EFFECT OF THE WIDTH OF THE BOW HAIR ON THE VIOLIN STRING SPECTRUM

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ABSTRACT

Violinists often claim that tilting the bow provides greater brilliance. By tilting, the effective width of the bow hair is reduced and the bow force distribution across the bow hair ribbon is changed. Considering that the width of the bow hair of a violin bow is roughly 1/32 of the string length (about 10 mm), and that the relative bow-bridge distance in playing typically varies between 1/8 and 1/32, an effect of the width of the hair on the slip-stick process seems reasonable. Pitteroff [1] has reported simulations and measurements showing that the slipping intervals become progressively shorter as the width of the bow hair ribbon is decreased. However, the effect, which mainly was attributed to a faster transition from stick to slip at release, was small. In this study, evidence gained in experiments using a bowing machine is presented, showing that a decrease of the width of the bow hair may boost the string spectrum considerably for higher harmonics. A gain in partial amplitudes of 3 – 6 dB has been observed above partial 20. Besides increased brilliance, it is clear that there are several other reasons for violinists to tilt the bow. For example, tilting the bow hair facilitates gentle note attacks due to a gradual buildup in string contact.

1. INTRODUCTION

String players often tilt the bow by leaning the stick towards the fingerboard. A line through the centers of the stick and bow hair will then no longer be perpendicular to the string plane, as in the case when the bow is placed flat on the string. There are several good reasons for tilting the bow, which applies both to playing in soft and loud dynamics. For a moderate tilting all hairs will remain in contact with the string, and the distribution in bow force across the width of the bow hair will decrease from a higher value at the edge towards the fingerboard (outer) to a lower value at the edge towards the bridge (inner) [1]. For strong tilting the effective width of the bundle of bow hair, which makes contact with the string is reduced. For a sufficiently high force the bundle of hair will twist so much that the entire width of the hair is brought in contact with the string, except when playing close to either the frog or the tip.

Pitteroff [1] showed through simulations that tilting in the correct way (the stick leaning towards the fingerboard) is advantageous by increasing the safety margins for Helmholtz motion, see Fig. 1. The distribution in bow force across the bow hair obtained by correct tilting reduces the penetrating depth of backward partial slips into the bow hair. (Backward slips are due to reflections from the bridge during nominal stick but do usually not reach through the entire width of the bow hair). This reduces the risk of total secondary slips, resulting in a division of the period into fractions of the fundamental. Also, with a tilted bow the partial slips will be less pronounced in the bridge force waveform. For strong tilting, the reduction in the width of the hair in contact with the string brings the bowing situation closer to the point-bow case. This reduces the discrepancy in string slopes at the inner and outer edges of the bow hair, weakening the strength of backward partial slips.

The simulations indicated that the duration of the release and recapture (the transitions from stick to slip and vice versa)

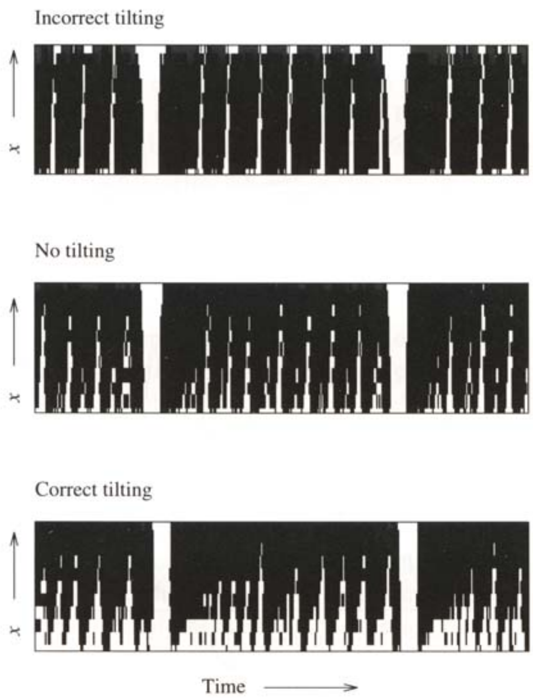

Figure 1: *Simulation of the effects of tilting the bow; bow flat on string (middle), bow tilted in the correct way towards the fingerboard (bottom), and bow tilted the wrong way (top). The panels are "friction maps" showing the contact conditions across the width of the bundle of bow hair vs. time with white color indicating "slip" and black "stick" (the edge of the hair towards the bridge at the bottom). The large white passages reaching through the entire width of the hair are the main slips of the Helmholtz motion. The smaller white encroachments are backward partial slips caused by reflections arriving from the bridge during nominal stick. Bow force 1500 mN, $\beta = 1/23.2$. (From Pitteroff [1])*

decreased when tilting the bow, while not affecting the total duration of the slip. This observation suggests a possibility for an influence on string spectrum.

2. METHOD

The velocity of a violin string was recorded under controlled bowing conditions using a PC-controlled bowing machine. The string velocity was picked up at the point of bowing by mounting a magnet (diameter 6 mm) under the string, and stored digitally with a sample frequency of 44.1 kHz. A carbon-fiber composite bow (Spiccato Solo) was used, playing a violin D string (Prim, steel core) mounted on a custom-designed monochord of dural. The design of the monochord copied the dimensions of a violin closely, including bridge height, and the speaking length of the string (L = 325 mm, f_o = 293 Hz). Spectra of selections from the steady-state part of 10 strokes were averaged. Each selected part had a duration 0.5 s, and corresponded to 5 to 15 cm of a bow stroke between the middle and tip. The spectra were calculated using a moving Hann window of width 1764 points, yielding a bandwidth of 50 Hz. The spectral envelopes were obtained from the harmonic peaks, and compensated for the influence of the width of the magnet.

Data for a set of three *widths* of the bow hair (4, 8, 15 mm), three *bow forces* (400, 550, 800 mN), and three *bow velocities* (10, 20, 30 cm/s) were collected. The bow-bridge distance was 30 mm, corresponding to a β close to 1/11. The 9 combinations of bow forces and velocities spanned a reasonable large range from “light” bowing with high velocity to “heavy” bowing at low speed, showing pitch flattening. The combination of high bow force and low velocity (800 mN/10 cm/s) gave non-Helmholtz motion (raucous).

The original width of the bow hair was 8 mm. The wide bow hair condition (15 mm) was implemented by spreading the hairs evenly with the aid of two small pieces of a densely spaced louse comb at the tip and middle of the bow. The narrow bow (4 mm) was obtained by lifting the outer parts of the bow hair from the contact path with the string by inserting small pieces of cardboard in the bundle of bow hairs at the tip and middle.

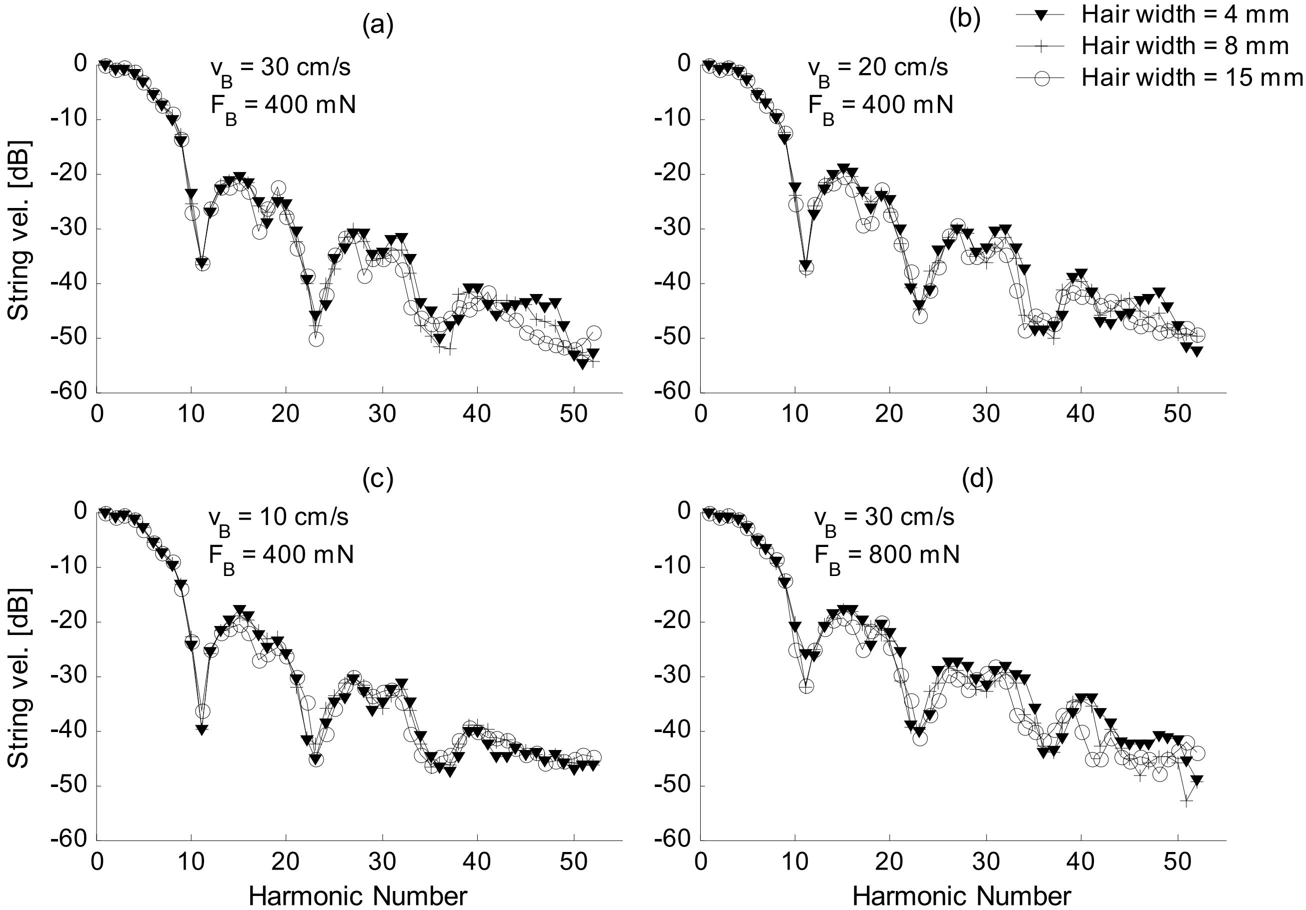

Figure 2: *Influence of width of bow hair on string spectrum for low bow force (400 mN) and a bow velocity of (a) 30 cm/s, (b) 20 cm/s, (c) 10 cm/s, and (d) high bow force (800 mN) and high velocity (30 cm/s). The width of the bow hair was 4 mm (▼), 8 mm (+), and 15 mm (○). Each spectrum is an average across 5 s of recorded bow strokes. The partial amplitudes have been normalized to the fundamental.*

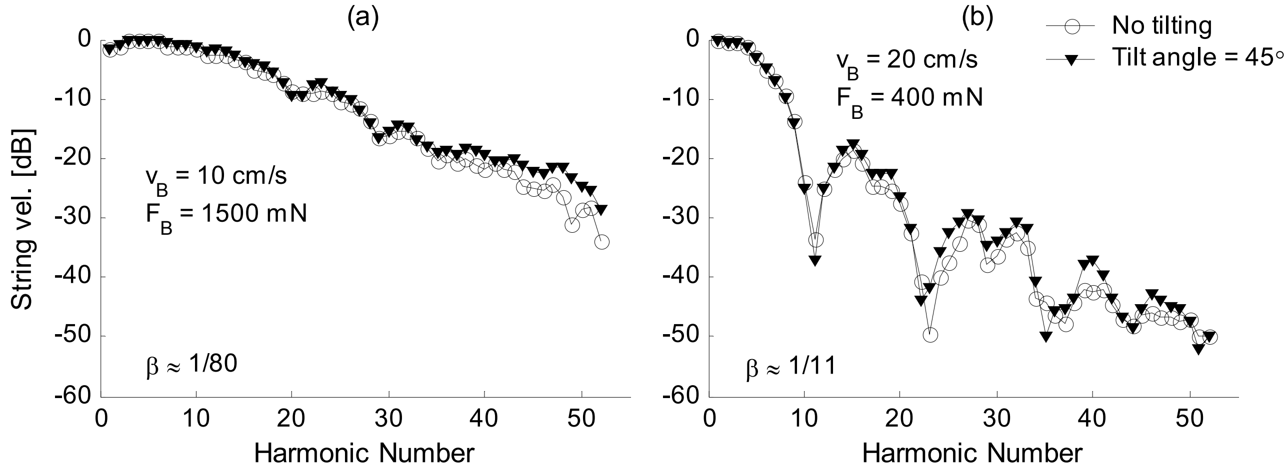

Figure 3: *Influence of tilting the bow. Comparison of string velocity spectra when playing (a) very close to the bridge (4 mm from bridge to center of bow hair) with a high bow force (1500 mN, 10 cm/s), and (b) at a normal bow-bridge distance (30 mm) with low bow force (400 mN, 20 cm/s). The curves compare the case of the bow flat on the string (○) with a tilting of 45° in the correct way (▼). For the tilted condition, the width of the hair in contact with the string was larger in (a) than in (b) due to the high bow force.*

3. RESULTS

3.1 Influence of bow width

Changing the width of the bow hair (while keeping the bundle of hairs flat on the string) had a clear influence on the string spectrum. A reduced hair width gave generally higher amplitudes of the high-frequency partials (see Fig. 2). The effect was most pronounced for the highest bow velocity (30 cm/s). Starting above the first "node frequency" (partial 11), the boost was typically 2 – 4 dB at 30 cm/s for both cases of reduction in bow width, from 8 to 4 mm, and from 15 to 8 mm. The effect increased more or less continuously in the frequency range observed (up to partial 50, ca 15 kHz), with individual gain in partials up to 6 dB. A high bow force enhanced the differences. At 10 cm/s the effect was marginal, and not possible to verify within the accuracy of the measurements.

3.2 Influence of tilting

Reducing the width of the bow hair by tilting gave a consistent boost of the amplitudes of higher partials. The situation when playing very close to the bridge with a high bow force (1500 mN) is illustrated in Fig. 3 (a). In this condition the inner bow hairs touch the bridge and β varies under the bow from 1/40 (outer edge of hair) to about 1/80 (center). A tilt of 45° in the correct way with the stick leaning towards the fingerboard, gave a boost in string partial amplitudes of about 1 dB from partial 6, continuously increasing to more than 5 dB at partial 50 (16 kHz). Tilting also had a clear effect on the quality of the attacks. With the bow placed flat on the string the tone was often unstable with persisting aperiodic pre-Helmholtz transients. Tilting of the bow resulted in a more "free" tone quality with reasonably long attacks.

Also when playing farther away from the bridge a clear effect of tilting was observed. Fig. 3 (b) shows a case with the same bow-bridge distance as in Fig. 2 (30 mm) and low bow force (400 mN). The tilting gives a gain in the partial amplitudes, typically 2 – 4 dB, starting at about partial 11. Tilting the bow in the incorrect way (the stick leaning towards the bridge) also gave a gain in high-frequency partials but slightly less consistent than for the correct way of tilting.

3.3 Influence of bow force

The influence on string spectrum available to the player by changing the bow force is shown in Fig. 4. As described by Schelleng [2] and Cremer [3] an increase in bow force boosts the high-frequency partials. The observed spectral changes when increasing the bow force from 400 to 550 to 800 mN,

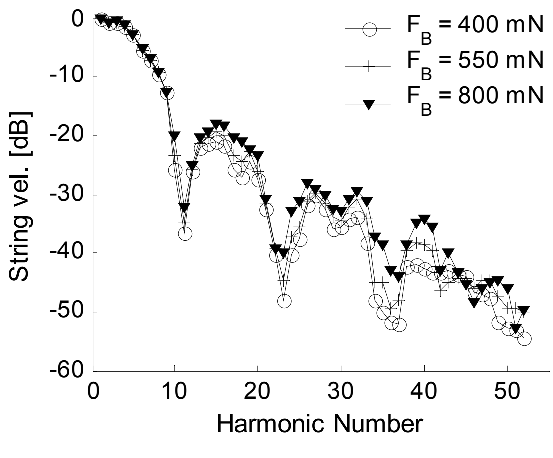

Figure 4: *Influence of bow force on string spectrum, 400 mN(○), 550 mN(+) and 800 mN (▼) (hair width 8 mm, velocity 30 cm/s, bow-bridge distance 30 mm).*

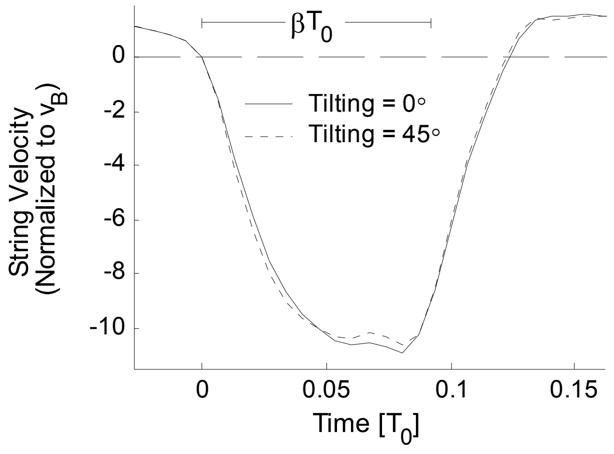

Figure 5: *String velocity under the bow during slip for the two cases in Fig. 3 (b) with the bow hair placed flat on the string and with the bow tilted 45° in the correct way towards the fingerboard (400 mN, 20 cm/s, bow-bridge distance 30 mm). Each curve is averaged across 10 periods.*

respectively, are of the same magnitude as the changes induced by reducing the width of the bow hair from 15 to 8 to 4 mm. A gain in partial amplitudes of 4 – 6 dB is observed, with maxima of about 6 dB. However, when increasing the bow force the effect is relatively large even at lower partials (from partial 11 and up) and more consistent compared to the effect of reduced hair width and tilting. When decreasing the hair width the general trend of a gain in partial amplitudes is occasionally punctuated by reductions in individual partials (cf. Fig. 2).

3.4 Influence of bow velocity

The influence on string spectrum by changing the bow velocity (30, 20, 10 cm/s) was of the same magnitude as changing the width of the bow hair (4, 8, 15 mm). In contrast to a widely spread belief, a gain in higher partials is achieved by lowering the bow velocity, rather than by bringing the bow closer to the bridge [4]. The effect of velocity changes was slightly larger at the lowest bow force (400 mN).

4. DISCUSSION

The results show that a reduction of the width of the bow hair, either by tilting or by a modification of the bundle of bow hair gives a boost in high-frequency partials. This applies to low as well as high bow forces and velocities. The effect can be traced in the velocity waveforms during slip (see Fig. 5). Reducing the width of the hair gives a faster transition from stick to slip, and a marginally faster transition from slip to stick in, both in line with the simulations by Pitteroff [1].

In playing, bow-bridge distance, bow force, bow velocity, and the width of the hair (tilting) are rarely varied one by one. As shown in studies of violinists´ performances, a key characteristic in string playing is a continuous coordination of all the bowing parameters [5]. Even when drawing long *steady* notes the bow pressure, bow bridge distance, and also tilting is varied as the contact point moves from frog to tip in order to maintain what is considered as a uniform timbre. The results of this study and an accompanying study [4] indicate that there might be a substantial combined effect on the spectral slope by bringing the bow closer to the bridge while simultaneously increasing the bowing force, lowering the bowing velocity, and adjusting tilting.

Perceptually tilting is claimed to increase brilliance and giving a more “free” tone quality (as opposed to “pinched” or “pressed”). The tilting is considered especially important when approaching the frog [6].

Besides the influence on spectrum and timbre of sustained tones described above, there are other good reasons for tilting the bow. A tilting may facilitate clean attacks by reducing the influence of secondary backward slips. By tilting, the note is started with a more point-like bow, successively bring the full width into play after the Helmholtz motion has started. In this way, the risk of long-lived pre-Helmholtz transients might be reduced.

ACKNOWLEDGEMENTS

Work supported by the Swedish Research Council.

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