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Bridge admittance measurements of 10 preference-rated violins

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The overall goal of the research presented here is to investigate correlations between measured vibrational properties of the violin and subjective judgments by violinists and to better understand what distinguishes one instrument from another. The novelty of this study is that 10 violins of different make and age were evaluated and preference-rated by 13 experienced musicians in a carefully controlled violin-playing perceptual experiment. Regarding the vibrational properties of the instruments, the classical bridge admittance measurements have been examined so far. The five "signature" modes below 600 Hz were identified in all of the tested violins. Comparisons between violin groups based on across-players average preference score generally showed no prominent preference-related trends for mode frequencies or frequency spacings. Further analysis showed no links between admittance correlations and preference.

1 Introduction

A long-standing goal of violin acoustics research has been to correlate measurable mechanical properties to instrument quality. What distinguishes one violin from another? What defines a "good" violin?

Alonso Moral and Jansson realized bridge admittance measurements on 24 violins, which had previously been played and tonal-quality-rated by two professional violinists based on *evenness*, *volume*, and *brilliance* of sound as well as *playability* [1]. From the admittance curves, 4 "acoustical quality" criteria were extracted and used to acoustical-quality-rate the instruments. Correlations between the two types of ratings showed a strong influence of the modes below 600 Hz and the bridge hill in the 2–3 kHz range on violin sound quality. Jansson later conducted bridge admittance measurements on 25 violins, which belong to a private collection of high quality instruments, and made similar conclusions [2].

Dünnwald conducted measurements on a large set of violins, which had previously been classified as of very good or moderate quality, and proposed that the four frequency bands 190–650, 650–1300, 1300–4200, and 4200–6400 Hz were critical in assessing the quality of the violin sound: 1. The first band contains the critical lower modes; 2. If the second band is too strong, the sound is boxy and nasal; 3. The third band is responsible for brilliance, effective radiation, and evenness in the lower playing range; and 4. The fourth band should be relatively low to create a clear sound [3]. However, recent virtual violin listening tests did not corroborate most of these suggestions [4].

Hutchins conducted acoustical measurements including input admittance on over 100 violins with "a wide variety of tone and playing qualities, as described by their owners-players," and proposed the $B1^{+}-A1$ frequency spacing as a violin quality criterion[1] [6]. She noted that violins with a $B1^{+}-A1$ frequency difference of less than 40 Hz were easy to play with little projection and preferred in chamber music; instruments with values between 40 and 70 Hz were preferred by soloists; violins in the 55–70 Hz range were more powerful in terms of projection; above 100 Hz instruments were "harsh" and hard to play. Schleske later remarked that the $B1^{+}$ mode strongly influences the "tonal color" of the violin [7]. According to Schleske, violins with $B1^{+} < 510$ Hz and > 550 Hz are soft-harsh, less-more resistant and characterized by dark-bright sound respectively.

Bissinger conducted a wide range of systematic vibration and radiation measurements on 17 violins with quality ratings from bad to excellent. All instruments were played by a professional violinist; 12 violins were rated by the violinist using a standardized qualitative evaluation procedure [8]; the other 5 violins, including two Stradivari and a Guarneri del Gesù, were rated by the author based on feedback from the violinist, comments of listeners, and the historical status of the old Cremonese instruments. The suggestions by Hutchins and Schleske were not confirmed as no quality trends for signature mode frequencies or total damping were found from bad-excellent comparisons [5]. More elaborate band-/modal-averaged mobility and radiativity comparisons further confirmed no significant quality differentiators except for the Helmholtz-like cavity mode A0, the radiation of which was significantly stronger for excellent than for bad violins [9].

The reliability and generalizability of the results of these studies is unclear, mostly because the quality judgments were based on only 1 or 2 violinists. Also, no specifics were reported concerning the conditions under which those judgments were made. In the study presented here, 13 experienced musicians were asked to play 10 different violins and evaluate them according to overall preference. We adopted a carefully controlled method whereby performers could provide uninfluenced judgments. Bridge admittance measurements were realized on all of the tested violins to investigate possible correlations between admittance features and preference ratings.

2 Method

2.1 Perceptual evaluation

Participants (N = 13; 9 females, 4 males; average age = 28 yrs) were selected according to their musical background. They had at least 15 years of violin practice (average violin training = 22 yrs; average violin practice per week = 25 hrs).

Ten violins of different make, age and price were investigated (see Table 1). The strings, bridge, and chin rest were optimally setup for each violin by the luthiers prior to the experiment. Participants were given the option to either use a provided shoulder rest (Kun Original model), or use their own, or use no shoulder rest.

The experiment took place in an acoustically dry room (surface = 27 m^2, $RT_{60} = .18s$) to minimize the effect of room reflections on violin sound. In order to remove visual cues that may influence judgment (e.g., varnish, wood grain, identifying marks), low light conditions were used and participants were asked to wear dark sunglasses. Considering the bow as an extension of the player, we asked participants to use their own bow.

The experimental session lasted two hours. Initially, participants were asked to play all instruments for twenty minutes to acquaint themselves with the set. Following a short training session, the main task comprised three subsequent blocks of ten trials (i.e., ten violins) in randomized order.

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[1] Hutchins originally considered only one first corpus bending mode, B1, which corresponded to $B1^{+}$. Bissinger noticed that this criterion was ambiguous as there are two such modes (see [5]).

Table 1: Investigated violins. The origin of violin *J* is based on a luthier's analysis, as there is no information regarding the make and age of the instrument. The names of living luthiers are not provided for confidentiality purposes.

Violin	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
Origin	Italy	Italy	Italy	Germany	France	Canada	China	France	France	Germany
Luthier	Storioni	Sderci	Gagliano	Fisher	Kaul	-	-	Guarini	-	Unknown
Year	1799	1964	1770-75	1787	1933	2005	2006	1877	2009	Unknown
Price	\$44K	\$20K	\$250K	\$22K	\$20K	\$6K	\$2K	\$11K	\$17K	\$8K

On each trial, participants were asked to freely play and rate the violin according to preference on a unipolar continuous scale.

2.2 Mechanical measurements

The input admittance, or mobility, relates velocity response of a system to some excitation force. Considering bowed string instruments, bridge mobility characterizes the vibrational behaviour of the body as "seen" from the strings. It is formally defined as the ratio of the resulting velocity at a string notch on the bridge to a force applied at the same point. Although not directly related to the radiated sound of the instrument, bridge admittance contains essential information about the energy transferred between the string and the body [10].

A standard measurement procedure was followed (e.g., [2]): The bridge was excited with a miniature force hammer (PCB 086E80) at the G-string corner, and the resulting velocity was measured using a laser-Doppler vibrometer (Polytec PDV 100) at the E-string corner. All measurements were conducted in the same room as the perceptual test. To resemble a person holding the violin, the chin and shoulder rests were removed and replaced by a fixture, while the neck of the instrument was attached to a foam block with a small strip at approximately the position where the left hand thumb holds the neck. All strings were damped to minimize string resonances in the measurements.

3 Results

For each of the violins, we computed a preference score determined by the proportion of times a violin was rated as more preferred than any of the other violins across all participants and trials. Figure 1(a) shows all 10 violins ordered from least to most preferred according to these across-participants average preference scores. The most-preferred violin *D* is a German instrument of the late 18th century. The second most-preferred violin *G* is a student level instrument from China. The least-preferred violin *F* is an advanced student level modern Canadian instrument.

For analyses purposes, we grouped violins based on average preference. A paired sample t-test revealed that the most-preferred violin *D* was significantly more preferred than violin *C*, a much more expensive Italian instrument from the same period, violin *H*, a French instrument of lesser value from the late 19th century, violin *B*, an Italian instrument of similar value from the 1960s, and violin *F*; the second most-preferred violin *G* was significantly more preferred than violins *H* and *F*; finally, violin *I*, a modern French instrument, was significantly more preferred to violin *H*. Accordingly, we divided the 10 violins into 3 groups $\{F, H, B, C\}$, $\{A, I, J\}$ and $\{E, G, D\}$. We found that to be a more meaningful way of looking at preference-related trends than comparing between individual violins that had significantly different across-players average preference scores.

3.1 Signature modes vs. preference

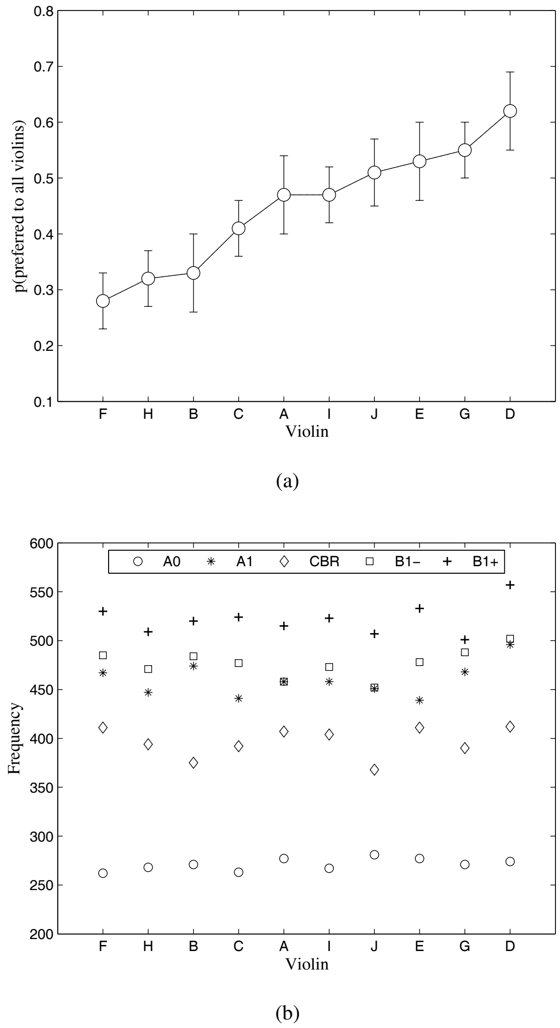
The development of elaborate experimental and computational modal analysis methods in the last decades has provided researchers, as well as luthiers, with a thorough insight into the complex acoustical behavior of the violin. In the open string region of the violin, 196–660 Hz, the sound is dominated by five normal "signature" modes [9]:

- A0, a Helmholtz-type resonance, the only cavity mode that radiates strongly through the f-holes;
- A1, a higher cavity mode with $f_{A1} \approx 1.7 \times f_{A0}$, the first longitudinal mode;
- CBR, the lowest corpus mode, usually a weak radiator; and
- $B1^-$ and $B1^+$, the first strongly radiating corpus bending modes.

Normal modes are important vibrational properties of any violin as they depend directly on material and geometry variables [5].

The signature modes were identified in all of the tested violins. Their frequencies are plotted versus average preference score in Fig. 1(b). Overall, A0 averaged 271 Hz, SD = 6 Hz, range = 262–281 Hz; A1 averaged 460 Hz, SD = 17 Hz, range = 439–496 Hz; CBR averaged 396 Hz, SD = 16 Hz, range = 368–412 Hz; $B1^-$ averaged 477 Hz, SD = 15 Hz, range = 452–502 Hz; and $B1^+$ averaged 522 Hz, SD = 16 Hz, range = 501–557 Hz. No large standard deviations were observed.

In particular, the most-preferred violin *D* had the highest A1, $B1^-$, and $B1^+$ frequencies; it had the highest CBR frequency together with violins *E* and the least-preferred *F*; its A0 mode frequency was close to the average for all violins. In contrast to *D* having the highest $B1^+$ frequency, the second most-preferred violin *G* had the lowest $B1^+$ frequency. Violins *F* and the old Italian *C* showed the lowest A0 frequency.



(a)

(b)

Figure 1: (a) The 10 violins ordered according to across-players average preference score; and (b) Signature mode frequencies vs. preference score. *F* is the least-preferred violin and *D* is the most-preferred violin.

Table 2(a) reports the average mode frequencies and standard deviations for the 3 violin groups. Overall, the signature modes are higher, in average, for the 3 more-preferred violins. Concerning Schleske's suggestion for the influence of the B1^+ mode on tonal quality, further investigations would require tonal-color information as well as judgments for the violins.

The A1/A0 frequency ratio averaged 1.64, SD = 0.06, range = 1.56–1.77; the highest value was recorded for the most-preferred violin *D*; the lowest value was recorded for violin *E*. The B1^+− A1 frequency spacing averaged 62 Hz, SD = 17 Hz, range = 33–94 Hz; the highest value was recorded for violin *E*; the lowest value was recorded for the second most-preferred violin *G*; for the most-preferred violin *D*, the difference between these two modes was 61 Hz. From his bad-excellent comparisons, Bissinger noted that the CBR mode and its relationship to the B1^- are two "interesting" quality differentiators because of their increased standard deviations compared to other modes and mode spacings [5]. The B1^-− CBR frequency spacing averaged 80 Hz, SD = 17 Hz, range = 51–109 Hz; the lowest value was recorded for violin *A*; the highest value was recorded for violin *B*.

Table 2(b) reports the average mode frequency spacings and standard deviations for the 3 violin groups. Considering the very different values for the middle-scored violins $\{A, I, J\}$ compared to the less- and more-preferred groups, which are extremely similar, it appears that there is no obvious correlation between mode frequency spacings and preference. Hutchins' hypothesis for the B1^+− A1 frequency spacing is therefore hard to verify. Furthermore, Bissinger's remark about the B1^-− CBR frequency spacing does not appear to agree with preference. Similar findings can be observed when plotting the bridge admittances of violins from the same group on top of each other. The middle-scored violins in the bottom left plot in Fig. 2 look most like "canonical" violins, with clear B1^- and B1^+ corpus modes and a typical bridge hill. The top and bottom right plots, less- and more-preferred violin groups respectively, look similar.

Table 2: Average mode (a) frequencies and (b) frequency spacings with standard deviations for 3 violin groups according to preference order.

(a)

	F, H, B, C	A, I, J	E, G, D
A0	266 ± 4	275 ± 7	274 ± 3
A1	457 ± 16	456 ± 4	468 ± 29
CBR	393 ± 15	393 ± 22	404 ± 12
B1^-	479 ± 7	461 ± 11	489 ± 12
B1^+	521 ± 9	515 ± 8	530 ± 28

(b)

	F, H, B, C	A, I, J	E, G, D
B1^-− A1	22 ± 11	5 ± 8	22 ± 17
B1^+− A1	64 ± 15	59 ± 5	63 ± 31
B1^+− B1^-	42 ± 5	54 ± 4	41 ± 24
B1^-− CBR	86 ± 16	68 ± 17	85 ± 16
B1^+− CBR	128 ± 14	122 ± 16	126 ± 17

3.2 Admittance correlations vs. preference

We computed the Pearson product-moment correlation coefficient (or correlation coefficient) ρ between the input admittance functions of all possible violin pairs to examine whether there would be any links between correlated or uncorrelated admittances and preference. Correlation coefficients were calculated over the 200–5000 Hz frequency region, as well as the 200–600 Hz region that includes the signature modes (see Table 3). Correlations up to 600 Hz were generally higher than that observed for up to 5000 Hz. This is a result of the increasing modal density of the violin in the mid- and high-frequency ranges. Overall, we found no obvi-

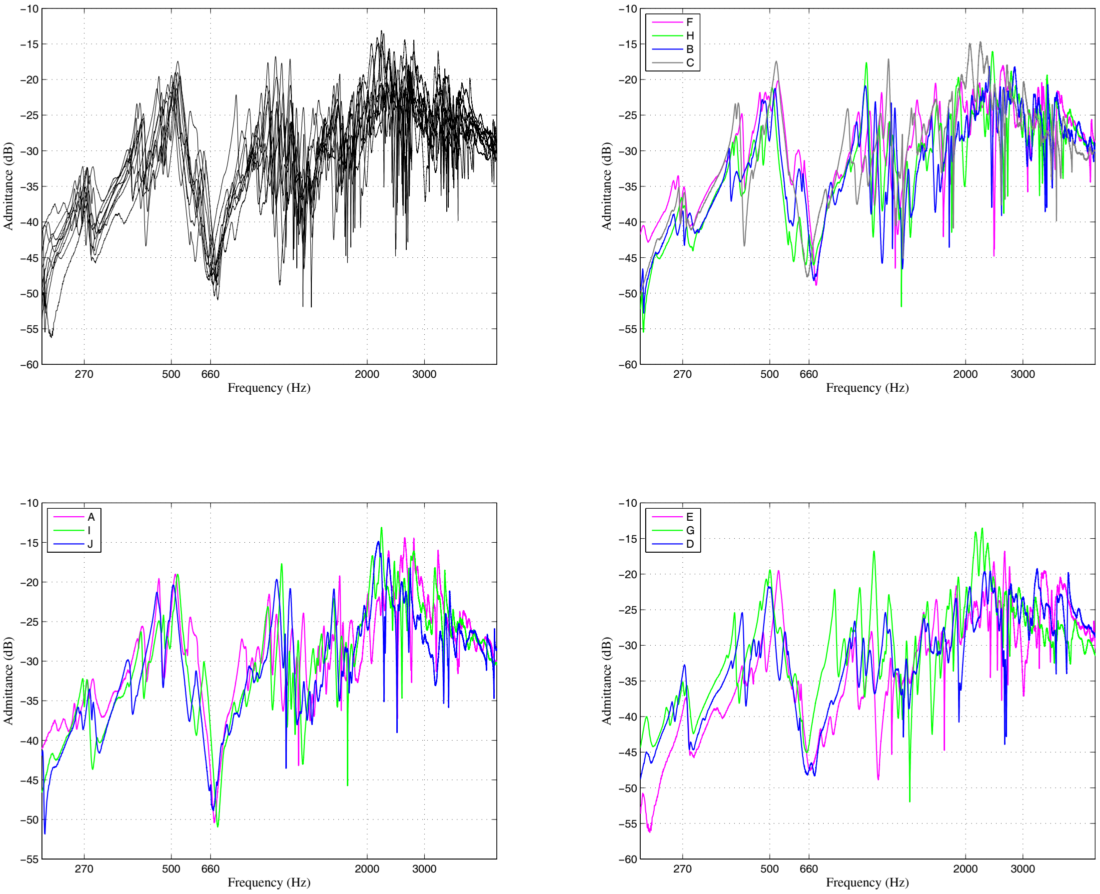


Figure 2: Bridge admittances plotted on top of each other. Top left: all 10 investigated violins; top right: the 4 less-preferred violins; bottom left: the 3 middle-scored violins; bottom right: the 3 more-preferred violins.

ous connection between admittance correlations and preference.

Table 3: Pearson product-moment correlation coefficients ρ between the bridge admittances of the most-preferred violin *D* and each of the other instruments over the 200–5000 Hz (upper line) and 200–600 Hz (lower line) regions.

	F	*H*	*B*	*C*	*A*	*I*	*J*	*E*	*G*
D	.59	.74	.68	.59	.62	.70	.62	.70	.58
	.87	.81	.80	.79	.81	.82	.78	.79	.85

4 Conclusion

This paper reports an investigation into correlations between violin bridge admittance measurements and preference judgements by experienced musicians. The novelty of this study is that a perceptual evaluation playing test was designed, based on a carefully controlled procedure. As a starting point, we considered the signature normal modes of the violin and attempted comparisons between violin groups based on average preference scores. The 3 more-preferred violins displayed higher mode frequencies than the other violins. However, we found no obvious preference-related trends in signature modes overall. There appears to be no association between mode frequency spacings and preference. Finally, we found no links between bridge mobility correlations and preference.

A couple of considerations are necessary about the interpretation of these results. First, participants in this experiment were asked to rate different violins according to preference rather than quality. However, preference judgments may be different from quality assessments. For example, two hypothetical players may prefer the same violin but rate its quality differently. Second, even though participants were self-consistent in their preference for the violins, we observed a significant lack of agreement between individual violinists. This is likely due to the fact that the perceptual evaluation of violin attributes widely considered to be essential to preference strongly varies across players [11]. Therefore, we need to better understand how these perceived qualities are assessed, and how they relate to measurable acoustical properties of the violin.

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