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Acoustical techniques

33 Pitch bending and multiple-mode reed vibration in mechanically-blown free reed instruments

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ABSTRACT

Pitch bending in the harmonica, in which manipulation of vocal tract resonances plays an essential role, has long been a common practice. Pitch bending in free reed instruments with mechanically driven air supplies, such as the reed organ, harmonium and accordion, is a different matter. At least two methods of pitch bending in the accordion have been studied and demonstrated. The first, likely to be musically useful only in limited circumstances, involves partial opening of the pallet valve combined with variations in blowing pressure. The second, recently described and implemented in the accordion by Tonon [Thomas Tonon, *J. Acoust. Soc. Am.* 126: 2217 (2009)], involves modifying the construction of the instrument to include a resonating chamber in addition to the standard reed chamber. Accordions implementing this pitch bending mechanism are currently being used by some professional players, notably Kenny Kotwitz. Another case of interest is that of a free reed is coupled to a pipe resonator. It has been established that, in certain cases, the vibrational frequency of the reed and the sounding frequency of the reed-pipe will approximate a resonant frequency of the pipe. A somewhat different case is considered here. It is shown that, if a free-reed pipe is constructed with a pipe resonator that provides a suitable mismatch in frequencies with the fundamental frequency of the reed, it is possible to obtain a reed-pipe combination in which the mechanically blown reed vibrates in the second transverse mode and the reed pipe sounds at this frequency. Furthermore, for some combinations of pipe length and blowing pressure, it is possible to produce multiphonics in which two, or occasionally three, frequencies are sounded simultaneously that are the frequencies of transverse modes of the reed rather than pipe mode frequencies. The musical possibilities of these reed-pipes have yet to be explored.

8 Theoretical Framework for Initial Transient and Steady-State Frequency Amplitudes of Musical Instruments as Coupled Subsystems

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ABSTRACT

A theoretical framework for initial transients of musical instruments is presented for string-body, reed-air column and bow-string interactions. The time dependent amplitudes of the frequencies present in the two coupled systems are written as sums of phase relations of complex amplitudes of both, the system itself and the coupled system. For the steady-state parts some terms cancel because of their limits summing to zero explaining the take-over of one system by the other, like the forced oscillation of a violin body by its string frequencies. For the initial transients the equation systems consist of additional terms explaining the complex time-dependent behaviour of the initial transients. These terms formulate the temporal development of the amplitudes of additional frequencies during the transients. This enables a simple and real-time simulation of the transient time series. Additionally, two main reasons are found for the slaving of one system by the other in the discussion of zero limit sums of the steady-state phase, which are the difference in damping of the two systems and the difference in dimensionality. So e.g. the one-dimensional string

with only two reflection points and low damping is much more capable to force the body to the strings frequencies as the three-dimensional body with strong damping and a complex geometry with multiple wave reflection points.

Brass

45 An Exploration of Extreme High Notes in Brass Playing

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ABSTRACT

Some of the most striking examples of playing at the extremes of the high register of a brass instrument can be heard in modern jazz trumpet playing. Many other examples of very high brass playing are also found in the clarino writing for trumpets and orchestral horns in the late 17th and early 18th centuries. A distinctive acoustical feature of this style of playing is that the notes sounded are above what is normally considered to be the cut-off frequency of the instrument. This means that there is little or no reflection of the pressure wave from the bell of the instrument back to the player's lips, which is a requirement for establishing a strong coupling between the lips and the air column. Below the cutoff frequency, the threshold pressure for a played note is lowest close to one of the air column resonance frequencies; the corresponding experience of the player is that the lips are guided into pitch 'slots' close to the resonance frequencies. However, skilled players frequently claim that they can also experience distinct 'slots' when playing in the extremely high register. This paper explores three different approaches for investigating the physics of the lips, air column and resonator in playing extreme high notes: a recently developed multiple microphone technique has been applied to the separation of the forward and backward going waves in an instrument under playing conditions, high speed filming of the player's lips using specially designed mouthpieces with optical access has been utilised to examine the mechanics of brass playing in the high register, and a study has been undertaken of the transfer function between mouthpiece and bell at high frequencies and high amplitudes.

48 Brassy sounds: from trombone to elephant.

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ABSTRACT

Brass instruments like trumpets or trombones sound “brassy” especially when they are played at high level dynamic. These brassy sounds are made of a lot harmonics as a consequence of the wave steepening in the bore. The wave steepening is a cumulative effect obtained during the nonlinear propagation along the internal bore. A parameter to judge the severity of the nonlinear steepening is the critical shock length distance associated to a given input pressure profile. When the length of the bore is comparable to this critical distance, highly distorted waves can be observed in the bore, and it is the case for brass instruments played at fortissimo level. On one hand it is clearly the case for brass instruments. On the other hand the question is open for reed instruments even if, strictly speaking, they are not able to produce brassy sounds. But it is sensible to investigate if

nonlinear propagation in reed instruments may result into a perceptible effect. Besides musical instruments, the question can be asked in vocal communication of animals. One of them is particularly interesting, the elephant! Elephants produce a broad range of sounds from very low frequency rumbles to higher frequency trumpets. Trumpets are produced by a forceful expulsion of air through the trunk. Some elephant trumpeting sounds are very similar to a trumpet or a trombone sound especially when playing “brassy”. The internal bore of the vocal system of the elephant, from the vocal folds to the open end radiating the sound - trunk end - is several meters long, like brass instruments. The vocal system is so long than the nonlinear steepening effect might be significant during elephant trumpeting. This hypothesis is discussed from elephant trumpet’s signals, and estimated by comparison with human voice and brass musical instruments under playing conditions.

51 Pitch Bending on Early Brass Instruments

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ABSTRACT

Horn and trumpet writing in the first half of the 18th century often called on the player to sound certain potentially problematic natural resonances of their instrument. These are notes which do not fit easily on any known tempered tuning system. A well-designed brass instrument typically produces a series of open notes which approximate a harmonic series, including the characteristically ‘out of tune’ 7th, 11th and 13th resonant modes. There is much debate concerning the extent to which players attempted to ‘correct’ the tuning of these wayward notes, either through pitch bending due to embouchure manipulation, using hand technique, or not at all. By manipulating the embouchure, a skilled player can, to some extent at least, bend certain notes to more closely match those of a tempered scale. The ease with which this can be achieved depends on a number of factors, including the bore profile, which largely determines the frequencies and bandwidths of the resonances. Recently developed computational models have been used in conjunction with playing tests carried out on a range of early orchestral horns from the Edinburgh University Collection of Historic Musical Instruments to investigate the influencing factors which determine how easily these instruments can be played in tune.

20 The effect of hand and mute on the impedance spectra of the horn.

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ABSTRACT

The effects of different horn players’ hand shapes and positions, and the effects of different mutes were quantified by the input impedance spectrum Z and related to players’ and listeners’ perceptions. Z was measured using a three microphone, two calibration technique for combinations of a horn with three different hands, four different practice mutes and representative fingerings, complete for some sets. The hands were casts of real players’ hands which could be reinserted with a typical reproducibility in the magnitude and frequency of

peaks in Z of 0.1 dB and 0.4 Hz rms variation in independent measurements. Different hand configurations showed reproducible, measurable changes in Z , with an rms difference in the amplitude and frequency of the impedance peaks 1 to 20 of up to 0.8 dB and 0.6 Hz, respectively. The relative magnitudes and the harmonicity of the peaks were measurably different for practice mutes compared to that for an average hand. Frequency differences in the Z spectrum correlated well with player’s perceptions of the intonation of the instrument.

42 The Influence of Transients on the Perceived Playability of Brass Instruments

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ABSTRACT

We know that the starting transient of a note is very important for the listener in determining the character of the note, and that this is also true of inter-note transients, or slurs. These transients, and the ease with which they can be executed, play an important role for the player in assessing the quality of a brass instrument. A skilled player may be able to make a slurred transient, for example, played on a poor instrument sound convincing to the listener, but is likely to prefer an instrument on which the same slur can be performed more easily. Recent studies using high speed video cameras, and mouthpieces designed to allow optical access, have revealed much about the mechanics of the brass playerlips and the initiation of the coupling between the lips and the air column, for both starting transients and slurs. In this paper, through the exploitation of recently developed time domain models of brass instruments, we explore upward and downward slurs from one note to another. Of particular interest is the ease with which the player can slur over larger intervals which encompass one or more intermediate resonant modes.

31 Vocal-tract influence during brass instrument performance

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ABSTRACT

Control of sound production in brass instruments requires the player to accurately adjust the mechanical properties of the lips and the applied intra-oral air pressure. The mechanical vibration of the lips involves an acoustical coupling with the air column and results in an auto-oscillation phenomenon similar to that in reed instruments. Recent studies conducted on clarinets and saxophones [1, 2, 3] showed that for specific tasks, the vocal-tract of the player can be used to significantly influence the vibration of the reed. This was especially observed in playing ranges where the downstream air column provides only weak support for a note or effect, such as in the extended register and when pitch bending. These findings raise the question of vocal-tract influence in brass instruments because players and pedagogues often report some adjustments of the throat and tongue, especially when in the higher register.

In this study, we conducted experiments on trombone and trumpet players using a customized mouthpiece and two calibrated pressure transducers to measure the acoustical pressure near the input of both the air-column and vocal-tract.

This setup allows an estimation of relative influence of downstream (air column) and upstream (vocal-tract) systems in driving the lip oscillations. Initial results show different behaviours according to subjects; some players do not seem to use their vocal-tract whereas others do appear to make use of their vocal-tract to support certain harmonics and even for the fundamental frequency of the sound when reaching high registers. These observations suggest different strategies according to performer, possibly linked to variations in vertical tongue position and slight variations in vocal-tract length.

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[2] C. Fritz, J. Wolfe. How do clarinet players adjust the resonances of their vocal-tracts for different playing effects? *J. Acoust. Soc. Am.*, 118 (5), November 2005.

[3] Chen, J.M., Smith, J. and Wolfe, J. (2008) Experienced saxophonists learn to tune their vocal tracts, *Science*, 319, 726.

General

29 Voice of the dragon: the mystery of the missing fundamental mode

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ABSTRACT

When a corrugated pipe is swirled it produces a musically interesting sound. By increasing its rotational speed one can produce a series of frequencies corresponding to the modes of the open-open pipe. An interesting issue, raised since the early studies on the whistling of corrugated pipes, is that the fundamental acoustic mode is not whistling. This aspect has been related in the literature to the onset of turbulence in the pipe flow. In the present paper we provide a critical literature review and a physical model for the sound production, which contradicts the explanation of the missing fundamental mode presented in the literature.

28 Acoustics of the Cristal Baschet

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ABSTRACT

The Cristal Baschet is a musical instrument which was developed by Bernard and Francois Baschet in 1952. Its sound is produced by friction-induced vibrations, resulting from the sliding contact between the musician's finger and a glass rod. Today, the Cristal Baschet is an instrument which can cover up to five octaves and has reached a maturity that makes it a key instrument in contemporary music. This instrument is composed of four major subsystems: glass rods (also called glass bows), metal rods (called vibrating rods), a metallic support plate (called collector) and large thin panels (called sound diffusers).

The aim of the paper is to provide further understanding of the acoustic functioning of the Cristal Baschet for manufacturing and musical interests.

Experimental study of the instrument shows that the friction of the wet fingers of the musician on the glass rods creates vibrations which are transmitted to the collector and are then radiated through sound diffusers. Fingers motions show a succession of adhesion and slip phases on the rod. Such behaviour is known as the stick-slip phenomenon similar to bow movements observed in violin playing. When playing, a key point is to control this stick-slip phenomenon. Drawing on similar studies on the violin and cello, we suggest here an adaptation of the Schelleng diagram which enable us to qualify the compromise between the force applied to the rod and the finger's velocity, which are two fundamental control parameters during this stick-slip phase. The contact surface between the finger and the glass bow, and the contact conditions (presence of fat or acid on the skin, roughness, the use of multiple fingers) are other control parameters of the instrument. Despite their relevance, these parameters are not addressed in the study presented here. The proposed diagram allows us to define ranges of the control parameters which correspond to a playable tune.

59 Vibrato in music – physics and psychophysics

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ABSTRACT

Vibrato is a common feature of most present-day musical performances, from violins to opera singers, but its ubiquity has developed only since about the beginning of the nineteenth century. To some people it is an essential feature of musical performance while to others it is an unpleasant distortion of a musical experience. There are several different types of vibrato depending upon the person or instrument producing the sound, and the effect can vary greatly. This paper examines these various production techniques and their audible outcomes and then discusses the psycho-acoustic effects of vibrato on the listener

13 The ISMA Tradition

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ABSTRACT

The ISMA tradition probably began in 1974 when Lothar Cremer and Helmut Mueller organized an International Symposium on Violin Acoustics in Mittenwald, although the first symposium to use the ISMA name took place in DeKalb, Illinois in 1982. An international symposium on musical acoustics in Wollangong preceded the Sydney ICA in 1980. We share some memories from more than 3 decades of ISMAs.

Organs

2 **Mechanical Pipe Organ Actions and why Expression is Achieved with Rhythmic Variation Rather than Transient Control**

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ABSTRACT

This paper is a progress report on a project funded by the Arts and Humanities Research Council at the University of Edinburgh.

Whether mechanical organ actions allow organists to control the way in which they move the key and thus influence the transients has been discussed for many decades. This is often given as their main advantage. A number of large organs built during the 1990's in the UK had dual mechanical and electric actions resulting in compromise and expense. In every case the electric action is reported to be used almost exclusively.

The original work leading up to this project analysed the mechanics of the standard bar and slider windchest and showed that certain characteristics worked against the player controlling the airflow into the pipe. The main ones were pluck, the initial resistance felt as the pressure difference across the pallet valve is overcome, and flexibility in the action resulting in the pallet not starting to open until the key had moved a significant distance – up to half its travel. Initial measurements of organists playing confirmed that variations in key movement were not reflected in the pallet movement. There were, however, significant variations in rhythm and timing of which the player was not always aware.

The current project has taken this further with work at the Göteborg Organ Art Centre (GOArt) in Sweden and The Eastman School of Music (ESM) in Rochester NY. One technique, demonstrated at GOArt, used to ensure expressive playing throughout a performance is “Rhetorical Figurings”. These were shown to introduce distinct and consistent rhythm and timing variations. Measurements of the pressure in the groove and under the pipe foot showed very strong grouping that indicated that there were just two different ways in which the pressure increased. Measurements of students at ESM also showed strong groupings of the pressure rise profile and wide variations in rhythm and timing.

These variations in pressure profile did not always result in audible differences, but this will depend on the voicing of the pipes, and highly trained organists may be more sensitive to these differences.

Organists clearly like mechanical actions, and it appears that tactile feedback is an important if not the most important characteristic, but there is a limit to their size if the key forces are to remain comfortable.

57 **Flow acoustical determinants of historic flue organ pipe voicing practices**

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ABSTRACT

Pipe organs sound differently depending on the regional and contemporary circumstances of their genesis. In order to adequately conserve them it is important, due to the scarcity of sources providing direct information on the building process

and particularly on pipe voicing practices, to be able to specify as much as possible the factors that determine their sound signature. To this purpose an organized overview of some of these practices is proposed as a starting framework, using elements from the classical flow-acoustical flue pipe models developed by, among others, Cremer & Ising, Coltman and Fletcher. On the other hand, a method is presented to assess the tonal signature of voicing configurations, using a 'voicing jack'-like system featuring a complete stop rank of experimental pipes with electronically controlled, continuously variable length, mouth and toe hole geometry. On this playable system the voicing (and tuning) of the pipes can be varied easily, rapidly, precisely and reversibly. In order to outline specific voicing strategies both approaches are combined by relating the musical significance associated with the test voicing configurations to corresponding values of a set of characteristic dimensionless ratios. Well-known voicing methods like open or closed toe and over- or underblown voicing are characterized accordingly, as well as less common or builder specific procedures.

Perception and analysis

21 **Subjective mood induced by singing in karaoke**

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ABSTRACT

This study investigated situation of participating in karaoke among college students in Japan and subjective mood induced by singing in Karaoke. In total, 186 college students (174 female and 12 male) completed on an originally developed questionnaire. Participants were asked to respond, for example, frequencies of participating in karaoke, partners with whom they went to karaoke, numbers of the partners, aims of participating in karaoke, degrees of reducing stress by singing in karaoke, moods before singing in karaoke, and moods after singing in karaoke. As a result most participants responded that they participated in karaoke one or two times per month and went to it with from 1 to 5 friends. Their aims of participating in karaoke were amusement, pastime, reducing stress, or socializing and most of them felt that singing in karaoke reduced stress. With regard to moods after singing in karaoke they reported feeling more excited, active, and tired and less depressed, anxious and nervous than before singing in it. These results suggest that college students in Japan go to karaoke with several friends occasionally for amusement or pastime and feel comfortable tiredness by singing in karaoke. It seems that singing in karaoke has positive effects on mood.

30 **Unsupervised Incremental Learning and Prediction of Audio Signals**

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ABSTRACT

The artful play with the expectations of a listener is one of the supreme skills of a gifted musician. We present a system that analyzes an audio signal in an unsupervised manner in order to generate a musical representation of it on-the-fly. The system performs the task of next note prediction using the emerged representation. The main difference between our system and other existing music prediction systems is the fact that it dynamically creates the necessary representations as needed. Therefore it can adapt itself to any type of sounds, with as many timbre classes as there may be. The system consists of a conceptual clustering algorithm coupled with a modified hierarchical N-gram. The main flow of the system can be

summarized in the following processing steps: 1) segmentation by transient detection, 2) timbre representation of each segment by Mel-cepstrum coefficients, 3) discretization by conceptual clustering, yielding a number of different sound classes (e.g. instruments) that can incrementally grow or shrink depending on the context resulting in a discrete sequence of sound events, 4) extraction of statistical regularities using hierarchical N-grams (Pfleger 2002), 5) prediction of continuation, and 6) sonification. The system is tested on voice recordings. We assess the robustness of the performance with respect to complexity and noise of the signal. Given that the number of estimated timbre classes is not necessarily the same as in the ground truth, we propose a performance measure (F-recall) based on pairwise matching. Finally, we sonify the predicted sequence in order to evaluate the system from a qualitative point of view. We evaluate separately the different steps in the process and finally the system as a whole as well as the interacting components of the complete system. Onset detection performs with an F-measure of 98.6% for a data set of a singing voice. Clustering in isolation yields an F-recall of 88.5%. Onset detection jointly with Clustering achieve an F-recall of 91.4%. The prediction of the entire system yields F-recall of 51.3%.

Percussion

23 Gliding Pitches of the Nanyin Xiangzhan (Small Gong) with a Cap-Shape

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ABSTRACT

The xiangzhan is a 5 cm horizontally struck bronze gong used in the Nanguan ensemble, a type of traditional music (also known as Nanyin) found in South China, Taiwan and Han-Chinese settlements in South East Asia. Its timbre is characterized by a downward gliding pitch, and the xiangzhan is believed to play a role in enlivening a Nanguan ensemble performance. This gliding pitch can be attributed to its cap-shape, whose vibration manifests a hardening spring effect and its frequency decreases along with the amplitude.

The major aim of this study is to reveal the acoustical properties of the xiangzhan, through comparing the experimental results with a model of shallow shell vibration. The nonlinear behavior in gongs has been previously studied by Rossing and Fletcher on the big and small Chinese opera gongs, which have complex shapes. The xiangzhan provides a simpler example for investigating the similar nonlinear behavior. Its shape is close to a plate, with edges folded at a 110 degrees angle. The curve is not precast, rather hand pressed onto the flat surface. Although the indentation is slight, the sound produced is quite different from a flat plate. We use a soft mould to obtain qualitative descriptions of shapes of the xiangzhan. An accelerometer is then used to measure the central vibration displacement when struck with its traditional elastic bamboo striking device. The obtained relationship between the vibration frequency and amplitude is used to determine the parameters of a model of shallow shell vibration. We examine five xiangzhans and try to explain their different behaviors of the gliding pitch in terms of their different shapes. In most sound samples, the overtones follow the fundamental in the downward curve of frequency. Interestingly, some higher overtones with raising frequency are produced by a xiangzhan, suggesting that a softening spring effect may occur for certain vibration modes.

Furthermore, we conduct a listening experiment in which subjects are asked to pronounce a Chinese word to mimic the sound of the xiangzhan. The result provides an interesting case study of the relationship between the physics of musical instruments and linguistic tones.

39 Percussion Instruments with Plural Sounds using Orthogonal Modes

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ABSTRACT

Bell-like percussion instruments of axisymmetry has two degenerate modes, which have identical eigen frequency. A cup without handle is of such a case. On the other hand, a cup with handle is able to make plural sounds by selecting hitting point, because the handle behave as a mass loading and the degenerate modes are separated. This means that we can choose the exciting eigen mode since the vibrating point of one mode overlaps the node point of another mode.

In our research, we aim to create a percussion instrument making plural sounds by using the principle explained above. In this paper, the shapes of such instruments are designed using Finite Element Method (FEM). We investigated the relationship between the hitting point and the sound in the shape by the analysis results of FEM. We made the prototypes of the porcelain and we examined the prototype by impact test. As a result, the experimental and numerical results agreed with each other. The shape we designed can make more plural sounds than the cup with handle using on a daily basis. We plan to investigate the relationship between the tone and the shape and we aim to create the new percussion instrument having abundant expression.

Pianos, harps, harpsichord

26 Experimental study of the plucking of the concert harp

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ABSTRACT

Each musician produces his own particular sound, not only through expressive patterns between successive notes (e.g. tempo and amplitude variations), but also at the individual note level, by the precise way the instrument is set into vibration. In the case of instruments for which the player has a direct mechanical action on the vibrating structure, this action represents an important part of the player's acoustical signature. Until recently, studies on musician's identity in individual tones mostly dealt with sustained instruments (violin, clarinet,...), where the player can modify the sound throughout its duration. However, according to musicians, this notion of acoustical signature also seems relevant for plucked string instruments. It means that, during the plucking action, the player gives initial shape and velocity to the string, which are characteristic of his musical skills or the technique he uses. The aim of the present study is to highlight characteristic parameters of playing techniques, dynamics, or musician skills, in the case of the concert harp. In order to analyse the finger-string interaction, a well-controlled experiment is performed with a panel of harp players playing in several musical contexts. The plucking action is filmed with a high-speed camera. Then, finger / string rotation and displacements are extracted using image processing techniques. These parameters will be used in order to define a set of musically-relevant descriptors of the musical gesture that can parametrize the initial conditions of the string vibrations depending on the skills of the player.

25 **Vibratory study of harps' soundboxes**

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ABSTRACT

The harps' soundbox manufacturing has evolved throughout centuries. The design of the harp soundbox is a key question still discussed by harp makers. Although harp soundboxes look very similar, each harp maker uses his own manufacturing technique to build an instrument. The sound radiation is produced by the soundboard vibrations and by the soundbox vibrations which arise when strings are excited. The relative importance of these two acoustic sources can be estimated thanks to mobility measurements.

The aim of this paper is to investigate these two sources in 11 harp soundboxes built by current manufacturers and 9 harps soundboxes built by historical manufacturers. For each instrument, mobilities on the soundboard and on the soundbox are measured by impact testing. Mean values of these mobilities are computed and are used as an indicator to compare instruments and to evaluate their capability to vibrate under an excitation imposed by the soundboard. A statistical study shows that the tested instruments can clearly be differentiated according to this indicator. Different strategies of harp makers are identified, showing that some makers favor the mobility of the soundbox when others choose to build a more rigid soundbox.

5 **Synthetic description of the piano soundboard mechanical mobility**

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ABSTRACT

An expression of the piano soundboard mechanical mobility (in the direction normal to the soundboard) depending on a small number of parameters and valid up to several kHz is given in this communication. Up to 1.1 kHz, our experimental and numerical investigations confirm previous results showing that the soundboard behaves like a homogeneous plate with isotropic properties and clamped boundary conditions. Therefore, according to the Skudrzyk mean-value theorem (Skudrzyk 1980), only the mass of the structure M , the modal density $n(f)$, and the mean loss factor $\bar{\eta}(f)$, are needed to express the average driving point mobility. Moreover, the expression of the envelope - resonances and antiresonances - of the mobility can be derived, according to (Langley 1994). We measured the modal loss factor and the modal density of the soundboard of an upright piano in playing condition, in an anechoic environment. The measurements could be done up to 2.5 kHz, with a novel high-resolution modal analysis technique (see the ICA companion-paper, Ege and Boutillon (2010)). Above 1.1 kHz, the change in the observed modal density together with numerical simulations confirm Berthaut's finding that the waves in the soundboard are confined between adjacent ribs (Berthaut et al. 2003). Extending the Skudrzyk and Langley approaches, we synthesize the mechanical mobility at the bridge up to 2.5 kHz. The validity

of the computation for an extended spectral domain is discussed. It is also shown that the evolution of the modal density with frequency is consistent with the rise of mobility (fall of impedance) in this frequency range and that both are due to the inter-rib effect appearing when the half-wavelength becomes equal to the rib spacing. Results match previous observations by Wogram (1980), Conklin (1996), Giordano (1998), Nakamura (1983) and could be used for numerical simulations for example. This approach avoids the detailed description of the soundboard, based on a very high number of parameters. However, it can be used to predict the changes of the driving point mobility, and possibly of the sound radiation in the treble range, resulting from structural modifications.

Strings7 **A new concept for string-instrument soundboards : the splitting board**

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ABSTRACT

All strings instruments function in the same way : a driving system –the strings–coupled with a radiating surface –the-soundboard– via an intermediating element –the bridge. The acoustic qualities are determined by the particular organization of these three elements: Exciter - Coupling - Resonator. The art of instrument making is in the optimum transformation from mechanical energy of the strings into radiating acoustical energy. Holding all other parameters constant between two given instruments, this radiated energy depends on both the modal shape of the eigenmodes of the soundboard and the location of coupling. There is always a compromise between different parts of the spectrum depending on the eigenmodes that radiate efficiently and those that radiate weakly. Indeed, whenever eigenmodes are symmetrical the far-field radiation for even-modes reaches its minimum by the destructive interference of its acoustic sources. On the other hand, if the modal geometry is odd, the radiation is maximized. Taking this into account, instrument makers working to create functional asymmetries such as all modes radiate as close to their respective maxima as possible. Should they arrive at a spectrum that lacks a given eigenmode of vibration, the structure does not radiate. The perceptual signature of a given instrument, therefore, depends on the adjustment of maxima and minima of radiation. A new manner of radiation optimization is possible by splitting the radiating element : the soundboard. We can first, by adjusting the modal properties of each of the aforementioned elements, ensure that the maximum radiation of an element corresponds to the minimum of the other element. As a result, a more homogeneous acoustical response is achieved. In addition, by judiciously choosing the location of coupling, we can systematically create asymmetries in the geometry of eigenmodes. As a consequence, the far-field radiation is considerably improved. Furthermore, by coupling these split elements, an exchange of energy is carried out in real time, thereby enriching the resultant sound. So, by assigning to each soundboard component a dedicated part of the spectrum to be radiated, a new paradigm of sound optimization is arrived upon. This paper presents a model and some measurements that endeavor to substantiate the model discussed above. A violin and a guitar will be shown and played.

22 **An Acoustical and Historical Study of the Taiwanese Horned Fiddle: Exaptation of Musical Instruments**

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ABSTRACT

The Taiwanese horned fiddle is a new member of the huqin (bowed-string instrument) family. Several components of this instrument are taken from the gramophone, such as the U-shaped tube and the horn (bell). Invention of the Taiwanese horned fiddle dates back to the Japanese colonial period and may be related to the banning of Han music. The Stroh violin may have inspire Taiwanese musicians to make substantial changes in the construction of the traditional huqin. During the Japanese colonial period, the Taiwanese horned fiddle may be regarded as a novel instrument and had nothing to do with Han music.

After the Japanese colonial period, the development of the Taiwanese horned fiddle was related to the characteristic timbre. The horn not only results in directional effects of sound radiation, but also emphasizes a formant at 1.8 kHz. Due to this formant, the timbre of the Taiwanese horned fiddle hardly fuses with other musical instruments. Therefore, it has become the principal instrument in several musical genres and is associated with alien, lonely, even melancholic characters. Through historical and acoustical investigations of this musical instrument, the present study provides an application of the biological notion "exaptation" (preadaptation) in the field of organology, i.e., a (structural) feature that fortuitously serves a new function during the evolution of this musical instrument.

34 **A situated and cognitive approach of violin quality**

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ABSTRACT

In order to better understand how violinists evaluate violin quality, playing and listening tests were conducted. Three French professional violinists assessed three violins with different qualities. The assessment was conducted orally, with violinists answering open questions regarding the quality of each violin while playing it and then while listening to it played live by somebody else. The violinists were further asked to rank these violins in order of preference. The oral reports were transcribed and linguistically analysed. It first allowed us to identify the linguistic resources in French available to speakers to account for their experience, in particular to describe what appeared as two different entities: the violin and its sound. Secondly, a semantic analysis of the discourses showed that these resources were shared by the participants but were used differently to qualify each violin in the two experiments. In particular, the analysis revealed aspects, like the "ease of playing" or the "projection", which were used frequently in the playing test but very little in the listening test. This can be explained by the fact that, in the listening test, the evaluation is made by relying on the sound only and, therefore, this evaluation is mainly based on the resultant sound without any possible comparison nor control on the nature of the sound and the manner by which it was produced. However such processes of comparison and control on the instrument when producing the sound are essential for the evaluation of the quality of a violin by violinists, as proved by the agency given to the violin in the assessments given during the playing task and the players' statements regarding what is a "good" or a "bad" violin.

3 **Experimental Approaches on Vibratory and Acoustic Characterization of Harp-Guitars**

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ABSTRACT

The paper describes the results of a research activity, still under development, oriented to the vibratory and acoustic characterization of harp-guitars. This particular category of instruments includes guitars with any number of additional unstopped strings that can accommodate individual plucking. The word harp is a specific reference to the unstopped open strings, and is not specifically a reference to the tone, pitch range, volume, silhouette similarity, construction, floor-standing ability, nor any other alleged harp-like properties. To qualify in this category, an instrument must have at least one unfretted string lying off the main fingerboard.

They are typically rare and uncommon in the popular music scene. Most consist of a regular guitar, plus additional rprings strung above the six normal strings. The instrument is usually acoustic and the harp strings are usually tuned to lower notes than the guitar strings, for an added bass range. Normally there is neither fingerboard nor frets behind the harp strings.

Two 14 strings- Italian style harp guitars (built at the beginning of 18th century by Settimio Gazzo, guitars maker of many different styles and variations of harp guitars for Pasquale Taraffo and others in the Genoa's area) are compared to good quality classical and acoustical guitars from vibratory and acoustical points of view.

Guitars are instrumented with external microphones in correspondence to the sound holes, internal surface microphones applied in the resonating chamber and micro-accelerometers for vibration detections. Excitation is directly generated playing the instruments on different notes. Signals are acquired by portable multi-channel acquisition units interfaced to graphical programming environment (LabView, by National Instruments) running on PC.

Acceleration signals are elaborated in order to evaluate displacements in specific points of soundboards and necks. Vibration analyses show interesting differences between harp-guitars and classical guitars about displacements detected on the soundboard and on the bridge and their dependence to frequencies. Acoustic analyses detect very different responses of harp-guitars to various frequencies, showing also the different acoustic emission at sound holes. Comparisons between signals detected by external and surface internal microphones allows to estimate effects of the acoustic damping in these particular instruments.

4 **Parallel Monitoring of Sound and Dynamic Forces in Bridge-Soundboard Contact of Violins**

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ABSTRACT

The paper refers on an original experimental activity oriented to correlate sound and internal forces generated in violins. In particular static and dynamic forces generated in the contacts between bridge and soundboard playing instruments belonging violins family are analyzed respect to the generated sound.

It is well known the role played by bridge in stringed instruments: its geometry, stiffness and damping condition the dynamic actions induced on the soundboard and consequently its behaviour. The bridge transfers some of the energy of vibration of the string to the body of the violin, at frequencies where the ear is most sensitive. This is one of the reasons for the bright timbre of the violin. The action of the violin bridge is essential to the tone of the instrument. Its shape and function

have been developed over centuries. Underneath the treble side of the bridge (where the E string rests) is the sound post which extends from the front to the back plate of the instrument. Since this side of the bridge rests on this post, it is essentially fixed and acts as a pivot for the rocking motion of the remainder of the bridge. It does however, couple the sound energy from the top plate to the back plate of the instrument.

These actions are essentially represented by forces at two feet: but force measurement on contact between bridge feet and soundboard is very difficult to do in practice. Specific experimentations have been developed involving innovative, low cost and non intrusive flexible piezo-resistive force sensors very thin (0.2 mm) with high dynamics ($< 5 \mu s$), low hysteresis and good repeatability. Sensing area consists on a circle of 9.3 mm of diameter. Sensors can be connected to PC through electronic interface. One sensor is placed under each bridge foot: foot surface is geometrically different to the sensing area. This problem has been solved implementing an original calibration procedure.

A classical violin has been instrumented with two force sensors, wireless interfaced to PC. Simultaneously acoustic acquisitions are detected. The violin is played following different techniques (pizzicato, vibrato) and applying several methods of attack with the bow (detaché, martelé, collé, spiccato and legato). The experimental approach is described in the paper with reference to violins, but the method is been conceived to be applied to different stringed instruments, changing calibration: in particular it can be successfully applied to the whole family of bowed instruments.

52 **The low down on the double bass: looking for the effects of torsional modes**

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ABSTRACT

The action of the bow produces torsional oscillations in a string, as well as the normal transverse motion [1]. The torsional modes have frequencies several times higher than, and not harmonically related to, the transverse modes. Via the strongly non-linear bow-string interaction, the torsional modes are driven at a harmonic of the translational modes [2]. The torsional mode frequencies for wound steel bass strings decreased weakly with increasing tension, while those of twisted gut increased weakly. When inexperienced string players bowed notes, the sound spectra of the relatively long starting transients contained strong components near the first torsional resonance.

In another experiment, eight professional bassists both played and listened to notes on steel strings of two brands prepared with different degrees of inharmonicity between torsional and translational modes. As both players and listeners, their responses were highly concordant. They showed no clear preference for harmonically related modes. They did, however, show a clear preference for one of the brands. Perhaps because of the relatively small quality factors (~15) of the torsional resonances and the high frequencies of the torsional resonances, it appears that any effects on playing of the coupling of inharmonic torsional modes are smaller than those due to other parameters controlled by string makers.

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40 **Numerical simulation of wolf-note in string instruments using string-body coupled model**

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ABSTRACT

Large size string-instruments, cello or contrabass, can ingenerate phenomenon called wolf-note. When we play a note of specific pitch, the body of the instrument strongly vibrates and the bow leaps on a string continuously, which makes it difficult to perform stably. In order to prevent this phenomenon, small equipments so called wolf-killer are often utilized. Such equipments have been empirically devised and it causes some troubles like timbre degradation. Consequently, we are trying to figure out the source of the wolf-note and control it with having an insignificant effect. In this paper, we consider a model in which a string and a body is coupled at a bridge. Wolf-note is numerically reproduced using this model. The model is experimentally validated.

15 **Analysis of Bowed-String Multiphonics**

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ABSTRACT

By carefully positioning the bow and a lightly touching finger on the string, the string spectrum can be conditioned to provide narrow bands of pronounced energy. This leaves the impression of multiple complex tones with the normal (Helmholtz) fundamental as the lowest pitch. The phenomenon is seen to be caused by two additional signal loops, one on each side of the finger, which through the repeating slip pattern get phase locked to the full loop of the fundamental. Within the nominal period, however, the slip pulses will not be uniform like they are during the production of a normal "harmonic", but may vary considerably in shape, size, and timing. For each string there is a certain number of bow/finger combinations that bear the potential of producing such tones. There are also two classes, depending on whether the bow or the finger is situated closest to the bridge. Touching the string with the finger closest to the bridge will somewhat emphasize the (Helmholtz) fundamental. The technique is applicable to double bass and cello, while less practical on shorter-stringed instruments.

41 **Inharmonicity of Guitar String Vibration Influenced by Body Resonance and Fingering Position**

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ABSTRACT

Sound of string instrument and piano has inharmonicity. This phenomenon is observed by many researchers. One of the causes is string stiffness, which is determined by Young's modulus and diameter of it. This means that string is not ideal flexible. The property of guitar sound is expected to be applied to estimation of picked guitar string. Other research reports perception of inharmonicity observed in guitar sound. Stiffness of string is not an unique cause. Coupling with body let the frequency of string vibration shift. Therefore, we consider that coupled vibration of string and guitar body relates with inharmonicity of guitar sound. In addition, we can play the same pitch with other strings using different fingering positions. Each fingering position to play the same pitch has unique length of string; therefore changing the position influences on vibration spectrum pattern. Therefore, string vibration may be influenced by both coupling with body and fingering position. In our paper,

to analyze the influences of stiffness and coupling vibration, we use simple model, in which a string with stiffness and a body of spring-mass system that has natural resonance is coupled at a bridge. The natural resonance frequency corresponds to the resonance peak of guitar body observed at the bridge. The peak is considered to have large effect on the string. By measuring parameter of string and body, we calculate each vibration mode frequency. We describe the influence on inharmonicity of coupling vibration with guitar body and changing fingering position to play the same pitch.

6 Modelling and experiments on string/body coupling and the effectiveness of a cello wolf-killing device

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ABSTRACT

A common annoying phenomenon which arises with most cellos and violas is the so-called wolf note. This is a warbling sound stemming from a severe interaction between the string and the body motions, coupled through the instrument bridge. Instrument builders have found that adding a small auxiliary mass on the so-called dead side of the string often inhibits the wolf phenomenon. However, the tuning of such wolf-eliminators is often laborious, erratic, if not ineffective, because the physical role of such devices is still poorly understood. Following our previous work on this problem, we address the dynamical behavior of the string/body/wolf-eliminator coupled system, which is studied here in a more systematic manner, both theoretically and through experiments performed on a XIXth century cello. We briefly recall our fully coupled model for this problem, and then perform extensive hand-bow experiments, as well as illustrative computations, which show the effectiveness of this wolf-eliminator as a function of the device mass and location along the dead side of the string. This experimental and numerical work contributes to clarify the functioning of this anti-wolf device and provides guidelines for an effective use.

Synthesis

56 Perceptual and Numerical Aspects of Spring Reverberation Modeling

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ABSTRACT

Among analog audio effects, spring reverberation presents one of the most difficult challenges when it comes to virtual digital modelling---the helical spring system exhibits a variety of interesting features, including strong coupling among various types of motion (longitudinal, transverse), cutoff and partial cutoff frequencies, and a combination of regimes of coherent and dispersive wave propagation, all of which lead to a characteristic sound which is not easily replicated digitally.

There is a variety of distinct models of helical spring dynamics--for applications in audio, one must ensure that the model is sufficient to reproduce phenomena which lie far outside the range of human audio perception, but not unnecessarily complex. The same holds for numerical methods used in simulation in mainstream applications, which may not be a good match to the peculiarities of audio, both from a perceptual standpoint, and with regard to computational efficiency.

In this paper, a hierarchy of spring models is presented, from the most complex to the most simple, with a focus on a simple perceptual characterization in terms of a minimum number of parameters---among these are the various cutoff frequencies, and echo densities in different frequency ranges. Simulated sound examples exhibiting these features will be presented, accompanied by a discussion of computational complexity.

46 Nonlinear propagation with frequency-independent damping: input-output simulation of entropic solutions

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ABSTRACT

We present an exact method to solve a one-dimensional nonlinear transport equation in a dissipative non homogeneous media when the damping is frequency-independent. This work was motivated by the case of brass musical instruments whose functioning at high sound levels implies nonlinear propagation. Though in that latter case, the medium is homogeneous, our approach is more general.

Usually, the wave propagation in musical wind instruments is justifiably considered to be linear. A well-known counter-example is the case of brass instruments at high sound level. In this case, the nonlinear effects become dominant. They account for the graduated waveshape distortion due to their cumulative nature which eventually leads to the arrival of shock-waves.

For the class of propagation models under study in this paper, we derive an exact method which allows to recover an input-output formalism and an efficient algorithm in the time domain. The method is based on three key points: (1) a change of function which turns the original problem into a conservative problem of hyperbolic type, (2) the adaptation of the standard characteristics method from which all possible solutions can be deduced, and (3) the introduction of an easily computable criterion which naturally selects the physically meaningful solution (this latter point provides a generalization of the potential function proposed by Hayes [1969]). This approach operates for regular and continuous solutions as well as shocks and multiple shocks. Finally, a fast algorithm is deduced and proposed for real-time sound synthesis issues.

Voice

50 Glottal jet behaviour in a self-oscillating in-vitro model of the vocal folds with downstream constrictions

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ABSTRACT

Within the larynx, complex soft tissue structures are made to oscillate periodically by an airflow generated by an overpressure in the lungs. Above the laryngeal ventricle are found two further structures termed the ventricular bands. These are like the vocal folds but have been observed to have a lower stiffness and be more viscous. From recent studies, it is known that the

interaction between the vocal folds and the ventricular bands is caused by the aerodynamic interaction of the glottal jet with the ventricular bands, with a pressure recovery due to flow reattachment. With the ventricular bands therefore having a direct impact on vocal fold oscillation (either inducing or hindering self-oscillation depending on their position), understanding the nature of their effect on the glottal jet may provide a useful insight into some voice pathologies. This paper describes a study using a three-times life size in-vitro model of the vocal folds constructed from latex and water, which replicates basic features of the fluid-structure interactions that take place in the human larynx. Using Particle Image Velocimetry, it has been possible to study the nature of the glottal jet during steady state oscillation of the vocal folds with downstream constrictions. A key advance on previous studies in this area is the ability to now observe the glottal jet from the point at which it emerges from the vocal folds. Preliminary results from flow-field measurements are presented for different constrictions, similar to the ventricular bands, placed downstream of the vocal folds.

53 Wagner's music is even better than it sounds: resonance tuning produced by matching vowels with pitch.

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ABSTRACT

The vowels of European languages are primarily distinguished by the frequencies of the two lowest formants in the spectrum of the output sound, which are in turn produced by the frequencies (R1 and R2) of the first two resonances of the vocal tract [1]. Under some conditions, many singers use the strategy of resonance tuning; i.e. they tune a resonance to a harmonic of the sung pitch f_0 . In particular, sopranos deliberately tune R1 to match f_0 , once the pitch frequency f_0 approaches or exceeds the value of R1 in normal speech [2]. According to simple models of oscillator-duct interactions [3], and the reports of singers, resonance tuning can increase the loudness, uniformity of timbre, stability and ease of singing, all of which are usually considered to be particularly advantageous in opera. There is, however, a reduction in intelligibility once R1 is varied from its value in normal speech.

The amount of deliberate resonance tuning required by sopranos would be reduced if the pitch of the note written for a vowel corresponded with its usual range of R1. Analysis of soprano rôles in operas by different composers indicates that Wagner aided the acoustics of the soprano voice at high pitch when setting text to music. Some other composers show either no correlation of vowel with pitch, or correlations that do not aid R1: f_0 resonance tuning.

Resonance tuning in other voice ranges is also considered and the paper will be illustrated with a collection of sound files.

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58 Lieder singers delay vibrato onset: some acoustic evidence.

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ABSTRACT

Acoustic analysis was applied to examine if a distinction could be identified between the performance of lieder as compared to opera. 18 single, quasi-unaccompanied notes from commercial recordings of two lieder were used as examples, and, for comparison, 20 single, unaccompanied notes from an opera. It was found that the vibrato rate in the lieder examples was statistically identical to opera at around 6.2Hz. The variability of vibrato rate was marginally greater for lieder, though not statistically significant. The vibrato extent showed that a narrower vibrato was used in the lieder examples of around 100 cents compared with opera which, on average, used a vibrato extent of 150 cents. The results of our acoustic vibrato onset measurements indicate that vibrato in lieder begins later within a note than in opera. The singerformant, which is generally associated with opera, was observed in the lieder recordings at times, but was overall significantly less strong than the opera examples. It was apparent from the data that professional, commercially recorded singers exhibited considerable flexibility in adapting to the different genres. The analysis also made clear that acoustic analysis can be used to develop and make clear definitions and descriptions of singing styles.

10 Automatic Scoring of Sung Melodies in Comparison with Human Performance

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ABSTRACT

Easiness or difficulty in transcribing sung melodies to score depends on quality of singing and degree of tonality of the sung melody itself. In case scoring is executed by human scorers, they can make use of their sense and ability in music, such as anticipation of future melody lines and confirmation of correctness of their anticipation by listening the part, regardless of degree of tonality. It is difficult for automatic scoring systems to simulate human scorers in the way mentioned above, but it is not so difficult to achieve better performance even for atonal melodies if the melodies are sung well, though human scorers feel difficulty in that case. The proposed system well judges "pitch name and "note value, estimating the "standard f_0 , or f_0 (fundamental frequency in Hz) of C2, and "standard tempo (number of quarter notes in a minute) of the singing using flexible templates for judging tone height and IOI (Inter-Onset Interval), yielding satisfactory performance comparable with human scorers. Performance is compared between the proposed automatic scoring system and human scorers on six eight-measure melodies and 24 two-measure melodies newly prepared for this performance test. One third melodies, or two eight-measure melodies and eight two-measure melodies, are designed as tonal melodies, another third melodies are atonal, and the rest third melodies are prepared as slightly-tonal melodies. Singers employed for the current performance comparison are those who can sing the presented score at least after short rehearsal using the piano. Twelve human scorers are employed for performance evaluation of the proposed system. The scoring rate by the proposed automatic scoring system proved to be superior to that by human scorers for both atonal and slightly-tonal melodies, though that for tonal melodies is somewhat poorer than that by human scorers. By the way no significant difference was recognized among scorer groups, though significant differences were detected among individual scorers.

11 **The tuning of vocal resonances and the upper limit to the high soprano range**

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ABSTRACT

The upper limit of the useful range for many sopranos is around C6 or 'high C'. Others can extend their range well above this. This study investigated how sopranos use the resonances of their vocal tracts in the high and very high ranges. Twelve sopranos (4 non experts, 4 advanced, 4 professionals) produced glissandi up to their highest note (from 1000 to 2300 Hz). Later, they sustained pitches on [a] vowels, from A4 (~440 Hz) to their highest sustainable note, while the frequencies (R1 and R2) of the first two vocal tract resonances were measured by broadband excitation at the mouth. Adjustment of R1 near to f0 (R1:f0 tuning) was observed below C6 for both expert and non-expert singers. Experts began this tuning at lower pitches. Some singers also exhibited R2:2f0 adjustment over the lower part of the R1:f0 tuning range. In the very high range (above C6), the singers used one of two strategies. Some extended the R1:f0 tuning as far as E6 or F#6. Others adjusted R2 near f0 over the highest pitch range (up to D7). The limit of the sustainable range corresponded to the end of these resonance tunings. This suggests that the upper limit of their useful singing range may be determined by the upper limit of a resonance tuning mechanism. Further, it seems likely that, for some sopranos, learning R2:f0 tuning might extend the practical upper range.

9 **Physiological and Acoustic Characteristics of the Female Music Theatre Voice in 'belt' and 'legit' qualities**

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ABSTRACT

A study was conducted on six female Music Theatre singers. Audio and Electrolottographic (EGG) signals were recorded simultaneously with the vocal tract impedance while the singers produced sustained pitches on two different qualities (chesty belt, legit). For each quality, two vowels (/E/, /o/) were investigated, at four increasing pitches over the F#4-D5 range (~370-600 Hz). Measured values of glottal parameters (Open Quotient, Amplitude of the EGG signal) support the idea that chesty belt is produced in the first laryngeal mechanism (M1) and legit in the second one (M2). The frequency of the first vocal tract resonance (R1) was found to be systematically higher in chesty belt, close to the second voice harmonic (2f0). These observations were consistent with greater intensities and energy above 1 kHz in chesty belt compared to legit.

Woodwinds

54 **Practice makes ... less imperfect: the effects of experience and practice on the kinetics and coordination of flutists' fingers**

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ABSTRACT

The key systems of woodwind modern instruments minimise the

need for cross fingering in lower registers. Nevertheless, performance often requires near-simultaneous movements of several fingers, often with some digits rising while others fall, especially in performance in the high registers. We measured the individual finger movements of a group of amateur and professional flutists as they played an original piece unseen before the experiment. They played a modified flute with a position detector mounted below each key. The detectors, via an interface and computer, gave the timing and speed of each key, as reported in an earlier study (Almeida et al., 2009). Here we report the changes in speed and coordination between sight-reading and performance after a short session of practice. We also report the variability among players within each group, and the differences between amateurs and professionals.

[1] Almeida, A., Chow, R, Smith J. and Wolfe, J. (2009) The kinetics and acoustics of fingering and note transitions on the flute. *J. Acoust. Soc. America*, 126, 1521-1529.

55 **Clarinet parameter cartography: automatic mapping of the sound produced as a function of blowing pressure and reed force**

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ABSTRACT

In simple models of a single-reed instrument mouthpiece, important control parameters include the air pressure in the mouth, the force applied by the lip on the reed, the position at which it is applied and the damping of the reed. In these simple models, position and damping are usually considered constant while pressure and force are regarded as the key control parameters. Pressure in the mouth is easy to measure during human performance. The lip force is harder to relate to the gesture of the musician because the range of forces applied by a player depends on several factors including the reed stiffness and profile, and the distribution of force on the reed. When the instrument is played by a mechanical device, greater independence and control of these parameters is possible. This study uses an automated clarinet playing system developed during a series of student projects involving NICTA and UNSW (hence the long author list). The mouth pressure is controlled, and two further parameters control the lip force and its position of application. The precision and short-term stability of this control allow a systematic study of the pitch, timbre and starting transients of the clarinet for a wide range of these three parameters and, in principle, up to 215 fingerings. This allows the mapping, in fingering, pressure and lip parameter space, of the regions that produce the intended note, poorly tuned notes, notes in another register, slowly starting notes, squeaks or no sound at all. Maps measured with different protocols are here compared with the predictions of theoretical models.

35 **Refinements to the Model of a Single Woodwind Instrument Tonehole**

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 Technology (CIRMMT)
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ABSTRACT

Using the Finite Element Method (FEM), a single unflanged tonehole was simulated for a wide range of heights and diameters in order to improve the accuracy of transmission-matrix calculations for instruments with toneholes of large diameter and short height, as found on saxophones and concert flutes. These calculations confirm the validity of existing models for toneholes of smaller diameter and longer height, as found on clarinets. Revised one-dimensional transmission-matrix models of open and closed toneholes are presented to extend the validity of the models based on the FEM results. Further, these tonehole models are verified to be valid for use with both cylindrical and conical (flare angles up to 6 degrees) air columns.

For open and closed toneholes, new formulas for the low frequency values of the shunt and series length correction are developed as a function of t/b and δ . Discrepancies with current theories are particularly apparent in the series length correction term. At higher frequencies, the open shunt equivalent length increases faster than previously predicted, corroborating recent experimental data (Dalmont et al., 2002). This effect is more important for short toneholes. These results do not take into account any possible internal or external interactions between the toneholes on an instrument, which may have an important effect for large-diameter toneholes.

36 **Finite Element Modeling of Woodwind Instruments**

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ABSTRACT

The input impedance of simple woodwind-like instruments is evaluated using the Finite Element Method (FEM) and compared to theoretical calculations based on the transmission-matrix method (TMM). Thermoviscous losses are accounted for with an impedance boundary condition based on acoustic boundary layer theory. The systems are surrounded by a spherical radiation domain with a second-order non-reflecting spherical-wave boundary condition on its outer surface.

For simple geometries, the FEM results are shown to match theory with great accuracy. When considering toneholes, boundary layer losses must be added to the TMM model to achieve good agreement with the FEM calculations. For geometries with multiple closed or open toneholes, discrepancies between the FEM and the TMM results become more significant and appear related to internal or external interactions. For closed side holes, this effect is more important at low frequencies, thus affecting the first few resonances. For open side holes, this effect is particularly important near the tonehole cutoff frequency but extends to lower frequencies as well. In general, the TMM does not model tonehole interactions, thus posing a limitation to its accuracy.

32 **Structuring music in recorder playing: a hydrodynamical analysis of blowing control parameters.**

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ABSTRACT

For musical instruments producing sustained tones, the sound of the instrument can be interpreted as a sounding transposition of the player's gesture during the duration of each tone. By shaping individual tones, the player may create a musical structure such as a melody.

The playing of wind instruments requires an expert control on the blowing. In the case of flutes and recorders, the player's control can be efficiently analyzed in the framework of the knowledge on sound production in flute-like instruments. The time evolution of the hydrodynamical parameters which determine the sound production conveys the player's intention. We present analysis of the control exerted by a recorder player playing written musical excerpts, varying the musical engagement, or rewriting the score by changing the time signature. The basic control parameters measured during playing are analyzed in terms of hydrodynamic jet parameters. The different tones can then be classified according to the time shaping of each tone. The structure emerging from this analysis is finally compared to the written structure of the music. Results show that the same parameters that are used to produce the basic balance necessary for sound production are also finely tuned to shape the time structure of the playing, turning the sound into music.

19 **Acoustics of the Flautas de Chinos**

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ABSTRACT

In central Chile, a sacred musical ritual dated from pre-hispanic times, has survived centuries of segregation, misunderstanding and alienation, first from the european regard and later from their own mestizo compatriots. The ritual incorporates dance and music produced by bands of flutes whose sound is not conceived under any formal aesthetic paradigm but as an ingredient to stimulate and perturb their senses creating a sort of trance in performers and great excitation in the community. The ritual can last several hours and the sound can reach impressive loudness that can be heard from distances of hundreds of meters. Groups of about 20 musicians split in two teams and armed with flutes of different sizes, repetitively alter sound clusters that fill the space, time and frequency spectrum. The musicians are referred to as "chinos", a spanish deviation from a Quechua word which means servant. They are serving catholic divinities in a continuously evolving tradition that has adopted the overwhelming influence of christianity in Latin America. An anthropologic and ethnomusicologic study of the ritual is required to properly describe it but, for the moment, is beyond the scope of this article. Throughout the paper acoustical aspects of the instruments are described as well as some observations on the instrumental technique: the simplicity of their construction, materials and geometry, their acoustical impedance, the mechanisms of playing and their characteristic sound called *sonido rajado* (literally torn sound) are addressed. The complex resonator of the instrument, formed by two wooden cylindrical bore sections of different radius, no toneholes, and one closed end, is described in detail. An analytical model of its impedance

is proposed and contrasted with measurements and spectrum analysis of field recorded sounds. Measurements of the control parameters show that the flow needed to produce the sound is about ten times larger than the one used on european transverse flute. High-speed visualizations of the air jet show its turbulent behaviors well as lips oscillations that could relate to the production of the sonido rajado.

24 How players use their vocal tract in advanced clarinet and saxophone performance

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ABSTRACT

How – and when – is the player’s vocal tract important in clarinet and saxophone performance? In a simple model, the acoustical impedances of the instrument (a resonator downstream from the reed) and the player’s tract (an upstream resonator) appear in series and in their sum is in parallel with that of the reed.

We made measurements of the acoustical impedance spectrum inside the mouths of clarinetists and saxophonists while they were playing (including these advanced techniques: altissimo, multiphonics, bugling and pitch bending), using impedance heads built into the mouthpieces of a functioning clarinet and a tenor saxophone [1]. Acoustic impedance spectra of the clarinet, soprano and tenor saxophone bores were also measured for all standard fingerings, and some others. From these, we calculate the series impedance, and add it in parallel with the inferred reed reactance.

For fingerings high in the tenor saxophone’s second register, impedance peaks of the bore decrease rapidly with increasing pitch, making the altissimo range of this instrument more difficult than that of the clarinet, which has strong peaks into the fourth octave. On the saxophones, above the first 2.7 octaves, peak values fall below $30 \text{ MPa}\cdot\text{s}\cdot\text{m}^{-3}$ and this ends the standard range available to amateurs. To play the altissimo notes, experts produced strong vocal tract resonances upstream with impedances $10\text{-}40 \text{ MPa}\cdot\text{s}\cdot\text{m}^{-3}$ and tuned them so that peak in the combined bore-tract-reed impedance corresponded to the desired note. While expert saxophonists adjust their vocal tracts thus for altissimo playing, inexperienced players do not, and consequently cannot produce these notes. Similar vocal tract adjustments were observed for other advanced techniques such as bugling and multiphonic selection.

When pitch bending in the second (clarino) register of the clarinet, experienced players produced strong tract resonances with impedances up to $60 \text{ MPa}\cdot\text{s}\cdot\text{m}^{-3}$, comparable in magnitude with those of the clarinet bore ($40\text{-}50 \text{ MPa}\cdot\text{s}\cdot\text{m}^{-3}$). Thus during pitch bending, the sounding pitch is controlled by smoothly varying a strong resonance in the player’s vocal tract. The phases of the bore, tract and reed impedances explain why pitch bending downwards is easier than upwards.

In contrast, during normal playing on both the clarinet and saxophone, both amateur and experienced performers produced vocal tract impedance peaks with only moderate magnitude, and do not tune that resonance specifically to the note being played.

[1] Chen, J.M., Smith, J. and Wolfe, J. (2008). “Experienced saxophonists learn to tune their vocal tracts”, *Science*, 319, 726.

37 Applicability of compressible LES to reproduction of sound vibration of an air-reed instrument

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ABSTRACT

Elucidation of acoustical mechanism of air-reed instruments is a long standing problem in the field of musical acoustics. The major difficulty of numerical calculation of air-reed instrument is in strong and complex interactions between sound field and air flow dynamics, which is hardly reproduced by hybrid methods normally used for analysis of aero-acoustic noises. We need a direct method which allows to simulate dynamics of the jet flow and sound field in a resonator simultaneously.

With recent improvement in computer performance, direct simulations based on fluid dynamics becomes applicable for study of the sounding mechanism of air reed instruments. Yagawa et al used a node-by-node finite element method (NBN-FEM) for the direct calculation of the edge tone (Computer Methods in Applied Mechanics and Engineering vol.195 pp.1896-1910 (2006)). Their result shows a good agreement with experimental data. However, this method was not able to reproduce pipe resonance, because the open end reflection was not reproduced by their method. The lattice Boltzmann method (LBM) has been used for a direct simulation of air-reed instruments in MIT. It has succeeded in simulating the vibration of the jet. But the result is still not realistic, because the method used requires an unphysically high viscosity to stabilize oscillations.

The aim of our study is to reproduce sound vibration of air-reed instruments and to analyze the interaction of the jet flow with the sound field by using statistical methods, e.g. correlation function. To do this, we choose compressible Large-eddy Simulation (LES) solver to reproduce the sound field and flow dynamics of the instrument by directly solving the Navier Stokes equation, because LES is very stable for a long term calculation, though it somewhat sacrifices accuracy.

Taking a 2D small air-reed instrument with an open or close end as a model, we have succeeded in reproducing sound vibrations in the resonator as well as the jet oscillation as a sound source. The relation of the sound frequency with the jet velocity which is predicted by the semi-empirical theory developed by Coltman and other authors based on experimental results is also reproduced well. We further discuss the characteristic problem, which driving mechanism, the momentum drive or the volume flow drive, dominates in a given condition and how it changes with the jet velocity, by using statistical methods.

18 **Toward the systematic investigation of periodic solutions in single reed woodwind instruments**

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ABSTRACT

Single reed woodwind instruments rely on the basic principle of a linear acoustic resonator -- the air column inside the cylindrical or conical bore, coupled with a nonlinear exciter -- namely the reed and the air jet entering the mouthpiece. The first one is described by its input impedance, which binds the acoustical pressure and flow at the entry of the bore through a linear relation, whereas the second one has a non-smooth, nonlinear characteristic which combines the pressure on both sides of the reed channel, the jet flow, and the reed motion. To find possible playing frequencies, one often analyses the input impedance spectrum in terms of central frequency, height and width of peaks -- a method used in various recent publications on bore geometry optimisation. The exciter influence has rarely been taken into account, and in a few restrictive cases only : for precise, fixed value of control parameters ; through time domain simulations, which cannot give all information on the dynamics ; through simplifications of the equations, allowing analytical calculations of some parts of the bifurcation diagram. A more systematic investigation of a given instrument behaviors depending on control parameters requires the framework of dynamical systems and bifurcation theory, as well as specific numerical tools. In the present work, two continuation methods were used to obtain the bifurcation diagram of a clarinet, as comprehensive as possible. Stable and unstable, periodic and static solution branches are shown, revealing instrument characteristics such as oscillation, saturation, and extinction thresholds, as well as dynamic range.

16 **Numerical Modal Analysis of a Recorder Fluid**

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ABSTRACT

In this talk the three-dimensional numerical modal analysis of a fluid inside and around a recorder is presented. The fluid inside and close to the recorder is meshed by Lagrangian tetrahedral finite elements. Complex conjugated Astley-Leis infinite elements are used to obtain results in the far field of the recorder. The numerical method for solving problems in unbounded domains and the characteristics of the formulation of the eigenvalue problem are explained before the results of those computations are discussed.

As three-dimensional model, a soprano recorder with German fingering, which is tuned to 442 Hz, is used. A modal analysis of all playable notes, except the ones with half open tone holes, is accomplished. The results of the numerical modal analysis are compared to the values of the MIDI-table. Graphical results of the eigenvectors as well as the convergence behaviour of different tones are presented.

43 **Input impedance computation of wind instruments based upon the Webster-Lokshin model with curvilinear abscissa**

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ABSTRACT

This work addresses the computation of acoustic immittances of axisymmetric waveguides, the shape of which is C1-regular (i.e. continuous and with a continuous derivative with respect to the space variable).

With this intention, a refined version of the Webster horn equation is considered, namely, the Webster-Lokshin equation with curvilinear abscissa, as well as simplified models of mouthpieces and well-suited radiation impedances. The geometric assumptions used to derive this uni-dimensional model (quasi-sphericity of isobars near the wall) are weaker than the usual ones (plane waves, spherical waves or fixed wavefronts). Moreover, visco-thermal losses at the wall are taken into account. For this model, exact solutions of the acoustic waves can be derived in the Laplace or the Fourier domains for a family of parametrized shapes. An overall C1-regular bore can be described by connecting such pieces of shapes under the constrain that junctions are C1-regular. In this case and if the length of the bore is fixed, a description with N pieces precisely has $2N+1$ degrees of freedom. An algorithm which optimizes those parameters to obtain a target shape has been built. It yields accurate C1-regular descriptions of the target even with a few number of pieces. A standard formalism based on acoustic transfer matrices (deduced from the exact acoustic solutions) and their products make the computation of the input impedance, the transmittance (and other immittances) possible. This yields accurate analytic acoustic representations described with a few parameters.

The paper is organized as follows. First, some recalls on the history of the Webster horn equation and of the modeling of visco-thermal losses at the wall are given. The Webster-Lokshin model under consideration is established. Second, the family of parametrized shapes is detailed and the associated acoustic transfer matrices are given. Third, the algorithm which estimates the optimal parameters of the C1-regular model of target shapes is presented. Finally, input impedances obtained using this algorithm (and the Webster-Lokshin model) are compared to measured impedances (e.g. that of a trombone) and to results of other methods based on the concatenation of straight or conical pipes.