

Research Article

Effects of peg systems on structural vibration and acoustic response in an oud

Emir Değirmenli¹

Instrument Education Department, Turkish Music State Conservatory, Ankara Hacı Bayram Veli University, Ankara, Türkiye

Article Info

Submitted: 13 July 2026

Accepted: 20 September 2026

Online: 30 September 2026

Keywords

Bridge mobility

Force-normalized acoustic response

Modal behaviour

Neck vibration

Oud acoustics

Peg systems

3023-7890/ © 2026 JTO

Published by Genç Bilge (Young Wise)

Pub.Ltd. This is an open access article
under the CC BY-NC-ND license.



Abstract

Peg systems form part of the mechanical structure of a stringed instrument, but their contribution to the oud's response has received limited experimental attention. This exploratory pilot study compared four conditions on one unstrung oud: No Pegs, Rosewood Pegs, Ebony Pegs, and Wittner Mechanical Pegs. Impact-based frequency-response measurements combined bridge and neck-pegbox vibration with force-normalized acoustic response. Three resonance regions selected by qualitative screening of the broadband spectra, labelled Mode 1–Mode 3 for this comparison, were tracked at a frequency increment of 1.5625 Hz. Of these three regions, Mode 3 showed the largest frequency shifts. Relative to No Pegs, the Wittner condition shifted the bridge peak downward by 10.94 Hz and increased the bridge, neck-pegbox, and acoustic peak levels by 2.51, 11.18, and 5.39 dB, respectively. Mode 2 showed contrasting bridge and neck responses, while acoustic changes were not consistently monotonic across conditions. At the evaluated frequencies, coherence was high for the No Pegs neck and Ebony bridge records and lower for the No Pegs and Rosewood acoustic records; no acoustic coherence was recorded for Ebony or Wittner. The results identify mode-dependent changes associated with peg-system substitution and support examining the pegbox within the coupled body-neck structure. This single-instrument comparison does not isolate mass from other mechanical differences or establish tonal superiority under playing conditions.

To cite this article:

Değirmenli, E. (2026). Effects of peg systems on structural vibration and acoustic response in an oud. *Journal of Turkish Organology*, 3(2), 111-127. DOI: <https://doi.org/10.5281/zenodo.23087728>

Introduction

A stringed instrument responds through the interaction of its body, neck, and attached components, rather than through the soundboard alone. Bridge motion links the vibrating strings to this distributed structure and to the enclosed air (Woodhouse, 2004). In violin studies, geometry and material properties are related to the spatial distribution of mass and stiffness and, in turn, to modal frequencies and vibration patterns (Schleske, 2002a). This perspective makes a component remote from the main radiating surface a legitimate subject of structural investigation.

The mechanical importance of a local mass change depends on where it acts within a vibration pattern. Roohnia (2026) examined this dependence using added masses and material removal at selected positions on wooden beams: mass loading near antinodal regions generally lowered natural frequencies more than loading near nodes. Material removal also changed stiffness, illustrating why a component modification cannot always be reduced to its mass difference. Modal mass is not simply the weighed mass of an attached component; its value depends on the mode shape and its normalization (Ewins, 2000). Consequently, peg-set mass can characterize an experimental condition without uniquely predicting its resonance response.

Neck and terminal components provide relevant precedents, although the evidence comes from different instruments and interventions. Experimental modal analysis of a violin identified neck-fingerboard bending and coupled motion involving the corpus (Marshall, 1985). Schleske (2002b) explicitly related the violin neck-fingerboard

¹ Assist. Prof. Dr., Instrument Education Department, Turkish Music State Conservatory, Ankara Hacı Bayram Veli University, Ankara, Türkiye. Email: emir.degirmenli@hbv.edu.tr ORCID: 0000-0001-8164-1448

bending resonance to neck stiffness and to the masses of the neck, scroll, and pegs. Neck shaping, equipment installation, and body assembly also alter the modal behaviour of electric guitars (Paté et al., 2015). Commercial headstock-mass accessories offer a practical motivation, but advertised sustain benefits are not experimental evidence for an oud (Fender Musical Instruments Corporation, n.d.). These precedents justify testing terminal components without assuming identical mechanisms across instrument families.

Structural response and acoustic output must also be distinguished. Modelling of a guitar resonance box shows that the soundboard, back, and enclosed air participate in coupled modes (Elejabarrieta et al., 2002). Schleske (2002a) contrasted weakly and strongly radiating violin modes and presented bridge mobility and pressure-to-force radiation responses as separate observables. A change at a local vibration measurement point therefore does not by itself establish a proportionate change in radiated sound.

Earlier oud research combined bridge mobility, acoustic response, and experimental modal shapes to investigate sound production (Değirmenli, 2023). That work identified both coincident spectral features and regions in which the relative prominence of the structural and acoustic responses differed. It provides an instrument-specific reason to examine the two responses together, but does not establish the effect of changing complete peg systems. Hollow-neck bağlama experiments offer a related structural–acoustic comparison; however, changing neck and cavity geometry is not equivalent to substituting tuning pegs (Şahinkaya et al., 2024). Brace–soundboard models likewise concern changes in combined mass and stiffness rather than an isolated terminal mass (Dumond & Baddour, 2012).

The remaining question is how real peg-system substitution is reflected in the responses measured at the bridge, near the neck–pegbox junction, and in the exterior acoustic response of an oud. This relationship remains insufficiently understood for the oud’s backward-angled, multi-peg structure. The present exploratory within-instrument pilot study addresses that question on one unstrung oud using No Pegs, Rosewood Pegs, Ebony Pegs, and Wittner Mechanical Pegs. It asks which tracked resonance regions are most sensitive, whether bridge and neck–pegbox changes have the same direction, and whether corresponding changes appear acoustically. Its contribution is a linked comparison of these observation areas for practical peg systems, not a causal calibration of total mass or a test of perceived sound quality.

Method

Experimental design

An exploratory within-instrument comparison was conducted on one oud under four conditions, presented throughout in ascending measured peg-set mass (Table 1). All strings were removed in every condition. This excluded differences in string tension and string vibration between conditions, but the results describe the structure without string-induced prestress rather than the instrument under playing conditions. No Pegs served as the experimental reference. Measurements were conducted on the same day, with sequential peg-system substitutions and no randomization of condition order. The ascending-mass order in Table 1 is the reporting order.

The oud had a Brazilian rosewood bowl and a cedar double-top soundboard. Its neck length was 195 mm and its nominal vibrating string length in the strung configuration was 585 mm. The latter is an instrument dimension, not a string length present during these unstrung measurements.

The mechanical system used WITTNER FINETUNE-PEGS, model 270111S. The manufacturer lists this model for 4/4–3/4 violin, with a nominal diameter at the ring of 7.8 mm and a taper of 1:30 (Wittner, n.d.); it was used on the oud in this experiment. These catalogue dimensions identify the product and are not measurements of its installed fit in this pegbox.

Each of the three photographed installed sets comprised eleven pegs (Figure 1). The No Pegs arrangement is shown in Figure 2a. All peg systems had been fitted to the pegbox before the measurement sequence. Substitution involved insertion and removal only, without further shaping or fitting during acquisition. The wooden pegs seated through their conical friction fit. The oud remained in the fixture throughout all substitutions.

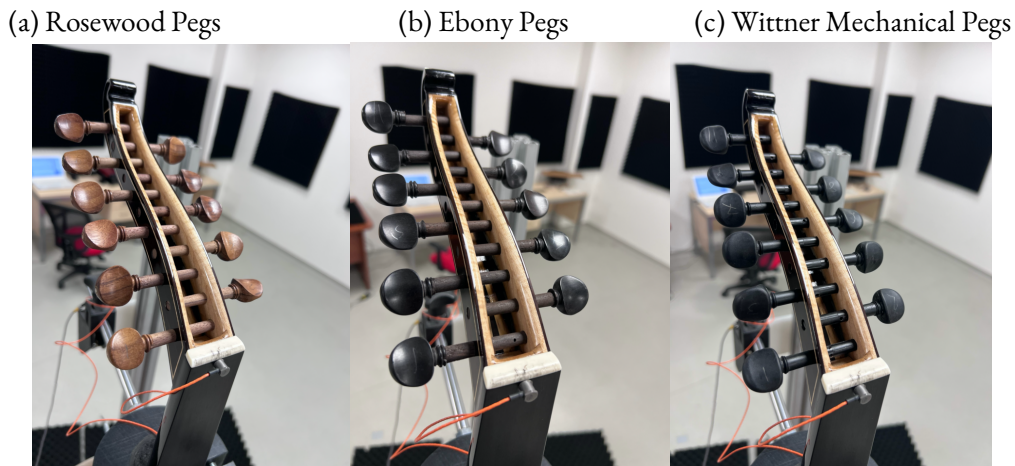


Figure 1. Installed peg sets in increasing measured set-mass order: (a) Rosewood Pegs, (b) Ebony Pegs, and (c) Wittner Mechanical Pegs. Each set contains eleven pegs. The neck sensor and its cable are visible below the nut. Photographs supplied by the author; the views are not to a common spatial scale. The No Pegs condition is shown in Figure 2a.

Group A denotes the structural measurements of bridge and neck–pegbox responses; Group B denotes the structural–acoustic measurements of bridge and microphone responses. Both groups include all four peg conditions. The letters identify acquisition datasets, not different peg systems or instruments. Group A measurements were completed for all four conditions before Group B began. The peg sets were reinstalled for Group B; thus, the A and B records for a given set were not consecutive measurements with the pegs left untouched. The oud remained on its supports and all sensors remained attached during these changes.

Table 1. Measured peg-set masses and acquisition averaging counts.

Condition	Set mass (g)	Group A bridge and neck	Group B bridge	Group B microphone
No Pegs	0.0	5	5	36
Rosewood Pegs	38.0	5	5	36
Ebony Pegs	54.0	5	5	36
Wittner Mechanical Pegs	112.5	5	5	36

The 0 g entry refers only to the absence of the peg set. The installed systems also differ in material, mass distribution, mechanism, and contact conditions. Their measured differences cannot be assigned to total mass alone. Masses were measured with a calibrated laboratory balance. For every peg condition, all accelerometer-based bridge and neck–pegbox FRFs used five impact averages, including the bridge records in both Groups A and B. All microphone-based acoustic FRFs used 36 impact averages (Table 1). Analyzer averages improve spectral estimation and are not independent experimental replicates.

Measurements and response quantities

The measurement chain comprised a Brüel & Kjær Type 8204 miniature impact hammer, Type 3050-A-060 six-channel LAN-XI module, Type 4517 miniature accelerometer near the bridge, and Type 4189-A-021 microphone set. An additional Type 4516 accelerometer was positioned near the end of the neck adjacent to the pegbox. The microphone and impact hammer were calibrated. In Group A, the force reference and both acceleration channels were acquired simultaneously, providing paired bridge and neck–pegbox responses with five impact averages. In Group B, the bridge acceleration and microphone channels were acquired concurrently with the force reference, providing structural and acoustic responses processed by separate averaging analyzers: five impacts for the bridge response and 36 for the acoustic response. Bridge (Group A) and Bridge (Group B) refer to the two measurement stages, separated by peg-set reinstallation, using the same bridge-region accelerometer at the same location. Neck–pegbox denotes the single neck-sensor location adjacent to the pegbox, not two measurement sites. The retained Group A and Group B spectra were analysed separately.

Complex H1 frequency-response functions (FRFs) were acquired in PULSE LabShop 20.0.0.455 using FFT spectrum averaging and uniform force and response windows. The exported spectra covered 0–10 kHz with 6401 points including zero, a 1.5625 Hz frequency increment, and a 0.64 s record length. The averaging counts were identical across

peg conditions within each response type: five impacts for every accelerometer-based FRF and 36 for every microphone-based FRF (Table 1).

Measurements were made in a room 11 m long and 7.5 m wide, with a ceiling height of 2.85 m. The setup centre was 3.2 m from the short wall shown on the left of the plan and centred across the room width (Supplementary Fig. S3). No separate acoustic characterization of the room was performed.

For acoustic acquisition, the oud and microphone were rotated together through 36 room orientations at 10° increments. The microphone remained 1 m from the soundboard along the normal through the midpoint between the two small sound holes, with its position relative to the oud unchanged. In PULSE, linear spectrum averaging was applied over 36 impact records, one at each room orientation: the force autospectrum and complex force–pressure cross-spectrum were each averaged in the linear spectral domain with equal record weights, and H1 was calculated from the ratio of these averaged spectra. Acoustic levels were obtained from the magnitude of the resulting complex H1, followed by conversion to dB re 1 Pa/N. Individual FRF magnitudes or dB values were not arithmetically averaged. Each peg condition was therefore represented by one force-normalized acoustic spectrum, compared through its spectral shape and the selected frequencies and levels. The joint rotation was intended to reduce room-mode contributions and followed the geometric arrangement described by Schleske (2002b, p. 43). This spectral estimator is not equivalent to Schleske’s energy averaging of transfer responses. The assembly sampled a fixed direction relative to the instrument, not different radiation directions, and did not measure total acoustic power. Orientation-resolved spectra were not retained, so residual room contributions and the effect of the averaging operator could not be evaluated retrospectively.

The oud was held upright on a graduated rotary base (Figure 2a–b). The neck restraint made light contact through a rubber piece, and elastic rubber bands supported the lower bowl. The oud was not removed from these supports during peg substitutions. During rotation, the instrument, supports, sensors, and microphone retained their relative positions. Both accelerometers were attached with beeswax formulated for accelerometer mounting, with their sensing directions normal to the soundboard. All sensors remained attached throughout the experiment, including the Type 4516 during acoustic acquisition and whenever its response was not being recorded. The Type 4516 was on the fingerboard immediately below the nut (Figure 2d); the bridge-region sensor and impact mechanism are shown in Figure 2c.

The miniature hammer had a metal tip and was operated as a pendulum to avoid double impacts. It was released from the same position for successive impacts and struck the bass side of the bridge normal to the soundboard surface. The impact location and direction were unchanged across peg conditions. A waiting interval was allowed between successive impacts for the response to decay. Although the Group B channels were acquired concurrently, their retained bridge and microphone FRFs represent different averaging populations rather than matched averages over the same set of impacts. The individual impact indices contributing to the five-impact bridge average were not retained. The retained Group A and Group B bridge spectra were therefore compared separately rather than pooled.

The raw complex acceleration-to-force response (accelerance, in $\text{m}/(\text{N}\cdot\text{s}^2)$) was preserved and converted to velocity-to-force mobility at nonzero frequencies. The microphone response remained a sound-pressure-to-force FRF:

$$Y(f) = H_a(f)/(i2\pi f), \quad H_a(f) = a(f)/F(f), \quad H_p(f) = p(f)/F(f).$$

Here, f is frequency, i is the imaginary unit, and a , F , and p denote acceleration, force, and sound pressure. Mobility is expressed in $\text{m}/(\text{N}\cdot\text{s})$, and acoustic FRF magnitude in Pa/N . Bridge mobility denotes the near-bridge transfer response; exact coincidence of the excitation and observation points was not established. The neck–pegbox channel is likewise a transfer response to bridge force, not a neck driving-point measurement.

FRF levels were calculated as 20 $\log_{10}$ of magnitude relative to 1 $\text{m}/(\text{N}\cdot\text{s})$ for mobility and 1 Pa/N for the acoustic response. Acoustic FRF level is therefore not sound pressure level. No A-weighting or spectral smoothing was applied. Peak-frequency and level differences, Δf and ΔL , were defined relative to No Pegs within each group. These comparisons use each condition’s own selected frequency and do not represent fixed-frequency gain. No significance tests or fitted causal models were applied.

The archived data used for this analysis comprise 16 complex FRF exports and four coherence exports. The reanalysis selected the largest sampled magnitude in each inclusive search window on the original FFT grid; an exact tie would select the lower-frequency bin. No sub-bin peak fit was applied. At a selected Group A bridge frequency, the neck/bridge ratio uses the two magnitudes at that same FFT bin, not the ratio of separately selected peaks.

Individual impact time histories, orientation-resolved acoustic spectra, and systematic independent installation-repeat records were not available in the analysed archive. Consequently, impact-to-impact variance, installation-related uncertainty, and the adequacy of decay within the 0.64 s uniform window could not be quantified retrospectively. The frequency increment is a sampling interval, not a confidence interval or a complete measurement uncertainty.

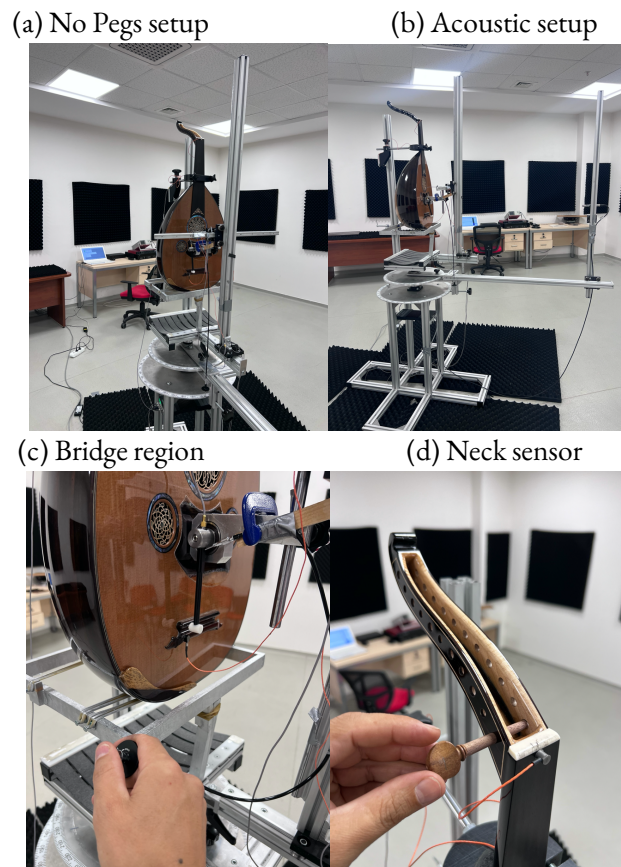


Figure 2. Photographic documentation of the experimental arrangement. (a) The unstrung oud without pegs in the upright fixture, including the lightly contacting rubber neck restraint, elastic rubber support beneath the bowl, and graduated rotary base. (b) The instrument and microphone on the shared rotary assembly. (c) The pendulum impact mechanism, bridge-region accelerometer, and lower-bowl support. (d) The Type 4516 sensor immediately below the nut during installation of a rosewood peg; this panel is not a photograph of the No Pegs measurement condition. Photographs supplied by the author; panel views are not to a common spatial scale.

Resonance tracking and measurement quality

Mode 1–Mode 3 designate three prominent resonance regions tracked in this comparison; they do not denote the complete ordering of the instrument's natural modes or a standard (m,n) nodal classification. The search windows were 200–220, 225–245, and 260–300 Hz, respectively. Selection followed an initial examination of the 0–10 kHz spectra and a more detailed comparison over 0–1 kHz. Changes in resonance position, peak level, and spectral shape across peg conditions identified these three characteristic low-frequency regions as showing particularly pronounced responses to peg-system substitution. Detailed tracking was then concentrated on these regions (Supplementary Figs. S1 and S2). This was qualitative spectral screening, not a calculated sensitivity coefficient, a statistical selection test, or a preregistered ranking of all resonances. The associated mass differences were not isolated from the other mechanical differences between peg systems. Figure 3 presents three vibration patterns adapted from Değirmenli (2023, Figure 1, p. 527), labelled Mode 1, Mode 2, and Mode 3 from left to right to provide spatial context for the tracked regions. These patterns belong to the earlier study and do not validate current mode shapes across peg conditions.

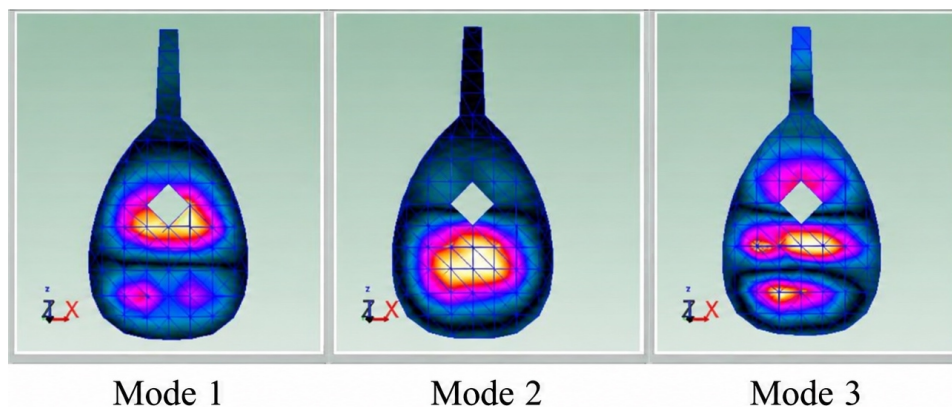


Figure 3. Oud vibration patterns adapted from Değirmenli (2023, Figure 1, p. 527; oud no. 2 in that study), labelled Mode 1, Mode 2, and Mode 3 from left to right. The patterns provide spatial context from the earlier study; they are not mode shapes measured in the present experiment and do not establish current phase or nodal lines.

The historical illustration provides qualitative spatial context only. The excerpt contains no quantitative colour key, so colour intensities are not compared as calibrated displacement, phase, or radiation efficiency between panels. Matching the present peaks to those historical mode shapes has not been independently demonstrated.

Within each window, maxima were obtained from the unsmoothed numerical spectra without sub-bin interpolation. Mode 1 did not exhibit a distinct acoustic peak. Its microphone magnitude was therefore sampled at the corresponding Group B bridge-peak frequency, with no independent acoustic Δf assigned. Mode 2 acoustic values represent band maxima among neighbouring local peaks. Mode 3 provided the clearest structural–acoustic correspondence. Coherence was assessed over 0–1000 Hz and at the corresponding FRF-derived evaluation frequencies for the four measured channel–condition combinations (Figure 7; Supplementary Table S1). These measurements provide local quality information only; they do not establish reliability for unmeasured channel–condition combinations.

Results

Mode dependent structural and acoustic changes

Figure 4 places the selected windows in the 100–1000 Hz responses, including the Group B bridge spectra. Shading identifies the three analysis windows without implying that other resonances are absent or less sensitive. Supplementary Fig. S1 shows the full acquired bandwidth, and Supplementary Fig. S2 extends the low-frequency overview below 100 Hz to document the spectral context of the screening.

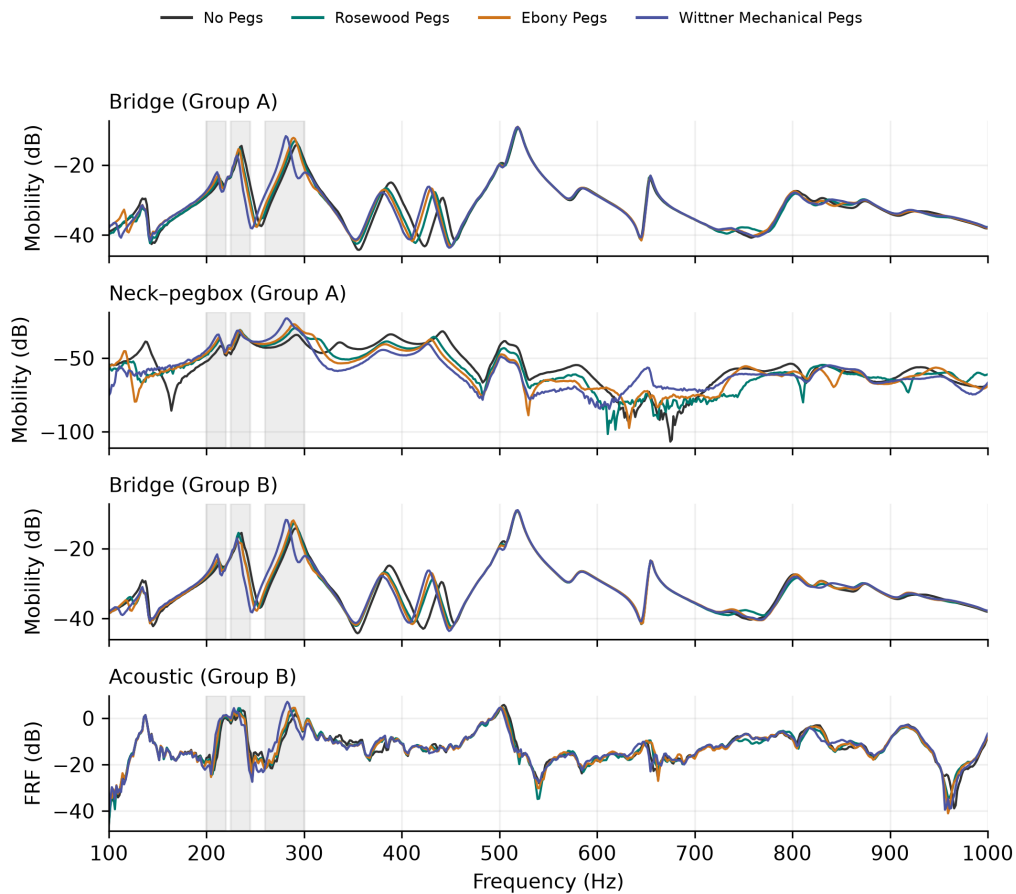


Figure 4. Unsmoothed responses from 100–1000 Hz. The rows show Group A bridge and neck–pegbox mobility, Group B bridge mobility, and Group B acoustic FRF. Mobility levels are relative to 1 m/(N·s), and acoustic levels to 1 Pa/N. Shaded windows are Mode 1 (200–220 Hz), Mode 2 (225–245 Hz), and Mode 3 (260–300 Hz). Group A is the structural dataset (bridge and neck–pegbox), and Group B is the structural–acoustic dataset (bridge and microphone). The bridge traces in the two groups come from the same sensor location in separate acquisitions; structural and acoustic averaging counts differ as specified in Table 1.

The response to peg-system substitution depended on the resonance region. Figure 5 resolves the three tracked regions. Tables 2 and 3 bring together the frequencies, levels, and changes relative to the reference. Structural Mode 3 had the largest frequency shift. Across the reporting sequence, Modes 1 and 3 increased in both bridge and neck–pegbox peak level; Mode 2 instead showed contrasting changes at the two structural observation points.

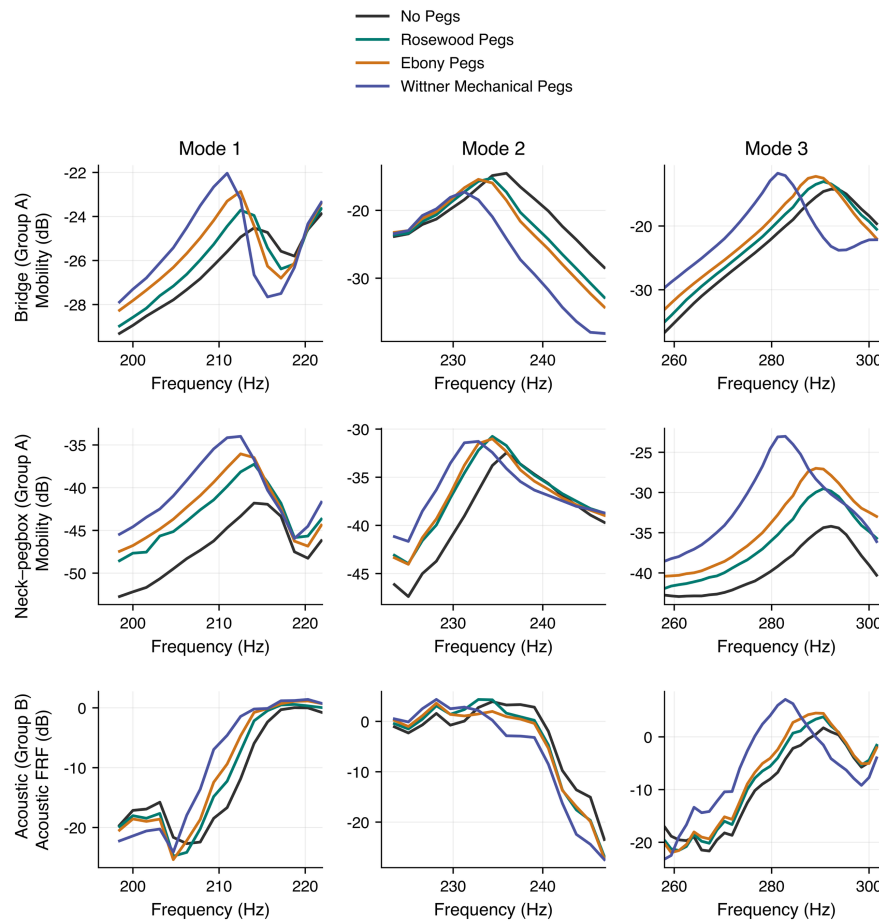


Figure 5. Responses in Mode 1–Mode 3. Columns identify resonance regions; rows show Group A bridge mobility, Group A neck–pegbox mobility, and Group B acoustic FRF. References are 1 m/(N·s) for mobility and 1 Pa/N for acoustic response. Vertical scales differ between panels. The Mode 1 microphone shoulder is not treated as an independent peak; neighbouring maxima remain visible in Mode 2. Group A denotes the paired structural measurements; Group B denotes the structural–acoustic measurements. Acoustic FRF refers to microphone pressure normalized by bridge input force.

For Mode 1, the bridge peak shifted by -3.13 Hz from No Pegs to Wittner, equivalent to two FFT bins. Bridge and neck–pegbox peak levels increased by 2.48 and 7.81 dB, respectively. The same-frequency neck/bridge magnitude ratio increased from 0.137 to 0.248. The acoustic samples followed a different sequence: Rosewood Pegs were 1.27 dB below No Pegs, while Ebony and Wittner were approximately 1.3 dB above it. These samples did not resolve a corresponding independent acoustic resonance.

Table 2. Selected frequencies and FRF levels for the three observation areas

M	Peg condition	Bridge (Group A) f (Hz); L (dB)	Neck–pegbox (Group A) f (Hz); L (dB)	Acoustic (Group B) f (Hz); L (dB)
1	No Pegs	214.06; -24.52	214.06; -41.80	214.06*; -5.94
1	Rosewood Pegs	212.50; -23.71	214.06; -37.25	212.50*; -7.22
1	Ebony Pegs	212.50; -22.87	212.50; -36.04	212.50*; -4.67
1	Wittner Mechanical Pegs	210.94; -22.04	212.50; -33.99	210.94*; -4.60
2	No Pegs	235.94; -14.53	235.94; -32.47	234.38; 3.92
2	Rosewood Pegs	234.38; -15.23	234.38; -30.76	232.81; 4.35
2	Ebony Pegs	232.81; -15.43	234.38; -31.01	228.13; 3.60
2	Wittner Mechanical Pegs	231.25; -17.29	232.81; -31.28	228.13; 4.36
3	No Pegs	292.19; -14.23	292.19; -34.20	290.63; 1.71
3	Rosewood Pegs	290.63; -13.03	290.63; -29.52	290.63; 3.81
3	Ebony Pegs	289.06; -12.21	289.06; -27.00	289.06; 4.51
3	Wittner Mechanical Pegs	281.25; -11.72	282.81; -23.02	282.81; 7.10

Note. **M**: Mode, Each cell reports frequency followed by level. Level references are 1 m/(N·s) for mobility and 1 Pa/N for acoustic FRF. *Acoustic Mode 1 is sampled at the Group B bridge-peak frequency, not at an independent acoustic maximum. Mode 2 acoustic values are band maxima. Decimal display does not imply finer resolution than 1.5625 Hz. Group A contains the paired bridge and neck–pegbox records; Group B contains the bridge and microphone records. Acoustic (Group B) denotes the force-normalized microphone response.

Mode 2 contrasted with Modes 1 and 3. From No Pegs to Wittner, the Group A bridge peak moved downward by 4.69 Hz and its level decreased by 2.76 dB. Nevertheless, every installed peg system had a higher neck–pegbox peak level than No Pegs; among those three systems, the neck level decreased slightly. The acoustic band-maximum levels were non-monotonic and did not follow the bridge decrease. For Ebony and Wittner, the dominant microphone maximum lay on the lower-frequency side of the window. This change in the selected maximum does not establish a continuous shift of the same acoustic pole.

Mode 3 showed the clearest correspondence across the observation areas. From No Pegs to Wittner, the bridge, neck–pegbox, and acoustic maxima shifted downward by 10.94, 9.38, and 7.81 Hz, respectively, while their peak levels increased by 2.51, 11.18, and 5.39 dB. At each Group A bridge-peak frequency, the neck/bridge magnitude ratio increased from 0.100 to 0.270. Both the absolute neck peak level and its response relative to the bridge therefore increased. The largest mass increment did not yield the largest level increment in every response. Because mass was not varied independently of peg-system construction and contact conditions, these observations do not identify a mass-only gain relationship or exclude other possible mass-dependent models.

Table 3. Changes relative to No Pegs within each resonance region.

M	Peg condition	Bridge (Group A) Δf (Hz); ΔL (dB)	Neck–pegbox (Group A) Δf (Hz); ΔL (dB)	Acoustic (Group B) Δf (Hz); ΔL (dB)
1	Rosewood Pegs	–1.56; +0.81	0.00; +4.55	—; –1.27
1	Ebony Pegs	–1.56; +1.66	–1.56; +5.76	—; +1.27
1	Wittner Mechanical Pegs	–3.13; +2.48	–1.56; +7.81	—; +1.35
2	Rosewood Pegs	–1.56; –0.70	–1.56; +1.71	–1.56; +0.43
2	Ebony Pegs	–3.13; –0.90	–1.56; +1.45	–6.25; –0.31
2	Wittner Mechanical Pegs	–4.69; –2.76	–3.13; +1.19	–6.25; +0.44
3	Rosewood Pegs	–1.56; +1.20	–1.56; +4.68	0.00; +2.10
3	Ebony Pegs	–3.13; +2.02	–3.13; +7.21	–1.56; +2.80
3	Wittner Mechanical Pegs	–10.94; +2.51	–9.38; +11.18	–7.81; +5.39

Note. **M:** Mode, No Pegs is the zero reference in every column. A dash indicates that no independent acoustic frequency shift was defined for Mode 1. Acoustic Mode 1 ΔL compares samples at condition-specific Group B bridge frequencies. Differences use unrounded source values.

Consistency and coherence

The Group A and Group B bridge spectra were generally close over 100–1000 Hz. In the reporting order, median absolute level differences were 0.33, 0.29, 0.15, and 0.06 dB. Mode 1 peak frequencies agreed between groups, and Mode 3 frequencies differed by no more than one bin. Mode 2 showed greater differences between stages. For Ebony, the selected bridge peak levels were –15.43 dB in Group A and –17.43 dB in Group B, giving $B - A = -2.00$ dB (Figure 6; Table 4). This compares each record's own selected bridge maximum, not microphone levels or a constant offset across the frequency band. The spectra were not pooled.

Relative comparisons used each group's own No Pegs reference. In Mode 2, the bridge-level changes for Rosewood, Ebony, and Wittner were –0.70, –0.90, and –2.76 dB in Group A, compared with +0.02, –1.91, and –1.56 dB in Group B, respectively, calculated from unrounded spectra. The Ebony–No Pegs contrast therefore changed by –1.01 dB between stages, rather than –2.00 dB, because the No Pegs level also changed. The magnitudes and ordering of the small Group A level changes were not fully preserved in Group B. The direction of the bridge-level decrease was retained for Ebony and Wittner, but not for Rosewood.

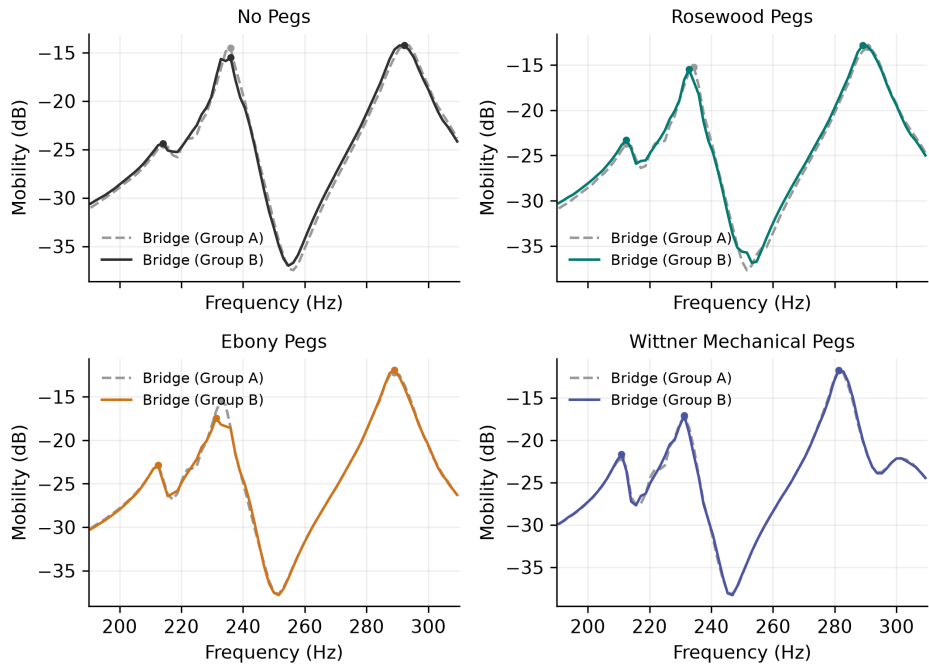


Figure 6. Group A and Group B bridge mobility over 190–310 Hz, separated by peg condition. Dashed grey lines indicate Group A and solid coloured lines Group B. Dots identify the selected FFT-bin maxima. Levels are relative to 1 m/(N.s). The peg sets were reinstalled between stages while the oud and sensors remained in place; these overlays are not a systematic installation-repeatability test.

Table 4. Group B bridge maxima and differences from Group A at each acquisition’s selected maximum. A and B identify the structural and structural–acoustic acquisition datasets, respectively; B – A is the between-dataset difference for the same bridge sensor location, not a comparison of different bridges. Peg sets were reinstalled between the two stages without removing the oud from its supports.

Mode	Peg condition	B f (Hz)	B level (dB)	B – A f (Hz)	B – A level (dB)
1	No Pegs	214.06	-24.37	+0.00	+0.15
1	Rosewood Pegs	212.50	-23.28	+0.00	+0.43
1	Ebony Pegs	212.50	-22.89	+0.00	-0.03
1	Wittner Mechanical Pegs	210.94	-21.66	+0.00	+0.37
2	No Pegs	235.94	-15.52	+0.00	-0.99
2	Rosewood Pegs	232.81	-15.50	-1.56	-0.27
2	Ebony Pegs	231.25	-17.43	-1.56	-2.00
2	Wittner Mechanical Pegs	231.25	-17.08	+0.00	+0.21
3	No Pegs	292.19	-14.25	+0.00	-0.02
3	Rosewood Pegs	289.06	-12.81	-1.56	+0.22
3	Ebony Pegs	289.06	-11.93	+0.00	+0.28
3	Wittner Mechanical Pegs	281.25	-11.79	+0.00	-0.06

Note. Each acquisition contributes its own selected peak. Level reference: 1 m/(N.s). Differences are between acquisitions, not uncertainty estimates. Differences were calculated from unrounded source values.

Figure 7 shows high structural coherence (>0.999) at the evaluated No Pegs neck and Ebony bridge peaks. Acoustic coherence was lower: at the Mode 3 peaks it was 0.720 for No Pegs and 0.745 for Rosewood, with minima of 0.204 and 0.153 elsewhere within the Mode 2 window. Thus, structural quality at these peaks was well supported, whereas the acoustic comparisons require greater caution. Frequency-specific values are provided in Supplementary Table S1; other channel–condition combinations were not measured.

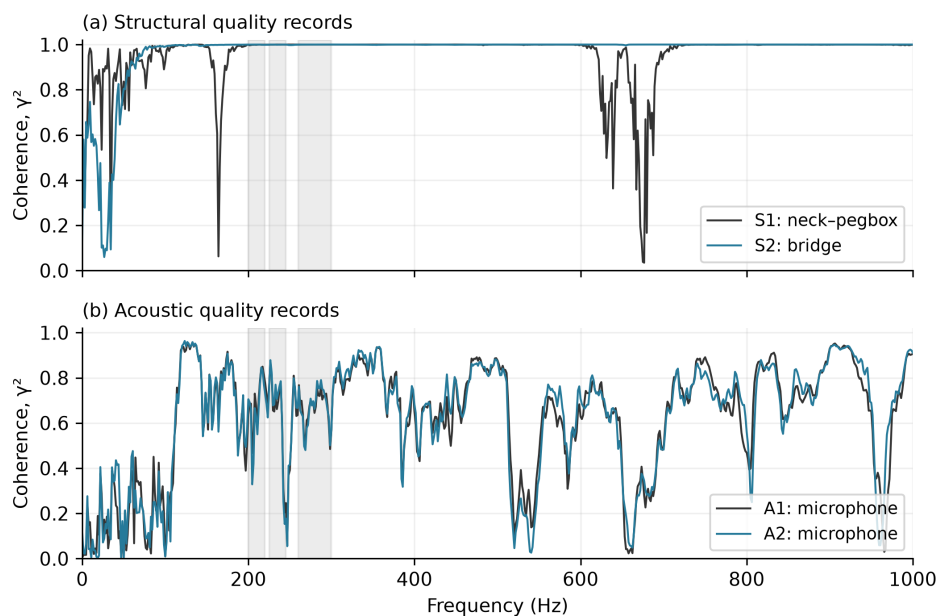


Figure 7. Coherence over 0–1000 Hz for the four acquired records. (a) S1: No Pegs neck–pegbox response, Group A; S2: Ebony bridge response, Group B. (b) A1: No Pegs microphone; A2: Rosewood microphone. Shaded bands indicate the three search windows. These records do not verify every channel and peg condition.

The low acoustic coherence may reflect low response magnitude, noise, or variation between room orientations; the retained data do not separate these contributions. Structural coherence cannot replace missing acoustic quality information. High coherence in an individual structural record does not demonstrate reproducibility after peg reinstallation.

Discussion

The comparison answers the research questions through a pattern of selective sensitivity, not a uniform response to increasing peg-set mass. Of the three selected regions, Mode 3 was the most frequency-sensitive and provided the clearest structural–acoustic correspondence. Mode 2 showed that the near-bridge and neck–pegbox responses need not change in the same direction, while Mode 1 did not provide an independently resolved acoustic peak. The peg-system comparison therefore concerns the distribution of response within a coupled instrument, rather than a single gain applied to all vibration and sound.

The downward structural-frequency shifts are compatible with a contribution from local inertia. Their unequal magnitudes across modes are also consistent with Roohnia’s (2026) position-dependent beam results. That analogy supplies a testable explanation, not a diagnosis: the present measurements do not show that the pegbox is an antinode of any tracked mode. Nor does weighing a peg set determine its effective modal contribution. Differences in mass distribution, contact behaviour, material, and mechanical construction remain inseparable here. In particular, substituting a geared mechanical system for wooden pegs is not equivalent to adding an inert mass while leaving the original assembly unchanged.

Peak levels require an explanation separate from frequency shifts. In a modal expansion, a transfer FRF combines contributions weighted by the mode-shape components at the excitation and response coordinates; its frequency dependence also includes modal stiffness, mass, and damping (Ewins, 2000). Thus, the increased relative neck response in Mode 3 and the bridge–neck contrast in Mode 2 could be associated with altered modal participation at the fixed sensors, damping changes, or contributions from neighbouring modes. The data do not separate these possibilities. The measured neck/bridge ratio describes relative local response; it is not a measure of vibration energy or a one-way transfer of energy from the pegbox to the bridge. The near-bridge and neck channels must likewise remain transfer responses, not be reinterpreted as exact driving-point mobilities.

The neighbouring acoustic maxima in Mode 2 warrant particular restraint. Schleske (2002b) showed that resonant coupling between a violin fingerboard mode and corpus motion can produce a split response. This provides one physical

reason why nearby peaks in an instrument need not behave as an isolated resonance. It does not establish mode splitting in the present spectra. The change in the dominant Mode 2 maximum may reflect altered relative contributions within the band, and peak selection alone cannot distinguish that explanation from a shift of a single modal pole. The between-stage bridge comparison also limits interpretation of the small Mode 2 level changes. Peg reinstallation may have altered seating and contact conditions, but the retained data cannot separate this possibility from other sources of between-stage variation. The -2.00 dB Ebony peak difference is not a general ± 2 dB uncertainty applicable to all channels or frequencies, nor a repeatability estimate from systematic independent installations. This local discrepancy qualifies the Mode 2 bridge-level ranking without invalidating the whole region or the findings in the other tracked regions.

The earlier modal image provides spatial context rather than a substitute for current mode-shape measurements. The pattern labelled Mode 1 shows coloured regions around and below the central sound hole, with additional lower-body regions, whereas the most prominent coloured area in Mode 2 lies further down the body. The pattern associated with Mode 3 contains several active regions across the upper, middle, and lower body. These observations connect the tracked regions to the earlier oud investigation (Değirmenli, 2023), but the static colours do not establish phase, current nodal lines, or pegbox displacement. The neck–pegbox accelerometer adds direct local response evidence in the present comparison; it does not validate full-field identity between the historical patterns and the current resonances.

The acoustic findings answer a different question from the mobility findings. Coupled cavity and structural motion can contribute differently to an exterior pressure response (Elejabarrieta et al., 2002), and the earlier oud study likewise documented differences in the relative prominence of mobility and acoustic features (Değirmenli, 2023). The coincident direction of the Mode 3 frequency and level changes supports a structural–acoustic association in that region; the other regions show why it should not be assumed generally. Bissinger's (2008) determination of violin radiation efficiency combined spatially sampled structural vibration with acoustic measurements surrounding the instrument. The present pressure-to-force response is therefore evidence about the measured acoustic transfer, not total radiated power or radiation efficiency. Rotating instrument and microphone together does not convert it into a directivity measurement.

The Mode 3 acoustic increase of 5.39 dB is a difference between selected FRF maxima for this observation geometry. Its interpretation remains provisional because acoustic coherence was recorded only for No Pegs and Rosewood, with no record for the Wittner response. It is not a validated increase in total sound power or a performance recommendation.

For instrument making, the defensible implication is that peg-system choice can be considered alongside the mechanical design of the neck and body, rather than solely as a tuning or ergonomic decision. This study locates response regions in which further testing is worthwhile while holding the instrument itself constant.

Conclusion

This pilot study compared four peg-system conditions on a single unstrung oud using bridge mobility, neck–pegbox vibration, and force-normalized acoustic measurements. The observed changes varied across the three selected resonance regions. Mode 3 exhibited the largest frequency shifts and the clearest corresponding acoustic change. In Mode 2, the Group A records showed opposite changes in bridge and neck–pegbox peak levels relative to the No Pegs condition, while Mode 1 showed structural changes without an independently resolved acoustic peak. These findings indicate that the response associated with peg-system substitution depends on the resonance region and cannot be described as a uniform increase or decrease in vibration and acoustic output.

The broader implication is that the peg system warrants consideration not only as a means of tuning, but also as a mechanical component of the coupled body–neck–pegbox structure. Changes to this component were associated with changes in both local structural vibration and the measured acoustic response, supporting its consideration in the acoustic assessment and design of the oud. This conclusion remains specific to the tested instrument and conditions: the measurements do not isolate total peg mass from other mechanical differences or establish tonal superiority under playing conditions.

Further work should combine repeated measurements and installations with controlled added-mass and contact-stiffness series on several ouds. Full-field vibration measurements, modal fitting, and mode-shape comparisons would

help distinguish frequency shifts from changes in modal participation and overlapping responses before assigning standard nodal labels.

Limitations

The comparison concerns one oud without string prestress. Peg-set mass, material, geometry, contact behaviour, and installation variability were not varied independently, so the experiment cannot estimate a separate causal effect for each.

Declarations

Ethics. The study involved instrument measurements only, with no human participants, listening tests, or animal experiments.

Author contribution. The sole author designed the study and conducted the experimental measurements.

Funding. This research received no external funding.

Conflict of interest. The author declares no conflict of interest.

Use of AI. OpenAI ChatGPT assisted with language editing, translation, source checking, and the preparation of deterministic analysis and visualization procedures. No experimental measurements were generated by AI. Scientific responsibility for the data, interpretation, and manuscript remains with the author.

Biodata of Author



Asst. Prof. Dr. **Emir Değirmenli** works in the Department of Instrument Education at Ankara Hacı Bayram Veli University Turkish Music State Conservatory. He received his bachelor's degree in physics engineering from Hacettepe University in 2004 and his master's and doctoral degrees from Gazi University in 2014 and 2018, respectively. His research focuses on musical acoustics, experimental and finite-element modal analysis, and musical-instrument making. He is also a physicist and oud maker and teaches courses in sound physics and musical-instrument acoustics. Affiliation: Department of Instrument Education, Turkish Music State

Conservatory, Ankara Hacı Bayram Veli University, Ankara, Türkiye. Email: emir.degirmenli@hbv.edu.tr ORCID: 0000-0001-8164-1448

Personal web site: <https://avesis.hacibayram.edu.tr/emir.degirmenli>

Academia.edu: <https://independent.academia.edu/DeğirmenliEmir>

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

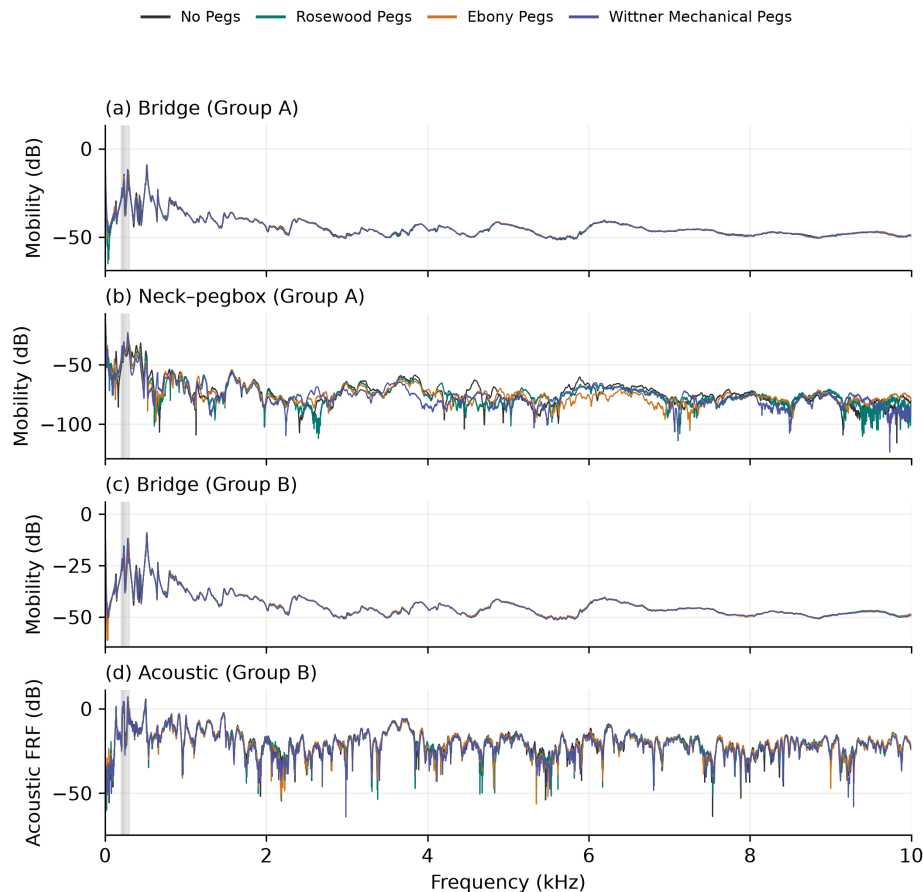
References

- Bissinger, G. (2008). Structural acoustics of good and bad violins. *The Journal of the Acoustical Society of America*, 124(3), 1764–1773. <https://doi.org/10.1121/1.2956478>
- Değirmenli, E. (2023). Titreşim ve ses yayılım analizleri kullanılarak telli çalgılardaki tınısal niteliklerin incelenmesi: Ud örneği [Examining tonal qualities in stringed instruments utilizing vibration and sound radiation analyses: The oud example]. *İdil*, 12(104), 525–534. <https://doi.org/10.7816/idil-12-104-08>
- Dumond, P., & Baddour, N. (2012). Effects of using scalloped shape braces on the natural frequencies of a brace-soundboard system. *Applied Acoustics*, 73(11), 1168–1173. <https://doi.org/10.1016/j.apacoust.2012.05.015>
- Elejabarrieta, M. J., Ezcurra, A., & Santamaría, C. (2002). Coupled modes of the resonance box of the guitar. *The Journal of the Acoustical Society of America*, 111(5), 2283–2292. <https://doi.org/10.1121/1.1470163>
- Ewins, D. J. (2000). *Modal testing: Theory, practice and application* (2nd ed.). Research Studies Press.
- Fender Musical Instruments Corporation. (n.d.). *Fatfinger guitar sustain enhancer* [Product description]. Retrieved September 10, 2026, from <https://www.fender.com/products/fatfinger-guitar-sustain-enhancer>
- Marshall, K. D. (1985). Modal analysis of a violin. *The Journal of the Acoustical Society of America*, 77(2), 695–709. <https://doi.org/10.1121/1.392338>
- Paté, A., Le Carrou, J.-L., Teissier, F., & Fabre, B. (2015). Evolution of the modal behaviour of nominally identical electric guitars during the making process. *Acta Acustica united with Acustica*, 101(3), 567–580. <https://doi.org/10.3813/AAA.918853>
- Roohnia, M. (2026). Localized mass and stiffness effects on beam natural frequencies and modal node-antinode analysis. *Mechanical Systems and Signal Processing*, 257, Article 114552. <https://doi.org/10.1016/j.ymssp.2026.114552>
- Schleske, M. (2002a). Empirical tools in contemporary violin making: Part I. Analysis of design, materials, varnish, and normal modes. *Catgut Acoustical Society Journal, Series II*, 4(5), 50–64.
- Schleske, M. (2002b). Empirical tools in contemporary violin making: Part II. Psychoacoustic analysis and use of acoustical tools. *Catgut Acoustical Society Journal, Series II*, 4(6), 43–61.

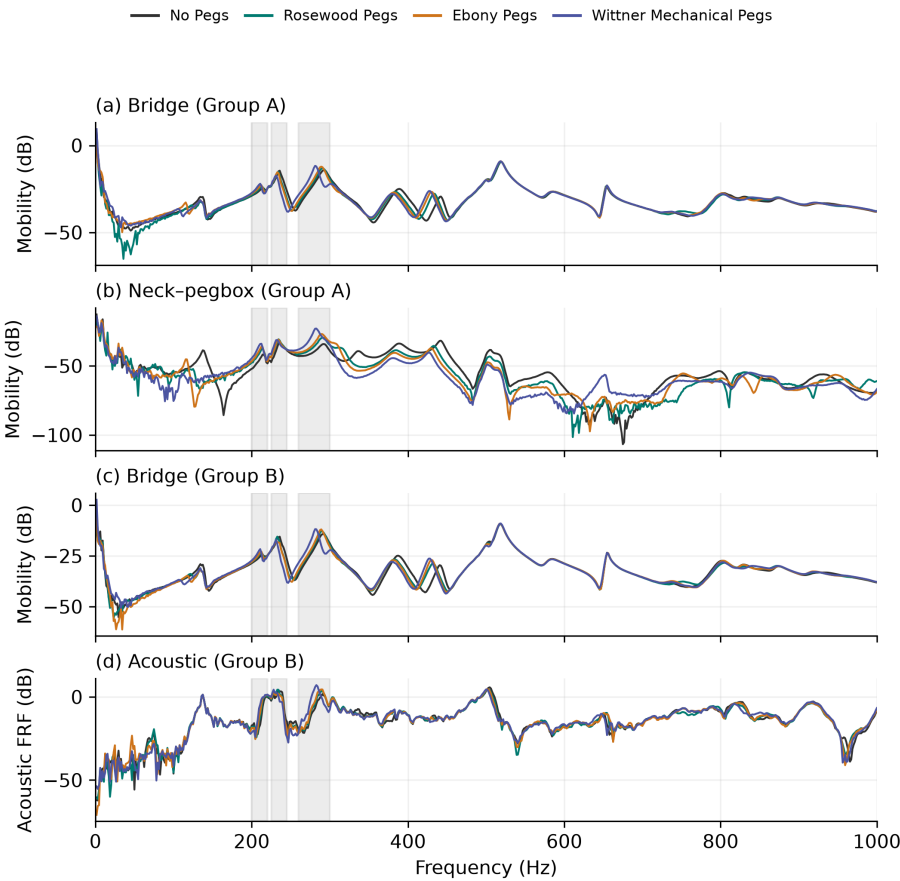
- Şahinkaya, Y., Değirmenli, E., Şahinkaya, H., & Öztörün, Ü. (2024). Effects of hollowed neck designs on sound radiation and loudness of bağlama. *Rast Musicology Journal*, 12(3), 245–276. <https://doi.org/10.12975/rastmd.20241231>
- Wittner. (n.d.). *Finetune-Pegs for violin* [Product specifications]. Retrieved September 24, 2026, from <https://wittner-gmbh.de/mobil/wittner-finetune-peg-violin-mobil.html>
- Woodhouse, J. (2004). On the synthesis of guitar plucks. *Acta Acustica united with Acustica*, 90, 928–944. https://euphonics.org/wp-content/uploads/2022/03/Guitar_I.pdf

Supplementary Material

Supplementary Figs. S1 and S2 place the selected resonance regions within the acquired bandwidth and the low-frequency spectral comparison. They use the same four-condition order as the main text: No Pegs, Rosewood Pegs, Ebony Pegs, and Wittner Mechanical Pegs. All curves are derived from the retained complex FRFs without smoothing; no new measurements or statistical sensitivity analysis are introduced. Supplementary Fig. S3 documents the room and setup location.



Supplementary Fig. S1. Full-bandwidth comparison on a 0–10 kHz axis. Panels show (a) Group A bridge mobility, (b) Group A neck–pegbox mobility, (c) Group B bridge mobility, and (d) Group B force-normalized acoustic response. Mobility levels are in dB re 1 m/(N·s), and acoustic levels in dB re 1 Pa/N. The three shaded tracking windows occupy a small part of this bandwidth. All positive-frequency FFT bins are shown (1.5625 Hz spacing); the zero-frequency point is omitted because the mobility conversion is undefined there. The overview documents spectral context, not verified modal identity or uniform measurement quality up to 10 kHz. Group A denotes the paired structural measurements, and Group B the structural–acoustic measurements; bridge mobility is retained separately for each acquisition dataset.



Supplementary Fig. S2. Detailed low-frequency screening view on a 0–1000 Hz axis, with the same panels, units and condition order as Supplementary Fig. S1. The display includes positive-frequency data below the 100 Hz lower limit of main-text Figure 4. Shading identifies Mode 1 (200–220 Hz), Mode 2 (225–245 Hz), and Mode 3 (260–300 Hz). These windows were selected by qualitative comparison; the figure does not rank all resonances by a quantitative sensitivity measure. No mobility value is plotted at zero frequency.

Supplementary Table S1. Coherence at FRF-derived evaluation frequencies for the four measured channel–condition combinations. Group A identifies the structural dataset, and Group B the structural–acoustic dataset; microphone records belong to Group B.

Record / channel / condition	Mode 1 f (Hz); γ^2	Mode 2 f (Hz); γ^2	Mode 3 f (Hz); γ^2
S1 / Neck-pegbox (Group A) / No Pegs	214.06; 0.999844	235.94; 0.999962	292.19; 0.999989
A1 / Microphone (Group B) / No Pegs	214.06; 0.789903	234.38; 0.661683	290.63; 0.719799
A2 / Microphone (Group B) / Rosewood	212.50; 0.666117	232.81; 0.769644	290.63; 0.745463
S2 / Bridge (Group B) / Ebony	212.50; 0.999878	231.25; 0.999683	289.06; 0.999888

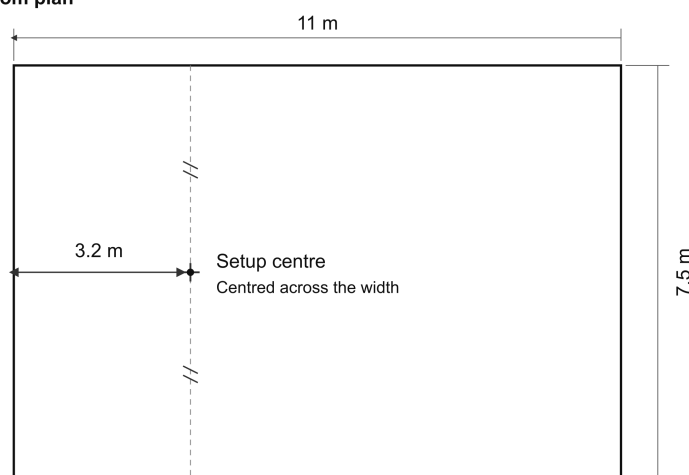
Coherence is dimensionless. Structural values are evaluated at the matched structural FRF maxima. Acoustic Modes 2 and 3 use the acoustic band maxima; acoustic Mode 1 uses the corresponding Group B bridge frequency because no independent acoustic peak was resolved. Frequency-specific values are local quality indicators, not quality estimates for an entire band. Six decimal places retain the exported values and do not express measurement uncertainty.

Across 0–1000 Hz, the median acoustic coherence was 0.684 for No Pegs and 0.700 for Rosewood. Within Mode 2, the window minima were 0.204 and 0.153, whereas coherence at the selected acoustic maxima was 0.662 and 0.770, respectively. No acoustic coherence was acquired for Ebony or Wittner. The full coherence curves, including low values, remain in main-text Figure 7.

(a) Measurement room and fixture



(b) Room plan



Ceiling height: 2.85 m

Centre marker is schematic; apparatus dimensions are not shown.

Supplementary Fig. S3. Measurement environment. (a) Room and fixture without the oud installed; the photograph documents the surroundings, including dark textured wall panels and material beneath the fixture, not an active oud measurement. (b) Plan redrawn from the author's sketch. Equal marks indicate centring across the room width. The centre marker is schematic and does not specify apparatus size or rotation radius.