BOWING GESTURE ANALYSIS —FOR WHOM, WHY, AND HOW?

Knut Guettler

Norwegian Academy of Music, Oslo, Norway
knut.guettler@tele2.no

ABSTRACT

To our knowledge the book "*Motion Study and Violin Bowing"* by Percival Hodgson, published by Lavender in London 1934 (and reprinted by American String Teachers Association in 1958), was the first attempt to describe the acoustical consequences of bowing gestures. At least, if reserving the term "bowing gesture" for *dynamic* bow movements. The study was aimed at string players, and was based on an ingenious method for recording the bow's motion during performance. Later the utilization of many novel techniques, including robotics, numerical simulation, and digitalized optical motion capture has greatly contributed to increased understanding of how the bow-string contact actually works, even on a rather detailed level. This presentation walks through a number of different projects and methods, and discusses the results and their usage as seen by the performer, the string teacher, and the acoustic researcher.

1. INTRODUCTION

The present author has background as a performing musician (principal double bassist of the Oslo Philharmonic), teacher (professor of double bass at the Norwegian Academy of Music and the Royal Conservatory of the Hague in the Netherlands)—and acoustician (with a Ph.D. from Royal Institute of Technology in Stockholm, Sweden, focusing on the bowed string).

During a convention organized by the International Society of Bassists, held in Madison, Wisconsin in 1968, I experienced a series of lectures on string and string-instrument physics given by physicist William Fry. Among other things, he explained how to modify double-bass bridges to achieve more brilliance and better response. After having returned home I did that on a number of basses in the Oslo Phil. with great success. This was the seed that later led to my growing engagement in string-instrument acoustics. To understand how the string moves under the bow has ever since been a great help in my teaching, even though I never introduced math and equations to my music students. However, I believe knowledge on how our instruments work is paramount when trying to utilize the instrument's potential of musical expression to its fullest extent. This is particularly true in the context of contemporary music.

2. PRESENT KNOWLEDGE ON BOWING GESTURES

In Hodgson's book [1], which obviously is written for players rather than acousticians, he presents the bowing movements of a large number of musical phrases familiar to the violinist. The main concept seems to be recommendation of rounded gestures to ensure continuity of movements (see Figure 1). He makes no real analyses of the acoustical consequences with respect to noise generation, bow speed etc, but it is a fact that rounded bow changes is a neat way to control the relative acceleration between the bow and the string. When the bow plays sustained tones, speed is an important parameter. During attacks, however, acceleration is the operative word.

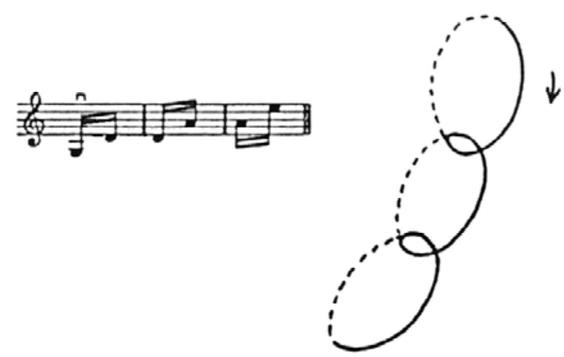

Figure 1: Gesture pattern as seen by the player when playing six notes on four strings (from Hodgson). Patterns obtained by extended-exposure photography in darkness with a small light bulb mounted on the frog. The circular movements ensure smooth and continuous bow movements.

When Hodgson's book was published it stirred up some discussion, as a lot of players disagreed with this circularity concept. On the other side, however, the great violin teacher Leopold Auer is said to have advocated rounded bow changes where the frog made excursions from the straight line back and forth. Such rounding can be carried out in several planes; vertically or horizontally, or both. The main issue is to keep the bow moving in order to avoid jerky movements. Figure 2 shows analysis of two different bow changes where the right panel suggests a strategy for making the deceleration greater than the following acceleration in order to carry out the bow change as quickly and inaudibly as possible. In a doctoral thesis, Williams [2] showed that good players do this, instinctively. All in all, shaping of the frog trajectory can provide good acceleration control. Our own numerical analysis [3] shows that the maximum/minimum bow acceleration acceptable for noise-free tone outsets is inversely proportional to the mass of the active string. This implies greater acceleration when moving up the string to higher pitches and vice versa. The rate of success can be judged from the string movement, readily measurable through the voltage difference of the string ends when a small magnet is placed under the bow.

Even though the works of McIntyre, Woodhouse, and Schumacher [4], [5] only to a limited degree discuss dynamic bowing gestures as such, their revolutionary numerical-simulation concepts of the bowed string, published 1979, made it possible for other researchers to go further along the gesture path, and check basic phenomena in more detail than would have been possible for Hodgson. Many years earlier, Raman [6], and later Schelleng [7], had analyzed the static use of basic bowing parameters thoroughly, of which *bow speed* is one.

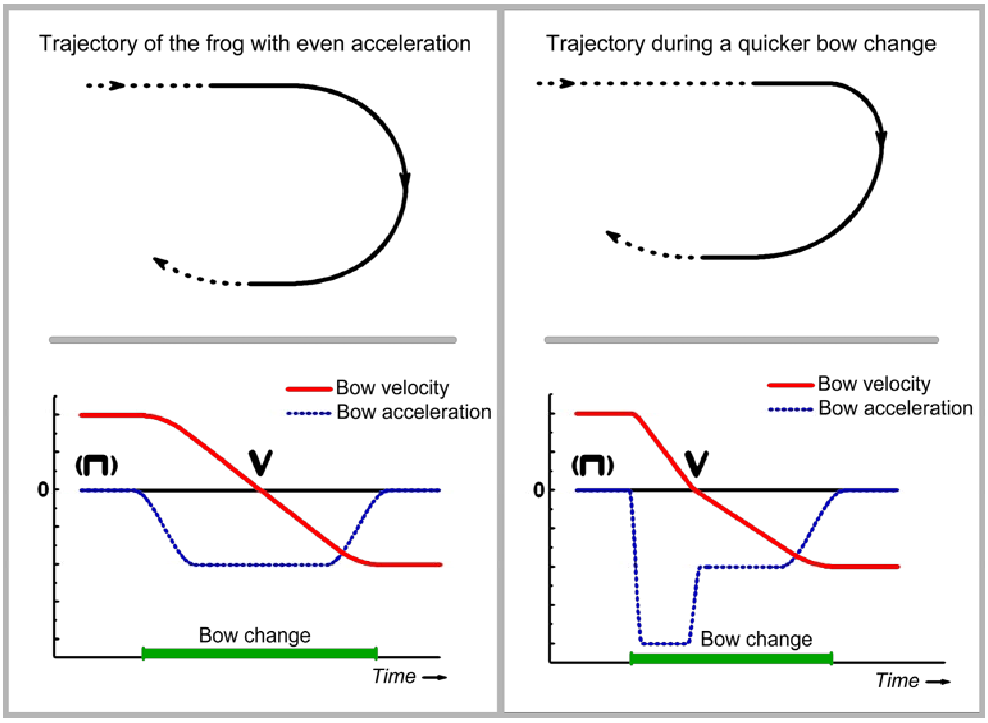

Figure 2: Analysis of the bow's velocity and acceleration resulting from quasi-circular frog movements when the frog is moving with constant speed. The thick green line indicates the duration of the actual bow change.

The right panel shows that by deviating slightly from the perfectly circular frog trajectory of the left panel a quicker bow change is possible (here, some 14%), since the string will accept a higher *deceleration* value at the end of a stroke than the *acceleration* value at the beginning of the next one. Excess values will in both cases produce slipping noise. The plots underline the importance of gesture.

In 1892 Cremer pointed out that some *acceleration* was a prerequisite for starting the string [8] with regular stick/slip intervals (i.e., "noise free"). Bow acceleration and speed are only two of many gesture parameters. Two more, of equal acoustical importance, are bow *position* (along the string) and *pressure* (the bow's force on the string). In the mid eighties Askenfelt designed an ingenious electric device for measuring speed, position, and bow force during actual playing [9], [10]. He found that players tend to change position more than speed for different dynamic levels, including crescendo and diminuendo, but also that there were differences in strategy between individuals. (In 2009 Schoonderwaldt revisited the topic, using even more sophisticated measuring methods on a greater variety of bow strokes [11].) At the end of the nineties Askenfelt cooperated with the present author on analyzing off-string bowing techniques, such as spiccato and ricochet [12], [13]. Here numerical simulations accompanied traditional measurements with accelerometers, force transducers, etc. An interesting observation was that in good, crisp spiccato (sautillé) the actual bow change would take place *after* the bow had landed on the string in preparation for the next attack, contrary to the general concept of the players, and what is claimed in many methods.

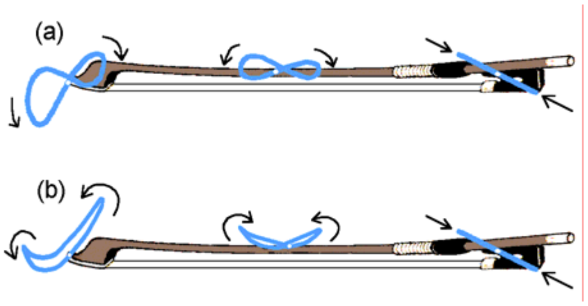

Figure 3: (a) correct and (b) incorrect movements of the bow during fast spiccato or sautillé. (b) will produce noisy attacks. Placing a small mark on the stick provides visual feedback to the student.

An important issue to settle was "How much onset noise is acceptable for the string player"? A study showed that it depended on what kind of noise, *slipping*- or *creaking*-, and that the acceptance limits for violins were ca 90 and 50 ms for "neutral attacks", respectively [14]. Of course, it also depends on the character of the music being performed.

Further topics have been discussed with concern to the acoustical effects of bowing gestures: Tilting the bow gives only a small spectral change (modestly increasing the brilliance), but is important enough when it comes to bowing close to the bridge, particularly in attacks [15]. If you think that bowing position is more important than bowing speed when it comes to spectral changes, you are wrong [16], [17]. The main reason why string players experience an increasing spectral brilliance as they move the bow towards the bridge is that they simultaneously (but unconsciously) increase the bow force.

In the last decade optical measuring methods have revolutionized the bowing-gesture research. Partly replacing accelerometers with their cables and sensitivity to gravity (not to speak about the challenge of double-integration), tiny reflecting spheres is now all you need in order for the motion-capture system to record the bow's movements in all planes. The resolution is good: ca 0.6 mm at a rate of 250 Hz. The McGill University of Montreal, Canada, has long been a foreground figure in utilizing such equipment for gestural research. However, the hardest obtainable bowing parameter is without doubt the *bow force*. Different strategies have been tested, but so far a special, lightweight electronic device designed by Matthias Demoucron seems to be giving the most reliable results and can readily be combined with motion-capture techniques [18], [19]. In all, this opens up possibilities for analyzing further gestural parameters such as skewed strokes, dynamic tilting, etc. Schoonderwaldt has done just that through a series of research projects [20], [21]. The same researcher did also utilize a Swedish-designed bowing machine [22] for mapping the real outcome of a vast number of strokes with one parameter changing at a time, thus confirming or disproving established concepts founded on purely theoretical considerations [23]. Theoretical conclusions need to be challenged regularly as they often miss important details even if they substantially might give rather good overviews. Musicians' skepticism to theoretical analyses is healthy as long as not *all* such analyses are thrown overboard. One might wish that string players had been equally skeptical with regard to myths conveyed by their teachers and colleagues, e.g. concerning hair friction, purpose of the soundpost, vibration in different parts of the instrument, etc.

3. WHO IS THE RESEARCH FOR?

Clearly, Hodgson did his research for the benefit of the players. Their gratitude does not seem to have been overwhelming. One reason (as Hodgson points out himself, [24]) is that string players not always realize how they actually are moving the bow when they play. As a double-bass teacher I have had the advantage of being able to demonstrate the differences for my students, who thus have been able to believe me through seeing and hearing. On the other hand, I have rarely come in the position to convey such information to other string students, simply because the other string teachers of my own or other music academies were lacking interest (albeit not proposals from my side). As an internationally acknowledged researcher of bowing gestures for about 15 years I must admit that I found it alarming that (with one single exception) I never got the opportunity to share my own and other scientists' findings with the string students and teachers in any of my own two academies (in Oslo and the Hague). The good thing was that as long as I kept it a secret that my suggestions were based on science, I could, particularly as the head of the string department in Oslo, teach also the non-bass players anything I wanted, as long as it worked.

In general, I believe that modern academies/conservatories should provide their students with a minimum of knowledge on how their instrument actually work acoustically, since such information is available and has now reached a level of good quality for most instruments and voice. Viola players could learn *when* to copy the gestures of violinists and *when not to*, if they had a better understanding of the underlying physics, etc. The instrumental teaching of classical music in academies and conservatories is mainly built around one single person, your private teacher. As a music student you are not encouraged to consult other teachers in order to get answers to instrumental challenges, unless through sporadic master classes or courses; just the same way your teacher once did it. This is in high contrast to general university-level education, where students are encouraged to seek expertise wherever it may be found and trusted, and where a supervisor does not think of himself as a person who has an answer to every question. We see that it is in cases where the student openly wants to go along a different musical path than the one that made his teacher famous, where educational cooperation is introduced, also with concern to details on instrumental techniques. Here, the scientific approach is suddenly not exotic anymore, but rather natural and logical.

The "classical" music student will most probably continue to copy the solutions of his/her teacher as long as the results are satisfactory. The change will happen through students that want to explore their instruments further for the purpose of creating novel musical expressions. Admittedly, most of the research literature in the fields of string instruments is not meant for the music community, but rather peers in the music-acoustic society. And it is actually here you will find most of the applications resulting from bowing-gesture research, as we know it today. It lies in the nature of scientific research that you have to prove your theories scientifically and let them be scrutinized by the scientific community before you produce text adapted for other user groups. So far, bowing-gesture analysis have mainly been utilized for three purposes: bowed-string synthesis [25], score recognition with automatic sound-filter switching at certain predefined points in the score—and real-time sound filtering activated by predefined gestures [26]. All founded on electroacoustic manipulation.

Still not mentioned: luthiers and string manufacturers constitute an important user group of bowed-string analysis. Many of these have already realized how important understanding the physics of the bowed string is for developing better instruments and strings. Again, we see a distinction between those who prefer to make true copies of well-functioning instruments, and those whose ambitions are to bring the craft even a step further.

4. COMMUNICATION PROBLEMS

There are several reasons why the communication between musicians and acousticians is so difficult. As a person who has experienced this from both sides, I would like to point to the following obstacles: **Terminology:** musicians do not have a precise terminology for common musical phenomena (e.g., accents, tone onsets in general, acoustical properties of the hall, etc.), and they are not familiar with the well-defined terminology of the acousticians. **Intrusion:** many musicians have experienced acousticians as intruders on their properties. It is experienced as a problem that so many acousticians want to define what good sound and good music is. Carl E. Seashore wrote that the best vibrato is sine-wave shaped [27]. It should be left to the musician to decide what sounds best, and how to practice it. **Fragmentation:** in order to study a phenomenon, the scientist will separate it from all other properties that could influence the outcome. The musician sees the total sound as an entity, and will usually not benefit from such disintegration, unless when trying to bring the same phenomenon to the absolute foreground. **Insults:** telling a flutist that she could have replaced her 100 000 € platinum flute by the same model in German silver, requires quite a bit of consideration and tactfulness—if at all it is true! It comes dangerously close to telling the flutist that she is stupid. **Patronizing:** I have on several occasions, as a musician, felt patronized by acousticians. Particularly during the design of the Oslo Concert Hall, which acoustically ended up just like the musicians' committee unanimously had warned the acoustician about, but to no avail... **Tradition:** at all times, apprentices have learned from imitating their Master. The fact that musicians' terminology appears somewhat limited is probably reflecting this learning method. This form of pedagogy works fine as long as the apprentice stays fairly well within the tradition being taught. If he wants to deviate from that track, he is probably better off by doing something similar to what so many young farmers choose: They educate themselves in universities of agriculture, getting more comprehensive and updated information than what their parents could possibly have provided themselves—even though the farm remains the same. Competition is getting harder in both arenas, and new challenges reveal themselves on a daily basis.

5. CONCLUSIONS

The idea that bowing-gesture analysis would make a strong impact on string pedagogy in general seems to be a wrong one, although many of us started our research with just that in mind. Instead, our research is mainly seen to be utilized in settings involving electroacoustic filtering or synthesis, an area that is interesting, indeed, but hardly contributing to raising the level of consciousness and understanding of the bowed string among players.

On a personal basis, scientific studies on bow/string interaction have been of great help and inspiration, both as a performer and as a teacher, and not least in facilitating and developing novel techniques in cooperation with my students. As a double-bass player/soloist I have given numerous master classes around the world. In some of these I have included a short section on bowed-string physics. These have always been well received. On the other hand, when I have been visiting an academy as an acoustician, i.e., without being presented as a high-level musician, the lectures have gained very little interest among teachers and students. In order to get their attention, I clearly need the authority of a respected musician.

It is my belief that not only music academies, but art schools in general, are facing crossroads, where they very soon have to choose directions. Like in pictorial arts, where new materials, new chemistry, new light effects, new stages, etc. pop up all the time, music—or at least parts of it—are given new opportunities and platforms with steadily increasing rapidity. Much time has expired since the wooden stage was the most important arena for music performance. To cope with this development we need new thinking, new information—in addition to preserving the best of our instrumental traditions. In plain words, this implies that the Master instrumentalist has to give away some of his/her hegemony over the student, and share it with other specialists. If principals of music academies don't see this, they will easily end up as directors of museums, if having jobs at all.

After having been researching, collecting and conveying relevant information on the bowed string over a substantial number of years, it was rather frustrating when a while ago one of my superiors at the Norwegian Academy of Music (which has mostly funded my efforts) remarked:

"*It would be nice if your research could be focused on something we could use in our teaching*!"

6. REFERENCES

[1] Hodgson, P. (1934) "*Motion Study and Violin Bowing*" Lavender, London. Reprinted by American String Teachers' Association (1958)

[2] Williams, C. E. (1985). "*Violin bowing skill analysis: the mechanics and acoustics of the change in direction*" Doctorate dissertation, University of Melbourne, Australia

[3] Guettler, K. (2002) "On the creation of the Helmholtz motion in the bowed string" *Acta Acustica united with Acustica* **Vol. 88**, 970-985.

[4] McIntyre, M. E., Schumacher, R. T. and Woodhouse, J. (1983) "Aperiodicity in bowed-string motion" *Acustica* **49**, 13-32.

[5] Schumacher, R. T. (1979) "Self-sustained oscillations of the bowed string" *Acustica* **43**, 109-120.

[6] Raman, C. V. (1920-21) "On the mechanical theory of the vibrations of bowed strings and of musical instruments of the violin family, with experimental verifications of the results: Part II. -Experiments with mechanically played violins" *Proceedings of Indian Assoc. for Cultivation of Science*.19-36.

[7] Schelleng, J. C. (1973) "The bowed string and the player" *J. Acoust. Soc. Am.* **53**(1), 26-41.

[8] Cremer, L. (1982) "Considerations of the duration of transients in bowed strings" *Catgut Acoust. Soc. Newsletter* **38**.

[9] Askenfelt, A. (1986)"Measurement of bow motion and bow force in violin playing" J. Acoust. Soc. Am. **80**(4), 1007-1015.

[10] Askenfelt, A. (1989) "Measurements of the bowing parameters in violin playing. II: Bow-bridge distance, dynamic range, and limits of bow force" J. Acoust. Soc. Am. **86**(2), 503-516.

[11] Schoonderwaldt, E. (2009) "The player and the bowed string: Coordination of bowing parameters in violin and viola performance" *J. Acoust. Soc. Am.* **126**(5), November, pp 2709 - 2720.

[12] Askenfelt, A. and Guettler, K. "The bouncing bow – An experimental study" Catgut Acoust. Soc. J. **3**-6(II), 3-8 (1998).

[13] Guettler, K. and Askenfelt, A. "On the kinematics of spiccato and ricochet bowing" Catgut Acoust. Soc. J. **3**-6(II), 9-15 (1998).

[14] Guettler, K. and Askenfelt, A. (1997) "Acceptance limits for the duration of pre-Helmholtz transient in bowed string attacks" *J. Acoust. Soc. Am.* **101**(5) Pt. 1, 2903-2913.

[15] Schoonderwaldt, E., Guettler, K. and Askenfelt, A. "Effect of the bow hair width on the violin spectrum" Proc. SMAC'03 (2003), Stockholm, Sweden. 91-94.

[16] Guettler, K., Schoonderwaldt, E. and Askenfelt, A. "Bow speed or bowing position-which one influences the spectrum the most?" Proc. Stockholm Music Acoustics Conference (SMAC'03) (2003), Sweden.67-70.

[17] Schoonderwaldt, E. (2009) "The violinist's sound palette: Spectral centroid, pitch flattening and anomalous low frequencies" *Acta Acustica united with Acustica* **95**, 901 - 914.

[18] Demoucron, M., Askenfelt, A., and Causse, R. (2009) "Measuring bow force in bowed string performance: Theory and implementation of a bow force sensor," Acta Acust. Acust. **95**, pp 718–732.

[19] Schoonderwaldt, E., Rasamimanana, N. and Bevilacqua, F. (2009) "Combining accelerometer and video camera: Reconstruction of bow velocity profiles" *J. Acoust. Soc. Am.* **126**(5), 2695 - 2780.

[20] Schoonderwaldt, E., Guettler, K. and Askenfelt, A. (2003) "Effect of the bow hair width on the violin spectrum" *Proceedings of SMAC'03* Stockholm, Sweden. 91-94.

[21] Schoonderwaldt, E. (2010) "On the use of skewness in violin bowing: Should the bow be straight or not?" *Acta Acustica united with Acustica* **96** # 4, 593 - 602.

[22] Cronhjort, A. (1992) "A computer-controlled bowing machine" *Speech Transmission Laboratory Quarterly Progress and Status Report, Dept. of Speech Communication and Music Acoustics, Royal institute of technology, Stockholm: STL-QPSR* **2-3/92**, 61-66.

[23] Schoonderwaldt, E., Guettler, K. and Askenfelt, A. (2008) "An empirical investigation of bow-force limits in the Schelleng diagram" *Acta Acustica united with Acustica* **94**, 604-622.

[24] Hodgson, P. (1935). Motion study and violin bowing (reply to reviewer). The Musical Times. **April**, 347 - 348

[25] Demoucron, M. (2008). "*On the control of virtual violins: Physical modelling and control of bowed string instruments*" Ph.D Thesis, Université Pierre et Marie Curie (UPMC), Paris, and Royal Institute of Technology (KTH), Stockholm, Sweden

[26] E.g., "*The K-Bow*", a commercial product developed by Keith McMillen (available for violin, viola, cello, and double bass).

[27] Seashore, C. E. (1938) "*Psychology of music*" McGraw-Hill Book Company - Dover edition, 1967. On "ideal vibrato", see page 52.