Violin making "tonewood": comparing makers' empirical expertise with wood structural/visual and acoustical properties

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The “resonance woods” for the making of violin family have benefited from more research than other instrument making woods, but the interactions between different disciplines and viewpoints in this field has seldom been addressed. The objective of this study is to improve the understanding of the interactions between physic-mechanical properties of resonance wood, their natural variability, and the actual expertise of violin makers in the selection and qualification of their raw material. An in-depth “socio-technical” survey has been designed to identify violin makers’ opinions and practices on both qualitative and quantitative grounds. In parallel, tonewood samples of various “qualities” were characterized for their physical and vibrational properties (density, anisotropic specific moduli and damping coefficients), acoustical “performance indexes”, and visual/structural characteristics (growth-ring uniformity and percentage of latewood). Correlations between visible structural characteristics, density and vibrational properties in spruce “resonance wood” were not typical of classical softwoods and highlight the peculiarity of this pre-selected material, which can be discussed through microstructural explanations. Empirical choice by violin makers, based on perceptual criteria that can be visual, physic-mechanical, auditory, are relevant to the acoustic properties measured but will require a more detailed study to evaluate the respective contribution of these different fields of perception. We also intend to construct a model to evaluate the properties of a full violin plate from sampling fabrication offcuts.

1 Introduction

Wood as raw material of many musical instruments plays an essential role in their acoustic, aesthetic or technical quality therefore in their identity. Among the many woods used in musical instruments, the term " resonance wood " is often employed to describe those used for the soundboard of string instrument (spruce) and for the resonator box (fiddleback maple) [1] .

From the single viewpoint of acoustical and mechanical approach, the evaluation of wood quality is only based on sets of physical criteria. Vibrational properties of wood can be described by the speed of sound, which results from dynamic Young’s modulus (E’) and density (ρ), therefore from specific modulus (E ' / ρ), also by the quality factor or damping coefficient reflecting the internal friction (tanδ) and the extinction of sound in the material [2]. It is often recognized that high quality resonance woods have high modulus of elasticity, low density and low damping [3]. Based on these basic properties, performance indexes like “characteristic impedance", “ratio of radiation” and “Acoustic Conversion Efficiency” can be obtained [4]. The wood has a strong anisotropy and a cylindrical orthotropy impacting the vibrational properties of soundboards. The axial-to-shear anisotropy plays an important role in defining the spectral characteristics and the timbre [5]. Softwoods, and particularly spruce, have higher anisotropy than hardwoods. Ideally it would be necessary to take into account the vibrational properties in the three directions of the timber (longitudinal, radial and tangential).

For some instruments, such as xylophone (idiophones), physical properties were found highly correlated with the perceived “sound quality” [6]. However, the complexity of stringed instruments and their structure makes this relation more difficult to establish. According to the only psychosensory study conducted, the wood selection made by luthiers would rather rely on visual criteria than on mechanical or acoustical properties that seem too difficult to be assessed on raw supply planks [7]. Moreover, it is likely that physical criteria of selection also interact with cultural preferences in the case of instrument making [8].

Although the “resonance woods” for the making of violin family have benefited from more research than any other instrument making woods, the interactions between different disciplines and viewpoints in this field has seldom been addressed.

The objective of this study is to improve the understanding of the interactions between physical mechanical properties of resonance wood, their natural variability, and the actual expertise of violin makers in the selection and qualification of their raw material

2 Materials and methods

2.1 Material preparation and conditioning

Specimens for characterization of vibrational properties and growth ring features were obtained from 24 soundboards of Norway spruce (Picea abies [L.] Karst). The provenance was Grisons mountains (Switzerland) and the wood had been air-dried for 5 years. Samples were obtained from a previous project of I. Brémaud. The 24 soundboard supplies were intended for the manufacture of violin (14 plates), and Viola (10 plates). They were valued by the supplier to be sold under the highest quality grades ("Excellent" and "Master Grade").

The quarter-cut spruce wood supplies were sawn in the center of their section in order to separate the two wedge-shaped halves of the future top plate, while extracting from the center very thin (2.5mm) boards representative of the plates and destined at laboratory tests. These thin boards were then cut according to a sampling plan that allows to assess the properties in the radial and longitudinal directions, as well as the variations within a given soundboard. For a board, three radial specimens (120 × 2.5 × 12mm, R × T × L) and seven to eight longitudinal (12 × 2.5 × 150mm, R × T × L) specimens were obtained. All specimens were conditioned at 65 % relative humidity and 20 °C for at least 3 weeks, until reaching equilibrium moisture content. Specific gravity (ρ) was then measured.

2.2 Characterization of vibrational properties and acoustical indexes

Vibrational properties of strip specimens were measured by non-destructive testing using non-contact forced-released vibrations of free-free beams (figure 1), based on a Japanese method [3, 5] and using a semi-automated device developed at LMGC Montpellier [9,10] . The specimens were suspended by thin threads at the theoretical location of the vibration nodes of the first mode. A laser triangulation sensor is placed above the specimen in order to measure displacement. Under each sample a piece of steel is glued and faces an electromagnet which is controlled by a software developed in Labview ®. A first frequency scan (150 to 750 Hz for longitudinal specimens and 80 to 500hz for radial ones) is emitted and causes vibration of the sample to identify the first resonant frequency, from which the specific modulus of elasticity E '/ρ is calculated according to Bernouilli equation. Then, a second narrower scan centered on the resonance frequency is emitted in order to measure the damping by bandwidth, or "quality factor" (Q=1/tanδ). Finally, specimens are excited at their resonance frequency and, after stabilization of the vibration, the excitation is stopped to measure the logarithmic decrement (λ=π×tanδ). Damping measurements in the frequency and temporal domains give identical values in average, however, for spruce, bandwidth measurement are more precise (mean error between repetitions is of only 2%).

Then, the Acoustical indexes combining several properties of materials are calculated [4]. The characteristic impedance, reflecting the difficulty of transmission from one place to another, is expressed as $z = \sqrt{E'\rho}$, the ratio of radiation $R = \sqrt{\frac{E'}{\rho^3}}$ indicating the average amplitude and the Acoustic Conversion Efficiency $ACE = \frac{\sqrt{\frac{E'}{\rho^3}}}{\tan\delta}$ describing the response of maximum intensity.

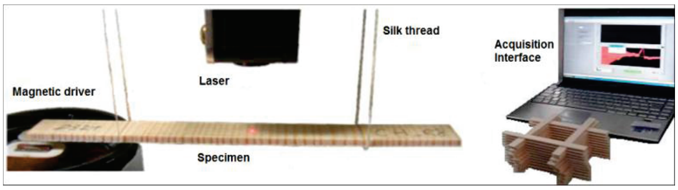


Figure 1: Vybris device, a non-contact forced vibrations of free-free beams developed in LMGC.

2.3 Measurement of visual/structural characteristics of growth-rings

The specimens already tested for vibrational properties were sanded with fine-grit paper on their section (transverse plane RT) in order to mitigate sawcuts, make the growth ring structure more visible and to obtain a perfectly flat surface. Radial-tangential surfaces were then scanned to obtain images (in Tiff format) with a resolution of 2400 dpi necessary for image analysis. The image processing was done thanks to a program developed by Tancrède Alméras (LMGC) with the Image J software plugin. This plugin (Figure 2) automatically identifies growth ring widths and percentage of latewood (percentage also called "texture") on a selected area.

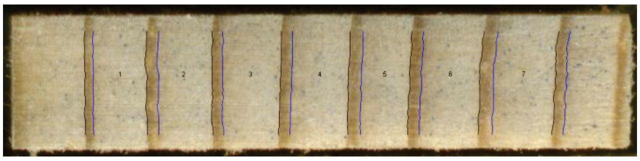


Figure 1: Example of identification of growth-rings features by image analysis using the developed plugin in Image J.

2.4 Development of a survey to identify violin makers' opinion and practices on both qualitative and quantitative grounds

To learn more about maker's practices and their main questions, a survey was created. It was developed as a face to face interview. The content is deliberately larger than the limits of the subject. It permits the survey to be adapted to different kinds of instrument making and to be used for other projects. The questionnaire (using the Sphinx software) is organized in 9 modules: the maker's profile, the concept of quality, the wood supply, the wood criteria choices for top plates, for back & sides, for bows, the treatments and varnish, the relation to scientific and historical research, and the questions and remarks.

As a first step, the method and the relevance of our questions was tested through the comments of the community of luthiers of Montpellier. Of the eleven makers we contacted, nine said they were willing to participate to this survey. At the same time they gave us their agreement to participate, the majority of the craftsmen (7/9) expressed explicitly they were interested and concerned in this study on violin wood. However, due to time, constraints and the length of the questionnaire, we have, at the time of writing, 6 complete responses to the questionnaire (67% of luthiers encountered, which already seems a satisfactory response rate for a questionnaire of 14 pages). Thanks to their work and advices, the questionnaire changed in time and several versions have succeeded to improve the efficiency and relevance of the survey, that can now be broaden to a national level. The results are analyzed on the basis of 6 complete questionnaires.

3. Relation between makers and wood

3.1 Concept of wood in instrument quality

To clarify the concept of quality, the makers defined a good instrument by using two very different ways. For some the concept of "quality" is spontaneously expressed with terms referring to physical criteria like "powerful", "with timbre" and "easy to play". For the others, a good instrument is defined by a notion of pleasure like "sensation of evidence", "instrument that is unanimously" "that pleases the one who plays". This large spectrum of answers will require lexical analysis to better understand this issue.

The choice of resonance wood, primarily for the top plate but also for the back plate, appears for craftsmen to rank amongst the most determining factor for the sound quality of the instrument and for its global quality. Luthiers judge that the role of wood is very important both for acoustic response, for stability and for aesthetics.

3.2 Wood supply

All makers buy their wood from a specialized supplier, whom they trust, and they never choose directly in the forest. Although they are interested in forestry, they do not consider themselves enough competent and/ or do not have time to look at the "forest" dimension. Some of them also recognized the image of the luthier choosing his own timber in the forest to be a myth that they find entertaining to maintain.

The two most important criteria in the choice of wood supply are the quality followed by price. To choose their tonewoods (Figure 3), they mainly assess density and visual criteria by using their experience.

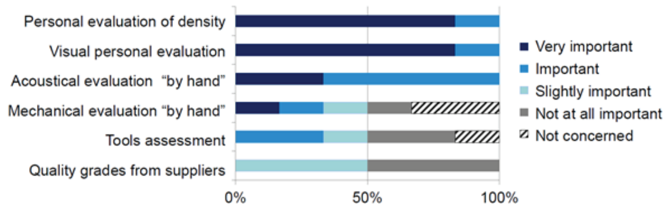


Figure 2 : Importance scale of different kinds of evaluations when buying resonance woods

3.3 Criteria for wood choice

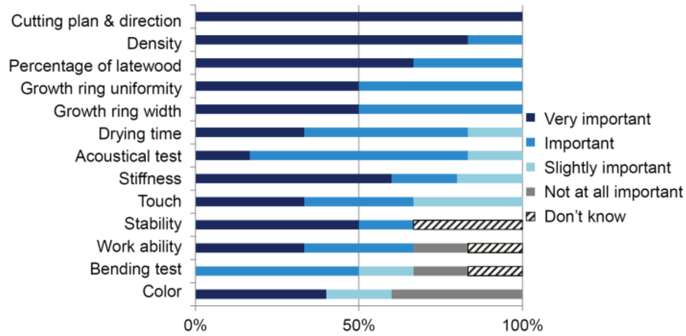


Figure 3: Importance scale of different criteria to qualify the spruce wood

The main criteria to qualify the spruce wood (Figure 4) are: good quality of cutting orientation, density, percentage of latewood, growth ring uniformity and width.

The desired "sound" for a soundboard of good quality is described as a *"clear and long lasting sound"*. Other concepts such as *"resonance"*, *"gradual disappearance of the sound"*, *"cleanliness"* and *"precision"* were also cited.

Given the priority importance attributed to visual features when choosing wood, one can wonder what is the relationship between these visual criteria and the mechanical and acoustical properties of wood.

4 Wood properties

4.1 Properties vs visual analysis

Table 1: Correlations between properties, acoustical index and visual characteristics of wood

	Rw (mm)	Lw mean (%)	Lw r/r (%)	Density ρ
Density ρ	-0.44	0.78	0.75	
EL/ρ	-0.63	0.86	0.86	0.69
ER/ρ	0.69	-0.55	-0.56	-0.36
tanδL	0.58	-0.63	-0.65	-0.28
tanδR	-0.74	0.73	0.73	0.59
zL	-0.51	0.84	0.82	0.98
RL	0.28	-0.58	-0.54	-0.93
ACEL	0.00	-0.25	-0.21	-0.72

Density is most affected by latewood percentage (Lw). Ring width (Rw) and Latewood reflect the vibrational properties, while density provides information on the acoustical indexes.

Visual parameters seem to be rather good perceptive indicators of wood mechanical phenomena (Table 1).

Correlation between density and axial specific modulus (R=0,69) wasn't expected. The young modulus E is taking into account the density, therefore the specific modulus is supposed to be independent of density. The explanation is probably linked to the relation between latewood percentage and density, reflected here by the correlation linking the specific modulus and Ring width and Latewood. A microstructural explanation based on the differences in cellulose microfibril angle in the cell walls could be the key [11].

4.2 Resonance Wood, a non-typical wood

When we compare our results with those of Kubojima [12] correlations between visible structural characteristics, density and vibrational properties in spruce "resonance wood" are not typical of classical softwoods (Figure5).

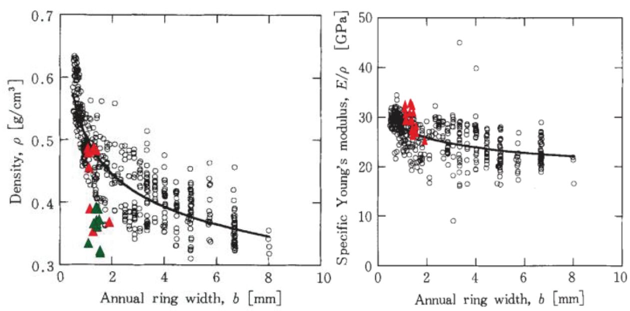


Figure 5: Relation between visual characteristics of spruce wood and its properties

We see first of all that the range of ring widths of "resonance wood" is very low compared to the general ring width of "common quality" spruce wood. Furthermore the ranges of variation in density and vibrational properties are very small for "resonance wood", compared to range of variation in properties generally found in spruce wood.

4.3 Inter-Soundboard Variability

Table 2: Variability between different boards.

	Minimum	Maximum	Variation range
Density	0.32	0.49	43%
EL/p	25.17	32.76	26%
ER/p	1.37	2.86	70%
tanδL	6.0E-03	7.4E-03	21%
tanδR	1.7E-02	2.2E-02	26%
Ring width (mm)	1.09	1.91	60%
Latewood	0.13	0.20	38%
Latewood r/r	0.14	0.20	39%

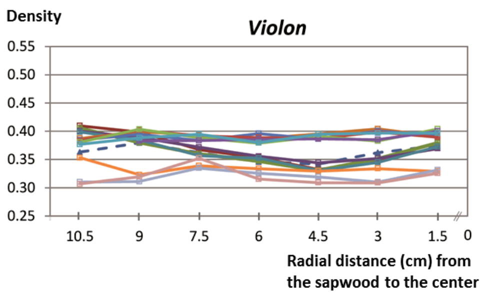
When considering the average characteristics measured for the different soundboards (Table 2), we observe a range of density of 0.32 to 0.49, of longitudinal specific modulus of elasticity (E_L'/ρ) from 25 to 33 GPa , of damping factor (tanδ) in the longitudinal direction of 0.0059 to 0.0072 , of ring width of 1.1 to 1.9 mm , and of latewood content of 13 to 20 % . In terms of extent of variation (range relative to average) , the radial specific modulus (ER'/ρ) is the most variable between plates (70%) followed by ring widths (60 %) and density (43 %), the percentage of late wood (39%), EL '/ ρ (26 %) and finally tanδL (26 %) which is most stable between plates .

4.4 Intra Soundboard Variability

Table 3: Variability in one board

	Minimum	Maximum	Average
Density	4%	21%	11%
EL/p	4%	65%	16%
tanδL	5%	24%	14%
Ring width (mm)	26%	103%	50%
Latewood	18%	43%	27%

However, when we observe the set of specimens which were characterized at different radial positions in the plate (Table 3), it seems that the variation within one plate is less important than the variation between different plates for density, but significantly higher for EL/p. The maximum of the extent of change within one soundboard is lower than from one board to the other for density (21% vs 43% between plates) significantly higher for EL '/ ρ (65% vs. 26% between plates) and for the ring width (103% vs 60% between plates), but that the inter- and intra-plate variability is equivalent for Latewood (43% vs 38%) and tanδL (24% vs 26% between plates). However, even in the latter case, when observing the variation from one point to the other we can see an influence of the intra-soundboard variations along the radial direction (i.e. radius of the trunk), represented in figure 6.



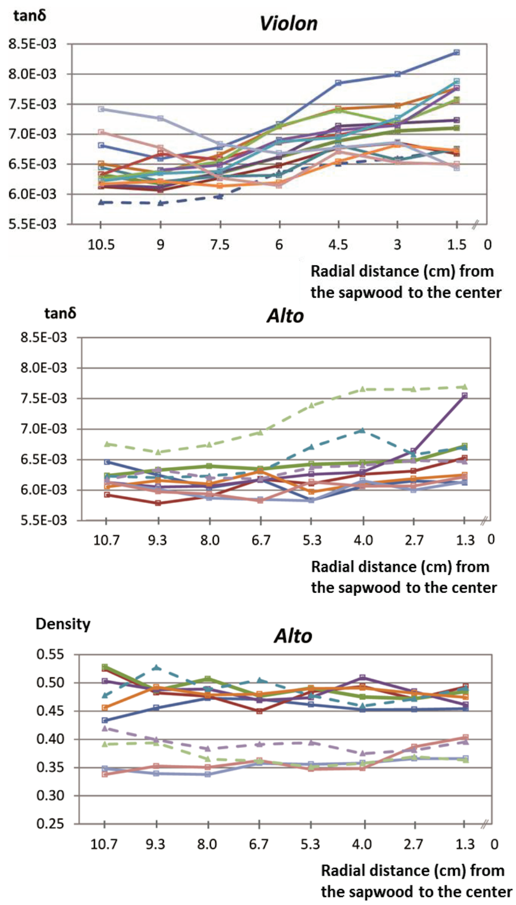


Figure 6: Evolution of the density and the damping of violins and altos soundboards according to the radial distance (each colour represents a different board)

5. Sociological aspects

5.1 Luthiers' opinion about some "clichés"

The makers tended to agree with the assertion that *'today's luthiers are at least as competent as those of past centuries'*. According to them, the quality of resonance wood was not "better" in the 18th century and the ancient luthiers had no more access to "good" resonance wood than current luthiers. In addition, if an absolute majority thinks that manufacturing a good bow with bad wood is not possible, 2/3 of them assume that we could obtain a very good violin with ordinary wood. Finally, they consider that the musicians, luthiers and public can't differentiate instruments of ancient masters from those of best modern craftsmen just by listening.

Most respondents (two thirds) believe that the "old masters" had a "secret" , a term they mainly interpret as a transmission of knowledge that would have been interrupted, or as " skills " and personal techniques that each maker develops in practice and often keeps for himself. According to them, and according to the interpretations of the term above, a "secret" would mainly concern the design, the geometry of the instrument and techniques

5.2 Relation to research and sciences

The makers say they mainly rely on empirical approaches, and also historical for their practices, but report a lot of interest in the scientific approach of resonance wood. Their interests for research (figure7) are mostly related to the history of art and techniques, to the drawing, varnishes and to the mechanics and wood science.

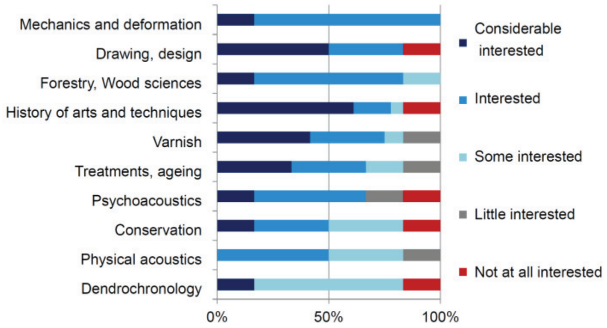


Figure 7: Interest scale of violin makers for different research approach

Their curiosity in research is manifested by reading articles, by discussions between professionals, participation to conferences and sometimes by conducting their own research. The main limitation of their relation to science is time and sometimes equipment. If all makers are aware of seminars and conferences on their work and wish the development of new courses or seminars, less than half participate in current conferences. 2/3 of luthiers are interested in the development of tools in the workshop if they are simple and allow them to better know the wood material.

6 Conclusions

The conducted survey highlights how important for makers is the wood choice for the instrument quality. It also helped to better quantify the respective importance of various criteria of choice. This study shows the **peculiarity of spruce "resonance wood"** in regards to classical softwoods. Empirical choice by violin makers, based on **perceptual criteria** that can be visual, physic-mechanical, auditory, **are relevant to the acoustic properties** measured but will require a more detailed study to evaluate the respective contribution of these different fields of perception. Perspectives in the continuation of this work will be first to broaden our survey to a national and international scale, and to simultaneously collect sampling of qualified wood. Thanks to our longitudinal and radial sampling we also intend to construct a model to evaluate the properties of a full violin plate from sampling fabrication offcuts. To test hypotheses on unexpected relation between specific modulus and density, microstructural features of resonance wood will be assessed. Finally we will enlarge the study to 'fiddleback' maple.

7 Acknowledgments

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