Knut Guettler

How Does Rosin Affect Sound?

Abstract

The effects of rosin properties on the bowed-string sound are frequently discussed among string players and luthiers. The following comments and questions are common: Rosin is rosin. Should I use different rosins for summer and winter? Does anyone actually have a method for quantitatively measuring the physical behavior of different rosins? What are the effects of hair scales and hair flexibility? In this article the author, who has been studying these effects over a number of years both as a professional player and as an acoustician, presents some of the underlying physical aspects relevant for further discussion.

Keywords

rosin, bowed-strings, tone quality, bowed-string acoustics

Introduction: What affects the bowed-string sound?

In order to understand the interaction between rosin and the string, it is necessary to take a look at how the string is moving under the bow. In the classical Helmholtz[1] analysis two segments of the string are moving in straight lines joined by a kink that rotates between the string's two endpoints (see Fig. 1). Due to losses and the string's bending stiffness the kink will never be perfectly sharp, but always somewhat rounded[2] (see the fine dots drawn under the upper kinks). However, every time the rounded kink passes under the bow on its way toward the bridge, friction will to some degree sharpen it while the string makes a transient from the sticking phase (sticking to the bow hair) to the slipping phase (where the string slides back on the bow-hair ribbon). There might also be some sharpening when the bow captures the string again as the kink passes under the bow on its way back and the opposite transition takes place. It is the shape of this kink that determines the spectral outcome of the string and instrument: the sharper the corner, the greater the brilliance. It is here

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the properties of the rosin play a crucial role by determining how quickly this transition can take place.

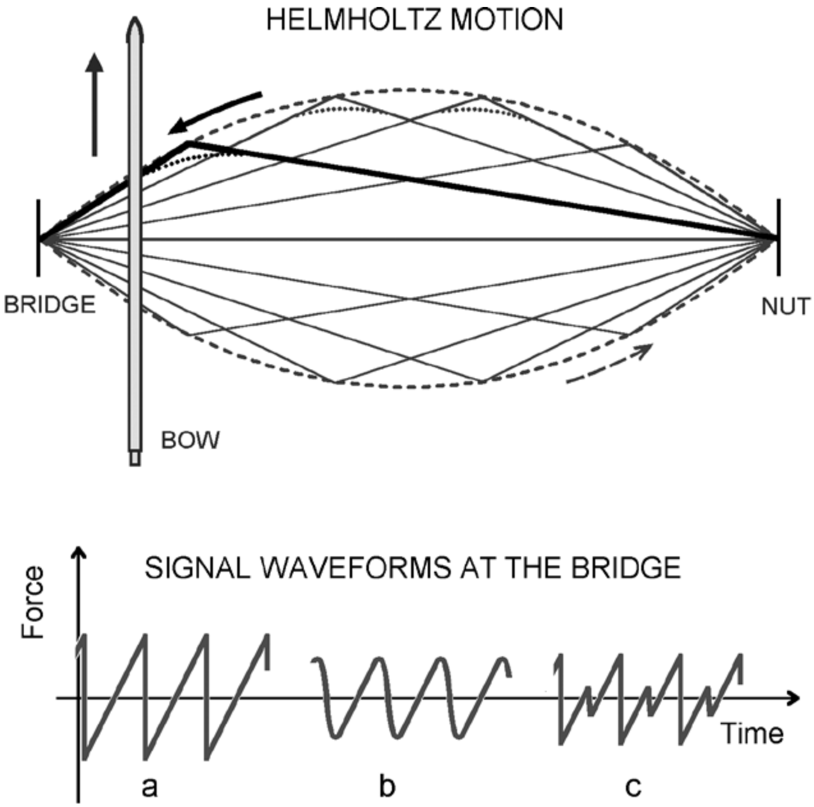

Figure 1. Helmholtz motion.
In principle the string moves like that shown in the upper plot during a "normal" bowed tone. The rotating kink describes a parabolic trajectory on its way between the string end points. The propagating speed of the kink is always very high (290 meters/second on a violin A-string), therefore we never observe the straight lines with the naked eye, but are left with the impression of a string bent to a parabolic shape. The lower plot illustrates that at the instant the kink is hitting the bridge, the force on the bridge makes a sudden change of value whereupon a slower buildup takes place during the remaining part of the period (waveform a). If the kink is rounded, the instant change will be replaced by a more gradual one, and the force signal will contain much less energy in the upper part of the spectrum (waveform b). Waveform c shows the signal of a "scratchy" tone where more than one kink (slip interval) is present, noticeably weakening the fundamental frequency.

In simplified theory, the string will be sticking to the bow for most of the period, as long as the kink travels on the nut/finger side of the bow. It will slip back on the bow-hair ribbon with a much higher speed for the remaining time interval. However, since the ribbon occupies a certain width, and the straight segments are changing angles all the time with respect to the bow, it should be clear from Fig. 1 that there will be a discrepancy between string speeds relative to the two hair ribbon edges: This implies that even during "stick" there will be small partial slips across the bow-hair ribbon, and even more so when the bow is tilted away from the bridge.[3] These would be perceived as noise, either "spiky" or plain "hiss," depending on the bow force.

Rosin and bow-hair properties

Before discussing further implications of the slips, let us have a look at the hair without and with rosin shown in Fig. 2. In the left panel, where the hair is not rosined, the structure with scales is clearly visible. The height of these has been measured to less than 0.5 μm, which equals 1/2000 of a millimeter. Compared to the string's diameter (even that of the violin's E-string), this is negligible in terms of contributing to friction, a fact obvious to anyone who has tried to play with un-rosined hair. But, even more importantly, in order to quickly start the string oscillation, a rapidly changing friction coefficient is required. Any structurally related friction would merely contribute to pulling the string out to one side. The right panel shows the same hair after applying rosin. The rosin has partly melted and is now covering the scales completely. On top of this layer, solid particles of glassy rosin "crumbs" are scattered, causing small obstructions as the string slides on the melting surface.

Rocaboy,[4] who measured scale heights and several other parameters concerning the hair, found that it is not its structure that makes horsehair well suited for holding rosin, but rather its chemical properties. He writes: "As a high polymer, keratin is capable of exhibiting surface activity, a property common to all high-molecular substances. The numerous secondary forces available in such large molecules are capable to attract and firmly hold together other substances such as rosin, thus making sound production possible." Those searching for synthetic-hair materials should remember these words.

Further, any positive effect of cleaning hairs with alcohol or another dissolving and evaporating chemical would probably lie in its ability to assist in the removal of unwanted layers of fat, dust, or other substances attracted to the hair keratin (that is, of course, without replacing the contaminating substance). The main issue seems to be accommodation of an inner-layer foundation of rosin. This author has many times been forced to clean brand new hairs with benzene or acetone in order to get rosin properly on the hair. I suspect fat from the manual handling of the hair bundle to be the underlying reason.

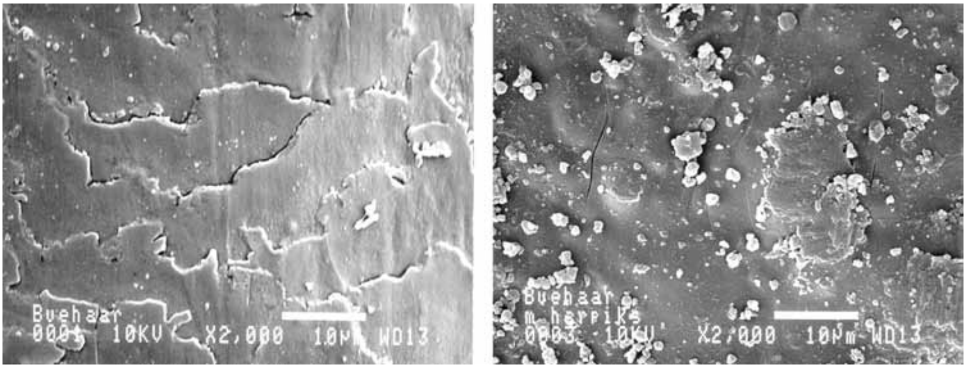

Figure 2. Bow hair without (left) and with rosin (right). In the left panel hair scales are visible, but when rosined, their orientation can no longer be detected. The white, horizontal line indicates 1/100 of a millimeter. The scales stand out in the order of maximum 1/2000 mm. (Photos by Norwegian Inst. of Technology, Trondheim)

"Dry" and "wet" friction

Earlier analyses regarded the resulting friction as "dry," meaning that the friction coefficient would be a function of relative speed between the string and the bow hair: the greater the relative speed, the lower the resulting coefficient (down to a certain minimum value). At zero relative speed (i.e., stick) the coefficient would reach a maximum, and, dependent of the circumstances, the force could take any value between zero and this maximum. Subsequent and far more sophisticated analyses have shown that a much better match with truly dynamic measurements can be obtained if one considers the friction coefficient a function of, not relative speed, but the rapidly changing rosin temperature.[5] Rosin gets soft right above room temperature (some even under), and any sliding between string and hair will cause the local contact-point temperature to rise. Dependent on temperature conductivity, a part of the rosin in the string's vicinity will also soften (not necessarily melt), permitting the string to move with less frictional resistance. During most of the slipping interval the temperature will be rising, so when the string again takes the speed of the bow (goes into a cooling "stick") the temperature is higher than when it departed, hence the lower frictional coefficient. The friction coefficient plotted against the relative speed thus describes a hysteretic loop (see examples in Figure 3). Together with the losses and the string's bending stiffness the shape of this loop influences the rounding of the kink, or "Helmholtz corner." If the temperature is slowly changing, the sharpening effect on the corner will be much less than if the temperature makes a sudden rise at release, causing the friction coefficient to fall correspondingly. In the latter case the kink would be more sharpened and the string would sound more brilliant or shrill.

The issue of choosing different rosins for summer and winter should be viewed in the perspective of ambient temperature. With modern air-conditioned rooms and halls the need for seasonal changes has been significantly reduced. In earlier days harder rosin might have been preferable in the summer season, because of its higher softening/melting temperature. This is particularly relevant to attacks (see below).

Friction and noise

When the string slides on the bow hair, the slide will not be a smooth ride. When looking at the contact point in slow-motion video, one can see dusty particles of glassy rosin (similar to that seen in Fig. 2, right panel) being tossed around after having been obstructing the quickly moving string. The temperature and plasticity of the rosin will vary locally and cause rapid, small, random fluctuations in the string's velocity. In sound these come out as noise or hiss, which is a characteristic part of the bowed-string tone. One interesting thing is that the spectrum of the noise, which is fairly independent of which note being played, invokes nearly all frequencies of the instrument and thus provides a wide-spectrum fingerprint. The instrument's main air and wood resonances appear particularly strongly (i.e., on the violin: bands around $C\#_4$ and A_4, respectively). A shrill instrument will sound even shriller because of this noise, which may constitute some 1% (–20 dB) of the instrument's output energy. Another source of noise is the partial slips described above. These slips occur with some irregularity and are partly related to the so-called "secondary waves": waves travelling between the bridge and the bow during stick. One might think that such small discrepancies in relative speed could be absorbed by bow-hair flexibility, thus avoiding these extra slips. The truth is that bow hair is remarkably stiff (around 0.2 N/mm for one hair of normal length). It is more likely that the entire hand-held bow is moving rather than local hairs prolonged in this process.

The farther away from the bridge the bow is positioned, the longer the noisy slipping interval will last within the nominal period. When playing *flautando* (flutelike) with the bow positioned *Sul tasto*, the combination of the bow's speed, force, and position ensures maximum relative noise content in the radiated sound and in this way provides some similarity to the wind instrument.

Attacks

Perhaps the most important attribute of a rosin is its ability to facilitate clean attacks. Clean attack means the shortest possible time interval before a regular periodic stick-slip pattern between the string and bow hair is established. That is, an attack with the least possible onset noise: on one side you have attacks that are "choked," "creaky," or "raucous" on the other side attacks that sound "scratchy" or "slipping." However, what produces a clean attack is not necessarily ideal for the timbre of a sustained tone.

In the following we shall look at three theoretical rosins, and, by use of numerical simulations, analyze how their differences play out. As shown in Figure 3, during slip (when the relative speed between bow hair and the string surface is different from zero) the temperature around the contact point determines the friction coefficient, with the supplied power being the product of friction force and relative speed. This implies that when the string starts sliding the temperature will rise, and soon thereafter the coefficient will drop. If holding a constant sliding speed, the temperature would drop to a certain quiescent level where the supplied power equals the power transmitted to the ambiance. In Fig. 3, the coefficients of two rosins, A (black) and B (gray), drop from nearly 0.8 to below 0.4 as the relative speed increases. Also the coefficient of rosin A is decreasing more quickly than the coefficient of B, and later returns in the same manner when speed is decreasing and the contact point is cooling off. During stick, the frictional coefficient can take any value up to a maximum (limiting) value, which is determined by further cooling. During normal Helmholtz motion, friction loops like these always exist. Due to the difference in loop shapes rosin A will sound more brilliant/sharp/shrill than B since it will provide a greater sharpening of the Helmholtz corner.

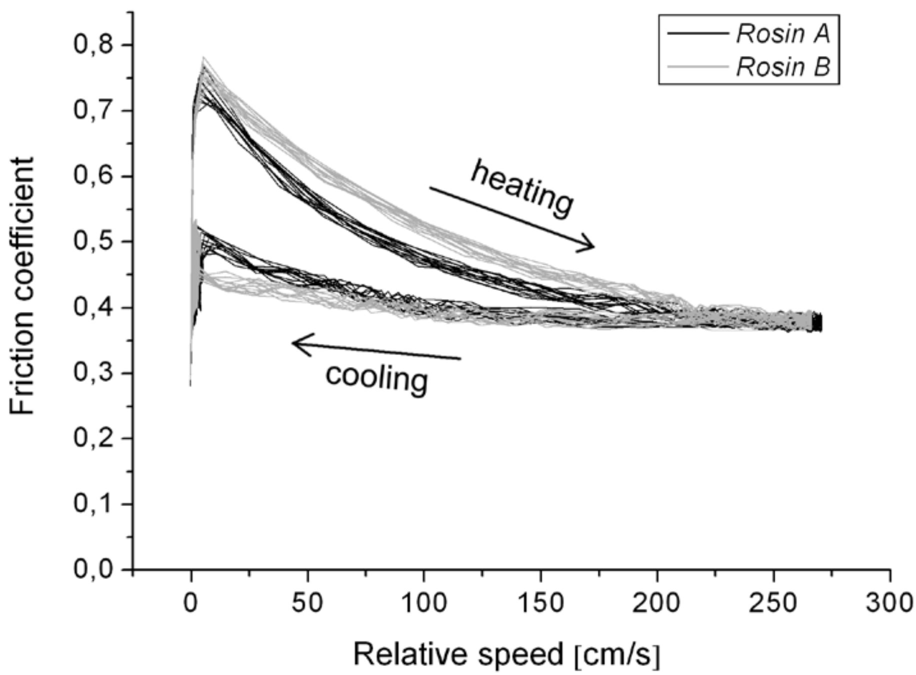

Figure 3. Friction loops of rosins A and B in a given steady-state situation with identical bowing parameters. As the friction-speed product causes the contact-point temperature to rise, the friction coefficients are falling, and vice versa.

A series of simulated attacks are presented to help determine which one of these two rosins, plus a third one, will behave best in terms of getting the string quickly started. Figure 4 displays three diagrams, which are to be interpreted in the following way: Each pixel in the diagram represents the outcome of a combination of bow force ("bow pressure") and bow acceleration. There are some 12,000 combinations in each diagram. Perfect noiseless attacks are marked white, while darker shading indicates greater duration of attack-noise components. Above the white wedge, to the left, the attacks appear choked/creaky/raucous (Chk), while below it, to the right, they sound scratchy/slipping (Slp). The scale on the right-hand side in the figure gives the number of nominal periods elapsing before a regular "correct" slip/stick pattern occurs. In the high-tension and rather stiff violin G-string used for the simulations, 10 nominal periods last some 50 milliseconds, or $1/20^{th}$ of a second. When comparing rosin A to B, we see that the light wedge of B's panel is slightly wider than the light wedge of A. That is, rosin B plays slightly better than A, as it provides a larger range of bowing parameters that result in clean attacks. However, the best-playing rosin appears to be C, which provides clean attacks also for much lower bow-force values than the two others. What are the reasons for this? The only difference between A and B, as we saw in Fig. 3, was the temperature conductivity, or the rosin's ability to quickly change temperature/friction coefficient. Both of these rosins would have maximum coefficients proportional to bow force at room temperature. However, rosin C is designed not to provide proportionality between bow force and the maximum coefficient. It behaves like some rosins designed for lower-pitched instruments (particularly for the double bass), where the friction coefficient gets higher as the bow force gets lower. These are "sticky" rosins with melting temperatures lower than for normal violin rosins. Such rosins provide clean attacks over the widest range of bow-force/acceleration. To some degree they would compensate for lack of bowing-parameter precision, and, which is of great importance to many double-bass players, they don't require quite as much bow force in order to have the string speak. In all other respects, rosin C behaves like rosin B. It should be added that when rosin B performs somewhat better than rosin A in these tests, it is for the same reason as a stopped string gets more easily going than an open one: Rosin B gives more corner rounding, as does the finger pad on the fingerboard in a stopped string. Spiky reflected impulses tend to jeopardize the bow's grip of string, particularly during transients.

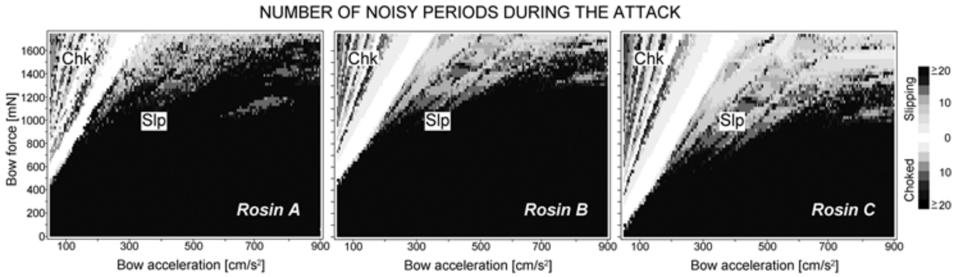

Figure 4. Comparison of attack quality as a function of bowing parameters for three different rosins. Each pixel refers to the outcome of a bow-force/acceleration combination: the lighter the color, the cleaner the attack (see text).

Timbre

Research has shown that qualified violinists are quite good at hitting the attack qualities they want.[6] In most cases this would be "clean attacks," corresponding to the light areas of the figures. However, different musical contexts call for different attack qualities. If rougher attacks were appropriate, the onsets would consistently be found in the choked ranges (Chk), while some Baroque pieces would be performed with slipping attacks (Slp).

Analyses of steady-state tones are shown in Figure 5. In the left panel, bridge-force spectra resulting from rosins A and B are compared with respect to two very different bow-force values: 300 and 2000 mN.* The bowing speed is 30 cm/s and the contact position is approximately 35 mm away from the bridge on the open string. There is a significant spectral difference between low and high bow forces for both rosins. We see that with low bow force, amplitudes fall about 35 dB at partial 6 compared to the fundamental, which implies a very soft tone color, suitable for mellow *flautando* playing. For rosin C (right panel), the corresponding partial appears about 15 dB louder, making true *flautando* almost impossible. Rosin C, which performed so well in the attack simulations, seems more limited when it comes to tonal variation. This is a typical feature of (very) soft rosins. The significant tone-color variation available with rosins A and B gets noticeably reduced with rosin C. The main cause lies in C's inability to accommodate genuine soft-color playing at low bow force since friction coefficients approach infinite values as bow force goes to zero.

*Approx. 31 and 204 grams force, or 0.067 and 0.45 pounds force, respectively.

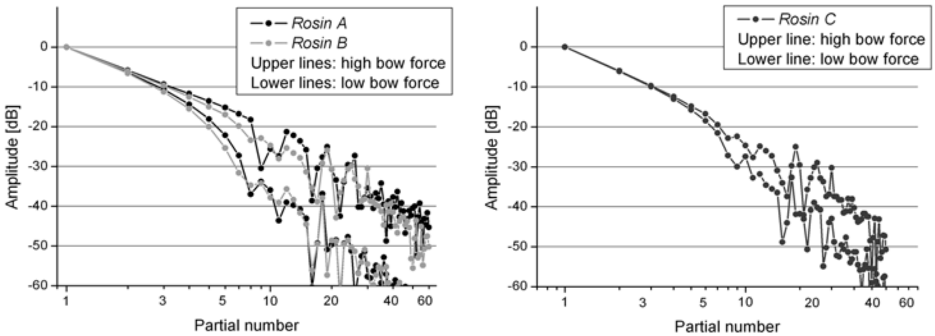

Figure 5. Comparison of spectral profiles resulting from the three different rosins. Upper and lower lines of each color indicate high and low bow force, respectively. Rosin A is slightly more brilliant than rosin B, but both rosins show great spectral variation between the two bow-force values (see left panel). At the right panel, rosin C is considerably more limited in this respect.

Tone color and rosin additives

Most rosins come with additives, whether it be waxes, oils, or metals. In principle there are two ways such ingredients may influence the tone quality: by changing the shape of the hysteretic loop, and by changing the noise content. With regard to the first, such changes could be caused by alteration of the plasticity/viscosity, which implies the general frictional resistance and/or temperature-related conductivity. The second could be related to change of homogeneity, which again might have an influence on noise level and noise spectrum. When the term "noise" is used in this connection, it is merely a technical term for stochastic (non-predictable) sound energy, not necessarily an unwanted sound component. The present author is unaware of any scientific study of the effect of such additives, some of which might be better sounding in advertisements than on the bow.

Discussion

The dynamic frictional behavior of rosin is very complicated to measure with accuracy. The flexible string is not only sliding on the bow hair, it is also rolling up and down the bow-hair ribbon during playing, and the frictional point of contact is constantly moving. This is the reason why numerical simulations of the bow/string contact are attractive: When the modeled string behaves in a way well matching the string as observed on the instrument, all relevant parameters are readily available for analysis. If manufacturers of rosin would provide information about one single property, melting temperature would be the most useful one, since it would most probably give information on how quickly frictional changes might take place, and thus the potential tone-color variation. In the same way string tension (now provided by several manufacturers) is a most useful piece of information on strings, since it affects loudness, playability, wolf adjustment, and other aspects.

Melting temperature would provide a fair first estimate of the "stickiness" of a rosin. Strings for the different instruments of the bowed-string family show certainly great varieties in thickness, weight, tension, etc. which implies great differences in their wave resistances (the strings' resistance to being moved to any waveform): the higher the wave resistance, the higher the required frictional force. Between the instruments violin, viola, cello, and double bass, the characteristic wave impedance varies typically with relative factors of 1 : 1.6 : 4 : 10 (compared to the impedances of violin strings). If utilizing the same rosin for all instruments, this would imply a bowing "pressure" about ten times higher for the double bass than for the violin. To get around this problem, rosins are usually made more sticky (with lower melting temperature) for the cello and double bass, so that the bow force can be eased somewhat. However, if the melting temperature is lower than the normal room temperature, so that the rosin is slowly running out of its container when placed sideways on the table, you would know that you have a highly sticky rosin that will not permit true *flautando* playing. Paradoxically, it might also complicate the attack if you want to start the stroke from the string, as the potential friction rapidly increases with the hair's resting time on the string before the first string release (while the rosin sets). To avoid unwanted "plings" at the tone onsets, many users hence try to limit this kind of preparation, and instead attack the string from the air.

It is my recommendation as a player to choose rosins that will not stick to the bow-hair bundle when the hair is pressed firmly straight down against the rosin cake, followed by a straight-up removal without any rubbing. With such rosins you are free to prepare the stroke as you like, and can choose from many more onset qualities at nearly any dynamic level. Another simple test to verify the softness/stickiness of rosin is to vary the bow force when playing the highest positions on the fingerboard. Soft rosins tend to cause much more pronounced pitch flattening at high bow force (due to prolonged sticking intervals) than do the harder ones. A third aspect is that the rosin should not be "powdery," as excess powder might interfere with the hair-string contact, making attacks unpredictable.

The greatest variations are found among double-bass rosins. This has to be considered in the perspective of onset transients (tone buildup), the duration of which, by nature, is inversely proportional to frequency. The transient consists of two independent factors: the instrument-body transient and the string-buildup transient, of which only the latter can be manipulated to some degree. If a violinist and a bassist attack tones three octaves apart, applying the same bowing strategy, the bass will develop its tone eight times more slowly than the violin, which means that in most cases it will definitely sound late. For this reason many bassists choose a rosin in the C category, to increase the probability of the cleanest and fastest buildup possible. However, it should be pointed out that this sacrifice of potential tone-color variation, which may or may not be noticeable in the orchestra, could have been avoided by combining a harder rosin (like B) with a more precise bowing technique. This strategy might be the better choice for solo playing if tone-color diversity is a prioritized feature. All in all there is a tradeoff between convenience and a palette of possibilities.

Author's Note

Knut Guettler is a former principal double bassist of the Oslo Philharmonic, and professor of double bass at the Norwegian Academy of music in Oslo as well as the Royal Conservatory of Music in The Hague, Netherlands. He holds a Ph.D. in acoustics from the Royal Institute of Technology in Stockholm, Sweden, with particular focus on bowed-string attacks.

Endnotes

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