Bowed strings and sympathy, from violins to indian sarangis

M. Demoucron[a] and S. Weisser[b]

[a]IPEM, Blandijnberg 2, 9000 Gent, Belgium
[b]Musée des Instruments de Musique, Montagne de la Cour 2, 1000 Bruxelles, Belgium
matthias.demoucron@ugent.be

The sarangi is an indian bowed string instrument that is characterized by a large set of sympathetic strings (sometimes up to over 30), called taraf, going below the three main strings. The tuning of the taraf varies among players, but generally one part is tuned chromatically and diatonically, while the other part is tuned according to the rag of the musical piece, resulting in a rich and highly reverberant sound when the main strings are bowed. The goal of this research is to determine how the sympathetic strings affect the resulting sound, as well as possible musical, perceptual and aesthetical implications in classical Indian music. Starting from the simple case of western classical violins, in which sympathetic vibrations occur because of the interaction with adjacent open strings, we will examine changes occurring in the timbre of the instrument when one string is allowed to vibrate in sympathy. Then, we will present sound analyses of several sarangis played by various musicians, with and without taraf, in order to characterize the role of the sympathetic strings on the resulting sound.

1 Introduction

Sympathetic strings are found in a number of bowed strings instruments from various cultures and periods. These instruments are played on a few main strings, but auxiliary strings are mounted and vibrate in resonance with the tones played by the performer. The most striking example is the sarangi, an indian instrument which is characterized by a large set of sympathetic strings (between 30 and 35), providing a very resonating sound. But similar instruments can be found in other traditions, such as the norwegian hardanger (a violin-like instrument with 5 sympathetic strings under the fingerboard), the welsh crwth, or the bulgarian gadulka, among others. In western art music as well, some bowed string instruments with sympathetic strings were used in the past, the most famous being the baryton (a cello-like instrument from the viol family, with ten sympathetic strings) and the viola d'amore (a violin-like instrument with 6 or 7 sympathetic strings). Although these instruments were quite popular in the european 17th and 18th century, they progressively disappeared while instruments from the violin family (without sympathetic strings) were preferred.

This may be a reason why there are very few studies on bowed strings and sympathy in the scientific literature: most of the research in the music acoustics field focus on classical western instruments, and sympathetic vibrations does not affect systematically the vibrating properties of bowed strings instruments, in contrast with the case of some plucked or hammered instruments, such as harps and pianos. However, the fact that bowed string instruments and sympathetic strings are associated in many traditions encourages to have a closer look to the phenomenon involved by this association. The indian sarangi is a striking example, but the classical violin as well presents some significant effects, with which players have to deal.

Focusing on sympathetic vibrations lead to several research questions. For example: how do sympathetic vibrations affect the vibration of the main string and the sound? From a perceptual point of view, we could also try to identify the signal features that make it possible to recognize the presence of sympathetic strings. Another question is to examine how musicians deal with these vibrations, and how the latter impact their playing. Finally, from a more ethnomusicological point of view, we could focus on the relation between these acoustical properties and the musical aesthetic they participate to.

This paper will present basic acoustical observations on the effect of sympathetic vibration in the violin and the indian sarangi. There are two reasons for presenting these analyses side by side. First, the sarangi is a very complex instrument with many sympathetic strings, some of them with a flat bridge, that can be tuned in very different ways. In comparison, the violin is a very simple case study, with only four strings, and the study of resonances may provide basic insights for the analysis of the sarangi. The second reason is that the role of sympathetic vibrations, the instrument builder considerations and the acoustical aesthetic looked for with the two instruments are drastically different. In the classical violin family, sympathetic vibrations are only a collateral effect of the instrument design, while in the sarangi, the sympathetic strings are an essential component of the instrument acoustical identity. This strong discrepancy make the comparison between the two interesting.

In the following section, we will shortly describe the mechanisms of string coupling from a theoretical point of view. Then, we will present measurements performed on the violin (Section 3) and the sarangi (Section 4).

2 Theoretical background on string coupling and sympathetic vibrations

When a string is excited (i.e. plucked, bowed or hammered), part of the vibration is transmitted to the instrument body through the bridge. The amount of the transmission for each frequency depends on the design of the bridge and the vibrating properties of the instrument body, and can be characterized by the bridge admittance. The admittance curve in function of the frequency shows hills, peaks and valleys representing specific resonances of the instrument.

However, most of stringed musical instruments present more than a single string. Adjacent strings, if there are not damped, represent strong resonators in which vibration can be transmitted and stored when excitation frequencies match their natural frequencies. The stored energy can then be released, for example when the string is not excited anymore. Consequently, the interaction and energy exchanges between the excited string and the resonating strings impacts both the vibration and the sound produced by the instrument.

Note that we use the general term "string coupling" or "sympathetic vibrations" to designate the general mechanisms involved in the interaction between different strings belonging to the mechanical system. "Sympathetic strings" is used to designate more precisely strings that are not intended to be played, but to resonate and shape the sound behind the main strings.

Previous works have described the theoretical basis of string coupling in piano [1] and in string instruments, from a more general point of view [2]. Researches very often focus on aftersound, i.e. the influence of string coupling on the decay of the sound in plucked or hammered string instruments. Coupling between strings and the two directions of vibration result generally in double-stage decay and/or beatings, which depend on the very fine tuning of the coupled strings. These effects have been mainly studied for plucked string instruments like guitars, harps [3, 4], or hammered instruments like pianos [5].

However, the specific case of bowed string instruments have received very little attention. For the violin, Hutchins [6] showed that the sound level increased by 1-2 dB when the experimenter damped a string vibrating in resonance to the played string. Analyzing sounds of a viola d'amore and a sarangi with and without sympathetic strings, Besnainou et al [7] showed that the amplitude of the decaying sound exhibited a perceptible "rebound" when the sympathetic strings were allowed to vibrate. They also used spectrograms to illustrate the varying rates in the decay of harmonics, representing the contribution of stored energy in the release of the sound.

It is often claimed that sympathetic strings provide an enrichment of the tone and a feeling of reverberation producing a "halo of sound". The purpose of the following sections will be to analyze and illustrate further the effect of sympathetic strings on bowed string instruments. In particular, we will be interested in examining which aspect of the sound is perceptually relevant to describe best this effect.

3 Observations on the violin

The violin comprises four strings that are tuned in fifth from G_3 to E_5, the two intermediate strings being D_4 and A_4. All strings are playing strings, which means that no string is especially intended to resonate by sympathy in order to modify the timbre of the tones. However, when a string is played, the other strings can vibrate if they are not damped, absorb part of the bowed string vibration and modify slightly the sound. In this section, we examine the effect of such sympathetic resonances, then we discuss their influence on violin performance.

3.1 Experimental setup and sound analysis

A violin player was asked to play tones on the G string while different damping configurations for the remaining strings were arranged. Strings were damped independently with pieces of felt placed at different positions between the string and the fingerboard. Five configurations were used: all strings damped, then all strings damped except one (successively D-A-E strings), and finally, all strings undamped. The violinist repeated bow strokes for each note of the G string, i.e. short staccato with the bow stopping on the string, then short staccato with the bow leaving the string, pizzicati, long détaché, and vibrato.

Sound was recorded at 44.1 kHz with a supercardioid microphone (Shure Beta 87A) placed about 30 cm above the violin, then the amplitude and frequency of the first 20 harmonics were computed every 12 ms using Fast Fourier Transform (Hamming window on 2048 points, size 8192 points) and quadratic interpolation around each spectral peak.

The various configurations for the resonating strings allowed to influence differently the harmonics of the main vibrations. We can theoretically foresee that the first common harmonic between the played tone and the resonating string will be affected, as well as multiples of this common harmonic. This

Table 1: Summary of expected influences of the resonating strings on the harmonics of the A tone played on the G string. The columns show the first matching harmonic between the string and the tone (expressed relative to the string), and the corresponding harmonic of the A tone.

String	Matching harm.	Corr. harm. for A
D (294 Hz)	3 (882 Hz)	4 (880 Hz)
A (440 Hz)	1 (440 Hz)	2 (440 Hz)
E (659 Hz)	1 (659 Hz)	3 (660 Hz)

is illustrated in Table 1 for the note A played on the G string. For example, all harmonics multiple of 4 for the tone A will be affected by the resonating D string.

3.2 Release of the sound

The most straightforward way to examine sympathetic vibrations is to look at the release of the sound when the main string is excited, then suddenly stopped. Remaining vibrations can then be attributed to the release of energy stored by the resonating strings. Furthermore, in order to study the influence of sympathetic vibrations, it is interesting to examine as well the more realistic case in which the main string contribute to the release of the sound. This is illustrated in this section by analyzing the two types of staccato performed during the experiment: short staccato with the bow stopping on the string, and short staccato with the bow leaving the string. These bow strokes will be called *solid staccato* and *flying staccato* in the following, after the Galamian's terminology [8]. The difference between the two bow strokes is that, with flying staccato, the main string is allowed to vibrate freely at the end of the stroke, while with solid staccato, the vibration of the main string is quickly damped and only the release of the sympathetic vibrations remains.

The results are illustrated in Figure 1, showing the power of the first six harmonics during and after the stroke (solid staccato on the left panel, flying staccato on the right panel). The violinist played A on the G string, a tone that has common harmonics with the remaining strings of the violin, as shown in Table 1. Starting from the top, the curves show the configurations with all string damped, only D string undamped, only A string undamped, and all strings undamped.

Looking on the left side of Figure 1, it can be seen that the measurements match theoretical expectations: with the D string undamped, only the harmonic 4 shows a longer decay, while with the A string undamped, harmonic 2 and 4 are affected. The last configuration with all string undamped shows an influence on all harmonics except 1 and 5, harmonics 3 and 6 matching natural frequencies of the E string. The right side of the figure shows a very peculiar behavior of sound decay with flying staccato. Without sympathetic vibrations (top) the decay time of the fundamental is rather long, while other harmonics are quickly damped. Because the power of the fundamental is low compared to other harmonics during the bowed part of the stroke, this leads to a double-stage decay, the total envelop following first harmonic 2, then harmonic 1 after 0.6 s. With the D string undamped, the global shape of the decay do not change significantly because the influence on harmonic 4 is not strong enough. On the other hand, with the A string undamped (affecting harmonic 2 and 4), the decay slope is much lower and

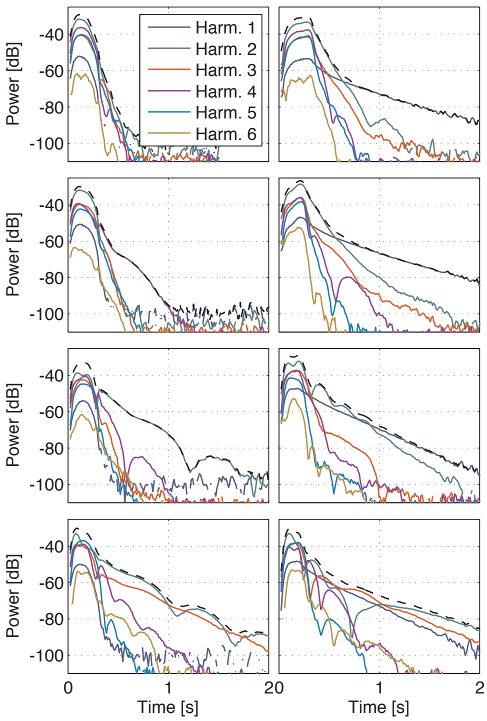

Figure 1: Time evolution of the first six partials during the release of tone A played on the G string with various configurations of string coupling for solid staccatos (left) and flying staccato (right). From the top: all strings damped, only D string undamped, only A string undamped, all strings undamped.

shows intensity modulations probably related to beatings between the harmonics of the main string and the A string. The effect is even stronger with all strings undamped, in which case the decay is not led anymore by the fundamental but rather by harmonics 2 and 3, resulting in a much lower decay rate.

3.3 Sound spectrum and intensity

The influence of sympathetic vibrations on the spectrum and the sound power is illustrated as following. A violinist played A_3 on the G string with all remaining strings open, resulting in a strong, clearly visible, sympathetic vibration of the A_4 string. After about 2 seconds, the A_4 string was damped with a finger in order to suppress the sympathetic vibration.
The fundamental frequency of the A_4 string matches twice the frequency of the played note, therefore we can expect that the even harmonics of the sound will be mostly affected. The result is illustrated in Figure 2, showing the intensity of the first six harmonics for the two situations and how they evolve when the string is damped.
The most striking feature of Figure 2 is the sudden increase in intensity of harmonic 2 and 4, which can be used to identify the moment when the sympathetic vibration is damped (here around 1.8 s): they both increase by a bit more than 10 dB. This increase is clearly noticeable when listening to the sound. In contrast, odd harmonics seem unaffected by the damping and their intensity is rather flat all along the bow stroke. It can also be noted that the total energy of the tone is not significantly changed, as it increases only by 1-2 dB.
Another striking feature is the strong amplitude modulations

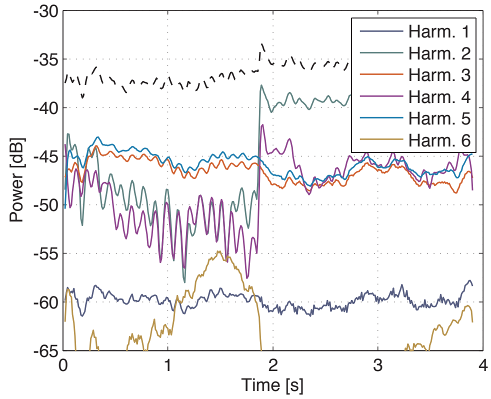

Figure 2: Time evolution of the first six partials for a tone A_3 played on the G string of the violin. At t=1.8 s, the open A_4 string is damped with a finger.

that can be observed on partial 2 and 4 when the A_4 string is allowed to vibrate (i.e. before 1.8 s). They may be due to beatings produced by slight frequency differences between the harmonics of the played note and the harmonics of the A_4 string. In comparison, harmonics 1, 3 and 5 do not show oscillations and vary consistently together.
This may be one of the most relevant effect of sympathetic vibrations. While the amplitude of harmonics can vary with various influences including bowing parameters, violin body or directivity of sound radiation, the modulations observed for some harmonics are a direct effect of sympathetic vibrations. What is maybe even more important from a perceptual point of view is the induced lack of consistency between these harmonics and the global shape of the sound. As a matter of fact, a strong correlation between the harmonic components of the sound is important to create the sensation that they are all emanating from the same musical source. The lack of correlation may be responsible for the somehow ”floating” character that a string vibrating in sympathy provides to the sound.

3.4 Influence on playing

As mentioned before, sympathetic resonances in violin playing are essentially a side effect of the violin design. Strong resonances can involve fine acoustical problems that musicians have to take into account in their performance: homogeneity of timbre and sound intensity, homogeneity of vibrato (a vibrato around a resonance involves strong amplitude modulations), or playability (playing around a strong resonance often requires more bow pressure to make the violin sound well). In particular, players often adapt their fingering or damp other strings in order to avoid sympathetic resonances. This is the case, for example, with very short bow strokes when a sudden stop is looked for.
On the other hand, string resonances involve a clearly perceptible change of timbre, which can be used as reference points when practicing technical exercises in order to check possible deviations in pitch accuracy on specific notes. The release of sympathetic resonances can also be used to make bow changes sound softer and almost imperceptible.
To our knowledge, there is only one example in which resonances of adjacent strings are used on purpose. Open strings can not be played vibrato and musicians tend to avoid playing them for long notes. When they have no other solution,

for example with the G_3 on the violin, which has to be played on the open G lowest string, they often simulate a kind of vibrato by putting down a finger one octave up on the D string and vibrating on the unplayed D string. The effect of such a "trick" can be seen in Figure 3: the large fluctuations in the intensity of harmonics 2 and 4 may contribute to give more liveliness to the tone and can be clearly perceived.

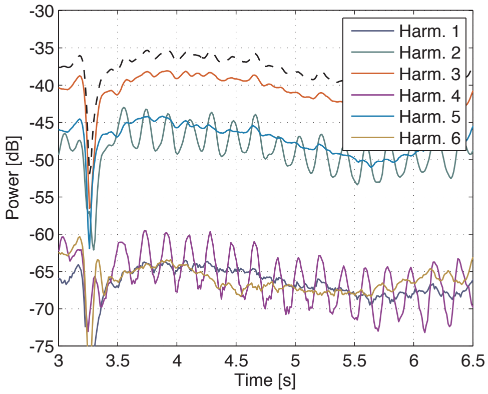

Figure 3: Using sympathetic resonances to perform a "vibrato" on an open string. The violinist plays the open G string while vibrating a G one octave up on the D string, resulting in amplitude modulation of the even harmonics.

4 Application to the sarangi

With the sarangi, sympathetic vibrations are such an essential component of the instrument identity that sympathetic strings, called *tarafs*, can be thought as the "soul of the sarangi" [9]. Without them, the sound is described as "dry and lifeless", and many musicians are unable to play without them. They give life to the sound, but they also help the performer to have an accurate intonation by providing acoustical and visual cues when the played tone matches the resonance frequencies of the tarafs.
In this section, we will first shortly present the instrument, then we describe an experiment aiming at studying the effect of tarafs on the sound.

4.1 Description, tuning of sympathetic strings

The sarangi is played with a bow on three main strings generally made of gut (a fourth string is sometimes added to be used as a drone). In addition, the instrument comprises around 35 sympathetic, metallic, strings. They are divided into four sets of strings, as shown in Figure 4. Two sets comprise most of the strings (usually 15 and 9, respectively) and are attached along the neck, with tuning pegs on the side. The remaining strings are attached at the top of the neck and pass over small flat bridges called *jawari*. All the strings pass through the main bridge: the three main string on the top and the tarafs through holes below.
Tuning the tarafs is an important problem of the instrument and each player has a personal tuning configuration. Narayam [9] recommends to tune the 15 side tarafs on a chromatic scale, the 9 other side tarafs to the notes of the *rag*, and the upper tarafs at the player's whim, but preferably to important notes of the rag. He also emphasizes the importance of tuning by recalling that "He who can tune the sarangi correctly is already half a sarangi player".

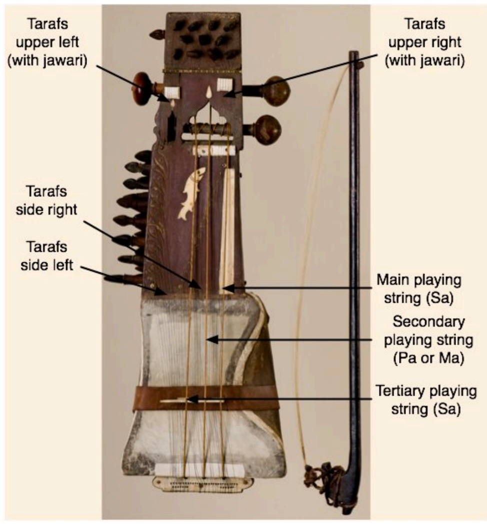

Figure 4: The sarangi comprises three playing strings and around 35 sympathetic strings arranged in four sets of strings ((Inv. Nr. 2007.001, Musical Instrument Museum, Brussels. Picture : Simon Egan, ©: MIM).

4.2 Experimental setup

Two renowned sarangi players and one of their students were recorded at ITC-Sangeet Research Academy (Kolkata, India). They were asked to play the successive tones of a rag first with a normal setting of the tarafs and second with tarafs prevented to vibrate thanks to a cloth wrapped around them. Notes were played separated and the next note did not start before natural extinction of the previous note. Tuning and rag was left to musicians' choice. Recordings took place in a sound-proof room of the school, with a two-channels Sound Device 702 portable audio recorder and two cardioid MBHO NBNM 440 CL microphones.
The tuning of the tarafs was determined by recording sym-

Table 2: Tuning of the tarafs (in Hz) for one of the sarangi players. For the notes, an equivalent (relative) western notation considering C as the tonic is given (K. and T. stands for Komal and Teevra).

Range	Note	Side		Up	
		left	right	left	right
Low	Sa (C)			156	
	Ma (F)			207	
	Pa (G)			233	
	Dha (A)			260	
	K. Ni (B♭)		295		
	Ni (B)		277, 281	277	276
Med.	Sa (C)	308	313	311	310
	Re (D)	345	352		345
	K. Ga (E♭)		369		
	Ga (E)		391		390
	Ma (F)	417			415
	T. Ma (F♯)		446		
	Pa (G)	468	469		
	K. Dha (A♭)		496		
	Dha (A)	514	521		
	K. Ni (B♭)	544	551		
	Ni (B)		587		
High	Sa (C)	624	620		

pathetic strings plucked one by one by the player. A fundamental frequency analysis was then performed for each taraf, and the frequency was averaged on the duration of the decay. As expected, the analysis revealed tuning differences among players. In the example shown in Table 2, it can be seen that the tuning follows Narayam's recommandations, with the set of 15 tarafs tuned chromatically and the set of side tarafs tuned to the rag. Most of the tarafs are tuned on the range of one octave, above the medium Sa corresponding to the main playing string. One set of the upper tarafs is especially used to coincide with the frequency range of the lowest playing strings (here, Low Sa and Ma).

4.3 Preliminary sound analyses

Sound analyses were performed on the recording of tones played with and without tarafs. The first 20 harmonics were extracted in order to examine their average amplitude and their time evolution during the bow strokes. The average amplitudes showed significant differences, but it is again difficult to claim that these spectral differences explain the "tone richness" and "liveliness" that most of the performers describe.

Instead, it is interesting to look again at the time evolution of the harmonics amplitudes, shown in Figure 5. The figure shows two notes Re played on the main playing string, without tarafs (top) and with tarafs (bottom). In the second case, it is hardly possible to determine when the bow stroke stops, while on the top, the decrease of harmonics amplitude shows very clearly the stopping of the bow. With tarafs, the decay of the sound is very slow and shows strong amplitude modulations of the harmonics.

If we look at the sustained part of the sound, it is again striking to observe how the first four harmonics vary consistently when tarafs are damped, while tarafs seem to degradate the harmonics correlation. Modulations observed for harmonics 5 and 6 may be due to couplings with the two other playing strings (not damped during the experiment), corresponding respectively to harmonics 11 of low Sa string and harmonics 10 of Ma string. With tarafs, the amplitude of harmonics at the start of the tone are first similar to the case without tarafs, then they quickly start to modulate intensively.

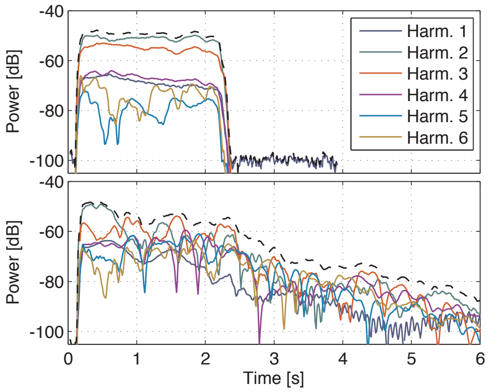

Figure 5: Time evolution of the first six partials for a tone Re played on the main playing string of the sarangi without tarafs (top) and with tarafs (bottom).

5 Conclusion

This paper aimed to examine and illustrate the effect of sympathetic vibrations in bowed string instruments by focusing on two specific cases: the violin, for which sympathetic vibrations can occur with adjacent, not played, strings, and the indian sarangi, for which sympathetic strings participate in a essential way to the acoustical identity of the instrument. In particular, we pointed out one feature that may be relevant to describe the perceptual effect of sympathetic vibrations: the consistency of harmonics time evolution in the sound when the string is bowed. However, this feature should be examined more closely in the future, in particular with perceptual tests aiming at evaluating its relevance. Another remaining question that should be addressed is the objective influence of various tunings of sympathetic strings on sarangi performance.

Acknowledgments

Recordings were performed at ITC-Sangeet Research Academy with a Grant for Mobility in Scientific Research from the National Fund for Scientific Research (FNRS-FRS), Belgium. Part of this work is funded by the EmcoMetecca project supported by the Flemish Government.

References

[1] G. Weinreich, "Coupled piano strings", *J. Acoust. Soc. Am.* **62**(6), 1474-1484 (1977)

[2] C.E.. Gough, "The theory of string resonances on musical instruments", *Acustica* **49**(2), 124-141 (1981)

[3] J.L.L. Carrou, F. Gautier, N. Dauchez, J. Gilbert, "Modelling of sympathetic string vibrations", *Acta Acustica united with Acustica* **91**(2), 277-288 (2005)

[4] J.L.L. Carrou, F. Gautier, R. Badeau, "Sympathetic string modes in the concert harp", *Acta Acustica united with Acustica* **95**(4), 744-752 (2009)

[5] H.M. Lehtonen, H. Penttinen, J. Rauhala, V. Välimäki, "Analysis and modeling of piano sustain-pedal effects", *J. Acoust. Soc. Am.* **122**(3), 1787-1797 (2009)

[6] C.M. Hutchins, "Sympathetic vibration and coupling of resonances", *Catgut Acoust. Soc. J.* **1**(6, Series II), 40-41 (1990)

[7] C. Besnainou, M. Castellengo "De la résonance, une étude acoustique du phénomène sympathique", *Amour et sympathie: actes du colloque sur les instruments à cordes sympathiques, Limoges 28/29 novembre 1992*, Edition Ensemble baroque de Limoges (1995)

[8] I. Galamian, *Principles of violin playing & teaching*, Prentice-Hall (1962)

[9] N. Sorrell, R. Narayan, *Indian music in performance: a practical introduction*, Manchester University Press ND (1980)