 1995; Elejabarrieta, Ezcurra & Santamaria, 2002; Paiva & Dos Santos, 2014; Corradi, Liberatore & Miccoli, 2016; Lercari et al., 2022; Bader, 2012). Baglama, an ancient stringed instrument existing from middle Asia to the Balkans, is performed widely in Turkish folk music. It, with regionally and ethnically different structural features, has a half-pear-shaped bowl, and a long, thin neck that functions as a fingerboard (Figure 1). The bowl and the soundboard comprise the soundbox. Its strings are fixed by tying them to the tailpiece and wrapping them around the tuning pegs on the neck. The strings touch the bridge on the soundboard and the nut on the neck. Traditionally, a soundhole does not exist on the soundboard, and no braces exist under the soundboard for support. The soundhole is usually at the bottom or upper side of the bowl. Generally, the neck is hardwood (beech, mahogany) in one piece, the bowl is mulberry or juniper in one or more pieces, and the soundboard is softwood (spruce, cedar) in one or two pieces.

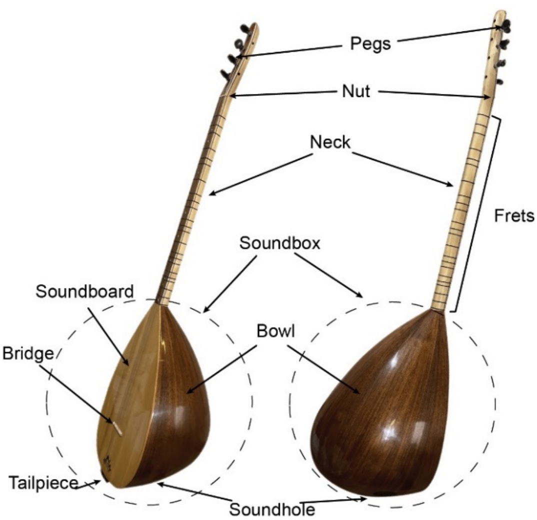


Figure 1. The baglama and its parts

In making stringed instruments, luthiers usually consider designing a soundbox and neck. In their designs, the soundboard is the central radiator of sound (Penttinen et al., 2005). As a general assumption (to our knowledge), the sound is expected to be produced in the soundbox. A comprehensive research tradition of stringed instruments with wooden soundboards helps us understand the baglama better functionally and structurally. For instance, both the guitar and the baglama produce sound through the vibration of their strings, which are excited by plucking or strumming. However, the efficiency of sound production from a vibrating string is inherently limited due to its minimal surface area, which consequently interacts with only a few air molecules. In essence, the primary role of the strings in stringed instruments is to transmit their vibrations to the soundbox via the bridge. The soundbox, particularly the soundboard, resonates and amplifies the sound, making it more audible. Despite this amplification mechanism, the efficiency of sound production in string instruments is relatively low (Zeren, 2007), leading to loudness issues in stringed instruments.

Research Problem

Loudness is a psychological term describing an auditory sensation's magnitude (Fletcher & Munson, 1933). It is the perceived volume or force of the sound (Ziemer, 2019). Loudness and sharpness, among subjective parameters, are good indicators of sound quality from the musical perspective (Limkar & Chandekar, 2022). There are some studies to increase the sound efficiency of stringed instruments. Most research on vibration and sound radiation in these instruments focuses mainly on the body, which is constituted by the bowl and the soundboard (Marshall, 1985; French & Lewis, 1995; Elejabarrieta, Ezcurra & Santamaria, 2002; Paiva & Dos Santos, 2014; Corradi, Liberatore & Miccoli, 2016; Lercari et al., 2022), and air inside and soundholes (Bader, 2012), not the neck. For instance, Penttinen et al. (2005) suggest three guidelines to enhance the kantele's loudness: increasing string tension, isolating the top plate, and enlarging the radiating area, resulting in a 3 dB sound increase. They believe these methods could benefit other string instruments.

In recent studies, subjective (psychoacoustic) evaluation of string instruments is carried out together with objective measurements such as experimental modal analysis and Finite Element Model (FEM) (Fritz & Dubois, 2015; Brauchler, Ziegler & Eberhard, 2021). Brezas et al. (2023) investigated carbon fiber bouzouki's sound and playability properties using experimental modal analysis, psychoacoustic tests, and FEM simulation methods. They suggested using this integrated method in the psychoacoustic evaluation of various carbon fiber string instruments.

A limited number of studies investigate the effects of the neck design and nut on loudness. For instance, Meinel and Jansson (1991) studied the impact of the physical properties of the neck, such as wood type, on vibration in the soundbox for stringed instruments. The neck has little or no effect on sound production for string instruments (Fletcher & Rossing, 1998; Eroğlu, 2012).

In this study, one of the objectives of the experimental neck designs is to increase the air volume of the soundbox and vibrating surface area so that the sound produces and radiates better, and gets louder. Unlike the previous studies, we focused on the potentials of the hollowed neck's sound efficiency, its general effects on sound production and radiation, and the perceived loudness in the baglama. In this respect, the study investigated the impact of two designed experimental necks on sound production and radiation, and perceived loudness compared to the traditional one. We sought to answer the following research questions:

- Based on the results of sound radiation analysis, what are the effects of experimental necks on the general sound production and radiation of the baglama compared to the traditional neck?
- Are there statistically significant differences between the median scores psychoacoustically given by the participants for the loudness of traditional and experimental necked baglamas?
- What are the participants' opinions on traditional and experimental necked baglamas?

Method

The study has two phases. In the first phase, we examined the effects of traditional and experimental necks, assembled in the same soundbox one by one, on sound production and radiation; in the second phase, we investigated the perceived loudness of baglama with these necks.

Baglama: Necks, Soundbox, and Junction

The necks in the study are the traditional neck, experimental neck-1, and experimental neck-2. Hatay Mustafa Kemal University patented stringed instrument design for baglama and guitar having these experimental necks (Şahinkayası, Şahinkayası & Öztorun, 2021). To compare the effects of necks in the study, we designed a baglama with a soundbox and three attachable/detachable necks compatible with the soundbox.

Quercus alba, the juniper, and the spruce tree were used to construct the necks, the bowl, and the soundboard, respectively. All the necks were from the same wood block in the exact dimensions and made under the same conditions and time. Of the necks with identical physical properties in all aspects, the traditional neck is unhollowed (Figure 2a), but the experimental necks are hollowed (Figure 2b and 2c). There are 'Neck Soundholes' in different numbers on the front face of the experimental necks (Table 1). In addition, there is a bigger 'Neck Soundhole' on the fret of the experimental necks closest to the nut (Figure 2b and 2c).

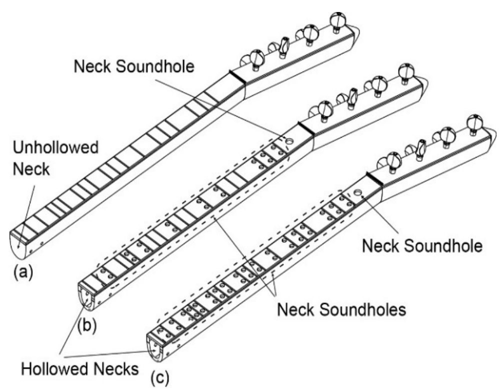


Figure 2. (a) Traditional neck (TN), (b) experimental neck-1 (EN-1), and (c) experimental neck-2 (EN-2)

The soundbox of baglama had been carefully handmade by an experienced craftsman. The bowl of baglama was made by gluing wood pieces together. A neck block was bored and embedded in the junction between the soundbox and the neck (Figure 3). Thus, airflow was possible between the soundbox and hollowed necks.

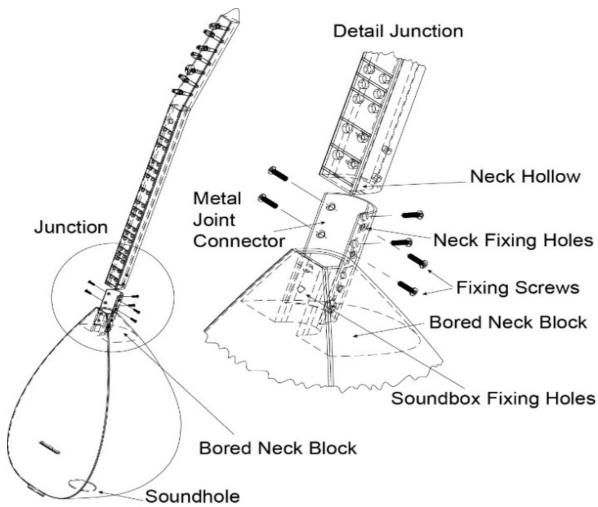


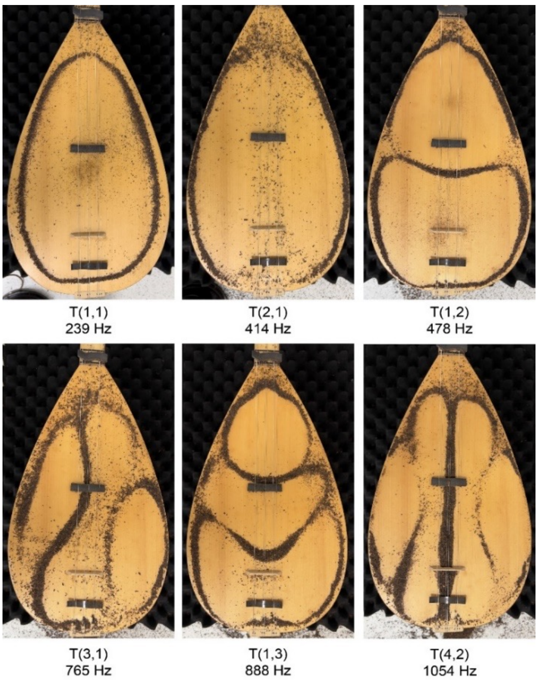
Figure 3. The junction of the soundbox and necks

We used a metal joint connector to assemble/disassemble the necks quickly to the soundbox (Figure 3). Half of this connector was fixed by embedding and screwing into the bored neck block in the bowl. The other half was outside the bowl, where the necks were placed and screwed. At the same time, this connector prevents neck from the problem of warping.

Table 1. Some measures of the baglama

	Unit	Traditional Neck	Experimental Neck-1	Experimental Neck-2
Length of the soundbox (from the tailpiece to the neck)	cm	40	40	40
Length of the neck (from the joint point to the nut)	cm	40	40	40
The air volume of the soundbox	cm^3	11650	11650	11650
Number of Soundhole (Ø: 5 cm)	#	1	1	1
Soundhole area	cm^2	19.7	19.7	19.7
Soundboard surface area	cm^2	665.5	665.5	665.5
The air volume of the neck	cm^3	–	*139*	*139*
The air volume of the neck block	cm^3	–	*14*	*14*
Number of Neck Soundhole (Ø: 1.2 cm)	#	–	*1*	*1*
Neck Soundhole area	cm^2	–	*1.13*	*1.13*
Number of Neck Soundholes (Ø: 0.6 cm)	#	–	*18*	*36*
Neck Soundholes total area	cm^2	–	*5.09*	*10.17*
The neck front face area	cm^2	*120*	*113.78*	*108.07*
Weight of neck without pegs	gr	*396*	*327*	*274*

The technical drawings of all solid models of the soundbox and necks were first created in SolidWorks and exported to Fusion 360 software, and all the necks were produced using a CNC router in these models (See appendices). The lengths, weights, volumes, and areas in Table 1 were calculated using solid models in Fusion 360. As seen in Table 1, hollowed necks increase the air volume and therefore the vibration surface area of the instrument compared to the traditional one, and they get lighter.



Photograph 1. Mode shapes of the first six normal modes of baglama

The vibrational modes of the soundboard play a crucial role in determining the acoustic characteristics of stringed instruments (Perry, 2014). Değirmenli (2017) identified a strong correlation (r=0.92) between the sound radiation from these vibrational modes and the long-term spectral representation of chromatic oud performances. In analyzing the vibrational behaviors of the baglama up to a frequency of 1 kHz, it is observed that as the frequency increases, there is a proliferation in the number of resonating regions on the instrument. As the frequency ascends, the size of each resonating region diminishes. This situation leads to an increased number of surfaces vibrating in the antiphase. At higher frequencies, these vibrational modes contribute less to the general sound radiation (Perry, 2014). To accurately assess sound radiation, our initial step involved using the Chladni technique to discern vibration mode shapes of baglama (Photograph 1). Our measurements of sound radiation covered a frequency bandwidth of 50 Hz to 20 kHz, sampled at a resolution of 3.125 Hz.

First Phase: Sound Radiation Analysis

Experimental modal analysis is a process to describe vibration characteristics, also called modal parameters. They are natural frequency, damping ratio, and mode shape. The Frequency Response Function (FRF) is a fundamental measure in experimental modal analysis (Schwarz and Richardson, 1999). FRF can be defined as either acceleration or sound pressure level per unit force concerning frequency (Elwali, Satakopan, & Shauche, 2010). In this research, the FRF measurement using sound pressure level per force is termed sound radiation analysis, as Curtin (2009) described. We conducted sound radiation analysis in July 2021 at Ankara Hacı Bayram Veli University, Turkish Music State Conservatory. We assembled each neck to the soundbox one by one, tuned the baglamas, and placed them in the experimental setup to measure the sound radiation. We stimulated the soundboard of baglamas from the bridge's bass side by the impact hammer's perpendicular hit to the soundboard and measured the sound pressure level with the microphone (See appendices).

We take some precautions to ensure the study's validity and reliability. We use one soundbox and the same measurement environment to decrease threats to the experiment's internal validity. Different necks attached to the same soundbox one by one allowed us to eliminate the possible effects of using different soundboxes for each neck. Since the sound radiation results are affected by humidity, the soundbox and necks were kept in the measurement environment a week ago to be measured beforehand. Instruments such as baglama made from wooden material and showing hygroscopic properties may exhibit different physical properties depending on the humidity and temperature of the environment. Therefore, the vibration and sound attributes of the instrument may vary. We quickly changed the necks, tuned the baglamas, and completed all measurements within the same day to minimize this variability, and temperature and relative humidity were recorded during the measurement process.

The room where the sound radiation measurements are made is a typical conservatory classroom with a volume of 184.6 m^3. At the beginning of the measurements, the temperature was 22.2°C, and the relative humidity was 34%. At the end of the measurements, the relative humidity did not change; the temperature increased by 0.1°C to 22.3°C. The main reason for choosing this environment is that it represents the actual performance conditions of the baglama. Psychoacoustics measurements -the listening and playability tests- were also done in similar environments, consistently making interpretations on the objective and subjective measurements. Since reflections increase the loudness compared to pure direct sound (Ziemer, 2019), the experimental and perceptual data on loudness for all the necks were collected under similar conditions.

In stringed instruments, sound radiation occurs equally and spherically in all directions at low frequencies, while a direction-dependent sound occurs at higher frequencies (Schleske, 2002; Pezzoli et al., 2022). For instance, Meyer (1972) stated that sound radiation remains consistent in all directions up to 500 Hz for the violin and viola. This study made sound radiation measurements in a typical room environment rather than in an anechoic chamber to understand the baglama's acoustic characteristics. However, it is possible to encounter variables such as room modes that may adversely affect the measurements in these cases, and extra peaks might appear in the graph of FRF. Averaging 36 measures by rotating the measuring device horizontally on its axis at angles of 10 degrees avoids this situation (Schleske, 2002). Using this approach, we made 36 measurements per locations A, B, and C (Figure 4). The distant miking location A is 20 cm above the tailpiece and 100 cm horizontally from the soundboard. The first close miking location, B, is 20 cm horizontally from the neck and vertically at 80 cm from the tailpiece to the nut, and the second close miking location, C, is 20 cm horizontally from the center of the soundboard. We made 1/3 octave band correction and dB(A) conversion to ensure that the data obtained from the measurements were more compatible with the perception principle of the human hearing system (Curtin, 2009). We comparatively interpret the graphs of FRF for sound radiation, smoothed using a 1/3 octave band filter, at locations A, B, and C.

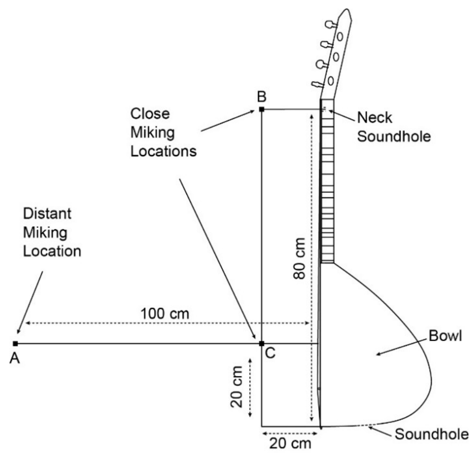


Figure 4. Distant and close miking locations in the experimental setup

Second Phase: Psychoacoustic Evaluation of Traditional and Experimental Necked Baglamas

Compared to stringed instruments like guitar or violin, the literature has no information to evaluate the loudness of baglama. Face-to-face focus group interviews were conducted with the participants to evaluate the perceived loudness of traditional and experimental necked baglamas (See Table 2).

Table 2. Demographics of participants and the given tests (*f*)

		Fine Arts High School		Conservatory		Total
		Teacher	Student	Instructor	Student	
Age	15-19		38			38
	20-24				3	3
	25-29	2		2	1	2
	30-34	1		1		2
	35-39	4	NA			4
	40-44	7				7
	45-49	3				3
	50-54	1				1
	55-59	1				1
Gender	Male	12	18	3	4	37
	Female	7	20			27
Grade	11		10		NA	10
	12		28			28
	Freshman	NA		NA		
	Sophomore					
	Junior				4	4
	Senior					
Baglama ability	Performer	9	38	3	4	54
	Listener	9				9
	Luthier	1				1
Professional Experience (year)	<= 5	3		3		6
	6-10	11	NA		NA	11
	11-15	2				2
	>= 16	3				3
Listening Baglama	Yes	18	38	3	4	63
	No	1				1
Baglama Background (year)	<= 10		38		4	42
	11-20	3				3
	21-30			2		2
	>= 30	15		1		16
Listening Music Preference	Turkish	10	15	3	2	30
	Western	6	14		1	21
	Both	3	9		1	13
Tests	Listening	10	28			38
	Playability	9	10	3	4	26

NA: Not Applicable

The interviews focused on either listening or playability tests in each session. The participants also expressed their opinions about the traditional baglamas in general and the experimental necked baglamas compared to traditional one.

Participants

Participants are either educators or students in formal music education: baglama performers, listeners, and a luthier (37 male, 27 female). They are instructors or undergraduate students at a state conservatory, music teachers or fine arts high school students. Most participants listened to and played the baglama (Table 2). While half of the teacher participants have professional experience of 6-10 years, all the instructors have less than five years. Students have a 10-year or less baglama background, while most teachers and all instructors have 20 years or more. Thirty-eight participants took listening tests, and the remaining (26) were involved in playability tests.

Data Collection Tool

We prepared semi-structured interview guides for participants as listeners and players. The guides contain questions about the participants' opinions on the baglamas with different necks. For ease of individual data collection from participants, a handout was prepared (See appendices). The handout consists of demographic information form, the definition of loudness, the rating scale for solo and ensemble perceived sounds of typical traditional baglama, and the rating scale for the loudness of traditional and experimental necked baglamas. It was delivered to each participant so that they could fill out the forms and rate the scales throughout the interview.

We searched the literature (Czajkowska, 2014; Fritz & Dubois, 2015; Duerinck et al., 2020), and three subject matter experts helped us determine the loudness scale for the interviews. We finalized the interview guides according to the experts' suggestions regarding content, language, and meaning.

In the study by Fritz and Dubois (2015), listeners rated the violins on a 1 (poor) to 10 (excellent) scale for five criteria worded as evenness, clarity, projection, distinctive character, and warmth. Instead of 10, we used a 9-point scale from 1 to 9 to indicate a neutral point. We defined 1 as poor, 5 as neutral, and 9 as excellent scores for loudness. The rating scale is explained to participants briefly before use. The interview guides, handout, and their implementations are available in the Appendices.

Data Analysis

Since the loudness scores were not normally distributed, the non-parametric Friedman test and post hoc Wilcoxon signed-rank tests were performed instead of the repeated measure ANOVA test and its post hoc tests (See appendices). The analyses were performed using the software (SPSS). We took the statistical significance level (alpha) as .05 for both tests and checked Type 1 error with the Bonferroni method in pairwise comparisons.

On the other hand, we conducted a descriptive analysis in answers to open-ended questions about baglama with different neck designs in the interviews. Descriptive analysis generally analyzes a qualitative data set that does not require interpreting (Miles & Huberman, 1994). In the descriptive analysis, we described all data after being collected with an objective approach. Participants' responses were interpreted based on the three emerging themes of the study by Saitis et al. (2013) of conceptualizing violin quality: handling, sound, and relevance (to the player).

Procedure

Participants in the listening and playability tests participated voluntarily. The face-to-face focus group interviews were done separately for the listening and playability tests. In the former test, the listeners listened to the intro of a Turkish folk music in the seating arrangement. In the latter, the players were allowed to examine the baglama and play the same intro melody (See Appendices).

We obtained official permissions from Hatay Mustafa Kemal University Social and Human Sciences Scientific Research and Publication Ethics Committee and Hatay Provincial Directorate of National Education to conduct interviews and use interview guides. We held focus group interviews in two typical rooms designated at Hatay Mustafa Kemal University Antakya State Conservatory and Hatay Bedii Sabuncu Fine Arts High School in the 2022 Spring semester. Fletcher and Munson (1933) emphasize the importance of typical conditions as follows: "In most engineering problems, we are interested mainly in the effect upon a typical observer who is in a typical condition for listening" (p. 82). At most, six participants participated in all sessions of interviews. The sessions lasted at least 30 minutes. We could not conduct a double-blind test on the interviews. However, to avoid bias, we did not explain the aim of our neck designs to the participants and objectively conducted interviews.

In the interviews, we had the participants sit at equal distances on the arc of the semi-circle with a radius of 1.5 m (See appendices). In all listening tests, the fouth author sat in the center of the semi-circle and played the baglama. As the interviewer, the first author sat at the back left of the player. Thus, the distance between all participants and the baglama was equal, and the baglama sound homogeneously radiated to the listener participants. Because listeners' evaluations can be influenced by the performer's way of playing the baglama (Duerinck et al., 2020), the same performer played the same intro melody with the baglama. They listened to traditional necked baglama and rated its loudness. By using the rating scale, the participants made perceptual evaluations individually. If the participants demanded, he played the same intro for listeners again. We repeated this procedure for experimental neck-1 and experimental neck-2 in each listening test.

In playability tests, the same seating arrangement and procedure were applied; not the fourth author but the player participants in the center played the baglamas in turn. After listening and playability tests and they rated the necks, their opinions were asked about experimental necked baglamas compared to traditional necked one.

Results

Results of Sound Radiation Analysis

Within the scope of this study, sound radiation analysis was carried out to examine the effects of experimental neck designs on general sound radiation at three locations (Figure 4). FRFs were calculated based on the data obtained from baglama with traditional and experimental necks.

According to the graph of the data obtained from location A (Figure 5), it was observed that the sound radiation of experimental neck-2 was higher than that of the traditional neck, starting from 1 kHz. This difference became more evident, starting from 7 kHz. While experimental neck-1 and traditional neck curves show similar sound radiation tendencies in the graph, it has been observed that after 15 kHz, traditional neck shows a lower sound radiation tendency than experimental neck-1. Two close miking locations were specified to understand the source of these differences in the general sound radiation at location A.

When the graph based on the data obtained from location B near the neck soundhole is examined (Figure 5), it was detected that the sound radiation differences between the experimental necks and the traditional neck became apparent, starting from 700 Hz. In particular, the experimental neck-2 consistently showed a higher sound radiation curve than the traditional neck, and this difference increased even more after 5 kHz. Similarly, experimental neck-1 showed a higher sound radiation than the traditional neck, although not as much as experimental neck-2 from 5 kHz.

As to the graph based on the data obtained from location C, the measurements determined high sound radiation in the frequency regions corresponding to the T(1,1) 239 Hz and T(1,3) 888 Hz modes (see Figure 5). However, no salient difference was observed across the three necks in these regions. It was concluded that traditional and experimental necks had more similar results in sound radiation near the soundboard (location C) compared to locations A and B. That means the effect of the soundbox and soundboard vibrations of the baglama on the general sound radiation was similar across the necks.

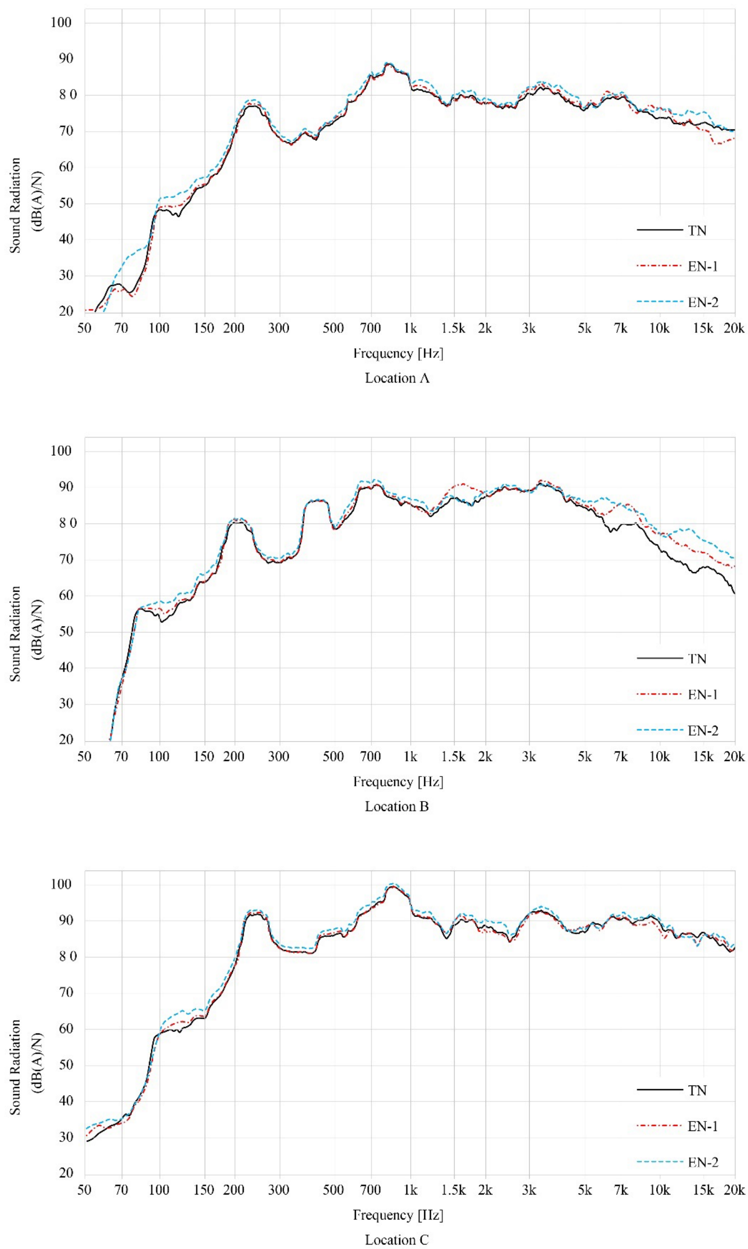


Figure 5. Sound radiation graphs: Location A (distant miking), B (close miking at the nut), and C (close miking at the soundboard)

Psychoacoustic Evaluation of the Necks

For the listening test (N=38), we analyzed whether the median scores given to the loudness of the baglama with different necks statistically diverged. The Friedman test confirmed the main effect of the neck design. The median scores of the three necks differed in loudness, $X^2(2)=57.706$, $p<.001$. As a post hoc test, we conducted three Wilcoxon signed-rank tests on the ratings of traditional neck, experimental neck-1, and experimental neck-2. The results indicate significant differences between the traditional neck and experimental neck-1 (z:-5.212, $p<.001$) and traditional neck and experimental neck-2 (z:-5.409, $p<.001$), while no difference between experimental neck-1 and experimental neck-2 (z:-0.916, $p=.359$).

Similarly, for the playability test (N=26), the Friedman test results showed that the median scores of the three necks differed in loudness as well, $X^2(2)=45.121$, $p<.001$. As to the post hoc test, Wilcoxon signed-rank tests on the loudness ratings for traditional neck, experimental neck-1, and experimental neck-2 revealed significant differences between the traditional neck and experimental neck-1 (z:-4.476, $p<.001$), and traditional neck and experimental neck-2 (z:-4.482, $p<.001$), while no difference between experimental neck-1 and experimental neck-2 (z:-1.417, $p=.156$). As a result, the distributions in Figure 6 demonstrated that both experimental necked baglamas were perceived as louder than traditional necked one in the listening and playability tests.

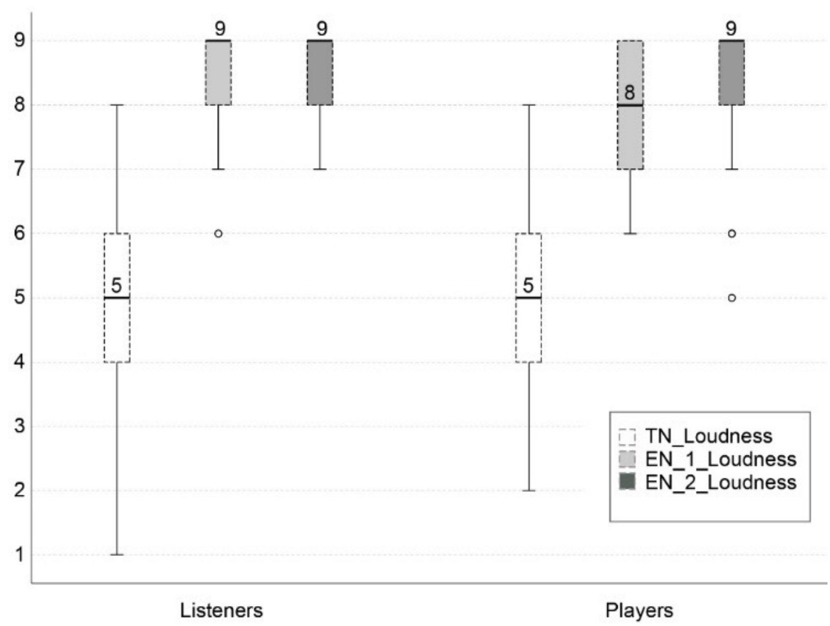


Figure 6. Distributions of the perceived loudness scores for baglama with traditional (TN_Loudness) and experimental necks (EN_1 Loudness and EN_2_Loudness)

Opinions of Participants on Traditional and Experimental Necks

In this section, the findings were given together for all participants in listening and playability tests. Before the listening and playability tests, we asked participants' opinions about a typical traditional baglama's loudness. Almost all participants rated the sound of traditional baglamas' indoor solo performance at a medium level and the indoor ensemble performance at a low level (Table 3). Most participants pointed out the bridge's location, the soundhole's size, the soundboard's structure and thickness, the bowl's structure, and the baglama's form as possible reasons for the results in Table 3.

Table 3. Opinions of participants on the loudness of the traditional baglama (*f*)

Performance	Loudness level	Fine Arts High School		Conservatory		Total
		Teacher	Student	Instructor	Student	
Solo	Low	2		1		3
	Middle	17	38	2	4	61
	High					
Ensemble	Low	18	37	3	4	62
	Middle	1	1			2
	High					

After the participants listened to or played the baglama and rated its loudness with traditional neck and experimental necks, we asked their opinions about the neck design and the loudness of experimental necks compared to the traditional one. All participants stated that the loudness of the experimental necked baglamas was higher than that of traditional necked one. Figure 7 shows the frequency distributions of reasons experimental necked baglamas are more favorable than traditional necked one regarding perceptions of the participants.

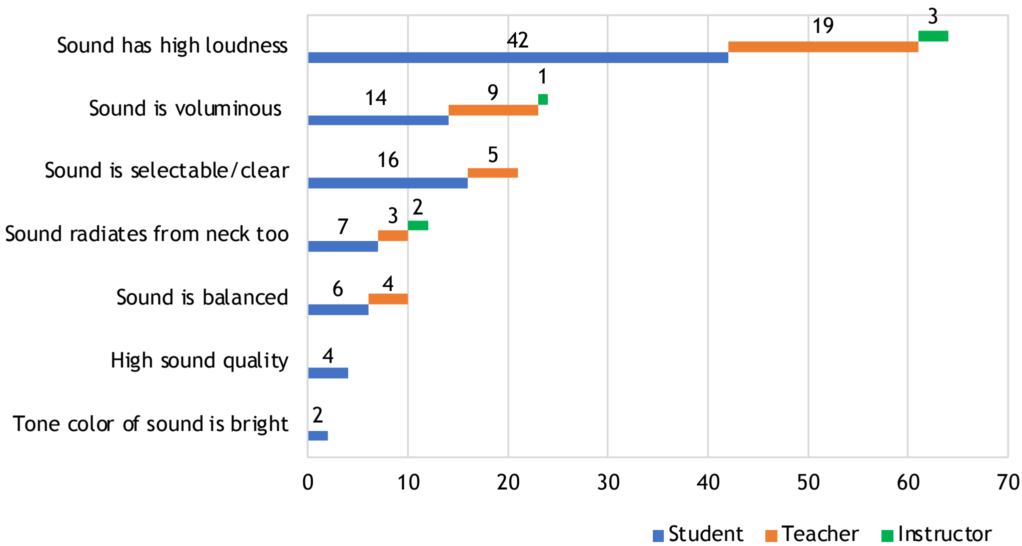


Figure 7. Distributions of reason why experimental necked baglamas are perceived more positively (*f*)

All participants emphasized the loudness of the experimental necked baglamas, and about a third of them underlined the clarity and volume of the sound, probably because of the increased vibration of the neck since it is hollowed and drilled. When we asked the participants, “Which baglama would you like to have?”, many of them (n=37) preferred experimental neck-1, and less than half (n=27) preferred experimental neck-2. Luthier participated in the listening test and was particularly interested in the experimental necks. He stated that these neck designs make the sound louder and voluminous by preserving the timbre and expressed the following about baglama with experimental necks’ sound and relevance to the player:

> In general, the sound of the traditional baglama is lower than that of instruments such as piano and violin. The baglama is an instrument with a weak capacity to produce sound. The soundhole is located under the bowl, and the thickness of the soundboard is also the reason for the low sound.
> …to increase the instrument's loudness while preserving the sound's timbre attributes, 5 mm 6 mm diameter or large soundholes are drilled into the soundboard or the top of the bowl. As a result, bass tones emerge, function as a monitor for the performer, and the volume increases.
> …Apart from this, other attempts increase the sound but negatively affect the timbre of the baglama. I think preserving the timbre is one of the critical issues. I evaluated this work as positive. I mean, the idea of creating a new soundbox by hollowing the inside of the neck. Nice work. The sound is louder and more voluminous.
> …The timbre features have been kept (Teacher [Luthier]-M-47).

On the other hand, regarding sound, one of the instructors emphasized harmonics coming out of the experimental necks,

> Experimental necks sound louder and more inclusive than the traditional neck. However, the intense hearing of harmonics in some frets bothered me. The number and diameter of the neck soundholes can be reinvestigated and worked on until the best result (Instructor-M-32).

In the interviews, some players said they felt experimental necks were lightweight. Another instructor interpreted the handling as follows,

> I evaluated this work positively. The necks get lighter. The neck soundholes did not bother me during the performance. The lightness of the neck facilitates long-term performance and thereby improves it. Further studies should be conducted on how the size and number of holes drilled on the necks will affect the sound of the baglama (Instructor-M-29).

In summary, the participants stated that various changes were made to the soundbox and soundboard to increase the sound of the baglama, which has a low sound production capacity compared to the piano and violin, and it was unsuccessful in preserving the timbre of the baglama. However, in this study, it was stated that carving the necks worked and a more voluminous and louder sound was obtained while preserving the timbre of the sound. On the other hand, it was recommended to reinvestigate the number and diameters of neckholes to prevent the intense hearing of harmonics in some frets. It is emphasized that lightening the neck, that is, reducing its weight, will facilitate and improve the longer-term performance of the baglama.

Discussion

For several hundred years, instrument makers have tried to make louder instruments for audiences at large concert halls (Penttinen et al., 2005). Researchers' efforts to amplify the sound of stringed instruments continue today. The baglama is used increasingly for musical activities in concert halls but is usually too quiet without electrical amplification. On the stage, the baglama needs to have a louder sound. In this sense, this study investigates how to make the sound of baglama louder by using the potentials of the neck. We hypothesize that hollowing the neck and drilling holes on its front face increase the baglama's vibrating surface area and air volume, thereby contributing to production and radiation efficiency, and loudness. To test our hypothesis, we investigated the effects of experimental neck designs on baglama sound by sound radiation analysis and psychoacoustic methods compared to traditional neck design.

Although many studies have been conducted on the effects of the soundbox and especially soundboard on the acoustics of stringed instruments such as violins and guitars, very few studies have been conducted on the effects of the neck on the acoustics.

Meinel and Jansson (1991) presented that guitar neck vibration characteristics could affect the number of soundboard vibration modes and directly affect sound radiation. Additionally, Schleske (2002) pointed out that the violin fingerboard, not directly part of the violin body, can increase the vibration modes of the instrument's soundboard. However, the focus of those studies is that the physical structure of the neck interacts with the soundboard or soundbox of the instrument, creating new vibration modes or changing existing vibration modes. As a result of the interactions between the stringed instrument's body and the neck, changes in the vibration modes of the stringed instruments affect the sound radiation.

In this study, however, the analysis of the data collected from the soundboard revealed that the general sound radiation of the traditional and experimental necked baglamas did not differ, which means experimental necks do not increase or change the vibrations of the baglama's soundboard and bowl dramatically. In other words, it was observed that the experimental necks, which were hollowed and had soundholes and a bigger soundhole, did not cause a significant change in the vibration modes of the baglama. On the contrary, it has been concluded that the increase in the sound radiation of baglama (at locations A and B) *directly* results from the sound produced in the hollowed experimental necks and radiating from all the neck soundholes. This result is an independent and direct contribution of the experimental neck designs to sound radiation.

In the second phase, in the interviews, most participants evaluated traditional baglamas' solo sound medium and ensemble sound low in general. Afterward, we examined traditional and experimental necked baglamas' loudness in a psychoacoustic way. In both listening and playability tests, the participants rated the experimental necked baglamas significantly higher than the traditional one in loudness. All the participants stated that the experimental necked baglamas' sound was louder than the traditional necked one.

There are also some design endeavors to amplify the sound of stringed instruments in organology. In particular, the inventions in (Namlı, 2006; 2020) patents can increase the sound of baglama since they function as a second soundbox (fixed or portable) in the neck. However, the double soundbox design moves the baglama away from the traditional form, increases the weight of the neck, and makes it difficult to perform. Furthermore, we could not encounter any scientific study on the effects of a second soundbox at the neck on loudness.

Previous studies on the bowl and soundboard did not focus on producing or hearing sound from the neck. In this study, we investigated the effects of the hollowed and drilled neck designs on the sound of baglama. All participants emphasized the loudness of the experimental necked baglamas, and about a third of them highlighted the clarity and volume of their sound. This result corroborated the sound radiation analysis results. Many of the participants preferred to have experimental neck-1. Some participants stated experimental necked baglamas were more ergonomic as they are lightweight and would facilitate long-term performance.

Since the hollowed neck produces sound, the soundholes in the bowl and experimental necks simultaneously radiate sound in experimental necked baglamas. Thus, the listeners and players feel themselves inside the sound. In other words, as some participants stated, experimental necked baglamas create a louder, more voluminous, and inclusive sense of sound, as if two different baglamas were being performed simultaneously. On the other hand, an instructor participant emphasized that hearing the harmonics more intensely around the nut should be further investigated.

Conclusion and Recommendations

The results of sound radiation analysis revealed that the experimental necks contributed to the general sound production and radiation of the baglama. This contribution means that the experimental necks directly create sound through their hollow soundhole/s, not by changing the vibration character of the instrument's soundbox. These findings indicated that neck design and structure directly and independently affect stringed instruments' sound efficiency, particularly sound radiation, and perceived loudness. In other words, experimental necks are integral to the instrument, not affecting its vibration modes but a direct sound source contributing to sound efficiency.

Research findings confirmed that experimental necks contribute more to the loudness of the baglama than the traditional neck psychoacoustically. Participant players emphasized that experimental neck designs provide more inclusive hearing than traditional one. This result is due to the design of the experimental necks, which converts the neck to a second bowl. Furthermore, the soundbox air hole at the junction and hollow in the necks enable air passage between the soundbox and the neck. How the air in the bowl and the neck behaves and its effects on acoustics need further investigation. Since we hollowed the experimental necks and drilled the holes on their front surfaces in the designs, experimental necks get lightweight and more ergonomic, thereby making the baglama's long-term performance possible. The experimental necks do not disturb the conservatives as they preserve the traditional form and dimensions of the baglama. Experimental necked baglamas can be effectively performed and carried out in existing cases.

This study focused on the potential contribution of the neck, verifying that the neck also contributes to sound production and radiation in stringed instruments, and suggested investigating the acoustic effects of neck designs for stringed instruments. It is concluded that not only the soundboard and the bowl affect the vibration and sound formation of the instrument, but also the neck designs can improve the sound radiation, and its perceived loudness. This study sheds light on further academic studies on the neck acoustics of stringed instruments. Researchers should study each integral part's effects on the acoustics of the stringed instrument in detail. All parts of the instrument's contributions to sound quality should be optimized by holistically investigating them. There is specifically a need for further applied research to examine the hollowed necks' warping problem, and the sound radiation through microphones and the sound in stage and studio environments.

Acknowledgments

We want to express our gratitude to all the interviewee participants and subject matter experts in this study. This study was produced from a master thesis under the first and second author supervision. It was supported by the Coordination of Scientific Research Projects of Hatay Mustafa Kemal University [Project No: 20.YL.046]. The funder financially supported making the necks and the instrument. The decision of ethics for the study was received from Hatay Mustafa Kemal University Social and Human Sciences Scientific Research and Publication Ethics Board with the date, 07.03.2022 and decision numbered 32. Permission approval for the research was received from the Provincial Directorate of National Education with the date, 23.03.2022 and number E-32889839-605.01-46314363.

References

Bader, R. (2012). Radiation characteristics of multiple and single sound hole vihuelas and a classical guitar, *The Journal of the Acoustical Society of America, 131*(1), 819-828.

Brauchler, A., Ziegler, P., & Eberhard, P. (2021). An entirely reverse-engineered finite element model of a classical guitar in comparison with experimental data. *The Journal of the Acoustical Society of America, 149*(6), 4450-4462.

Brezas, S., Katsipis, M., Orphanos, Y., Kaselouris, E., Kechrakos, K., Kefaloyannis, N., Papadaki, H., Sarantis-Karamesinis, A., Petrakis, S., & Theodorakis, I. (2023). An Integrated Method for the Vibroacoustic Evaluation of a Carbon Fiber Bouzouki. *Applied Sciences, 13*(7), 4585-(4596).

Corradi, R., Liberatore, A., & Miccoli, S. (2016). Experimental modal analysis and finite element modelling of a contemporary violin, in *ICSV 2016-23rd International Congress on Sound and Vibration: From Ancient to Modern Acoustics* (International Institute of Acoustics and Vibrations), pp. 1-7.

Curtin, J. (2009). Measuring violin sound radiation using an impact hammer. *The Journal of the Violin Society of America. VSA Papers* 22, 186-209.

Czajkowska, M. (2014). *Subjective assessment of classical guitars tonal quality in relation to spectral analysis*, European Acoustics Association, Krakow.

Değirmenli, E. (2017). Türk müziği telli çalgılarının akustik analizlerinde kullanılan yöntemler (the methods used for the acoustic analysis of the Turkish stringed instruments). *Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım ve Teknoloji*, 5(2), 23-35.

Duerinck, T., Verberkmoes, G., Fritz, C., Leman, M., Nijs, L., Kersemans, M., & Van Paepegem, W. (2020). Listener evaluations of violins made from composites, *The Journal of the Acoustical Society of America, 147*(4), 2647-2655.

Elejabarrieta, M. J., Ezcurra, A., & Santamaria, C. (2002). Coupled modes of the resonance box of the guitar. *Journal of the Acoustical Society of America, 111*(5), 2283-2292.

Elwali, W., Satakopan, H., & Shauche, V. (2010). Modal parameter estimation using acoustic modal analysis. *IMAC-XXVIII*, Florida USA.

Eroğlu, S.C. (2012). Bağlamanın akustik özelliklerinin çözümlenmesi. *Porte Akademik, 2,* 140-151.

Fletcher, H., & Munson, W. A. (1933). Loudness, its definition, measurement and calculation. *Bell System Technical Journal*, *12*(4), 377-430.

Fletcher, N.H., & Rossing, T.D. (1998). *The physics of musical instruments*. Springer Science & Business Media.

French, M., & Lewis, K. (1995). Modal Analysis of an Acoustic Guitar. *Proceedings of the 13th International Modal Analysis Conference, Vols 1 and 2, 2460*, 808-814.

Fritz, C., & Dubois, D. (2015). Perceptual evaluation of musical instruments: State of the art and methodology. *Acta Acustica united with Acustica*, *101*(2), 369-381.

Lercari, M., Gonzalez, S., Espinoza, C., Longo, G., Antonacci, F., & Sarti, A. (2022). Using mechanical metamaterials in guitar top plates: a numerical study. *Applied Sciences*, *12*(17), 8619.

Limkar, B., & Chandekar, G. (2022). Dynamic Analysis of Psychoacoustic Parameters to Evaluate Sound Quality of an Indian String Instrument Sitar. In *Technology Innovation in Mechanical Engineering: Select Proceedings of TIME 2021* (pp. 83-90). Singapore: Springer Nature Singapore.

Marshall, K.D. (1985). Modal-Analysis of a Violin. *Journal of the Acoustical Society of America*, *77*(2), 695-709.

Meinel, E., & Jansson, E.V. (1991). On the Influence of the Neck on The Guitar Body Vibrations. *STL-QPSR*, *32*(4), 11-18.

Meyer, J. (1972). Directivity of the bowed stringed instruments and its effect on orchestral sound in concert halls. *The Journal of the Acoustical Society of America*, *51*(6B), 1994-2009.

Miles, M.B., & Huberman, A.M. (1994). Qualitative data analysis: *An expanded sourcebook*. Sage.

Namlı, Z.Ç. (2006). *Çift Rezonans Kutusuna Sahip Telli Müzik Enstrümanı* (*Stringed Musical Instrument with Double Resonance Box*), TR Patent No. *TR200602443*. Türk Patent ve Marka Kurumu. https://portal.turkpatent.gov.tr/anonim/arastirma/patent/sonuc/dosya?patentAppNo=2006/02443&documentsTpye=all

Namlı, Z.Ç. (2020). *Detachable, portable resonance box for providing acoustic stereo sound from stringed instruments*, US Patent No. US2022130353A1. Patent and Trade-mark Office. https://worldwide.espacenet.com/patent/search/family/070774114/publication/US2022130353A1?q=pn%3DUS2022130353A1

Paiva, G., & Dos Santos, J.M.C. (2014, July). Modal analysis of a Brazilian guitar body. In *Proceedings of the ISMA International Symposium on Music Acoustics*, pp. 233-239.

Penttinen, H., Erkut, C., Polkki, J., Valimaki, V., & Karjalainen, M. (2005). Design and analysis of a modified kantele with increased loudness. *Acta Acustica United with Acustica*, *91*(2), 261-268.

Perry, I. (2014). Sound radiation measurements on guitars and other stringed musical instruments. Doctoral dissertation, Cardiff University. England.

Pezzoli, M., Canclini, A., Antonacci, F., & Sarti, A. (2022). A comparative analysis of the directional sound radiation of historical violins. *The Journal of the Acoustical Society of America*, 152(1), 354-367.

Saitis, C., Scavone, G. P., Fritz, C., & Giordano, B. L. (2013). Evaluating violin quality: a comparison of player reliability in constrained vs unconstrained tasks. In *Proceedings of the Stockholm Musical Acoustics Conference (SMAC), Stockholm (Sweden)*, pp. 109-114.

Schleske, M. (2002). Empirical tools in contemporary violin making: Part II. Psychoacoustic analysis and use of acoustical tools. *CAS Journal*, 4(6), 43-61.

Schwarz, B. J., & Richardson, M. H. (1999). Experimental modal analysis. *CSI Reliability week*, 35(1), 1-12.

Şahinkayası, Y., Şahinkayası, H., & Öztorun, Ü. (2021). *Yüksek sesli stereo akustik telli çalgılar: bağlama ve gitar* (Loud-stereo-acoustic stringed instruments: baglama and guitar), TR Patent No. TR202012480A. Türk Patent ve Marka Kurumu. https://portal.turkpatent.gov.tr/anonim/arastirma/patent/sonuc/dosya?patentAppNo=2020/12480&documentsTpye=all

Zeren, A. (2007). *Müzik fiziği (the physics of music)*. Pan Yayıncılık.

Ziemer, T. (2019). *Psychoacoustic music sound field synthesis: creating spaciousness for composition, performance, acoustics and perception* (Vol. 7). Springer.

Appendices

Materials and Production Method of the Baglama

For the study, we designed a baglama, including one soundbox and three attachable/ detachable necks for the soundbox. All the necks were from the same wood block in the same dimensions and made under the same conditions and time. Of the necks with identical physical properties in all aspects, the traditional neck is unhollowed, but the experimental necks are hollowed. On the front face of the experimental necks are 'Neck Soundholes' in different numbers. In addition, there is a bigger 'Neck Soundhole' on the fret of the experimental necks closest to the nut (Figure 1).

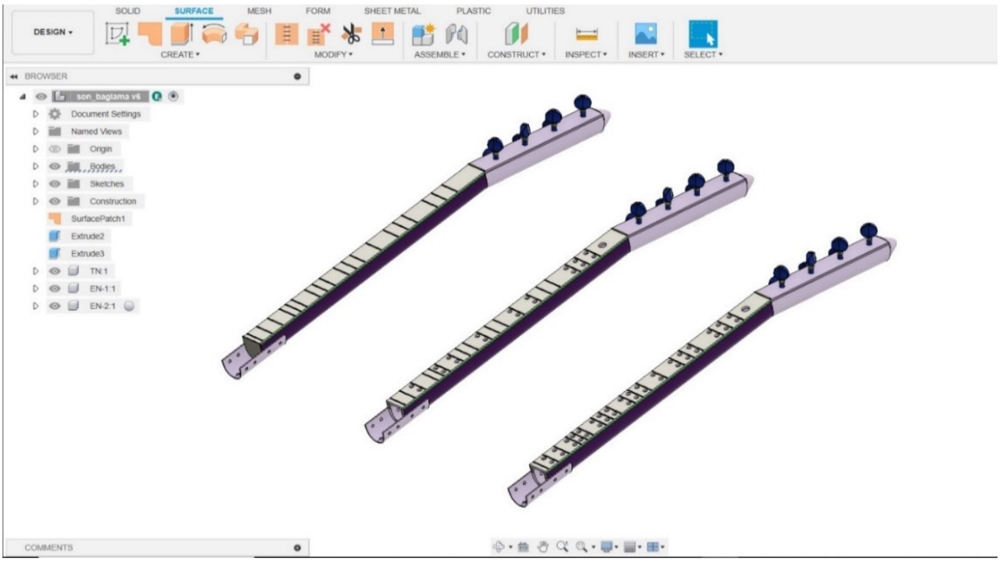


Figure 1. Solid models of the necks

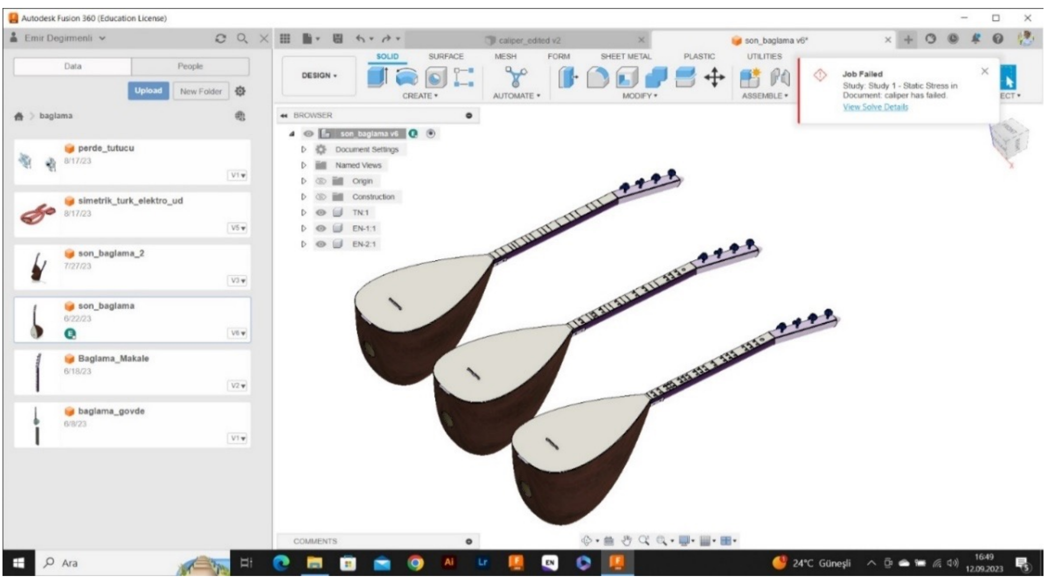


Figure 2. Solid models of the necks attached to the same soundbox

Technical drawings of the baglama (Figure 1 and Figure 2) were first created in SolidWorks and exported to Fusion 360 software, and all the necks were produced using a CNC router in these models. The lengths, weights, volumes, and areas were calculated using solid models in

Figure 3. Finished traditional neck, attached to the soundbox

(b)

(a)

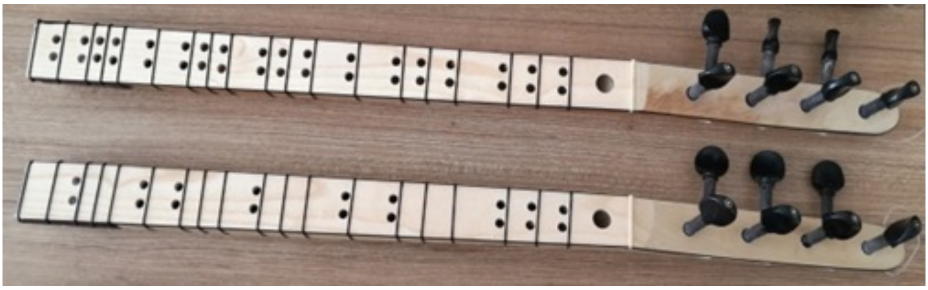
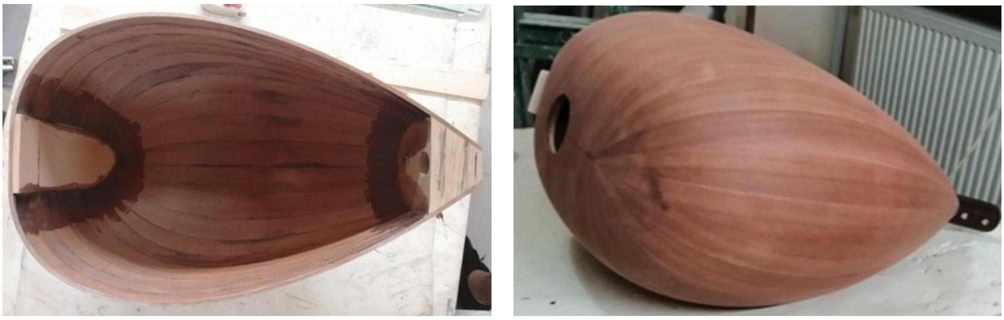


Figure 4. Finished Experimental neck – 1 (a) and Experimental neck – 2 (b)

(a) (b)

Figure 5. Connecting the neck to the soundbox (a) placing and (b) screwing the neck

Fusion 360.The soundbox of baglama had been carefully handmade by an experienced craftsman. The bowl of baglama was made by gluing wood pieces together (Figure 6). Quercus alba, the juniper, and the spruce tree are used to construct the necks, the bowl, and the soundboard, respectively (Figure 7). A neck block was bored and embedded in the junction between the soundbox and the neck (Figure 6).



(a) (b)

Figure 6. The bowl of baglama made by gluing wood pieces together (a) Inside view (b) outside view

We used a metal joint connector to assemble/disassemble the necks quickly to the soundbox. Half of this connector was fixed by embedding and screwing into the bowl. A neck block (Figure 6) was bored and embedded in the bowl to connect the soundbox and the neck. The other half (Figure 5 and 7) was outside the bowl, where the necks were placed and screwed.

Figure 7. A piece of spruce tree for the soundboard

The Sound Radiation Analysis

Sound radiation measurements were performed in a typical room. The baglama with different necks was mounted on a rig and excited with a miniature impact hammer (B&K 8204); the acoustic response was measured with a microphone (B&K 4189-A-021) at the locations A, B, and C (distant miking location: A, close miking locations: B and C), as seen in Figure 8. A distant miking location, A, is 20 cm above the tailpiece and 100 cm horizontally from the soundboard.

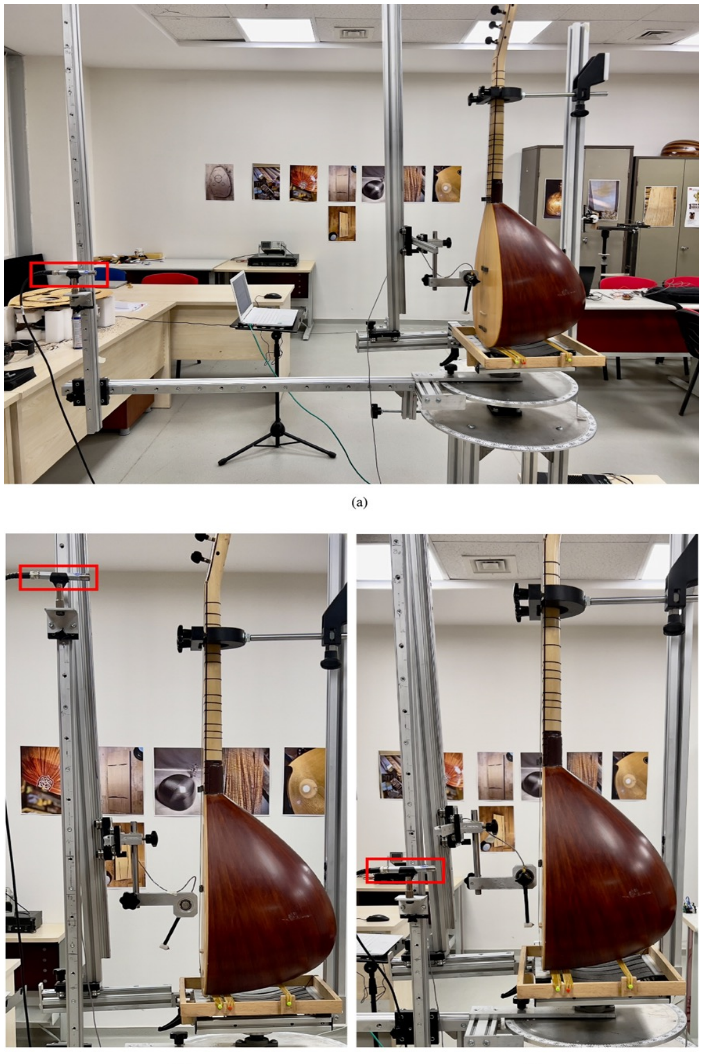


Figure 8. The experimental setup: (a) distant and (b and c) close miking locations

The first close miking location, B, is 20 cm horizontally from the neck and vertically at 80 cm from the tailpiece to the nut, and the second close miking location, C, is 20 cm horizontally from the center of the soundboard. It was averaged 36 measures by rotating the measuring device horizontally on its axis at angles of 10 degrees. B&K 7781-N6 Pulse Access FRF Analysis Software was used as acquisition software.

Focus Group Interviews, Including Listening and Playability Tests

In the interviews, we had the participants sit at equal distances on the arc of the semi-circle with a radius of 1.5 m (Figure 9). In all listening tests, the fourth author sat in the center of the semi-circle and played the baglama. As the interviewer, the first author sat at the back left of the player.

Figure 9. Seating arrangement in focus group interviews

The interview guide for focus group interviews, including listening and playability tests, and the handout are given below. It should be noted that the handout was delivered to each participant. When requested, the participants filled the following in the handout individually and anonymously: the Demographic Information Form, Definition of Loudness, Rating Scale for Loudness of Traditional Baglama, and Baglamas with Different Necks.

Focus Group Interview Guide: Listening Tests

Place of Interview	:..............................	**Interview Date**	:..............................
Time Frame	:..............................	**Interviewer**	:..............................
Listeners	(1) :..............................	**Player**	:..............................
	(2) :..............................		
	(3) :..............................		
	(4) :..............................		
	(5) :..............................		
	(6) :..............................		

Introduction

This research investigates the psychoacoustic effects of three different necks, assemblable and disassemblable to the same soundbox, on the baglama sound quality. Your contributions to the research are valuable since you are ear-trained listeners of the baglama sound and educated musicians. For this reason, we would like to take your perceptual evaluations and opinions about the baglama having a "Traditional Neck" and two "Experimental Necks."

In the first part of the interview, I will give you a handout, including " Demographic Information Form, Definition of Loudness, Rating Scale for Loudness of Traditional Baglama, and Baglamas with Different Necks." Firstly, you will fill out the " Demographic Information Form". Secondly, I will read the definition of loudness written in the "Definition of Loudness." Thirdly, consider this definition you will rate solo and ensemble performances of the traditional baglama through the "Rating Scale for Loudness of Traditional Baglama". Finally, I will explain the "Rating Scale for Loudness of Baglamas with Different Necks" and how to rate the loudness of baglamas with different necks as a listener. We assume that you conceptually perceive the "loudness" concept as the same.

In the second part of the interview, my graduate student will assemble into/dissemble from the same soundbox the necks (Traditional Neck, Experimental Neck-1, and Experimental Neck-2). He will tune the baglamas and play the intro of a Turkish folk song (Seherde bir baga girdim), and you will listen to the same intro each time. In this process, I expect you to evaluate comparatively the effect of the necks on the loudness by using the rating scale. Everything you say during the interview will remain confidential. That is, the identity and personal information of the interviewees will not be reflected in the report. Are there any thoughts you would like to express or any questions you would like to ask about what I explained before starting the interview?

Participation in the interview is voluntary. You can give up participating at any time. I want to take notes to make the interview and its analysis more qualified. Can I take notes on the interview?

This interview will take at least 30 minutes. Thank you very much for participating in the interview. Now, I would like to start the interview.

I. Demographic Information

Please fill out the forms I gave you on your demographic information.

II. Traditional Baglama in General

Now, I will ask several questions about traditional baglama in general.

1. How do you perceive the traditional baglama in the acoustic venue? Can you evaluate it?

Please, by using the "Rating Scale for Loudness of Traditional Baglama" rate the loudness of traditional baglama for solo and ensemble performances in general.

2. Do you know that there are any empirical studies to increase the loudness of traditional baglama?

(In case of a negative answer, remember the studies in which changes were made to the soundboard and bowl.)

a) What do you think about these studies?

b) Do you think these studies contribute to raising the loudness of the baglama? Why do you think so? Can you explain?

III. Psychoacoustics Evaluations Using "Rating Scale for Loudness of Baglamas with Different Necks"

Now, I read the definition of loudness in the handout at your hands. The fourth researcher, my graduate student, will play the intro with the baglama having the traditional neck; please listen to it and rate the loudness using the rating scale. If you request, the intro will be played again. Please read the definition and consider your listening experience when evaluating them.

3. How did you perceive the "Traditional Neck" baglama regarding loudness? Can you evaluate the positive or negative aspects of its sound?

a) Loudness

b) Do you want to add anything about the traditional neck?

We will go through the same process for the experimental neck–1. The fourth researcher will dissemble the traditional neck from the soundbox, assemble the experimental neck-1, tune, and play the same intro; please listen to it and rate the loudness using the rating scale. If you request, the intro will be played again. Please read the definition and consider your listening experience when evaluating them.

4. How did you perceive the "Experimental Neck - 1" baglama regarding loudness? Can you evaluate the positive or negative aspects of its sound?

a) Loudness

b) Do you want to add anything about the traditional neck-1?

We will do the same process for the experimental neck–2. The fourth researcher will dissemble the experimental neck–1 from the soundbox, assemble the experimental neck-2, tune, and play the same intro; please listen to it and rate the loudness using the rating scale. If you request, the intro will be played again. Please, read the definition and consider your listening experience when evaluating them.

5. How did you perceive the " Experimental Neck - 2" baglama regarding loudness? Can you evaluate the positive or negative aspects of its sound?

a) Loudness

b) Do you want to add anything about the traditional neck-2?

IV. Comparative Evaluation of the Necks

You listened to the song with the baglama having three different necks.

6. What were the most prominent similarities and differences regarding sound quality among the necks? Do you think the experimental necks improved the baglama's sound compared to the traditional neck?

a) If yes, in which aspects? And why?

b) What else can be done to improve the sound quality?

7. Do you think the experimental necks worsen the baglama's sound quality compared to the traditional one?

a) What else can be done to improve the sound quality of baglamas with the experimental necks?

8. Which of the baglama having different necks would you like to own?

IV. Closure

Our interview is over. Would you like to add anything else?

Can we call you back if we need to interview you again about anything that needs to be clarified? Thank you very much for participating and contributing to the research.

Focus Group Interview Guide: Playability Tests

Place of Interview :............................ **Interview Date** :............................

Time Frame :............................ **Interviewer** :............................

Players (1) :............................

(2) :............................

(3) :............................

(4) :............................

(5) :............................

(6) :............................

Introduction

This research investigates the psychoacoustic effects of three different necks, assemblable and disassemblable to the same soundbox, on the baglama sound quality. Your contributions to the research are valuable since you are ear-trained players of the baglama sound and educated musicians. For this reason, we would like to take your perceptual evaluations and opinions about the baglama having a "Traditional Neck" and two "Experimental Necks."

In the first part of the interview, I will give you a handout, including " Demographic Information Form, Definition of Loudness, Rating Scale for Loudness of Traditional Baglama, and Baglamas with Different Necks." Firstly, you will fill out the " Demographic Information Form". Secondly, I will read the definition of loudness written in the "Definition of Loudness." Thirdly, consider this definition, and you will rate solo and ensemble performances of the traditional baglama through the "Rating Scale for Loudness of Traditional Baglama". Finally, I will explain the "Rating Scale for Loudness of Baglamas with Different Necks" and how to rate the loudness of baglamas with different necks as a player. We assume that you conceptually perceive the "loudness" concept as the same.

In the second part of the interview, my graduate student will assemble into/dissemble from the same soundbox the necks (Traditional Neck, Experimental Neck-1, and Experimental Neck-2). He will tune the baglamas, and you will play the intro of a Turkish folk song (Seherde bir baga girdim). You will repeat the same intro with each neck and listen to other players' performances. In this process, I expect you to evaluate comparatively the effect of the necks on the loudness by using the rating scale. Everything you say during the interview will remain confidential. That is, the identity and personal information of the interviewees will not be reflected in the report. Are there any thoughts you would like to express or any questions you would like to ask about what I explained before starting the interview?

Participation in the interview is voluntary. You can give up participating at any time. I want to take notes to make the interview and its analysis more qualified. Can I take notes on the interview?

This interview will take at least 30 minutes. Thank you very much for participating in the interview. Now, I would like to start the interview.

I. Demographic Information

Please fill out the forms I gave you on your demographic information.

II. Traditional Baglama in General

Now, I will ask several questions about traditional baglama in general.

1. How do you perceive the traditional baglama in the acoustic venue? Can you evaluate it?

Please, by using the "Rating Scale for Loudness of Traditional Baglama" rate the loudness of traditional baglama for solo and ensemble performances in general.

2. Do you know that there are any empirical studies to increase the loudness of traditional baglama?

(In case of a negative answer, remember the studies in which changes were made to the soundboard and bowl.)

a) What do you think about these studies?

b) Do you think these studies contribute to raising the loudness of the baglama? Why do you think so? Can you explain?

III. Psychoacoustics Evaluations Using "Rating Scale for Loudness of Baglamas with Different Necks"

Now, I read the definition of loudness in the handout at your hands. You will play the intro with the baglama having the traditional neck; please play it and rate the loudness using the rating scale considering your playing. If you need, you can play it again. Please read the definition and consider your playing experience when evaluating the neck.

3. How did you perceive the "Traditional Neck" baglama regarding loudness? Can you evaluate the positive or negative aspects of its sound?

a) Loudness

b) Do you want to add anything about the traditional neck?

We will go through the same process for the experimental neck-1. The fourth researcher will assemble the experimental neck–1 to the soundbox and tune it. Then, you will play the same intro; please play it and rate the loudness using the rating scale. If you need, you can play it again. Please read the definition and consider your playing experience when evaluating the neck.

4. How did you perceive the "Experimental Neck - 1" baglama regarding loudness? Can you evaluate the positive or negative aspects of its sound?

a) Loudness

b) Do you want to add anything about the experimental neck-1?

We will go through the same process for the experimental neck-2. The fourth researcher will assemble the experimental neck–2 to the soundbox and tune it. Then, you will play the same intro; please play it and rate the loudness using the rating scale. If you need, you can play it again. Please read the definition and consider your playing experience when evaluating the neck.

5. How did you perceive the " Experimental Neck - 2" baglama regarding loudness? Can you evaluate the positive or negative aspects of its sound?

a) Loudness

b) Do you want to add anything about the experimental neck-2?

IV. Comparative Evaluation of the Necks

You played the same intro with the baglama having three different necks.

6. What were the most prominent similarities and differences regarding sound quality among the necks? Do you think the experimental necks improved the baglama’s sound compared to the traditional neck?

a) If yes, in which aspects? And why?

b) What else can be done to improve the sound quality?

7. Do you think the experimental necks negatively affected the baglama’s sound quality compared to the traditional one?

a) What else can be done to improve the sound quality of baglamas with the experimental necks?

8. Which of the baglamas having different necks would you like to own?

IV. Closure

Our interview is over. Would you like to add anything else?

Can we call you back if we need to interview you again about anything that needs to be clarified? Thank you very much for participating and contributing to the research.

Handouts for Listening and Playability Tests

Demographic Information Form

1. Gender	☐ Male ☐ Female
2. Age	☐ 15-19 ☐ 20-24 ☐ 25-29 ☐ 30-34 ☐ 35-39 ☐ 40-44 ☐ 45-49 ☐ 50-54 ☐ 55-59
3. Grade (if applicable)	☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ Freshman ☐ Sophomore ☐ Junior ☐ Senior
4. What is your profession?	☐ Teacher at Fine Arts High School ☐ Instructor at Conservatory ☐ Student at Fine Arts High School ☐ Student at Conservatory
5. Are you a performer, listener, or luthier?	☐ Performer ☐ Listener ☐ Luthier
6. How many years have you been working in this profession?	☐ <= 5 ☐ 6-10 ☐ 11-15 ☐ > = 16
7. Do you listen to the baglama?	☐ Yes ☐ No
8. How many years have you been interested in baglama?	☐ <= 10 ☐ 11-20 ☐ 21-30 ☐ > = 30
9. What kind of music do you listen to?	☐ Turkish ☐ Western ☐ Both

Defination of Loudness

Loudness	In acoustics, loudness is the subjective perception of sound pressure. More formally, it is defined as the “attribute of auditory sensation in terms of which sounds can be ordered on a scale extending from quiet to loud.” American National Standards Institute. Committee on Bioacoustics, S3, & Sonn, M. (1973). *American national standard psychoacoustical terminology.* American National Standards Institute.

Rating Scale for Loudness of Typical Traditional Baglamas

How do you perceive typical traditional baglamas' loudness in an acoustic venue?			
Solo performance	☐ Low	☐ Medium	☐ High
Ensemble performance	☐ Low	☐ Medium	☐ High

Rating Scale for Loudness of Baglamas with Different Necks

Loudness											
	(Neutral)										
	(Poor)	1	2	3	4	5	6	7	8	9	**(Excellent)**
Traditional Neck	Quiet	☐	☐	☐	☐		☐	☐	☐	☐	**Loud**
Experimental Neck - 1	Quiet	☐	☐	☐	☐		☐	☐	☐	☐	**Loud**
Experimental Neck - 2	Quiet	☐	☐	☐	☐		☐	☐	☐	☐	**Loud**

Analysis of Loudness Ratings: The Friedman Test and Wilcoxon Signed-Rank Test

The Friedman test is the non-parametric alternative to the one-way ANOVA with repeated measures. It analyses whether the medians of a group of participants' responses to the same variable under different conditions/times differ significantly. If this test is significant, pairwise comparisons are conducted as a post hoc test with the Wilcoxon signed-rank test, a non-parametric 2-related samples test.

The Intro Melody, Listened and Played in the Tests

Table 1. "Seherde Bir Bağa Girdim" folk song intro and informations

Region	Tercan / ERZİNCAN	**Transcriber**	Nida TÜFEKÇİ
Composer	Âşık İsmail DAİMİ	**Notated Date**	13.10.1969
Song Name: Seherde Bir Bağa Girdim			
			

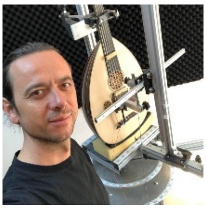
Biodata of Authors

Yunis Şahinkayası graduated from the Middle East Technical University in 2008. He is an assistant professor at the Department of Computer Education and Instructional Technology at Hatay Mustafa Kemal University. His focus is the rights of intellectual property, educational technologies, instructional design, and digital games. Music (playing and designing baglama) is of special interest.

Affiliation: Department of Computer Education and Instructional Technology, Hatay Mustafa Kemal University, Hatay, Turkiye. **Email:** ysahinkayasi@gmail.com

ResearchGate: https://www.researchgate.net/profile/Yunis-Sahinkayasi

Academiaedu: https://mku.academia.edu/Yunus%C5%9Eahinkayas%C4%B1



Emir Değirmenli graduated from the university as a physics engineer in 2004. He was a founding member of the Gazi University Turkish Music Conservatory. Degirmenli has earned his master's degree in 2014 and PhD in 2018. He is currently a lecturer at Ankara Hacı Bayram Veli University Turkish Music State Conservatory. He lectures about the physics of sound and the acoustics of the musical instruments.

Affiliation: Department of Instrument Training, Ankara Hacı Bayram Veli University, Ankara, Turkiye. **Email:** emirdegirmenli@gmail.com

ResearchGate: https://www.researchgate.net/profile/Emir-Degirmenli

Academiaedu: https://ahbv.academia.edu/EmirDe%C4%9Firmenli

Dr. Hamide Şahinkayası is an Assistant Professor in the Department of Computer Education and Instructional Technology at Hatay Mustafa Kemal University in Turkiye. She received her PhD in Computer Education and Instructional Technology from Middle East Technical University in Ankara, Turkey. Her research interests include educational technologies, e-learning, digital game-based learning, and teacher education.

Affiliation: Department of Computer Education and Instructional Technology, Hatay Mustafa Kemal University, Hatay, Turkiye. **Email:** hsahinkayasi@gmail.com

ResearchGate: https://www.researchgate.net/profile/Hamide-Sahinkayasi

Academiaedu: https://mku.academia.edu/Hamide%C5%9Eahinkayasi

Ünal Öztorun was graduated from İnönü University, Faculty of Education, Department of Music in 2006. He took a master's degree from Hatay Mustafa Kemal University, Institute of Science, Department of Informatics in 2022. He currently works as a Music (Baglama) Teacher at Hatay Bedii Sabuncu Fine Arts High School.

Affiliation: Ministry of National Education, Hatay Bedii Sabuncu Fine Arts High School, Hatay, Turkiye. **Email:** unaloztorun@hotmail.com