String Vibrato in the Age of Recording: a Wavelet Study

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Introduction

The study of vibrato from recordings, particularly string vibrato, has gained considerable attention in recent years [1, 2, 3, 4, 5]. Of particular importance are the recordings of performers from around 1900 like Joachim, Sarasate and Ysaÿe as they inform us about nineteenth century string performing style. In the early decades of the 1900s recordings witness a transition in the use of vibrato, as follows from these observations: a sparing use of a shallow vibrato was employed around the turn of the century, and around 1930 a wide, almost continuous vibrato was commonplace in cantabile pieces, the major exponents of this change being well known fiddlers like Kreisler, Heifetz and later Menuhin.

The vibrato on the violin is brought about by a complex motion involving the lower left arm, the wrist and the fingers, resulting in a small periodic change of the effective length of the string. This produces small variations of pitch. As the acoustic impedance of the violin body is strongly frequency dependent, this also results in a periodic variation of loudness. Vibrato is used as a means of expression.

The taste regarding vibrato is continuously changing with time. Many violin treatises warn against its overuse [6, 7, 8]. In the de Beriot, Spohr and Joachim and Moser treatises musical examples are given to illustrate where the use of vibrato is appropriate: only as an embellishment of certain notes [8, 9, 10]. Opposite to this view is the Geminiani treatise, which gives the advice to use vibrato whenever possible [11].

There is general agreement among researchers that both recordings and written sources point to a transition in the use of vibrato in the early 1900s: from shallow and employed as an embellishment in the nineteenth century to wide and continuous in the twentieth century. Given the written and the recorded evidence one might think we have a consistent picture here. But is it? The recordings were studied by merely listening. To what extent can we observe such a subtle effect as shallow vibrato in early, scratchy, noisy recordings by listening? And, is what people write, always in line with how they act? The use of a modern signal analysis technique very soon resulted in discrepancies between observations by some authors and my results. This motivated a systematic study. Here I will present results of an analysis of the opening phrase of two cantabile pieces: Bach's Adagio from the first Solo Sonata (BWV 1001) and Brahms Hungarian Dance no. 1 (arranged for violin and piano by Joachim).

Technique

Our auditory system can detect changes on a timescale of about 10 milliseconds and frequency deviations of about 1 percent [12]. Fourier analysis is the common method of analyzing musical signals in the time-frequency domain [13]. However, an FFT cannot meet the requirements of simultaneous time and frequency resolution: it is possible to meet the requirement of time resolution using a 512 point FFT for a 44.100 kHz digital audio signal, but at frequencies of about 400 Hz the frequency resolution would be about 100 Hz which is far from appropriate for this purpose. Spectral analysis using wavelets, invented some decades ago, and recently applied to musical signals [14], can do the job satisfactorily. Instead of decomposing the signal into sinusoidal wave trains of infinite length, waveforms that are localized in time are used as base functions. Many types of wavelets exist, among which Morlet wavelets are popular. In terms of these Morlet wavelets the signal F(t) may be expanded as:

$$F(t) = \sum_n CWT(t, a_n)$$

$$CWT(\tau, a_n) = \frac{1}{\sqrt{a_n}} \int_{-\infty}^{+\infty} F(t)\, h^*\left(\frac{t-\tau}{a_n}\right) dt$$

$$h\left(\frac{t-\tau}{a_n}\right) = \pi^{-\frac{1}{4}} \frac{1}{\sqrt{a_n}} e^{j\omega_0 t}\, e^{-\frac{1}{2}\left(\frac{t-\tau}{a_n}\right)^2}$$

where h(t) is the complex Morlet wavelet, and a_n is a time scale. This wavelet is a sinusoidal wave (the term between brackets), modulated by a Gaussian function (the last exponential term) and therefore localized at $t = \tau$. The result of the wavelet transform is a series of amplitudes $T(a_n,\tau)$ with various time scales a_n and locations in time τ. The important difference with the Fourier transform is the spacing between frequency components: in the case of the Fourier transform the spacing is linear, but in the case of the Morlet wavelet transform the spacing is logarithmic. It is worth noting in this context that the spacing between pitches in the cochlea is logarithmic as well.

The wavelet transform on audio data was carried out using the R programming environment [15]. This software package may be equipped with plug-ins for converting sound files into data arrays and performing wavelet analysis, and is freely distributed on internet.

The result of the wavelet analysis is a large three dimensional data array with the wavelet amplitude as a function of time and frequency. The frequency spectra contain 6 to 12 octaves and 48 frequencies per octave. The time resolution is 12.5 milliseconds; the pitch resolution equals a quarter semitone, which can be further improved by interpolation to about a tenth of a semitone, wich is adequate for our purpose. A few characteristic examples are given in Figure 1. Here the first bar from Bach's Adagio from the first Solo Sonata is shown as recorded by Joachim (1903) (top) and Enesco (1940) (bottom). The horizontal axis gives the time, the vertical axis the pitch (1 scale division corresponds to an octave) and the shaded relieves give a three dimensional impression of the amplitudes. For every

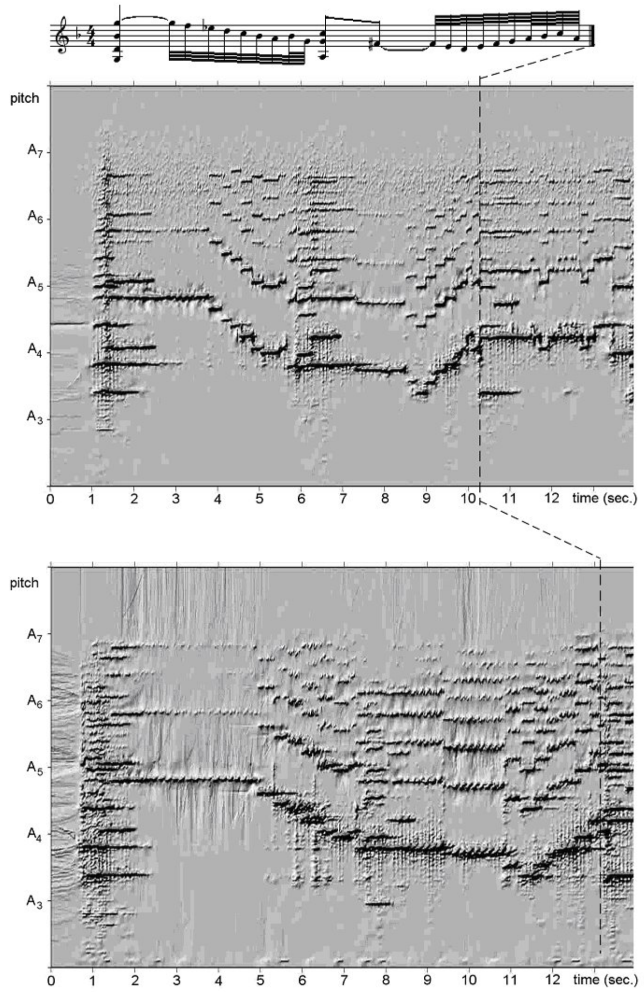


Figure 1: Wavelet analysis results for bar 1 of Bach Adagio from Solo Sonata 1 (BWV 1001). Top: Joachim (1903), bottom: Enesco (1940)

tone on the violin we see a series of traces, starting from the fundamental at the lowest pitch to the higher harmonics. As the vertical scale is logarithmic, the spacing between these partials is not constant. If the violin is playing the A_4 at 440 Hz, we will also observe the A_5, E_5, A_6, C#$_6$, E_6, G_6, A_6 and so on. This is why we see the parallel traces in the pictures. Note that the pattern in this picture also corresponds to the vibration pattern of the basilar membrane (one may imagine nerve cells connected to the vertical axis). Thus, the wavelet analysis closely follows the properties of our auditory system.

If a tone is played without vibrato, a series of flat horizontal lines will be observed. If vibrato is used, an undulating pattern will be visible, with a characteristic frequency of about 6-7 Hz. Enesco is using the device almost continuously, even on passing notes, whereas in Joachim's recording some small periodic features are visible (the second half of the G_5 of the opening chord and the F# quaver about in the middle). The vibrato of the recordings will be characterized by two parameters: its width (in cents, 100 cents corresponds to a pitch variation of one semitone) and its continuity (measured as the time fraction the vibrato is used). So the vibrato of the Joachim recording has a maximum width of 33 cents and a continuity of 14 %, for the Enesco recordings the values are 133 cents and 92 % respectively.

In the Enesco recording effects of room reverberation are visible: the fundamentals of the shorter notes are overlapping in time. As a result of this, the vibrato pattern of the fundamental frequency looks blurred. This phenomenon was described by Meyer [16]. In a reverberant room the listener (or the microphone) hears a combination of direct and reflected sound; the time delay between these two has a maximum value of about half a second in the Enesco recording. As a result, the sound from different portions of the vibrato period with slightly different pitches arrive at the same time at the position of the listener or the microphone, creating a kind of chorus effect. This effect is important for distant positions (either occupied by a listener or a microphone), and for frequencies where the acoustic absorption of the room is low (i.e. low frequencies). It can't be observed in the Joachim recording or other recordings from the period of the acoustic horn: the performer always had a position as close as possible to the horn, to get sufficient signal. The early acoustic recordings therefore only pick up direct sound, no reverberant sound. In the time of electric recording however often a distant microphone position was chosen to create a natural reverberant sound and the fundamental frequency cannot be used for this study. Because of the possible interaction between the vibrato and room reverberation, not the fundamental frequency, but the first harmonic was used for the analysis throughout this study.

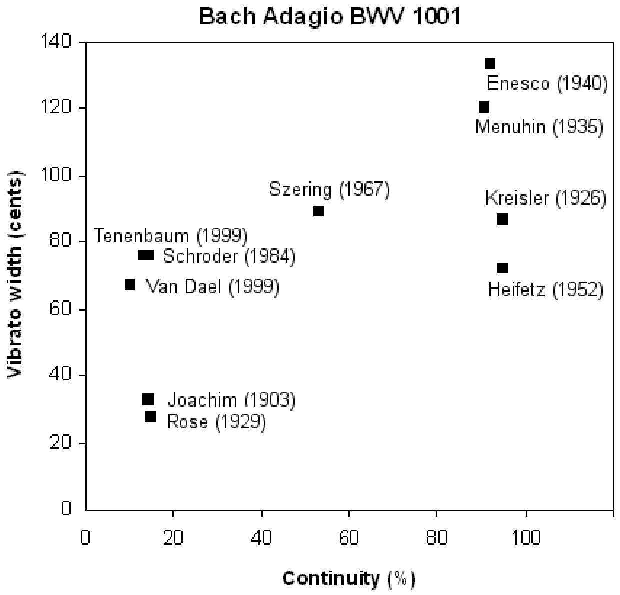
Results

Figure 2 shows the results for the two pieces that were studied. Here the continuity of the vibrato of every recording is plotted versus its width. In this type of plot we will find recordings with a shallow, incidental vibrato in the lower left corner, and recordings which exhibit a wide continuous vibrato in the upper right corner.

The observations in the Bach recordings are in line with the familiar picture: performers who follow the nineteenth century tradition (Joachim and Rosé) employ sparingly a shallow vibrato; Kreisler is the first to break with this tradition in 1926 with a wide almost continuous vibrato. Enesco and his pupil Menuhin champion the modern trend. But if we follow the development throughout the century, we observe a counterclockwise motion: Szeryng is the first to reverse this trend in 1967 and the most recent recordings by Schröder, van Dael (both specializing in authentic performance using period instruments) and Tenenbaum (playing on a modern instrument) show a sparing use of vibrato of moderate width.

With the Brahms recording the situation is completely different. In Brahms' Hungarian Dance no. 1, less variation in continuity is observed than in Bach's Adagio. In the

Brahms piece the exponents of the nineteenth century style, Joachim and Auer, employ vibrato on almost every dotted quarter note and longer stopped notes. Joachim's vibrato is much wider and more continuous than in Bach's Adagio; Auer's vibrato is even more wide and continuous.



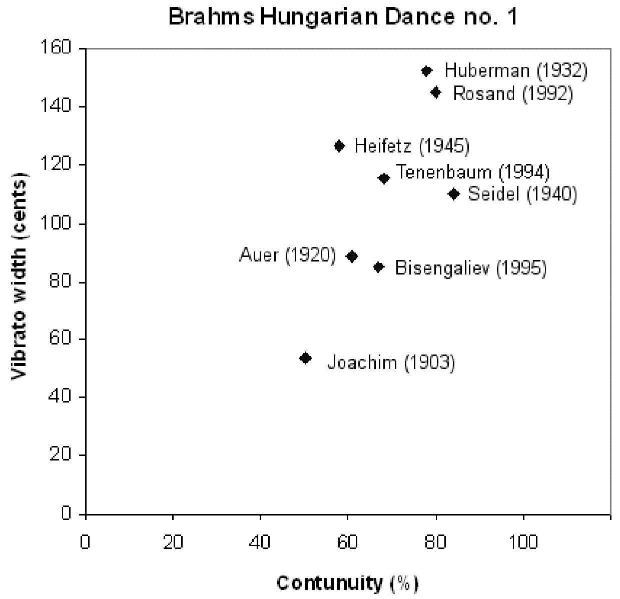


Figure 2: Wavelet analysis results for bar 1 of Bach Adagio from Solo Sonata 1 (BWV 1001). Top: Joachim (1903), bottom: Enesco (1940)

At first sight, the playing of Joachim and Auer seems to contradict the writing in their violin treatises. To elucidate this point, I have checked some other recordings. Joachim's vibrato in his own Romanze in C is somewhat less continuous (42 %), but he makes expressive use of the device on this recording. Thus, both Joachim's recordings and his writings fit into the same picture: he used vibrato when he felt it was appropriate. Obviously, in Bach's Adagio this was not much the case. In his Romanze he made expressive use of the device. In the opening phrase of the first Hungarian Dance, he used it as much as he could as this piece naturally invites for the use of vibrato, because of its association with Gypsy Music [17, 18]. Joachim, born in Hungary, was very much aware of the 'Style Hongrois', he even composed a Violin Concerto entirely in this style. Thus we can understand Joachim's recordings in a manner which is line with his writings: vibrato is sometimes used as an embellishment of isolated notes, but if he felt it was artistically necessary, he might use it to embellish a whole phrase. In the case of Auer, the situation is more puzzling. He only made two recordings, the second being 'Souvenir d'un Lieu Cher' by Tchaikovsky. This is also a cantabile piece. The analysis shows that he is using vibrato continuously (width: about 60 cents) in the opening phrase. So for him it can't be proven that he restricted his vibrato when he found it necessary, like Joachim.

Listening to vibrato: a clue from psycho-acoustics

Compared with previous observations, made by listening to recordings, this study reveals substantially more vibrato. This raises the question: 'Is it possible to study vibrato on poor quality recordings simply by listening?'. I found numerous examples of other authors making observations that are different from this study. Table 1 gives an illustrative example (Joachim's performance of Brahms' Hungarian Dance no. 1). Only Brown's results approach the findings in this study, though he admits to be a bit uncertain because of the poor quality of the recording; the other results differ substantially.

Table 1: Observations of vibrato in Joachim's recording of Brahms' Hungarian Dance no. 1, bars 1 - 24

Author	Observation
Philip	Occasional tremor on long notes
Brown	A tight almost imperceptible vibrato seems to be used on every stopped note
Milsom	Bars 1 and 2
Katz	Continuity = 5 %
This work	Continuity = 50 %, width = 54 cents

In psycho-acoustics, the phenomenon that is working here, is known as 'partial masking'. In the case of a tone, modulated by vibrato, partial masking may occur by other sounds: the tone is still audible, but the modulation (the vibrato) is not. This phenomenon was investigated by Fastl and Zwicker [19]. A frequency swing of less then 1 percent (corresponding to about a sixth of a semitone) is inaudible, even in a noise free environment. If noise or other sounds are present, then the modulation may be inaudible while the original tone may still be heard, depending on the loudness of the tone, the loudness of the noise within a critical frequency band and the width of the modulation. Now let us apply the data from these authors to the Joachim recording. At a frequency of 1000 Hz his 50 cents vibrato corresponds to a frequency swing of 30 Hz. For a 1000 Hz tone, the loudness has to exceed the background noise in a 160 Hz bandwidth at least by about 10 dB, to make the vibrato audible. From the wavelet analysis data the value of the loudness of the tone and the background noise in a given bandwidth are easily calculated. The result of this calculation, by coincidence, also yields a value of about 10 dB. Therefore, Joachim's vibrato is just at the limit of audibility, which means that 50 % of a listening panel will hear it. But other sounds, such as the sounds produced by scratches or a higher partial of the piano accompaniment within the critical frequency band at 1000 Hz, will easily render Joachim's vibrato inaudible.

Conclusion

Wavelet spectral analysis proves to be a useful tool in the study of performance style. Just listening to old scratchy, noisy 78-rpms may be inadequate to make accurate observations of the use of vibrato. It follows that in most cantabile pieces the vibrato is almost continuous, even in most recordings from the beginning of the twentieth century. The transition in performance style which occurred at the beginning of the century is primarily due to the width of the vibrato, and to a lesser extent due to a change in continuity.

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