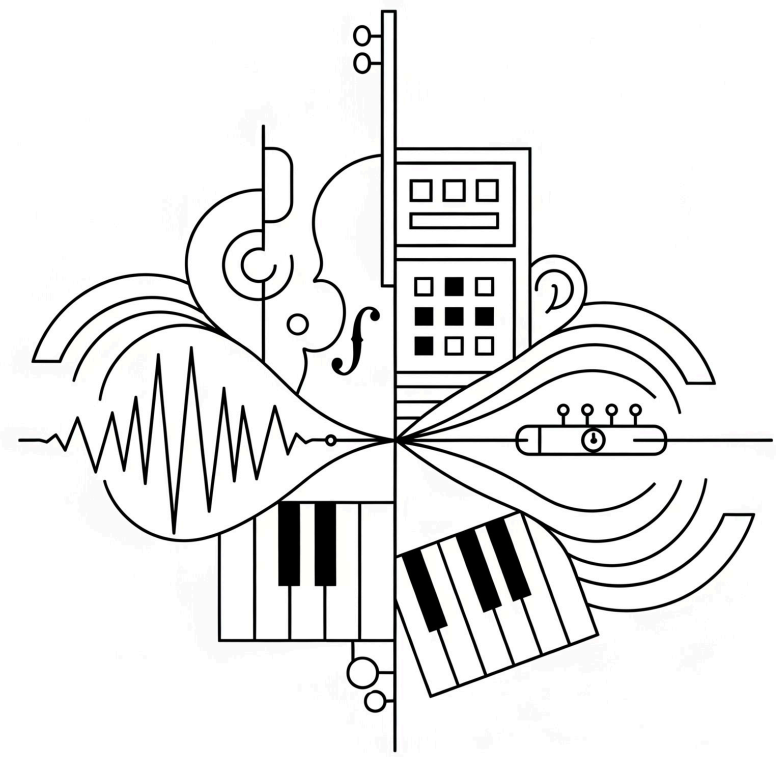
# ABSTRACTS



INTERNATIONAL SYMPOSIUM ON

**MUSICAL ACOUSTICS**

June 15-17, 2026, Helsinki, Finland

UNIARTS HELSINKI

Akustinen Seura ry
Acoustical Society of Finland

Aalto University

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# Monday, June 15

## 09:45–10:40 Keynote 1

### *From the Sounds of the Past to the Instruments of the Future: Five Years of NEMUS*

**Michele Ducceschi — Department of Industrial Engineering, University of Bologna, Italy**

This talk presents a retrospective on NEMUS (Numerical Restoration of Historical Musical Instruments, https://nemusproject.eu/), a five-year ERC-funded project at the University of Bologna. Drawing on the conference theme, I will reflect on how advanced mathematical modelling and numerical simulation can be used to study, preserve, and ultimately revive the sound of historical keyboard instruments currently out of playing condition. I will discuss the project's main research threads — from nonlinear string simulation to real-time physical modelling and haptic control — and offer broader reflections on open-science practices and reproducible methodologies in the context of digital lutherie. The talk will close with a forward-looking perspective on what numerical restoration can offer to the musical acoustics community.

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## 11:00–12:20 Harpsichords and Pianos, *Chair Hanna Järveläinen*

**11:00–11:20**

### *Tuning Shapes Perceived Tension in Historical Harpsichord Music*

**Matias Häkkinen and Hanna Järveläinen**

We conducted an experiment on how tuning systems affect perceived tension in 17th-century harpsichord music. A work by Froberger was recorded in equal temperament and quarter-comma meantone tuning; participants rated tension continuously while listening to versions in randomized order. Bayesian inference revealed that meantone boosted high-tension peaks across groups, with musicians expert in historical tunings showing both stronger peak and lower valley effects. These findings are relevant to music perception, musicology, and historically informed performance.

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**11:20–11:40**

### *Sound impact of simple viscoelastic damping changes due to aging and the role of the double bentside on soundboard tension in a 1755 Dulcken harpsichord*

**Rolf Bader, Niko Plath and Patrick Kontopidis**

The sound perception of wood aging is investigated on a Dulcken harpsichord of 1755 from the Museum of Applied Arts in Hamburg, Germany using a Finite-Difference Time Domain (FDTD) model of the harpsichords soundboard. The soundboard thickness was measured on the instrument at 497 positions during strings being deattached and used in the model. Impulse responses were taken on the instrument to estimate the present internal damping by calculating the T60 decay time and used as a model input. By varying the internal damping from this measured damping as a logarithmic decrement, impulse responses were simulated at 52 string positions on both, the 8' and 4' bridge. To estimate the changed sound brightness due to changed internal damping, spectral centroids were calculated from the simulated impulse responses. A dependency of brightness change due to aging on string position was found, where the lower strings have higher brightness, as expected, while the higher strings have decreased brightness. This counterintuitive finding is caused by the frequency-dependent filter effect of changed damping. Future studies need to incorporate viscoelasticity to differentiate this effect further. Furthermore, the attachment of the 8' string to the outer instead of the inner wall, a characteristic feature of Dulcken harpsichords, is investigated using a 3D Finite-Element Method (FEM) model simulation of the whole instrument. No considerable changes on the soundboard tension were found compared to an attachment of the 8' strings to the inner wall, pointing to another reason for this special construction.

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**11:40–12:00**

### *Physics-based modelling of an early British piano*

**Pablo Miranda Valiente, Giacomo Squicciarini, David Thompson, David O. Norris and Cesar Hernandez**

The digital conservation of historical instruments is crucial for preserving cultural heritage. Pianofortes before the development of the modern piano occupy a prominent place in Western music, as a vast repertoire was originally written to be performed on these instruments. Pianofortes differ from their modern counterparts in their design and construction, inherited from the harpsichord. Given the technological constraints of the period, they do not present a cast-iron frame, and the physical properties and materials of the strings and hammers were different. Consequently, their tonal characteristics differ noticeably. In this study a physics-based model of a Broadwood piano from the 18th century is developed using time-domain modal models. Strings are modelled considering their different materials and a finite element soundboard model was created to obtain its response at different locations at the bridge. The modelling considers transverse and longitudinal motion of the string and the soundboard. Results for selected notes are shown and compared to modern pianos.

**12:00–12:20**

### *Analysis of attack and harmonic components in piano sounds using harmonic/percussive source separation*

**Kyosuke Sato, Atsushi Marui and Toru Kamekawa**

Piano sounds primarily consist of harmonic components originating from string vibration and percussive components caused by the hammer-action excitation mechanism. The percussive components are essential to the characterization of piano sound, and their relationship to subjective evaluations of touch quality and timbre has been noted in previous studies. In this paper, single-note piano recordings were separated into harmonic and percussive parts using the Harmonic/Percussive Source Separation (HPSS) method based on median filtering, as proposed by Fitzgerald (2010). As an advance preparation for planning experiments to investigate the effect of percussive component on timbre perception of piano sound, we analyzed the temporal and spectral characteristics of these components and the separation parameters across different pitches and velocities. Our results show that the percussive component determines the steep attack of the piano sound, but it does not affect the double decay. Comparing the recordings in bridge and keyboard side of grand piano, although the total loudness was higher in bridge side, the ratio of percussive component was higher in keyboard side.

## 14:00–15:40 Sounds of the Past into the Future, Part I, *Chair Vesa Välimäki*

**14:00–14:20**

### *Inverse Problems in Musical Instrument Modeling: A Structured Taxonomy and Review*

**Xinmeng Luan and Gary Scavone**

Musical instrument modeling and inverse problems are essential in musical acoustics, particularly in physics-based sound synthesis, instrument design, and optimization, where they are used to infer physical model parameters and to fit measured data. Inverse problems are widely encountered in engineering and are known to be inherently challenging due to ill-conditioned, and strong sensitivity to noise. This paper presents a structured taxonomy and review of inverse problems in musical instrument modeling, providing a unified framework for their classification.

**14:20–14:40**

## *Studies of Historic Musical Instruments Using X-ray Computed Tomography and Acoustic Measurements*

**Mark Rau, Jared Katz, Jin Woo Lee, Benjamin Sabatini and Nate Steele**

A collaborative effort between Music Technology and the Department of Materials Science and Engineering at the Massachusetts Institute of Technology, and the Museum of Fine Arts (MFA), Boston, to study their historic musical instrument collection, is presented. The MFA's collection includes over 1,100 musical instruments dating back to 1550 BCE. The geometry and density of the instruments are recorded via a Lumafield Neptune industrial X-ray computed tomography (XCT) scanner located in the museum. Additionally, vibration and acoustic measurements are conducted using setups for specific instrument classification. To date, over 30 instruments have been measured. The overarching goals of the project are to produce digital simulations and physical replicas of the instruments that can be played by musicians and museum patrons. This paper will provide an overview of the project and present examples of the studied instruments.

**14:40–15:00**

## *Towards a Framework for CT-Driven FEM Analysis of Musical Instruments: Impact of Geometric Detail on the predicted modal behaviour*

**Sebastian Duran, Henna Tahvanainen and Michele Ducceschi**

In recent literature on the modelling of musical instruments, the use of computed tomography (CT) scans has been increasingly explored. Compared to other 3D imaging techniques, CT offers the crucial advantage of enabling full volumetric reconstruction of an artefact, thus allowing the identification of internal features and structural details without disassembling the instrument. However, less research has aimed at establishing a standardized reverse-engineering workflow translating CT data into a geometry suitable for finite element vibroacoustic analysis, and it remains unclear whether CT-derived geometries provide sufficient added value compared to simpler models built from direct measurements. In this paper, a pilot study is presented on a small kantele. Three geometric representations are considered: a Detailed model derived from CT data, a Reduced version obtained through mesh decimation, and a Simplified model constructed from direct measurements. A FEM-based eigenfrequency analysis is performed on all three models. The Reduced model shows good modal agreement with the Detailed reference, while the Simplified model exhibits substantially larger discrepancies, highlighting the significant impact of geometric fidelity on modal predictions.

**15:00–15:20**

## *Acoustics of an ancient Egyptian cordophone: study of the copy of the Dra' Abou El-Naga arched harp*

**Jean-Loïc Le Carrou, René Caussé and Sibylle Emerit**

During excavations in the years 2002-2005 around the pyramid of the pharaoh Nebkheperrê Antef in the necropolis of Dra' Abou el-Naga, archaeologists found three harps. One of them, although fragmentary when exhumed, has been successfully restored to its entirety, including part of its skin soundboard, which has survived the test of time. Due to the rarity of this vestige, an interdisciplinary study was carried out, including acoustic analysis of the instrument. Unable to directly assess the sound quality of this ancient Egyptian harp, a copy was made by an experienced instrument maker, based on a precise survey of the dimensions and raw materials identified for the body, tailpiece and "pegs". Vibratory and acoustic analysis of this copy has enabled us to gain a better understanding of the expertise of the ancient craftsmen who designed this cordophone around 1350 B.C., and to reflect on the instrument's tuning. In addition, a comparison with the acoustics of harps currently made and played in Central Africa shows similar properties, highlighting a design with similar characteristics, despite different choices of making.

**15:20–15:40**

### *Tuning Principles and Harmonic Alignment in the Mong Kang Gong Ensemble*

**Simon Linke, Robert Mores and Rolf Bader**

The Mong Kang is a ceremonial gong ensemble from northern Thailand, usually played alongside drums. It consists of seven gongs mounted in a frame that allows them to be struck simultaneously by a lever-operated mechanism. Acoustic measurements show a tuning system based on octave and fifth relationships. Depending on the tuning mode, the fifth refers either to the second-lowest or, as observed in detail in this study, to the lowest-tuned gong of the ensemble. The analysis indicates a high degree of tuning accuracy not only among the fundamental frequencies but also in the first overtones. The overtone structures are aligned such that octave and fifth relationships dominate, and harmonic partials of the individual gongs coincide closely, resulting in a stable combined sound spectrum.

## 16:00–17:40 Sounds of the Past into the Future, Part II, *Chair Claudia Fritz*

**16:00–16:20**

### *Authentic Temple Acoustics sub specie heterotopiae (based on the Materials of the Acoustic Study of the Transfiguration Cathedral of the Solovetsky Monastery)*

**Ekaterina Khmara**

The research is devoted to the problem of studying the acoustic features of the interiors of ancient Russian churches in the context of hierotopy as a special type of medieval art. The object of the study is the "sound landscape" of the Transfiguration Cathedral of the Solovetsky Monastery, built in 1558–1566, and the singing tradition of the Solovetsky Monastery as related components of a single "hierotopic project". Based on field studies conducted in an authentic architectural space, the author analyze the objective parameters of the volume and resonant characteristics of the temple, the reactions of the "sound landscape" to sounding liturgical chants, the features of the impact of the sound field of the cathedral on the perception of the liturgical text. The study comes to the conclusion that the features of the "sound landscape" of the Transfiguration Cathedral of the Monastery are an important factor in the organization of sacred space, serving not only as a physical environment for the existence of a musical text, but also as a means of generating meaning.

**16:20–16:40**

### *Effect of Acoustic Variations of Performance Environments on artistic and physiological vocal performance: A Case Study of Medieval Monodic Music*

**Charlotte Fernandez, Nathalie Henrich Bernardoni and Brian F. G. Katz**

Recent research in musical performance analysis has shown that architectural acoustics influence both artistic and physiological aspects of vocal performance. In historically informed performance studies, such interactions have been examined for medieval polyphonic repertoires. Medieval monody, however, has received little comparable attention. This study applies established methodologies to medieval monodic music. A four-voice female ensemble performed four twelfth-century monodic pieces. Each piece was recorded under four acoustic conditions: three positions within the church of Saint-Pierre de Montmartre (Paris) and one adjacent, acoustically drier room. Singers were equipped with head-mounted microphones and electroglottographs. The aim is to identify room acoustic parameters involved in musical, gestural, and physiological variations, with particular focus on contact quotient and perceived vocal fatigue.

**16:40–17:00**

## *Do listeners like vibrato?*

**Noam Amir and Laure Azoulay Chacham**

Vibrato is prevalent in many styles of singing, though not in all of them. Numerous previous works analyzed stylistic variations in vibrato parameters and the way to measure them, but few have actually examined whether singing with vibrato is truly preferred by listeners. The present study is intended as an initial step in addressing this question. We recorded eight professional singers singing the beginning of a major scale from C to G, prolonging the last note in four ways: no vibrato, with their customary vibrato, slow vibrato and fast vibrato, giving 32 recordings in all. Twenty naïve listeners were presented with these recordings in random order, judging their pleasantness on a continuous scale. Statistical analysis revealed a significant, but small (~15%) preference for regular-vibrato over non-vibrato recordings. This is somewhat surprising, given the widespread use of vibrato, indicating that it might also be associated with the preference of the singers themselves. In addition, regular vibrato was preferred over slow and fast vibrato, probably indicating that listeners could perceive whether the singers were performing in their customary range.

**17:00–17:20**

## *A Compact Statistical View of Musical-Instrument Directivity*

**Gioele Greco, Mirco Pezzoli, Raffaele Malvermi, Gian Marco Ricci and Fabio Antonacci**

Directivity is a defining feature of musical-instrument radiation and is known to vary strongly with frequency. With the growing availability of measured directivity datasets and their use in sound-field simulation and spatial audio, there is a practical need for representations that are both compact and comparable across sources. This work addresses that need by proposing a statistically grounded description of frequency-dependent directivity that reduces complex radiation patterns to a small set of meaningful descriptors. The approach enables directivity patterns to be summarised in an interpretable way and compared consistently across frequency bands, even when the radiation is not well described by a single dominant direction. Results on a substantial set of measured orchestral-instrument directivities illustrate how the proposed description facilitates comparison and highlights commonalities and differences between sources.

**17:20–17:40**

## *Spatial modal reverberation*

**Michele Ducceschi, Craig Webb, Matteo Gualeni and Riccardo Russo**

Spatial reverberation is a topic of growing interest in the audio industry. Many applications, such as virtual and augmented reality, gaming, and others, rely on the spatialisation of an acoustic field to achieve realistic audio rendering. Here, we explore the possibility of rendering a moving receiver dynamically inside an acoustic space via a modal architecture. First, the poles of the acoustic space are retrieved for a number of source-receiver positions within the space. Then, the modal weights are computed at each location. Since the poles are invariant with location, the modal weights can be interpolated across locations to render dynamic reverberation at no additional cost, and without loss of quality.

# Tuesday, June 16

## 09:30–10:30 Keynote 2

### *Modeling of the recorder. What we have learned (and continue to learn) from this simple instrument*

**Nicolas Giordano — Department of Physics, Auburn University, USA**

The recorder and its close cousin, the flue organ pipe, are arguably the simplest of wind instruments. Due to their simplicity, they have been ideal instruments for studying fundamental questions common to virtually all wind instruments. Those studies began more than a century ago, with famous contributions from Helmholtz and Rayleigh (among others), and continue to the present. Over the decades, theory, experiment, and modeling have become more sophisticated, answering many important questions and spawning new ones. Much of this work has been concerned with one simple question: Exactly how does the input of energy via a more or less steady air jet give rise to the oscillations of pressure and air velocity associated with the sound of the instrument? This talk will describe how the understanding of these instruments has evolved, and highlight how recent studies employing direct application of the Navier-Stokes equations have led to new insights.

## 10:50–12:50 Wind Instruments I , *Chair Vasileios Chatziioannou*

**10:50–11:10**

### *Digital Revival: Acoustic Documentation and Digital Reactivation of Historical Woodwind Instruments*

**Lior Arbel and Itai Weissman**

Historical woodwind instruments exhibit complex acoustic behaviors that are central to their musical, organological, and cultural significance. However, due to material fragility, aging, and strict conservation requirements, many original instruments held in museum collections can no longer be played. Digital Revival is an ongoing research project developed in close collaboration with the Rijksmuseum (Amsterdam) and the Kunstmuseum Den Haag. The project investigates how controlled, non-invasive acoustic sampling and digital sound modeling can be used to document, preserve, and reactivate the sonic characteristics of historical woodwind instruments while fully respecting conservation constraints. The resulting datasets function both as analytical resources and as playable digital instruments, enabling comparative study of spectral envelopes, transient behavior, and response characteristics across registers and playing techniques.

**11:10–11:30**

### *Study of sub-harmonic tones in the recorder*

**Nicholas Giordano and K. L. Saenger**

In previous work we observed and studied the properties of "half-harmonic" tones in the recorder. These are tones with frequencies (n+1/2)*f1 where f1 is the fundamental frequency and n=1,2,3... We have now found that, at certain blowing pressures, "quarter-harmonics" can be present. They have been observed in both Navier-Stokes-based simulations and in experiments, and have been found only at low blowing pressures. The existence of both half- and quarter-harmonics is surprising, since it implies that the velocity oscillations associated with these tones do not exhibit anti-nodes at the blown end of the instrument, contrary to what is expected for instruments like the recorder. We also describe the results of an analysis of the simulations using spectral filtering to extract the flow patterns in the mouthpiece region which are associated with these subharmonics.

**11:30–11:50**

### *Evaluation of perceptual and acceptability thresholds of recorder detuning*

**Corto Bastien, Claudia Fritz and Augustin Ernoult**

This study aims to determine the just noticeable difference (JND) threshold for tuning variations on recorders, assessed in an expert population comprising professional musicians and instrument makers. To date, no discrimination threshold specific to the tuning of wind instruments has been established for such a population. Determining such a threshold may provide useful benchmarks for instrument makers and acousticians, allowing them to more precisely guide the design, adjustment, and optimization of instruments.

To this end, a corpus of recorder bodies was built around an initial model using 3D printing, in which small, controlled geometric variations were introduced following an acoustic optimization process. These modifications change the tuning of specific notes or intervals, enabling a precise exploration of the participants' sensitivity.

The perceptual evaluation is based on an A/not-A protocol with constant reference, designed to measure the experts' ability to identify, in a playing context, a pitch variation expressed in cents relative to the reference geometry.

Moreover, because pitch in performance is not only determined by the instrument but also by the musician's corrective and compensatory actions, a second objective is to examine musicians' capacity for compensation during performance. By comparing the perceptual threshold with the acceptability threshold, defined as the level at which a tuning correction becomes necessary or perceptibly disturbing for the musician, this research seeks to better understand the relationship between perception, instrumental adjustments, and musical practice.

**11:50–12:10**

### *Development of an Inclusive Wind Instrument Enabling Pitch Control via Neck-Opening Area Variation in Helmholtz Resonance*

**Kojiro Nishimiya and Seiji Adachi**

Inclusive and accessible musical instruments that enable performance by people with physical disabilities have been developed in various forms. This study aims to develop an inclusive wind instrument based on a bottle flute utilizing Helmholtz resonance. In a bottle flute, pitch can be controlled by varying the opening area at the neck using the lips, eliminating the need for finger holes for pitch control. The results confirm that variation of the neck opening area enables pitch control over a range of approximately two octaves. Furthermore, in the lower frequency register under human blowing conditions, lip vibration was observed to function as a lip reed, resulting in a noticeable change in timbre.

**12:10–12:30**

### *Power-balanced simulation of a Paracas whistle*

**Champ Darabundit, Mark Rau, Jared Katz, Benjamin Sabatini and Gary Scavone**

In collaboration with the Museum of Fine Arts, Boston, X-ray computed tomography (CT) scans were made of a ceramic whistle from the Paracas culture (600–175 BC). A repaired crack in the whistle, along with the ceramic's sensitivity to moisture, prevents the instrument from being played. By scanning the whistle, it was possible to produce 3D-printed replicas which can be handled and played. From measurements, a lumped power-balanced model was derived using the port-Hamiltonian system framework and numerically simulated using finite-difference time domain (FDTD) methods. These simulations were used to produce a real-time interactive audio application reproducing the sound of the whistle.

**12:30–12:50**

### *Numerical Study of Air-jet Instrument Sounds using Hydrodynamic-Acoustic Splitting*

**Jin Woo Lee, Benjamin Sabatini, Jared Katz, Nate Steele and Mark Rau**

This study presents a coupled hydrodynamic-acoustic model for simulating jet oscillations in air-jet instruments. This approach integrates an incompressible Navier-Stokes solver with a linear acoustic wave equation to efficiently simulate the sound without relying on lumped parameters. The model employs a hydrodynamic/acoustic splitting formulation along with Lighthill acoustic analogy to model the air fluctuations induced by jet flow near the labium and in the resonator. The simulations reproduce characteristic jet displacement oscillations and their periodic coupling with the acoustic pressure near the labium. The resulting flow fields and oscillation patterns demonstrate agreement with established recorder instrument sounds.

## 14:00–15:00 **Wind Instruments II,** *Chair Amélie Gaillard*

**14:00–14:20**

### *Acoustic Impedance of FDM-Printed Cylindrical Waveguides: Influence of Surface Conditions and Infill Structures*

**Daniel Ha and Gary Scavone**

Fused deposition modeling (FDM), a form of additive manufacturing, has wide application in prototyping wind instruments and their components. This study quantifies the resonance frequencies and peak impedance of polylactic acid (PLA) cylindrical waveguides via input impedance measurements and comparison with viscothermal theory. Two infill densities were explored: 100% (solid) and 40% (partial). Input impedance (Zin) was measured under closed-closed boundary conditions in a hemi-anechoic chamber. Measured frequencies aligned with theory to within 18 Hz across modes 1–9, a maximum relative deviation of less than 0.31% (5.3 cents). Solid-infill FDM PLA samples do not have a substantial offset from smooth-bore PVC across all modes, indicating that FDM-printed cylindrical waveguides are acoustically comparable to extruded PVC at the parameters tested.

**14:20–14:40**

### *Transverse flute dynamics explored using a jet-drive model*

**Tom Colinot**

The dynamics of the flue instruments at high velocities are usually described using a jet-drive model. However, this model has only been used in the literature for recorder-like instruments, with fixed channel and labium positions. The present work explores the potential of the jet-drive model to be extended to model a transverse flute, where the channel parameters are linked to the position of the mouth of the player with respect to the labium. Real-time synthesis, carpet-bombing cartography and Support Vector Machine cartography give a nuanced understanding of the dynamics of the model, outlining multistability zones and quasiperiodic regimes.

**14:40–15:00**

### *Experimental acoustic characterization of a three-hole flute*

**Damien Forgeot D'Arc and Augustin Ernoult**

Three-hole flutes are fipple flutes played one-handed in historical or traditional music from southern France and northern Spain (e.g., galoubet, txistu). The few fingerings possible with these three holes are combined with mouth pressure variations to produce a diatonic scale over multiple octaves. Unlike most wind instruments with side holes, these flutes can play up to five registers using the same fingering. Experiments with artificial mouth show that the same pressure range allows playing up to six registers on a three-hole flute, while only three registers on a baroque recorder. This property appears linked to subtle aspects of the whistle geometry (e.g., windway and edge), which current flute models struggle to explain.

## 15:00–16:00 Idiophones, *Chair Masanobu Miura*

**15:00–15:20**

### *Influence of Membrane Viscoelasticity on Timbre Perception of the Colombian Alegre Drum: A Combined Experimental, Psychoacoustic, and Physics-Informed Machine Learning Approach*

**Cristhiam Fidel Martínez Orellanos and Rolf Bader**

The Alegre, a single-headed wooden vessel drum with a goat skin membrane from Colombia's northern coast, plays a fundamental role in the region's cultural traditions. This study investigates the relationship between viscoelastic damping of leather, the Alegre's frequency spectrum, and timbre perception. A viscoelastic Finite Difference Time-Domain (FDTD) model of the drumhead is used to systematically explore a parameter space of possible viscoelastic behaviors. A physics- and psychoacoustics-informed Machine Learning (ML) model trained on FDTD simulations is employed to retrieve the viscoelastic parameters of the real drumhead by finding the best fit between predictions and recorded spectra.

**15:20–15:40**

### *Sound radiation-based optimization for the design of undercut idiophone bars*

**Vincent Debut and Filipe Soares**

Previous studies have demonstrated that the optimization of musical bars toward predefined modal frequencies can lead to the production of precisely tuned vibraphones and marimbas. However, most optimization procedures have relied solely on vibrational criteria, without explicitly accounting for the acoustic radiation properties of the instruments. The present work addresses this limitation by formulating the bar-tuning optimization problem from a sound radiation–based perspective. The proposed approach is anchored in a modal description of the bar vibrations and employs a method to estimate the resulting acoustic radiation based solely on the geometry of the mode shapes. Non-symmetric bar geometries are considered, as they naturally offer enhanced flexibility for controlling and optimizing acoustic radiation.

**15:40–16:00**

### *Fine motor control of cymbal-to-cymbal collision in orchestral cymbal performance*

**Masanobu Miura and Hidehiko Kozai**

We aim to analyze how performers control their arm movements during the collision of two orchestral cymbals, using motion-capture recordings. We compare two performers: a professional orchestral cymbal player and a doctoral-level music student. In orchestral cymbal playing, performers often describe two contrasting collision strategies: "to strike", in which the cymbals are brought together with a clear impact, and "to rub", in which the cymbals make contact while sliding or pressing against each other. Our preliminary observations suggest that these two strategies produce distinct arm-control patterns. Clear differences emerge around the time point when the relative velocity between the two cymbals approaches zero, a timing that appears critical for characterizing how performers regulate the collision event.

## 16:20–18:00 Guitars and Strings, *Chair Mark Rau*

**16:20–16:40**

### *Gradient-based design optimization of classical guitars under material variability*

**Pierfrancesco Cillo, Pascal Ziegler and Peter Eberhard**

Classical guitar manufacturing traditionally relies on reproducing historical designs that serve as tonal benchmarks. However, variability in the mechanical properties of tonewoods results in substantially different vibrational behavior among instruments built to identical specifications. This work presents a computational framework for systematically compensating material variability through targeted geometric modifications using virtual prototyping. A finite element model of a guitar body is developed and parameterized with respect to

soundboard and back bracing thicknesses. Parametric model order reduction is used to construct an efficient surrogate, and analytical eigenfrequency gradients enable sensitivity analysis and accelerate optimization convergence. The framework accurately reproduces the target modal response, demonstrating its potential as a virtual prototyping tool for improving tonal consistency across instruments.

**16:40–17:00**

## *A physical synthesis framework for vibro-acoustic interaction of plucked strings in classical guitars*

**Tharindu Danushka Nandalal, Pierfrancesco Cillo, Pascal Ziegler and Peter Eberhard**

The dynamic behavior of a classical guitar arises from complex coupled interactions among vibrating strings, the resonating wooden body, and the enclosed air cavity. This study proposes the Udwadia-Kalaba formulation as an alternative framework for simulating constrained vibro-acoustic dynamics within a finite element context. The approach is extended through projection-based model order reduction, preserving the essential coupled dynamics while significantly reducing the system dimensionality. The method is applied to a reverse-engineered and experimentally validated finite element model of a classical guitar, encompassing pre-tensioned strings, the wooden body, and the enclosed air cavity.

**17:00–17:20**

## *Study of the influence of the bridge on the sound of an acoustic guitar using virtual prototyping*

**Victor Piton, Kerem Ege, Jean-Loïc Le Carrou and Quentin Leclère**

The work presented here focuses on acoustic guitar prototyping, including the bridge. A hybrid model is proposed, combining semi-analytical formulations for the bridge and strings with numerical formulations for the soundboard. This model introduces a surface coupling between the bridge and the soundboard using a modal substructuring formalism. The inclusion of the bridge in a general guitar model enables a detailed assessment of how the bridge's mechanical and geometrical properties influence the instrument's modal behavior. The sounds radiated by the virtual prototype would be synthesized for subsequent perceptual studies, aiming to relate the perceptual qualities of the instrument's timbre to the mechanical parameters of the bridge and soundboard.

**17:20–17:40**

## *Parametric Modeling of Tanbūr-Family Lutes for Finite Element Analysis*

**Adam Łapiński, Marguerite Jossic and Claudia Fritz**

The tanbur is a long-necked lute widely used across a diverse geographical and cultural range. The instrument exists in numerous regional variants, varying in form, nomenclature, and construction details. This study proposes a fully parametric model for reconstructing tanbur-family long-necked lutes natively within COMSOL Multiphysics. Using a minimal set of parameters and curves, the model mathematically defines Eastern lutes to enable precise, intuitive, and efficient adaptation. The presented work forms the initial stage of a doctoral project dedicated to the systematic investigation of the relationship between constructional features and the vibro-acoustic behaviour of the tanbur.

**17:40–18:00**

## *Physics-based Modeling of the Yehu, a Chinese Bowed String Instrument*

**Zhen Zheng, Champ Darabundit and Gary Scavone**

The yehu is a traditional Chinese bowed string instrument featuring a resonator carved from a coconut shell, a shell-based bridge, and two silk strings. This study combines a physics-based bowed string model with acoustic measurements to enable realistic sound synthesis of the yehu. The proposed physical model comprises a linear stiff string with frequency-dependent losses driven by a moving bow, with the excitation force computed through

a nonlinear friction curve linking bow force and bow velocity. A finite difference scheme is employed to simulate transverse string vibrations in the time domain. Both the bridge admittance and radiation responses are obtained from measurements.

## 19:00–22:00 **Poster Session,** *Chair Henna Tahvanainen*

### *Finite-Difference Time-Domain Modeling of a Historical Ocarina*

**Anthony Wang, Irene Dong, Jared Katz, Jin Woo Lee, Benjamin Sabatini and Mark Rau**

This study investigates the use of 3D finite-difference time-domain (FDTD) schemes to model the acoustics of a historical ocarina housed at the Museum of Fine Arts, Boston. X-ray Computed Tomography (XCT) scanning is employed to generate high-resolution 3D models for FDTD grids. Two methods for modeling excitation are examined: a stochastic approach using random noise to simulate turbulence, and a coupled model that directly calculates the interaction between the air jet and the labium. Dynamic boundary conditions at the tone holes enable the model to capture the effects of note transitions and different articulation styles. Results are compared against fabricated replicas of the ocarinas to validate the simulated spectral features.

### *Identifying the nonlinear string dynamics with port-Hamiltonian neural networks*

**Maximino Linares, Guillaume Doras and Thomas Hélie**

Hybrid machine learning combines physical knowledge with data-driven models to enhance interpretability and performance. This work demonstrates how to learn the nonlinear string dynamics from data in a physically-consistent framework through a Port-Hamiltonian Neural Network (PHNN) extension to PDEs. By constructing structured neural network architectures based on Port-Hamiltonian Systems, we can recover both the Hamiltonian governing the string and the dissipation affecting it. This approach outperforms baseline, non-physics-informed methods in terms of both accuracy and interpretability. Numerical experiments using synthetic data demonstrate the ability of the proposed PHNN model to identify and emulate the nonlinear dynamics of the system.

### *Optimization of the baroque transverse flute geometry for tuning modifications*

**Amélie Gaillard, Augustin Ernoult, Patricio de la Cuadra and Benoît Fabre**

The traverso is a kind of transverse flute from the Baroque period. A common practice is to have several traverso bodies for a single headjoint in order to play with different concert pitches or tessitura. The design of these different bodies had to compensate for the fact that the headjoint was designed for a specific pitch. The aim of the present study is to apply acoustical optimization results to the case of the traverso, focusing on optimizing the geometrical modifications to be applied to the instrument body to move from one tuning to another while maintaining the same timbre characteristics and relative pitch between notes.

### *Contribution of sound simulations by physical model and machine learning models for the prediction of spectral centroid trumpets sounds: influence of the leadpipe bore*

**Jean-Francois Petiot, Mauricio Payan, Vincent Freour and Keita Arimoto**

This work studies the contribution of sound simulations by physical model and machine learning models for the prediction of trumpet sound spectral centroid. A training set of 1000 virtual instruments is constituted by varying the internal geometry (the leadpipe) of the bore of a trumpet. A supervised learning using random forests is performed on the training set, modeling each variable according to the geometric variables of the leadpipe. Different maps are proposed to show how spectral variables evolve as a function of the geometry of the leadpipe, allowing visualization of typical leadpipe profiles corresponding to given levels of the spectral variables.

## *Lip-Specific Mouthpiece Force in Brass Performance: Effects of Pitch and Intensity in a Note-Synchronised Dataset*

**Paul Amann, Vasileios Chatziioannou, Pascal Nicolay and Roland Willmann**

Mouthpiece force is widely discussed in brass pedagogy and performance science, yet lip-specific force behaviour under realistic playing conditions remains insufficiently understood. This study quantifies how upper- and lower-lip mouthpiece forces vary with performed pitch and realised intensity using a custom sensor mouthpiece. The dataset comprises more than 80 brass players ranging from beginners to professionals and represents the largest note-synchronised dataset of lip-specific brass embouchure measurements reported to date. Lip-specific mouthpiece force increased systematically with both ascending pitch and increasing realised intensity. The results provide large-scale evidence that embouchure force regulation in brass playing combines robust pitch- and intensity-related trends with substantial performer-specific strategies.

## *Understanding Oscillation in Membrane-Based Mouthpiece Models*

**Gioele Greco, Vincent Freour, Filipe Soares, Jean-Baptiste Doc, Christophe Vergez, Mirco Pezzoli and Fabio Antonacci**

Membrane-based mouthpieces can act as self-oscillating exciters when coupled to an acoustic resonator, providing an alternative to reed and lip-valve mechanisms. This work develops and studies a one degree of freedom physically grounded model that captures the essential coupling between a vibrating membrane, the resonator response, and a nonlinear airflow drive. Linear stability analysis combined with time-domain simulations identify onset conditions across representative parameter choices. The main contribution is a description of how oscillation onset and playing frequency vary with respect to a small set of design factors, supporting comparison between membrane mouthpiece configurations and guiding design decisions.

## *Modeling the Acoustics of a Veracruz Classic Period Three Chamber Polyglobular Flute with COMSOL Multiphysics*

**Victoria Pham, Jared Katz, Mark Rau, Alex Tung and Benjamin Sabatini**

To study an ancient Veracruz earthenware human effigy polyglobular flute dating to 500-900 CE, 3D meshes were acquired non-destructively via X-ray Computed Tomography (XCT). This particular instrument is notable because it is multi-chambered yet only has a total of three tone holes in two out of its three chambers. The air input velocity was modeled in COMSOL to simulate the instrument's sound pressure levels and determine the resonant frequencies. These results were cross-checked with empirically gathered data to confirm the model's validity.

## *Geometric and Acoustic Studies of a Collection of Historically Significant Saxophone Mouthpieces*

**Alexander Mazurenko, Benjamin Sabatini, Caleb Burkhardt and Mark Rau**

A collection of twenty-five historically significant alto saxophone mouthpieces was studied using a Lumafield Neptune industrial X-ray computed tomography (XCT) scanner, producing high-resolution 3D models. The mouthpieces in the collection represent notable manufacturers, including Selmer and Meyer, and contains two made by Adolphe Sax himself. Patterns and characteristics in mouthpiece development and relationships between production and manufacturers are identified to establish a database of specific information on historical mouthpieces. Progress toward measuring their acoustical impedance using a custom-built impedance probe is also reported.

# Wednesday, June 17

## 10:00–11:00 Reed Instruments, *Chair Seiji Adachi*

**10:00–10:20**

### *Deep neural network-based optimization of oboe geometry from target sound spectrum*

**Fumihiko Kurosawa, Naoto Wakatsuki and Tadashi Ebihara**

Oboe reeds making has traditionally relied on individual players' empirical rules. To overcome this dependence on subjective methods, this study developed a system that solves an inverse problem: predicting optimal reed shape parameters from target acoustic characteristics. This method generates a comprehensive training dataset through a two-step physical simulation process. First, a simplified 3D reed model with four local thickness parameters is analyzed using finite element analysis to calculate mechanical properties. A deep neural network was trained using the constructed database to determine the geometric thickness parameters corresponding to the desired acoustic characteristics. The trained model demonstrated acceptable prediction even for unknown test data, suggesting it reasonably captures the complex physical phenomena underlying reed vibration.

**10:20–10:40**

### *Development of a prototype accordion with the aid of digital fabrication*

**Artturi Vuorinen**

Digital fabrication has gained a lot of popularity with affordable machinery for consumers as well as with the accessibility to makerspaces and fablabs. This master's thesis focuses on musician-led instrument development, building a prototype instrument based on an idea developed as a musician. The research explores the possibilities that digital fabrication offers for instrument research, the use of Aalto University's Aalto Fablab in the building process, and examines the advantages and disadvantages of digital fabrication tools for a musician with novice skills in woodworking.

**10:40–11:00**

### *Reproducing Accordion Pitch Bending using a Physical Model with Reed Box Resonance and Laminar and Turbulent Resistance*

**Hyuga Okada, Seiji Adachi, Toshiya Samejima, Masakazu Takeda and Kojiro Nishimiya**

Pitch bending is a phenomenon wherein the frequency of the sound from the instrument decreases. In accordions, pitch bending occurs when the keys are lightly pressed while the bellows are strongly pushed or pulled. A physical model of the accordion was developed incorporating the acoustic resonance of the reed chamber as a Helmholtz resonator with laminar flow resistance. Time-domain simulations based on this model successfully reproduced pitch bending when the pallet opening was narrowed. An improved model incorporating a variable turbulent resistance at the pallet opening and the aerodynamic inertia of the air successfully eliminated the frequency re-increase and reproduced pitch-bending behavior dependent on the blowing pressure and pallet opening area.

## 11:20–12:40 Brass Instruments I, *Chair Naoto Wakatsuki*

**11:20–11:40**

### *Nonlinear dynamics of brass instruments in loud playing conditions: confronting models with artificial blowing experiments*

**Filipe Soares, Vincent Fréour, Christophe Vergez and Bruno Cochelin**

In this study we explore the nonlinear dynamics of brass instruments in large amplitude playing conditions through experiments on an artificial blowing machine and numerical continuation on a physical model involving the coupling between a 1-DoF lip-valve and an acoustic resonator including nonlinear propagation. While experiments confirm the expected spectral enrichment resulting from nonlinear propagation, they also reveal several phenomena not captured by the model, including upwards/downwards shifts in playing frequency, the apparition of "ghost" regimes, quasi-periodic oscillations and chaos, as well as the character of the transitions between regimes.

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**11:40–12:00**

### *Experimental characterization of artificial lips and benefits for the physical modelling of the trumpet*

**Vincent Freour, Filipe Soares, Christophe Vergez and Bruno Cochelin**

In physical modelling of wind instruments, the choice of the physical model of the excitation mechanism (reed, lips, etc.) is often quite critical. In this study we measure the frequency response of artificial lips mounted on an artificial player system used for the trumpet. The values of the parameters of a one-degree-of-freedom lip model extracted experimentally are discussed in light of the experimental conditions. These parameters are then used for numerical simulations to assess the ability of a physical model to reproduce some specific behaviours observed experimentally.

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**12:00–12:20**

### *Lip dynamics in brass instruments: A sparse system-identification approach*

**Marco Aragó Bishop, Christophe Vergez, Vincent Fréour, Filipe Soares and Bruno Cochelin**

In brass instruments, sound is generated through the self-sustained oscillation of a coupled system consisting of the player's lips and the air column within the instrument. This paper studies the dynamical response of the lips using a combined experimental and data-driven approach. Lip motion, mouthpiece pressure, and blowing pressure are recorded using an instrumented trumpet coupled to an artificial player system with silicone lips. Differential models are derived using the Sparse Identification of Nonlinear Dynamics (SINDy) framework, applied to the measured datasets. The identified models are evaluated for parsimony, physical interpretability, and predictive performance under unseen operating conditions.

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**12:20–12:40**

### *Vocal-Tract Acoustic Effects on Self-Sustained Oscillation in Trumpet Sound Production*

**Hiroshi Shirai, Ukyo Inomata, Naoto Wakatsuki, Keiichi Zempo and Yuka Maeda**

In trumpet sound production, previous studies have indicated that the acoustic characteristics of the vocal tract can influence the conditions required for generating and maintaining oscillation. To address this issue, we constructed a simplified acoustic model of the vocal tract using a cylindrical resonator with adjustable length. Experiments and numerical simulations by playing a trumpet through this resonator were conducted. The findings revealed that mode-8 oscillation can be sustained over a wide range of blowing pressures when the resonance frequency of the cylindrical resonator lies within a certain interval. Furthermore, it was confirmed that the resonance mode selection of the oscillation can be determined by the vocal-tract acoustic properties.

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## 14:00–15:40 **Brass Instruments, Part II,** *Chair Vincent Fréour*

**14:00–14:20**

### *Identification of Acoustic Maps for Sound Production and Intonation of a Trumpet*

**Harry Mayrhofer, Samy Missoum and Christophe Vergez**

This study investigates the explicit decomposition of the control-parameter space into regions corresponding to desired acoustical behaviors in brass instruments. The work focuses on identifying the conditions under which sustained sounds at a target frequency, with a given pitch accuracy, occur. The mapping is performed using a Support Vector Machine (SVM) classifier combined with a dedicated adaptive sampling scheme. It is applied to

a trumpet model in which the player's lips are coupled to a linear resonator characterized by an experimentally measured input impedance. In addition, these maps can be used to determine the probability of achieving a desired acoustical behavior under uncertainty in the player's control parameters.

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**14:40–15:00**

### *Perceived Loudness in Trumpets in Relation to Directivity Patterns and Psychoacoustic Metrics*

**Juan Luis de la Torre and Daniel de la Prida**

This study examines whether differences in sound radiation among three professional B♭ trumpets influence perceived loudness and whether these differences can be captured using acoustic and psychoacoustic descriptors. Thirteen professional trumpet players performed controlled excerpts at piano and forte dynamic levels. Recordings were conducted in an anechoic chamber using a horizontal microphone array and binaural in-ear microphones. Results show measurable differences in acoustic radiation between the three trumpet models while SPL values at the player's ear direction remain similar across instruments, suggesting consistent dynamic regulation based on local auditory feedback.

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**15:00–15:20**

### *Double Hopf Bifurcations in Brass Instruments: A Comparison Between a Numerical Model and Results Obtained with an Artificial Player System*

**Martin Pégeot, Tom Colinot, Jean-Baptiste Doc, Vincent Fréour and Christophe Vergez**

Brass instruments have several periodic solutions accessible to musicians through control parameters. This paper shows that double Hopf bifurcations are common in brass instruments and compares the behavior of a physical model of soprano trombone with experimental results obtained with an artificial player system near one of these bifurcations. Both linear and statistical analysis methods are used to study the steady-state and transient regimes of these systems. This comparison shows that a model with only two acoustic resonances is able to encapsulate the rich dynamics of the instrument near a double Hopf bifurcation, including its transient and multistable behaviors.

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**15:20–15:40**

### *Deep Learning-Based Estimation of Geometric Parameters from Acoustic Impedance for Inverse Design of Brass Instruments*

**Ukyo Inomata, Naoto Wakatsuki, Tadashi Ebihara and Yuka Maeda**

This study presents a deep learning-based approach to estimate geometric parameters from acoustic impedance for the inverse design of brass instruments. A dataset of various geometric parameters and their corresponding input impedance was constructed using numerical simulations based on the transfer matrix method. A one-dimensional convolutional neural network (1D-CNN) was applied as the estimation model due to its effectiveness in feature extraction from sequential signals. Numerical simulation results suggested that this approach could reasonably approximate the true geometric profiles within the defined search ranges for unknown impedance data, providing an objective optimization tool for the instrument design process.

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## 16:00–17:40 Violins, *Chair Tom Nania*

**16:00–16:20**

### *Simulating bow-string transients using a thermal elasto-plastic friction model*

**Vasileios Chatziioannou, Maarten Van Walstijn and Alessio Lampis**

One way to model the interaction between a musician's bow and a vibrating string is to use an elasto-plastic friction model. An extended model within the elasto-plastic friction modelling framework takes into account

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temperature variations of the rosin layer between bow-hair and string. It has been shown that the steady-state behaviour of the extended model closely replicates that of the experimental setup for a large control-parameter space, without the need to fine-tune friction-related parameters. This work shifts the focus to analysing the transient behaviour of the model. The simulated Guettler diagrams are qualitatively similar to the experimental ones for different types of strings and various bow positions, demonstrating that including temperature effects leads to more reliable simulations.

**16:20–16:40**

### *Bow Hair-Plate Coupling in Obliquely Bowed Plates*

**Shodai Tanaka, Julius Smith and Nathaniel Grinkrug**

Bowing a plate normal to its surface can stably excite a specific vibrational mode throughout the bow stroke, as demonstrated in the original Chladni plate experiments. In contrast, bowing at an oblique angle often leads to modulations and pitch jumps at specific locations along the stroke. In this study, we simultaneously measured plate vibration using a lightweight piezoelectric accelerometer, and bow-hair vibration using a Laser-Doppler Vibrometer. The results reveal a strong coupling between the self-excited vibration of the plate and the transverse modes of the bow hair during oblique bowing, which governs the observed modulations and pitch jumps.

**16:40–17:00**

### *Choosing a Violin: Professional Players' Perspectives on Instrument Testing*

**Jaska Uimonen**

This study investigates how violinists assess the sound quality and playability of an unfamiliar violin, focusing on the instrument's role as a functional tool in professional musical practice. An online questionnaire was distributed to professional violinists in Finnish symphony orchestras and international professional forums, yielding 35 responses. The findings show that violinists prioritise sound qualities that support a wide range of playing approaches, such as a strong core sound, balance across registers, and timbral flexibility. These qualities are understood as characteristics that emerge through interaction between the violin and the player, highlighting an interaction-based understanding of sound quality.

**17:00–17:20**

### *Violin "Playing-In": Disentangling Physical Change from Player Adaptation*

**Hugo Pauget Ballesteros, Philippe Lalitte, Vincent Lostanlen and Claudia Fritz**

Can a violin which is rarely played improve in sound quality after being played? It is a strong belief among musicians and manufacturers that playing "opens up" an instrument. We conduct a controlled longitudinal study centered on three rarely-played violins involving one test violinist who plays the target violin daily for six months. The protocol includes input admittances measured via laser vibrometry, musical recordings analyzed via Long-Term Average Spectra, and violin ratings provided by players. Our results show no evidence of acoustical change in the played violin compared to control instruments, nor do they indicate any adaptation by the player based on audio feature analysis.

**17:20–17:40**

### *Sound differences between Stradivari and del Gesù violins*

**Claudia Fritz, Angelica Cagnetta, Mj Kwan and Sam Zygmuntowicz**

Although Antonio Stradivari is the most widely known Cremonese violin maker, professional violinists and collectors hold both Stradivari and Giuseppe Guarneri "del Gesù" in equally high esteem. We conducted a large-scale listening test to examine whether del Gesù violins possess sound qualities distinct from those of Stradivari instruments. Participants, primarily violin makers and violinists, first reported their beliefs about the characteristic sounds of each maker. They then listened to paired synthesized recordings. Linguistic analysis

reveals a strong bias toward describing Stradivari instruments as "bright and clear" and del Gesù instruments as "dark and deep." This bias significantly influenced listeners' choices but did not reliably correspond to the actual instrument model.

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