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### ► To cite this version:

Aurelie Tomezzoli, Benjamin Michaud, Eric Gagne, Mickaël Begon, Sonia Duprey. Bow influence on violinist performance. FA 2020, Forum Acusticum 2020, Dec 2020, Lyon, France. 4p, 10.48465/fa.2020.0697 . hal-03131211

**HAL Id: hal-03131211**

**<https://hal.science/hal-03131211>**

Submitted on 4 Feb 2021

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# BOW INFLUENCE ON VIOLINIST PERFORMANCE

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## ABSTRACT

To date, it is not clear why a violinist prefers a bow over another. To investigate this issue, 10 expert violinists were asked to play the same score with 18 bow configurations, in a random order. The bow configurations were generated by modifying the camber of the same bow and by adding 1 or 2 g masses at the tip and/or the frog. Firstly, the violinists rated each bow configuration on a scale from 0 to 10, for the spiccato playing, the legato playing and in general. Secondly, one expert assessed the accuracy of the pitch, rhythmic precision, respect of articulation, and timbre flaw on the sound records. Lastly, audio-descriptors were calculated. Then, variables were normalized by violinist, before performing ANOVAs: the explanatory variables were bow parameters and their interaction with the subject effect. It was found that the performance assessment by experts explained 6 to 20%, and audio-descriptors 6 to 17% of bow appreciation variances. Models containing both expert assessment variables and audio-descriptors explained 14 to 22% of bow appreciation variances. Thus, violinists assessed the bows partly by accounting for their acute ability to play properly the musical score, and the timbre of the violin.

## 1. INTRODUCTION

Bow material and shape were little changed since the end of the 18<sup>th</sup> century [1]. But today's bow makers face two challenges. Firstly, it's well known now than musculoskeletal disorders are widespread among violinists [2], reaching a 10.3% incidence rate among students [3] and a 77.4% prevalence rate among orchestra violinists [4]. Secondly, the trade of the bow stick wood, *i.e.* the Pernambuco (*Paubrasilia echinata*), an endangered species, is now restricted [5]. To overcome these challenges, understanding what violinists expect from a bow might be a first step: why does a violinist choose one bow over another? For now, the answer is still not clear.

The link between bow quality and its statics or dynamics was assessed, as far as we know, in only one study [6]. Quality criteria were expressed as verbal descriptors while bow statics or dynamics were measured, or estimated by finite element modeling, respectively. No link was found. More is known about the choice of the violin itself. The sound, as well as the vibrotactile feedback, are important parameters for determining preference,

and the relative importance of each depends of the violinist [7]. Saitis et al. found that playing, rather than only listening to the violin, enables people to better discriminate between violins in terms of sound richness [8]. It is also known that sound "richness" and "dynamic range" are important criteria for the preference ranking of violins, according to the instrumentalists [9]. The sound "richness" seems associated with low spectral centroids and high tristimuli 1 and 2 [8], and therefore computed audio-descriptors may help describe a violin or bow quality.

But surprisingly, it seems that no study based on by ear musical analysis [8-9] assessed the violin or bow quality. Yet, such metrics has been proven to be reproducible for assessing students' musical performances, reaching intra-rater correlation coefficient of 0.87 to 0.99 [10-11] and inter-rater correlation of 0.95 to 0.98 [11]. The goal of this study was to assess the influence of the sound on violinist's appreciations regarding the bow, using both a by ear musical analysis-based approach and audio-descriptor computation [14].

## 2. MATERIAL & METHODS

Ten professional violinists (nine women;  $27.7 \pm 7.6$  years) were included. They played the violin for  $21.0 \pm 8.0$  years. They had to play a musical theme composed by MB (co-author), under all combinations of different musical conditions: 2 articulations (spiccato and legato), 3 octaves (octave 3, 4 or 5) and 2 tempi (60 and 120 bpm), which make a 12 musical section music piece. A single bow (mass: 62g) was modified by GE (co-author) behind a curtain, in a two-step randomized order: the camber was modified first, and then all combinations of additions of 0, 1 or 2 g masses at the tip and/or 0 or 2 g at frog were tested. The violinists played each of these 18 bow configurations. The protocol was approved by the ethics committee of the University of Montreal (17-018-CERES-D).

### 2.1 Data collection

The sound was recorded by a Zoom Q3HD recorder (condenser microphone, XY, with a 120° angle), using a sampling rate of 44.1 kHz, and placed on the music stand. Marks were drawn on the ground to help place the violinists reproducibly relative to the music stand.

After playing, the violinists rated the bow on a scale of 0 to 10 for the spiccato playing, the legato playing

and in general. One randomly chosen bow configuration was blindly played twice by 6 out of 10 violinists.

Then, an expert (coauthor TA, composer) assessed the presence or absence of pitch, rhythmic, articulation and timbre flaw(s) in each section. One penalty score was calculated for each of these kinds of flaw, as the number of musical sections flawed within the music sheet. One penalty score was also calculated for each musical condition (for example, for legato sections), as the number of musical sections pertaining to this musical condition, and flawed by any kind of flow. Then, each penalty score was scaled, to reach 10 if every musical section was flawed. Thirty randomly chosen musical records (three per violinist) were re-assessed one month later by the same expert.

Finally, 14 among the less correlated audio-descriptors in Peeters et al. [14] were calculated, using the Timbre Toolbox [15]: attack, release, amplitude of energy modulation, frequency of energy modulation, RMS-energy envelope, spectral centroid, spectro-temporal variation, fundamental frequency, inharmonicity, noisiness, odd to even harmonic ratio, tritstimuli 1 to 3. Three notes were manually extracted [16] from each record: the octave 3 C# (C#3) played legato at 60 bpm, the C#3 spiccato 60 bpm, and the C#3 legato 120 bpm.

## 2.2 Statistical analysis [17]

Each variable was plotted to ensure their normal distribution or transform them. Levene's tests were performed to assess homoscedasticity between groups.

To estimate the percentage of violinists' appreciation variance due to between trial variability, analysis of variance (ANOVA) coefficients of determination ( $R^2$ ) were estimated. The dependant variable was the first rating and the explanatory variable was the difference between two rating of the same bow configuration.

Between assessment penalty score variability was quantified by the concordance rate, defined as assessment concordance frequency regarding the presence or absence of a particular kind of flaw in one section.

Then, to understand to which extent the penalty scores or the audio-descriptors could explain the violinists' appreciations, both were assessed as ANOVA's explanatory variables. A high subject effect was expected, which means that the more important part of the coefficients of determination would be due to this subject effect. As it represents a systematic between-violinist rating offset, the pure subject effect would not explained why violinists preferred one bow over another. So, violinists' appreciation, penalty scores and audio-descriptors were normalized to get the same mean and standard deviation for each violinist. Then, two-factor ANOVAs included the explanatory variables, their interaction with the subject effect, but not the pure subject effect. Each penalty score and audio-descriptor were assessed separately. Then penalty scores with statistically significant effects ( $p < 0.05$ ) were added one by one in a

model, starting from the more significant variable and keeping only those that improved the  $R^2$  of the model. The same was made with audio-descriptors. Finally, penalty score and audio-descriptor models variables were gathered in one single model.

## 3. RESULTS

### 3.1 Variability of appreciations and penalty scores

The violinists' between-trial appreciation variability explained 23% of the overall appreciation variance, 30% of the legato appreciation variance and 17% of the spiccato appreciation variance.

The one-month concordance rate of expert's assessment was very good (81.4%).

### 3.2 Explanatory variables for violinists' appreciations

The pure effect of one single penalty score or audio-descriptors was always absent or low ( $R^2 \leq 0.06$ ), whereas the interaction between those variable and a subject effect could reach  $R^2 = 0.20$ . Multivariate model based on either penalty score or audio-descriptors improved these results (Tab. 1). Multivariate models containing both of them had coefficients of determination of 0.22, 0.14, and 0.15 for overall, legato and spiccato appreciations, respectively, which was always less than the sum of coefficients of determination of penalty score plus audio-descriptor models (Fig. 1).

## 4. DISCUSSION

This work aimed to assess the influence of the sound on violinist's appreciations regarding the bow, using both a by ear musical analysis-based approach and audio-descriptors computation. In this study, both had an influence.

The by ear musical analysis-based approach was added to the parameters usually encountered in the literature because it pertains to musicians' field of expertise and background. Therefore, it seemed likely to be one of the first criteria a musician considers when assessing his or her own performance. And indeed, this study shows that violinists actually considered, among others parameters, their ability to play properly the musical score, in order to rate the different bows. Therefore, we recommend to include a by ear musical analysis-based approach in the assessment of the quality of musical instruments and of musicians' preferences.

Computed audio-descriptors also partly explained the violinists' appreciation variances, with an overlap between these two approaches. The relative contribution of by ear analysis and audio-descriptors computation in explaining variations of violinists' appreciations were not very consistent, but the overall share of variance explained by the sound seems substantial, even more since we considered the other expected sources of variance. Firstly, another important part may be due to the uncertainty of measures. In particular, if the variability of violinists' appreciations might be due to actual between trial

performance differences, it could as well be due to a random rating variability. Secondly, audio-descriptors were calculated on three sounds, which were C# only, played at two tempi and two articulations, but only at one octave. The inclusion of additional sounds, and an improved quality of sound records may also help increase

the proportion of appreciation variance explained. Finally, variables related to the gesture, *i.e.* electromyographic and kinematics data, have been recorded during this study, but have not been processed yet. These variables are expected to influence violinists' appreciations [7].

		R <sup>2</sup> of appreciations		
		Overall	Legato	Spiccato
<b>Penalty score by musical condition</b>	Legato sections	0.05**	0.06***	0.04*
	Octave 3 sections	0.03*		
	Octave 5 sections - subject interaction	0.09**		0.20***
	Tempo 60 sections		0.04**	
<b>Penalty score for a kind of flow</b>	Timbre flaw	0.03*		
	Rhythm flaw	⇒ 0.14***	0.04**	
<b>Audio-descriptors</b>	Tristimulus 1 – subject interaction, C#3 spiccato 60	0.09**	0.09**	0.06*
	Tristimulus 2 – subject interaction, C#3 legato 60		0.02*	
	Tristimulus 3, C#3 legato 120		0.06*	
	Inharmonicity – subject interaction, C#3 legato 60	0.06*		
	Attack – subject interaction, C#3 spiccato 60	⇒ 0.17***	⇒ 0.11**	

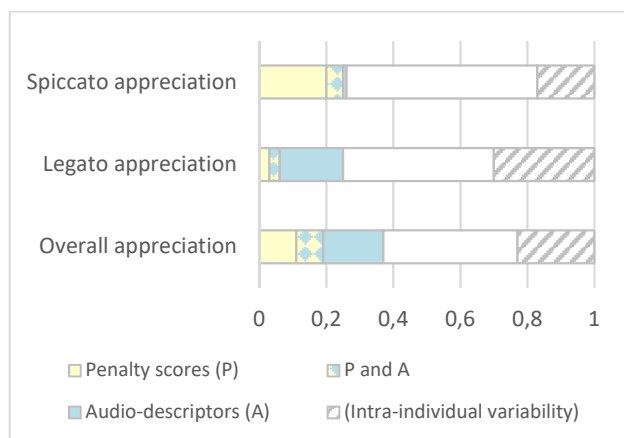
\*p < 0,05

\*\* p < 0,01

\*\*\* p < 0,001

In red : multivariate models (variables included and coefficient of determination R<sup>2</sup>).

**Table 1.** Explanatory variables for violinists' appreciations.



**Figure 1.** Coefficient of determination of appreciations of models containing either penalty scores, or audio-descriptors, or both of them. The inter-trial variability of appreciations is only reported as an indication of its order of magnitude.

A high inter-subject variability was expected, even if the study analyzed the performance of elite musicians, and deserve comment. Here, most sound variables interacted with the subject effect, which means that they had an actual influence on bow appreciations given by the violinists, but that it could be an opposite influence according to the violinist. That was not a surprising result regarding audio-descriptors, which are without value judgement sound assessments. Furthermore,

it is known that preference criteria differs between violinists [7]. Regarding penalty scores however, this interaction is more intriguing. The appreciation may reflect either the performance itself, or the degree of difficulty to perform with the same quality. Besides, the expert noticed how difficult it was to assess the presence or absence of flaw when something was not played exactly as written but sounds well: it was violinist dependent indeed, but was it intentional freedom of interpretation, or happy mistakes ? In any case, because of these interactions and because of the small number of violinist, generalization of our results should be done with caution.

To conclude, we highlighted that two kinds of sound parameters could partly explain violinists' appreciations regarding a bow: a by ear musical analysis-based rating and audio-descriptor computation. Finding ways to reduce each parameter variability, as well as adding other parameters such as audio-descriptor computation of additional sounds and violinists' upper limb kinematics and electromyography, could also help predict the selling succes of new, not pernambouc-made bows. Understanding violinists' choices could also help to know if their short term purchasing behavior trends are in line with the musculo-skeletal diseases risk prevention.

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