Key signal and wood anatomy parameters related to the acoustic quality of wood for xylophone-type percussion instruments

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The purpose of this study is to gain further insight into the relationship between the physical properties and the perceptual classification of woods to be used in xylophone-type percussion instruments. The preliminary results are presented.

Materials

58 tropical hardwood species selected within a wide range of density (210 to 1 280 kg/m^3). The species were not selected for their known musical quality.
Dimensions: 350 mm long (L axis), 45 mm wide (R axis), 20 mm thick (T axis).
Small clear wooden beams as far as possible.
Theoretical wood moisture content of 12% at equilibrium.

Methods

Flexural vibration tests

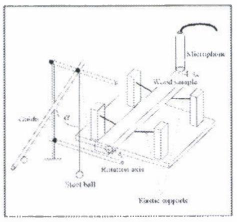

Figure 1. Experimental set up for dynamic tests (α = 30°, d_1 = 1.5 cm, d_2 = 2.5 cm).

Dynamic tests performed (Figure 1) in order to:
- obtain an accurate analysis of the mechanical and acoustic properties of each sample,
- build a sound database used for the xylophone maker classification.

Perceptual classification

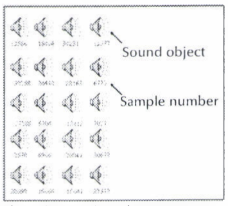

Figure 2. Example of the computer interface developed for the acoustic classification.

Acoustic classification conducted on the basis of recorded sounds by a xylophone maker.
Classification performed via a computer interface (Figure 2) with no direct access to wood specimens.

Key signal parameters

Temporal signals *s(t)* considered as a sum of exponentially damped sinusoids:

$$s(t) = \sum_{i=1}^{\infty} \beta_i \exp(-\alpha_i t)\, \sin(2\pi f_i t + \varphi)$$

Where s is the radiated signal as a function of time t, f_i is the resonance frequency of the order i and φ is the phase shift.

Parametric method of Steiglitz-McBride (1965) used to simultaneously determine:
- the first resonance frequency f_1,
- the amplitude β_1 associated with f_1,
- the temporal damping α_1 associated with f_1.

Specific longitudinal modulus of elasticity E_L/ρ computed using the Bernoulli's model (Brancheriau and Baillères, 2002). The first vibration frequency depends notably on the specific modulus so this parameter appeared to be an appropriate descriptor:

$$\frac{E_L}{\rho} = \frac{1}{13}\frac{AL^4}{I} f_1^2$$

Where A is the cross-sectional area and I is the moment of inertia.

Internal friction computed using a combination of additive synthesis models and wave guide synthesis:

$$\tan\delta = \frac{2}{\pi}\frac{\alpha_1}{f_1}$$

Results

Relationship between key signal parameters and acoustic classification

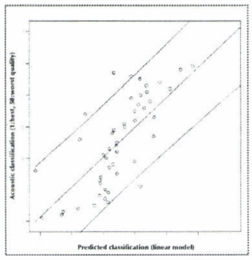

Figure 3. Linear regression between temporal damping and acoustic

8 outlier samples, due to defects or cutting problems, excluded from the analyses.
A unitary distance between two samples in the acoustic classification arbitrarily attributed in order to make the acoustic classification variable quantitative.
Significant correlation found between acoustic classification and temporal damping α_1 of the fundamental frequency (r = 0.77).
Similar result for the internal friction tan(δ) (r = 0.77) explained by a narrow variability of the first frequency ($\overline{f_1} \approx 1000$ *Hz* and $\sigma_{f1} = 100$ *Hz*).

Table 1. Pearson correlation coefficients.

r	Classification	Amplitude β_1	Damping α_1	Frequency f_1	Specific modulus E_L/ρ
Amplitude β_1	- 0.04				
Damping α_1	0.77*	0.08			
Frequency f_1	0.02	0.58*	0.25		
Specific modulus E_L/ρ	0.04	0.45*	0.29	0.95*	
Internal friction tan(δ)	0.77*	- 0.17	0.89*	- 0.21	- 0.15

Amplitude β_1 (related to the sound intensity) irrelevant (r = - 0.04).
First frequency f_1 irrelevant (r = 0.02).
Similar result for the specific modulus E_L/ρ (r = 0.04):
⇒ The samples tested were not musically tuned; this could explain why E_L/ρ and f_1 (frequency descriptor) were not correlated with the classification.
⇒ Or sufficient narrow variability of f_1 regarding the classification.

Relationship between wood anatomy and acoustic classification

Anatomical study focused on species ranked at both extremes of the acoustic classification (7 samples with a good quality and 7 with a poor acoustic quality, see Table 2).
The organization of wood components in the tested species highlighted the importance of the regularity and homogeneity of the anatomical structures.
It was observed that:
- acoustic quality could not be explained by any vessel characteristics,
- fibre morphology did not seem to have a major impact on the acoustic quality,
- axial parenchyma seemed to be the key trait (paratracheal, and not very abundant for a good quality),
- rays were also an important feature (short, structurally homogeneous but not very numerous for a good quality).

Table 2. Species ranked at both extremes of the acoustic classification (determination accuracy on α_1 = 4.3% and on tan (δ) = 4.4%).

Good acoustic quality	Temporal damping α_1	Internal friction tan(δ)	Poor acoustic quality	Temporal damping α_1	Internal friction tan(δ)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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