The Vienna Horn: Its Acoustics and Playing Technique

Gregor Widholm

There are many reasons to have a closer look at the acoustical properties of musical instruments. In the case of the Vienna horn it is definitely true that a nineteenth-century instrument (the Vienna horn can be seen as a hand horn with added valves) is the first choice of several top orchestras in the twenty-first century.[1] My article shows the difference in design between the Vienna horn and the double horn used in most orchestras in the world, proves its particular acoustic properties by physical measurements, and explains the consequences for musicians in terms of playing technique.

As mentioned above, the Vienna Horn can be seen as a hand horn with added valves. This is obvious if you look at its dimensions: the bore of the cylindrical section of the Vienna horn and the hand horn in Figure 1 is for both instruments 10.8 mm and the bell section of the Vienna horn has the same shape and dimensions as that of the hand horn. I have played these instruments for nearly thirty years, but now their home is in Edinburgh at the "Scottish Vienna Horns."

Figure 1: Vienna horn (left), signed "Leopold Uhlmann K:K:Hof Instrumenten Fabrik in Wien," and hand horn (right), signed "Leopold Uhlmann K:K:priv: Instrumenten Fabrik in Wien."

It is remarkable that the detachable F-crook and the double-piston valves, which dominate the visual appearance of the Vienna horn, have no influence on the response, intonation, or timbre and therefore contribute nothing to the particular acoustical properties of the instrument! However, the "removability" of the F crook presents the option of combining different crooks on an instrument very easily. This is a simple way to change the character of an instrument very quickly, and with little effort. Although double and triple horns sometimes offer the option of replacing the

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leadpipe, replacing the F crook (length: 105–20 cm) has a much more pronounced effect on the sound because the leadpipe is only about 30–50 cm long.

The principle differences between the Viennese horn's construction as compared to the standard double horns are as follows:

- the length of the tube
- the diameter and shape of the bore
- the valve section
- the detachable F-crook

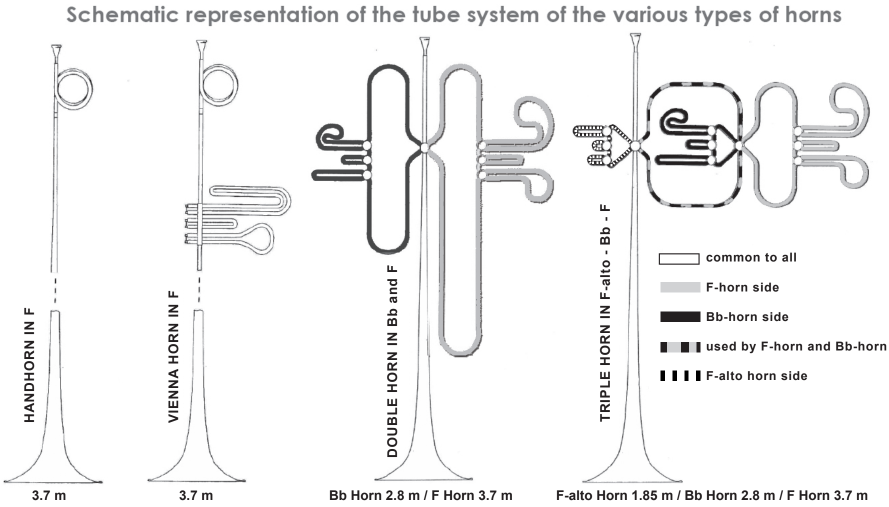

Figure 2: Schematic representation of the tube systems of the various types of horn.

Length of the tube

The length of a Viennese horn in F, taken from the mouthpiece rim to the end of the bell, is about 3.7 meters. Using a double horn, the player can switch with the thumb valve between two horns with different length:

- the F-horn side with the same length as the Viennese type of instrument and a B♭-horn side with a length of 2.8 meters.
- In the case of a triple horn, the player has three different instruments at his/her disposal: one with a tube length of 3.7 m, one with 2.8 m, and an F-alto horn with a tube length of 1.8 m.

The length of the tube influences the required energy, the accuracy and, in an indirect manner, the timbre.

Energy demand

Figure 3 shows the "acoustic fingerprints" of the three types of horn. The "BIAS" computer system developed in the Institute of Music Acoustics (Wiener Klangstil) has produced these curves by automatically measuring and evaluating the quality of a brass instrument (see website www.artim.at). For the plots of Figure 3, the three sides of a Paxman triple horn were-excited with the same signal.

It is a fact that the horn player can produce notes (natural harmonics) only at those frequencies where the curve shows the greatest amplitude (peaks), which represent the resonance frequencies of the air column inside the instrument. The higher the peaks, the more energy is stored in the standing wave inside the instrument and the easier it is for the player to play the desired harmonic. As can be seen from the curves, the F-alto side requires the smallest amount of energy (i.e., it has the highest peaks; but see Figure 3, caption). Why should this be so?

In playing the written *g* marked by arrows in Figure 3, for example, the player's lips open and close like a valve 523 times per second. At each opening, air particles, whose volume depends on the open lip area and the lung pressure, are pushed into the mouthpiece cup and collide with the air particles already there. In other words, inside the mouthpiece cup a high-pressure impulse is created that propagates toward the bell because each air particle is pushed toward the next neighboring particle, and so on. With such periodic pulsed air passing through the lips, the player creates "kinetic energy," which causes the air column within the instrument [= mass] to oscillate at the required frequency. Since its length is only half that of the Vienna horn, it is clear that the air column of the F-alto horn possesses only half the mass. Therefore a comparable amplitude of oscillation also requires only half the energy. In short, in order to produce a standing wave of comparable intensity in the instrument, the player has to use more energy with the Vienna horn than with a double horn.

Figure 3 proves this effect for the steady-state condition of the played note, but at the start of the note the difference caused by the tube length and its related air volume is much more noticeable by the player. The oscillation within the instrument is set up in the first 20–100 milliseconds. We know that it needs at least approximately four to six cycles to establish a note. One cycle means that the high-pressure impulse travels from the mouthpiece to the end of the bell, where approximately 90–96% is reflected (depending on the relationship between the bell diameter and the particular frequencies) and travels back to the mouthpiece. The remaining 4–10% is radiated into the room and perceived as the sound of the instrument. Thus one cycle in the Vienna horn takes about 21 milliseconds, the B♭ horn, about 15.8 ms, and for the F-alto horn, 10.6 ms. If the music requires a very short onset time because the note

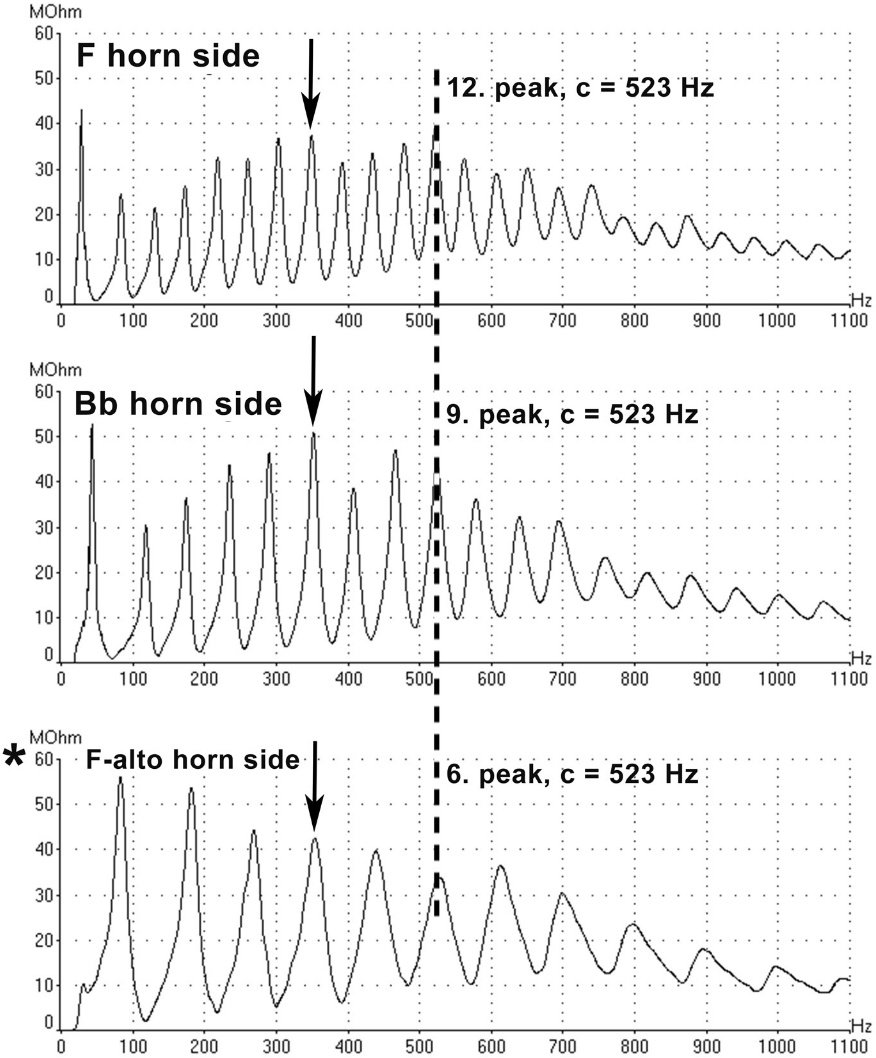

Figure 3: Input impedance of the three sides of a Paxman triple horn. x-axis: frequency in Hz; y-axis: input impedance in ohms.

The F-alto side was measured with older equipment. Because of a different software calibration, the values of the y-axis must be multiplied by a factor of 1.4 to obtain comparable values. The arrows mark the 8th/6th/4th Peak, which is a written c (in F) and has a value of about 38 Megaohms (Mohms) for the F-horn side, 50 Mohms for the B♭ horn side, and about 59 Mohms for the F-alto side. The dotted line marks the written g (in F) and is discussed in section 1.2 below.

values are short, the Vienna horn player can manage this only by means of a greatly increased energy supply [=air]. But once the note is sounded only the amount of energy lost through dissipation (what we hear as the characteristic “sound” of the instrument) and through friction losses inside the instrument has to be replaced.

In summary, the player’s input serves two different aspects of the internal energy management of brass instruments:

- During the starting phase of a played note, a standing wave has to be established in the system inside the tube. The time needed for this phase is determined by the length of the tube, while the amount of required energy depends on the air volume [=mass] inside the tube.
- For the steady-state note, only the radiated energy [=sound of the instrument] and losses through friction inside the instrument have to be replaced.

As the starting phase of a note is an important part of its “Gestalt,” the duration of such a phase is obviously specified only by the musical context; and music does not care which instrument is used by the player. The consequence for playing technique is that a Vienna-horn player has to increase the energy input significantly as compared to a double-horn player if short notes are required. This means that works that contain many repeated staccato passages or notes of short value in the upper register (as in Verdi’s operas) are more tiring for them, whereas the many sustained notes in the works of Wagner or Bruckner, for example, favor the Vienna model, since less energy is dissipated by the somewhat narrower bell-throat and so less has to be replaced.

Figure 4 illustrates the need for a higher energy input for the attack of a note when using the Vienna horn. It shows the result of an experiment in which a triple horn was artificially excited by a digital Brüel & Kjaer sine-wave generator coupled to the instrument’s mouthpiece by a Brüel & Kjaer artificial mouth. For all three sides of the triple horn the generator provides exactly the same amount of energy: 103 dB, with an onset time of 20 milliseconds. The excitation frequency is exactly adjusted to the particular impedance peak of each side of the horn. The F-horn side of the triple horn (equivalent to the Vienna horn) needs 105 ms settling time for a stable note and provides a sound level of 110 dB at the bell’s end. The B♭-horn side needs only 95 ms and achieves a sound level of 112 dB. The F-alto side, with 60 ms onset time, is the fastest and, with a sound level of 118 dB, also the loudest.

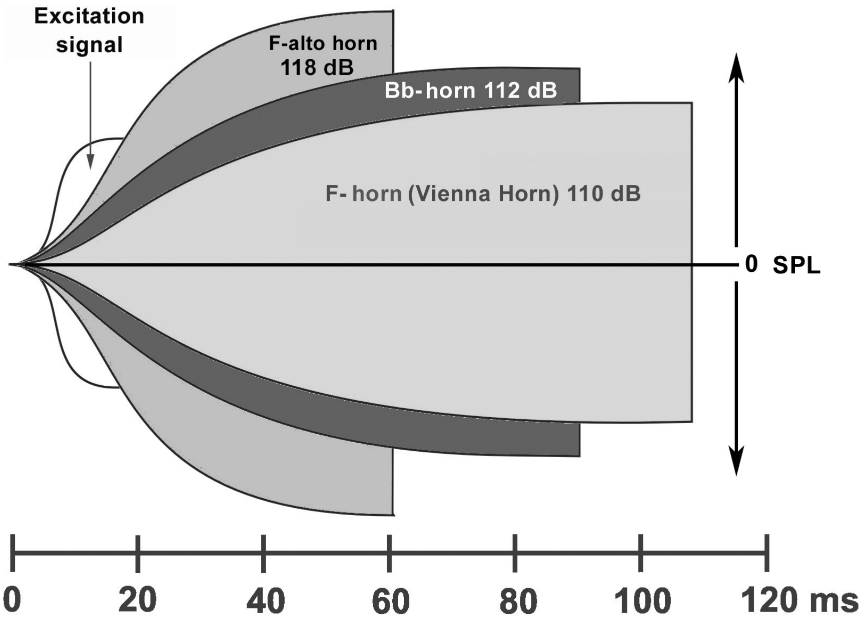

Figure 4: Envelope of the sound waves [=time function] for the three sides of the horn and the excitation signal by identical excitation. Shown is only the time span before the note is established (starting phase).

Accuracy and "cracked" notes

Pitching notes with accuracy is to a large extent determined by the overall length of tubing involved. It is a topic that interests players and audience alike, associated as it is in the public's mind with the well-known sound of "split" notes. If one compares the relationship of the peaks [i.e., playable harmonics] on the frequency axis (Figure 3), it can be seen that the distance between them diminishes as the tube length increases. On the F-alto horn the distance between individual harmonics is 88 Hz, on the B♭ horn, 58 Hz, and on the Vienna low-F horn only 44 Hz. For written *G* on the Vienna horn (see Figure 5) this represents a semitone, on the B♭ horn, a whole tone, and on the F-alto horn, a third. What is more, although the difference in frequency between individual harmonics is the same throughout the playing range, the ear hears the distance between the first and second peak of the impedance curves of Figure 3 as the musical interval of an octave, the same distance between second and third peak as just a fifth, and so on, while between the twelfth and thirteenth peak we hear only a semitone. This means that the player of the Viennese instrument has to adjust lip tension with much greater accuracy than the double-horn player in order to hit the required frequency and avoid "landing" on a neighboring peak. Playing the Vienna horn in the upper register consequently requires rather more concentration and more accurate control of musculature. Figure 6 shows two examples for split notes.

TYPE OF INSTRUMENT	Ordinal number of neighboring lower note	DISTANCE in musical terms and Hz	**Reference number of the written g^2 (523 Hz)**	DISTANCE in musical terms and Hz	Ordinal number of neighboring higher note
F horn	11	semitone 41 Hz	**12**	semitone 44 Hz	13
B-flat horn	8	whole tone 57 Hz	**9**	whole tone 58 Hz	10
F-alto horn	5	minor third 82 Hz	**6**	minor third 89 Hz	7

Figure 5: Distance of the neighboring peaks/notes for the three sides of a triple horn.

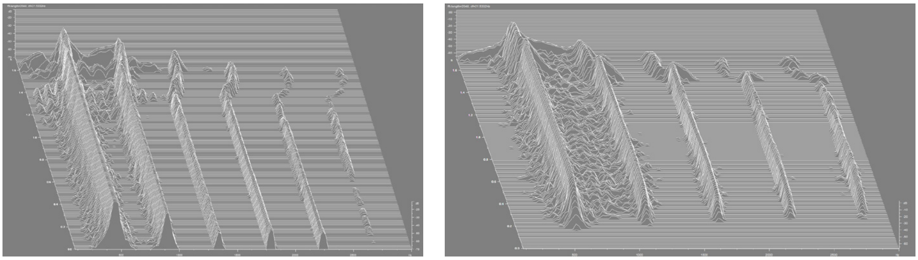

Figure 6: Waterfall spectra of "cracked" notes. Time proceeds from rear to front. Frequency is on the x-axis from left to right (0–3000 Hz); y-axis, magnitude in decibels (dB). The first "ridge" on the left-hand side in each plot is the fundamental frequency, which represents the pitch, while the other ridges represent the harmonics contained in the sound of this played note. Left: e^2 (written), the player starts with too much lip tension. Right: g^2 (written), lip tension is too slack, and the player catches a note between f^2 and $f\sharp^2$.

Length of the tube, bore profile, and sound

The diameter of the cylindrical tube section of the Vienna horn is about 10.8 mm (max. 11 mm), while double horns have a considerably wider bore of 11.5–13 mm (depending on the model). As with tube bore, the bell and bell-throat of the Vienna horn are also narrower, but even differences of a few tenths of a millimeter have a significant effect on the sound. A narrower bore leads to a greater frictional loss in the standing wave on the inner surfaces of the tube (a factor in all brass instruments!) This is because sound waves tend to propagate spherically, which is impossible inside a tube where propagation is possible only in the direction of the tube axis. All the air particles that move against the wall inside the tube are reflected back, interfere with the others, and thus convert kinetic energy into heat. The area where this effect occurs is a layer of about 0.2 mm, close to the inner surface of the tube. Figure 7 shows the situation for two different bores: one with a diameter of 10 mm and another of 15 mm. In both cases the friction-loss layer is about 0.2 mm. But while the area of this layer is about 4% of the entire cross-section area of the narrow-bore tube (10 mm), the share for the large bore (15 mm) is only 2.6%, which means that a larger bore leads to ~~a~~ slightly lower friction loss.

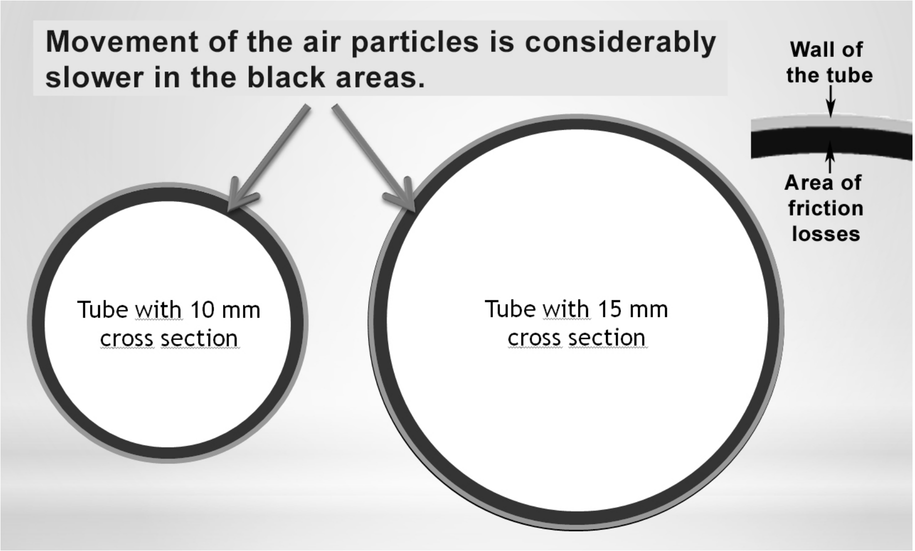

Figure 7: Skin layer where friction losses occur.

The narrower bore in combination with the length of the Vienna-horn tube causes a significantly higher friction loss. To compensate for this, more energy (amount of air) has to be introduced simultaneously. This leads, for the duration of one "opening cycle," to a sharper angle on the outer edges of the surface of the lip aperture and, as a result, to a sound containing a richer combination of partials (more about this effect and its origin and causality in the section on "Spectrum dynamics," later in this article). The differing combination of partials can be clearly seen in Figure 8, which shows the spectrum envelopes for written e^2 played fortissimo, both spectra obtained at the same sound level of 100 dB. The graph at the top shows a Vienna horn with 55 partials; at the bottom, a rather extreme comparison, with the same note played on the F-alto side of a double horn with only 28 partials.

At similar objectively measured volume levels the Vienna horn consequently sounds "brighter" than a double horn (although paradoxically the Viennese player refers to the ideal sound of the instrument as being "mellow" and "dark," even though such a sound color is made up of fewer partials). For the listener the impression of volume is conveyed primarily by tone color rather than by the actual sound level, so a *fortissimo* on the Vienna horn can be achieved at a lower volume than on a double horn. Because of its wider range of partials, the Vienna horn is less easily obscured by other instruments, and so penetrates more readily than a double horn played at the same volume through the overall texture of the orchestra.

Legato slurs with valves

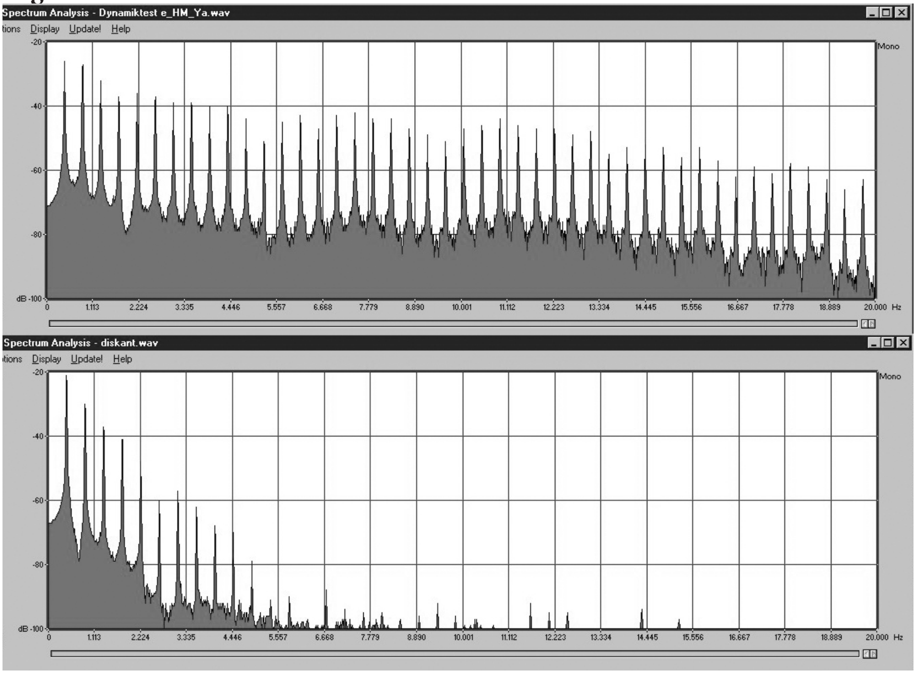

Figure 8: Sound spectrum of a written *e^2* at the same sound level (100 dB).
Top: Vienna horn; bottom: F-alto side of a Paxman triple horn.

Apart from the F-crook, the most significant visual feature of the Vienna horn is the double piston valves. Experience shows that "smooth" legato slurs in which the notes appear to flow into one another are often easier to carry out on the Vienna horn. But even when executed faultlessly, fast sequences of notes are usually somewhat less sharply defined and may sound fuzzy. On the double horn (in an adagio passage, for example) smooth slurs are more difficult to play, while the more abrupt change from one frequency to another has its advantage in rapid passages. These are not only easier to play on account of the clearer separation between notes; they also sound technically more brilliant.

Figure 9 shows the three-dimensional pattern (waterfall spectrum) formed by a slur in which a short noise band between the two notes of the double horn, lasting about 15 milliseconds, is clearly visible. Until recently this effect of a slur on the sound pattern was attributed to the different types of valve mechanism—i.e., double-piston valves on the Vienna horn and rotary valves on the double horn. New research, however, shows that it is not the type of valves as much as their position on the instrument that is the determining factor. If the valve mechanism is placed in a similar position on the tubing, the sound of a slur with a Vienna valve is absolutely identical to that of a rotary valve! If the valve is situated at a point where the standing wave within the instrument for the initial note of a slur has an antinode, the slur will be "abrupt, clear"; if it is at a node, the slur will be "smooth."

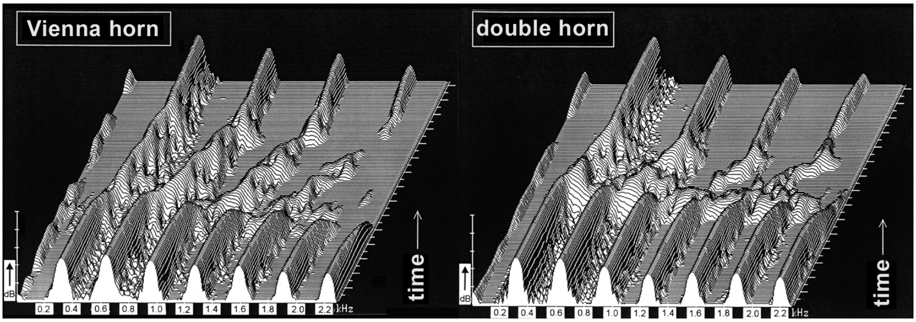

Figure 9: Waterfall spectra for an octave slur, f^1-f^2 (written), played on a Vienna horn (left) and an F-B♭ double horn (right). Horizontal axis: frequency from 100 to 2200 Hz. Vertical axis: magnitude in dB. The time proceeds from front to rear.

By way of explanation of what happens during such a slur, Figure 10 shows the pressure response (not the sound!) in the mouthpiece during a slur; in other words, the environment in which the player's lips have to act.

As the valve finger-plate is depressed, the player makes constant adjustments to the tension of the lips in such a way as to move from the frequency of the starting note to the frequency of the target note; in the diagram the player "travels" from left front (starting note) to right rear (target note). If positioned at an antinode (Figure 10, right), the break of the standing wave after the first third of the slur, which causes the noise band, is clearly seen. If on the other hand the valve mechanism is positioned at a node (Figure 10, left), the continuing high impedance allows a smooth, glissando-like slur.

Some additional information concerning Figures 9 and 10 is important: the octave slur of Figure 9 (beginning of the Horn Concerto No. 1 by Richard Strauss) was taken in the early 1980s from recordings in the anechoic room of the Institute of Music Acoustics (Wiener Klangstil) at the University of Music and Performing Arts

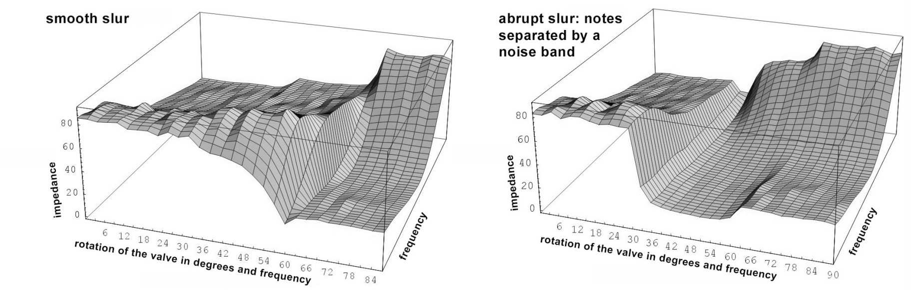

Figure 10: Pressure response inside the mouthpiece during a semitone slur in the plane of the player's lips. Left: Vienna horn; right: double horn. The plots are the result of impedance measurements inside the mouthpiece cup in the plane of the lips during the slur. The valve of the Vienna double-piston valve was depressed in 1 mm steps, and in the case of the double horn's rotary valve, in such a way that one step corresponds to an angle of 3 degrees. At each step an impedance measurement was taken. The range displayed on the x-axis is only from the starting note (frequency) on the left side to the target frequency on the right side. (The numbers on the x-axis (0 to 84 on the left, 0 to 90 on the right) are neither degrees nor millimeters; they show the internal labeling of the visualization software). This approach automatically implies that the player's lip tension is changed continuously in order to move from the starting frequency to the target frequency.

Vienna, and played by a member of the Vienna Philharmonic Orchestra on a Vienna horn and by a member of the London Philharmonic Orchestra on a double horn. A horn player will immediately reply that such an octave slur can be executed on a Vienna horn only as a lip-slur (for both notes, the first valve is engaged), whereas the double-horn player will start with the long tube (F-horn side) and switch during the slur with the thumb valve to the shorter tube (B♭ side) for the f^2 in order to avoid a split note. Therefore, in this special case the objection is legitimate—the difference in the microstructure of the octave slur is not caused by the position of the valve section, rather it is a function of whether the valves are used or not. But I chose this example because it shows the fundamental differences between Vienna horns and double horns in an explicit and clear way. The difference is easy to see.

The proof that the position of the valve makes the difference described above can be seen in Figure 10. For these measurements we used a "straight" horn. The valve section could be replaced by the opposite model and additionally shifted along the tube axis in 1 cm steps. If the two different types of valves are located at the same position along the tube axis, they produce an exactly identical impedance waterfall plot and the same sound spectrum over time! Such plots can be seen on the homepage of our institute[2].

Figure 11 further demonstrates the instrument's dependence on the position of the valve section along the tube axis by means of another example: a slur (written $b\flat^1$–$e\flat^2$) taken from recordings of the same two horn players from the Vienna Philharmonic and the London Philharmonic. In this case both players used the valves. The double horn (right) shows its characteristic short noise band between the notes, whereas the waterfall plot of the Vienna horn (left) indicates a smoother, glissando-like transition.

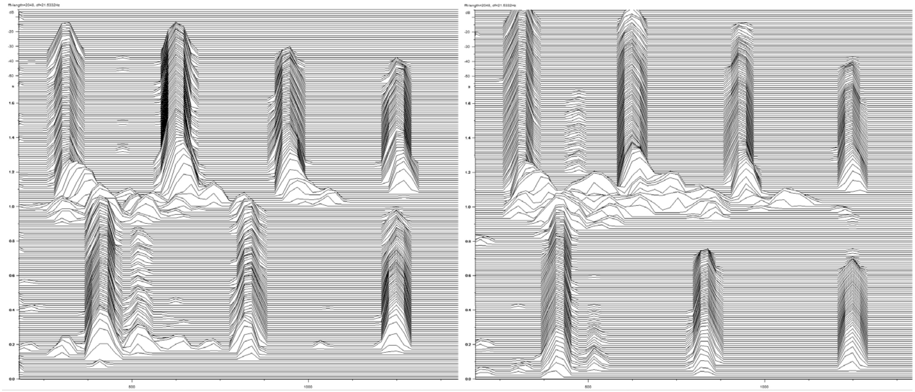

Figure 11: Waterfall spectra for the slur b♭1–e♭2 (written), played on a Vienna horn (left) and on an F/B♭ double horn (left). Both players used the valves.

Spectrum dynamics

A closer look at the differences in sound between Vienna horns and double horns shows no difference for notes played *piano,* and only a slight difference in tone color for *mezzoforte* notes. But for a crescendo to *fortissimo*, the Vienna horn, unlike the double horn, displays an enormous increase in the number and intensity of the higher dynamics. We use the term "spectrum dynamics" for this extreme change in sound color that is dependent on loudness.

Figure 12 illustrates the phenomenon of spectrum dynamics for the Vienna horn and the F, B♭, and F-alto sides of a triple horn (Paxman) for a crescendo played on a written *e*^{2}. Further elucidation of this figure may be helpful: the SPL (measured sound level in dB) of the sound of the note in its entirety was taken as a reference point and thus set at zero. It is represented by the horizontal line/axis at the top of the figure. To provide information on the increase of the SPL during the crescendo, this axis is labeled with the measured values in dB (84–97 dB). The amplitude of each partial/harmonic was then taken and set in relation to the overall SPL of the note, as shown by the numbered wavy lines. As an example, for the Vienna horn the fifth harmonic starts at 45 dB below the reference SPL of 84 dB and ends 16 dB below the reference SPL of 97 dB. The increase for this harmonic over the plotted part of the crescendo is 29 dB, whereas the overall SPL shows an increase of only 13 dB.

At first glance it seems unrealistic that the first harmonic (= fundamental), for example, of the F-alto horn has a higher amplitude value (+3 dB) than the note as a whole, which contains all the harmonics. This phenomenon occurs because the SPL value is taken from the entire sound wave ("time domain") and the amplitude values of each harmonic are taken from the sound spectrum ("frequency domain"), whereas during the FFT(Fast Fourier) Transformation) the phase information gets lost due to mathematical reasons. Nevertheless, the figure shows very clearly what can be heard while listening to a crescendo played with these four types of horns.

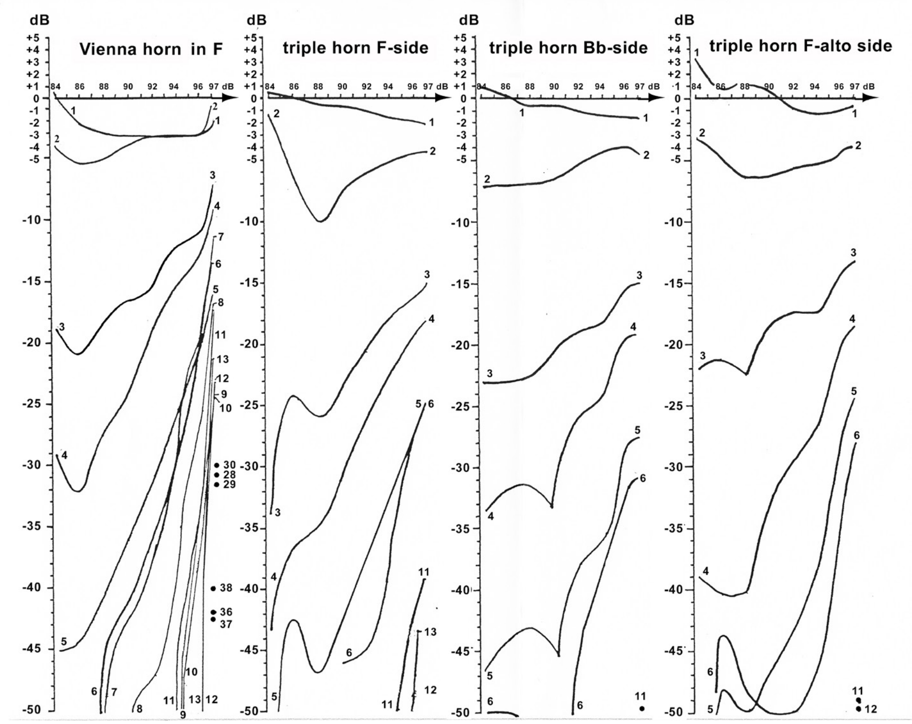

Figure 12: Horizontal axis: increasing sound level of a crescendo progress in dB (84–97 dB). Vertical axis: intensity of the partials in dB. Numbered wavy lines: normalized increase for each partial separately during the crescendo. Example: 1 = fundamental or first partial of the sound spectrum, 3 = third partial, etc.

What is the reason for such a large difference in the spectrum dynamics? Looking at the two extremes, the Vienna horn and the F-alto horn, the most important difference is in tube length. The Vienna horn is twice as long the F-alto horn, and therefore theoretically needs a doubled input of energy. Second, the significantly narrower bore of the cylindrical section and the bell section of the Vienna horn causes significant higher friction losses and thus requires a higher energy input to achieve a comparable SPL. Generally, in order to obtain the same SPL, the Vienna horn needs a significantly higher energy input by the player than a double or triple horn. From the physical point of view, this means that the player has to provide an increased amount of air compared to the other horn types. This requires a closer look at the player's lips during a "crescendo."

The upper part of Figure 13 (left) shows ~~4~~ four cycles of the opening and closing of the lips over the time on the x-axis. The y-axis indicates the area of the lip opening over time, which determines the amount of air pushed into the mouthpiece cup. It can be seen that the increase and decrease of the open lip area (and the amount of air thereby connected) has a somewhat sinusoidal shape. If an FFT is done on such a curve, the result will be a sound spectrum that looks like the one shown in Figure 13 (upper part, right side). If the player increases the lung pressure, the pressure in the oral cavity rises as well and induces a larger open lip area, which means that during the same time span more air enters the mouthpiece cup (=higher energy input). This works only to a certain extent, because the lip opening is limited by the mouthpiece rim. If the maximum has already been reached and the player nevertheless increases the lung pressure, a self-adjusting process starts that no longer can be controlled by the player himself: the phase of the lip opening and closing becomes extremely abrupt and thus the maximal opening is extended without any change in the frequency (Figure 13, lower part, left).This increases the amount of air pushed into the mouthpiece beyond the limit set by the mouthpiece rim without any change of the frequency. In this case, the shape is similar to the well-known rectangular curve, which contains many harmonics (lower part, right).

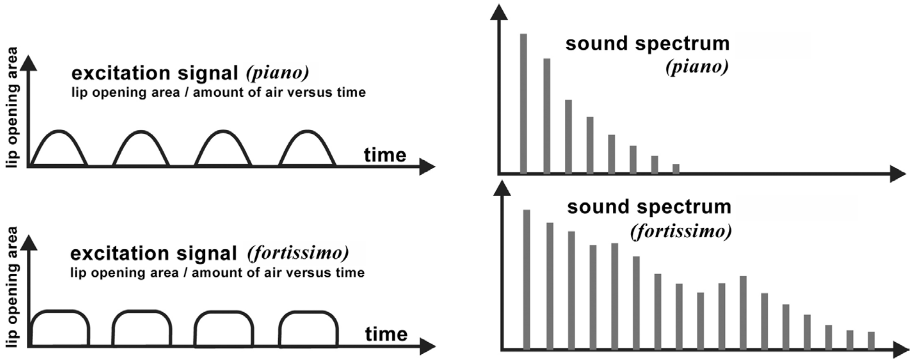

Figure 13: Shape of the lip opening area and its influence on the production of higher harmonics.

` This phenomenon is proved by high-speed video recordings of lip motion, and every professional brass player feels exactly the point when the process described above begins. It is clear that when using a Vienna horn with its higher energy demand, this critical point is reached at a lower sound level than with the B♭ side of a double horn, for example.

In this context, mention should be made of the discussion of the "shock waves" that occur at high pressure levels and create many harmonics. Shock waves were discovered by the music acoustics community around the turn of the century, when simulations indicated their existence in trumpets, trombones, and horns. As their existence in brass instruments was measurable, it tempted some who do not play a brass instrument professionally to regard them as the cause of the "brassy" sound. This is a misapprehension. Experiments and a number of serious papers have shown that such shock waves abruptly disappear outside the instrument and are not perceived by the audience due to the masking effects of the much stronger components of the lip-generated frequencies.

An experiment that proved the insignificant contribution of shock waves to the spectrum dynamics of brass instruments was done by the author in the early 1980s, but unfortunately it is not documented. Additionally, a central device of the experiments, a special kind of an artificial player that acts like a siren and was built according to a concept developed by Klaus Wogram, is not available anymore.

Summary

The typical Viennese style of horn playing can be seen as a consequence of the instrument itself, as well as of a musical taste transmitted from generation to generation, combined with the musician's own personality.

1. Vienna horns are characterized by a more distinctive "spectrum dynamic." The player is in a better position to affect the tone color. On the whole, the player has at her/his disposal a greater palette of possible tone colors than with the double or triple horn.

2. The Vienna horn sound is fundamentally richer in partials (except when it is played softly), while the volume of sound produced is somewhat less. For these reasons, Vienna horns playing *fortissimo* are less likely than double horns to "cover up" other instruments (such as the violins in Bruckner's symphonies).

3. In contrast, the "energy requirement" is (mostly) somewhat greater, as is also the need for a more exact adjustment of lip tension in the upper register in order to avoid "cracked" notes.

4. The positioning and the mechanical properties of the valve mechanism in the Vienna horn enable the player to influence consciously the timing and tonal quality of a legato slur. A smooth, glissando-like merging of notes is facilitated by the position of the valves. But in passages of very fast notes ("runs") the separation of individual notes is less easily perceived by the listener.

5. The Vienna horn gives the player a greater range of possibilities for musical articulation. In sustained notes the sound quality is fundamentally richer in partials. In moving from one note to the next the player has better control over slow procedures, such as slurs, though rapid passages tend to expose an inherent sluggishness (tube length!). This has to be counteracted by increased concentration and energy input on the part of the player.

Gregor Widholm (born 1948) is Professor emeritus at the department "Music Acoustics – Wiener Klangstil," which he founded in 1980 at the University of Music and Performing Arts, Vienna. As member (2nd horn) of the orchestra of the "Vienna Volksoper" 1971–2007 he took part in some 5,000 opera performances, concerts, and recordings all over the world. His scientific work includes research on the acoustic properties of the typical Viennese instruments and the playing tradition as well as the development of digital methods for optimizing musical instruments and investigations on the control loop player-instrument. He is President of the Austrian Acoustics Association and acts as lecturer and keynote speaker at international scientific congresses all over the world. The New York Times *named him "veritable Mr. Wizard for musicians."*

Notes

[1] In the majority of Austria's top orchestras, the Vienna horn is used exclusively for day-to-day playing: Wiener Philharmoniker, Wiener Symphoniker, NOE Tonkünstler Orchester, Orchester der Wiener Staatsoper, Orchester der Wiener Volksoper, Grazer Philharmonisches Orchester, Bruckner Orchester Linz, and to a certain extent the ORF Symphonieorchester.

[2] http://iwk.mdw.ac.at/?page_id=87&sprache=2&Semester=&showabstract=&url_ex=&art=&ma_id=&Cat=