TIMPANI-HORN INTERACTIONS AT THE PLAYER'S LIPS

Jer-Ming Chen **John Smith** **Joe Wolfe**
School of Physics, The University of New South Wales, Sydney
jerming@unsw.edu.au john.smith@unsw.edu.au j.wolfe@unsw.edu.au

ABSTRACT

This study investigates the observation by some horn players that a timpani sounding nearby can interfere with their playing. By determining the horn's transfer function and measuring the pressure response in the bell and mouthpiece during moderate to loud timpani strokes, the horn is found to behave as an acoustic impedance-matching device capable of transmitting an overall impulse gain response of at least ~16 dB from the bell to the mouthpiece, while some non-linear propagation in the bore is also observed. Further resonance interactions between the bore of the horn and the timpani stroke show gain responses of up to ~26 dB, which depend on the timpani's tuning. Lastly, pressure measurements in the mouthpiece made during horn playing show that timpani strokes played near the bell can affect the amplitude, periodicity and frequency of the pressure signal generated at the horn player's lips, and may be large enough to perturb the player's musical performance.

1. INTRODUCTION

The function of the bell of a horn is well known: it is an impedance matcher. When the horn is played, the bell efficiently radiates high frequencies outwards, and so contributes to the instrument's characteristic timbre. In the inwards direction, however, the bell is expected to increase the pressure amplitude of waves travelling into the horn from outside the bell. This property may explain the observation by orchestral horn players and teachers [1, 2, 3] that, when the horn and the timpani play in close proximity, and especially when the bell of the horn faces the timpani, there is a tendency for timpani strokes to interfere disruptively with horn playing.

The celebrated horn player, composer, conductor and jazz musician Gunther Schuller (b. 1925) writes: "The timpani's spreading wave-lengths back up through the horn, violently jarring the player's lips. Under these conditions split notes abound and what notes can be played develop a strong rasp. A half minute of this and the horn player will retain no sensitivity in his lips." [1]

The scope and explanation of this phenomenon remains an active source of discussion amongst horn players and teachers (*e.g.* online horn forums [4]) but, to the authors' knowledge, there have been no acoustical studies on this matter so far.

Accordingly, this paper reports preliminary measurements of the pressure measured in the mouthpiece of the horn in response to external sounds (either timpani strokes or sustained broadband excitation) applied outside the bell of the horn.

2. MATERIALS AND METHODS

Three experimental setups were used to make the measurements in this study.

2.1 Measurement of Horn Transfer Function

In a room treated to reduce external noise and reverberation, a Yamaha YHR-664 double horn is suspended over a loudspeaker, such that its bell faces the loudspeaker coaxially with a separation of one bell radius.

The transfer function of the horn is usually measured from mouthpiece to bell. Here, it is measured from bell to mouthpiece using a source at the bell. Two ¼-inch pressure-field microphones (Brüel & Kjær 4944A) are used: one is positioned at the plane of the bell, near the centre, while the second is fitted into a specially modified horn mouthpiece which enables the microphone to measure the pressure at the mouthpiece via a 1 mm vent drilled into the cup. The mouthpiece, with the microphone attached, is sealed and isolated from the external radiation field using a specially fitted nylon cap.

A broadband probe signal (25-1000 Hz, at 2.7 Hz intervals) is produced by the loudspeaker. The pressure spectrum of this broadband probe signal was 'flattened' with respect to the microphone situated at the plane of the bell, using the software ACUZ [5]. The resulting FFT of the two microphone signals are then time-averaged and divided to yield the horn transfer function.

Measurements were made for both F and B♭ horns for the fingerings 000, 0X0, X00 and XX0, where X means depressed for index, middle and ring fingers respectively.

2.2 Impulse Measurement Using Timpani Strokes

In the same room, the same horn (with the same microphones located at the bell and mouthpiece) is now suspended over a single timpani (26" drum, Evans USA, nominal sounding range F2-E3), such that its bell faces the drum skin coaxially with a separation of one bell radius. The horn transfer function from bell to mouthpiece is not simply related to that from mouthpiece to bell.

Nevertheless, the peaks in the transfer function measured here correspond approximately to the sounding frequencies of the horn.

For the 000 fingering on the F horn:

- 2nd resonance, 86.1 Hz (F2-23 cents)
- 3rd resonance, 131.9 Hz (C3+14 cents)
- minimum between the 2nd and 3rd resonance, 107.7 Hz (A2-37 cents)

For the 000 fingering on the B♭ horn:

- 2nd resonance, 118.4 Hz (A#2+27 cents)
- minimum between the 2nd and 3rd resonance, 145.3 Hz (D3-18 cents)
- the 3rd resonance occurred above the range of the timpani and so was not measured

To investigate the effect of a timpani tuned close to horn resonances, the timpani was tuned over a range of pitches deviating up to ±100 cents from the above frequencies, and struck at dynamic levels ranging from *mp* to *mf*. The resulting pressure signals at the bell and in the mouthpiece were then recorded by the two microphones, and analysed.

For reproducibility, these measurements were made without a hand in the bell.

2.3 Timpani Strokes During Horn Playing

The horn remains positioned as before with the cap removed from the mouthpiece so the instrument can be played, but without the hand in the bell. Greater sound pressure levels are now expected in the mouthpiece, and consequently the mouthpiece microphone is relaced by a piezoresistive pressure transducer (Endevco 8507c-2). While the player plays sustained, steady notes at the horn resonances identified earlier (sounding F2, C3 and B♭2, but written C3, G3 and F3 respectively for the horn in F) at *p* and *mf* dynamic levels, the timpani (tuned to these notes, and also tuned to ±70 cents) is struck at dynamic levels ranging from *mf* to *ff*, while the pressure in the mouthpiece is recorded and analysed.

Lastly, an 'ecological' measurement is made while the horn player plays sitting in the normal concert position, hand in the bell in the usual position, with the bell pointing at the timpani, struck 1 meter away.

3. RESULTS AND DISCUSSION

3.1 Transfer Function Measurements

The acoustic transfer functions measured for the 000 fingering on the F and B♭ horn are shown in Figure 1.

In both plots, the overall transmission gain from bell to mouthpiece increases steadily with frequency, and local maxima indicate resonances of the horn. For the 000 fingering on the F horn, the second resonance has a gain of 20 dB, rising steadily to 27 dB by the sixth resonance. For the B♭ horn with 000 fingering, the second resonance has a gain of 23 dB, and rises to 28 dB at the sixth resonance. (The first resonance in the horn is below the pedal note and is not played.) A comparable gain profile is observed for the transfer functions of other fingerings measured.

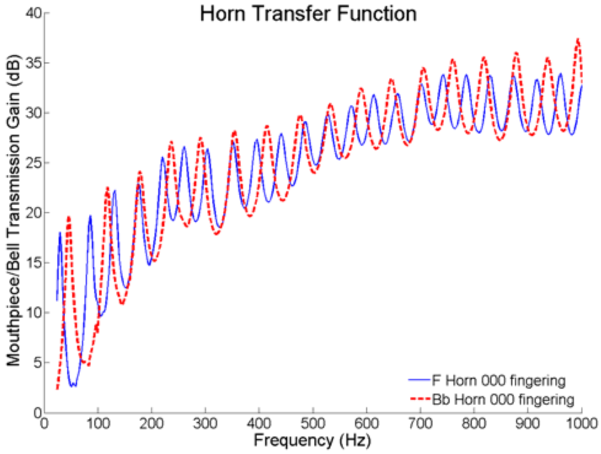

Figure 1. Bell-to-mouthpiece horn transfer function measured for the 000 fingering on the F and B♭ horn.

3.2 Impulse Measurements Using Timpani Strokes

Figure 2 shows a typical pressure pulse waveform of a timpani stroke, measured in the bell (top) and in the mouthpiece (bottom), both shown on the same scale. In this example, the timpani is tuned nominally to A2+25 cents and the 000 fingering on the B♭ horn is used.

Here, the pressure pulse arriving at the mouthpiece arrives 8 ms after the pulse enters the bell, consistent with the ~2.75 m length of the B♭ horn. The largest trough of the pressure signal in the mouthpiece exceeds that in the bell by 17 dB. Similarly, the first pressure peak arriving at the mouthpiece exceeds that in the bell by 16 dB. The initial trough and peak at the bell and mouthpiece are comparable in shape but the subsequent pressure signal received in the mouthpiece is noticeably different from that measured at the bell, because of the standing waves produced in the bore.

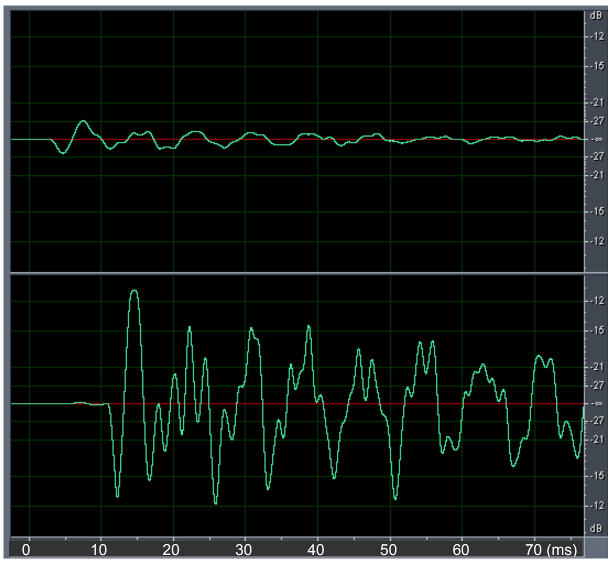

Figure 2. Typical waveforms of the pressure pulse of a timpani stroke, nominally tuned A2+25 cents, measured in the bell (top) and in the mouthpiece (bottom) for the B♭ horn 000 fingering, shown on the same scale and measured using equal microphone amplifier gains.

Impulse gain values measured for F Horn 000 fingering (dB)

2nd resonance (R2)		3rd resonance (R3)		Trough
R2-32 cents	14.8±2.7	R3-134 cents	15.6±1.8	**16.0±1.0**
R2-22 cents	15.6±2.0	R3-104 cents	16.9±1.1	
R2+02 cents	15.4±2.5	R3-74 cents	16.5±1.3	
R2+13 cents	16.0±2.7	R3-34 cents	16.8±1.3	
R2+38 cents	16.3±1.9	R3-04 cents	15.9±1.2	
R2+58 cents	16.1±1.7	R3+21 cents	16.0±0.7	
R2+88 cents	16.2±3.1	R3+46 cents	16.2±1.0	
(Average	**15.8±0.6)**	R3+76 cents	15.5±1.5	
		R3+106 cents	16.7±1.3	
		(Average	**16.2±0.5)**	

Impulse gain values measured for Bb Horn 000 fingering (dB)

2nd resonance (R2)		Trough	
R2-102 cents	17.2±1.0	-98 cents	17.7±0.8
R2-52 cents	17.3±1.0	+02 cents	17.2±0.8
R2-02 cents	17.4±0.7	+102 cents	17.7±0.6
R2+03 cents	17.3±1.1	**(Average**	**17.5±0.3)**
R2+48 cents	18.0±0.8		
R2+98 cents	17.7±0.7		
(Average	**17.5±0.3)**		

Table 1. The gain values (average ± standard deviation) of the pressure impulse (initial trough & peak) extracted for each timpani stroke, measured at a range of timpani pitches tuned near a corresponding peak (resonance) and trough of the measured horn transfer function.

The averaged impulse gain values of the initial trough and peak in the pressure signal, extracted for each timpani stroke and played at a range of timpani tunings, are collated for the 000 fingering on the F and B♭ horn and tabulated in Table 1.

For each fingering, the impulse gain values obtained are fairly consistent in magnitude and are only weakly dependent on the frequency difference between the timpani note and the horn resonance: a consistent gain of ~16 dB for the F horn 000 fingering, while the B♭ horn 000 fingering (which has a shorter pipe and hence less attenuation) shows a higher gain of ~18 dB. On a time scale too short for reflections, resonances are irrelevant and the horn acts as an acoustic impedance-matching transformer for the external pressure impulse from the struck timpani. For pressure amplitudes up to the linear limit, which at this separation corresponds to timpani notes up to *mf*, this gain is approximately independent of the magnitude of the pressure pulse.

Pressure pulses exceeding ~1 kPa (~150 dB) are sometimes measured in the mouthpiece if the external impulse signal at the bell is of the order of 100 Pa (~130 dB) or greater. At these larger amplitudes (strokes > *mf*), the pressure pulse is observed to arrive at the mouthpiece with somewhat larger gain and an altered shape, *e.g.* for the F horn 000 fingering, peaks arrive 5% (0.6 ms) sooner than the trough, on average. This is consistent with the effects of nonlinear propagation in the bore, which are expected to be noticeable at this sound level because of the relatively long distance travelled in the narrow bore [6].

For the initial impulse, there is no dependence on the relative tuning of timpani and horn. In the later response, once the energy transmitted from the timpani sets up standing waves in the bore of the horn, we should expect to see the effects of such tuning. Figure 3 shows two contrasting timpani strokes both measured using the B♭ horn 000 fingering: one is tuned to the second horn resonance, and the other is tuned to the transfer function minimum between the second and third resonances.

In both strokes, the large-amplitude aperiodic transient of the timpani signal at the bell lasts about 0.1 s and is followed by a quasi-periodic slow decay. During this quasi-periodic mode, we can observe the effects of resonance in the case where the timpani is tuned to the horn resonance. The envelope of the signal measured at the bell, which is largely due to the signal produced by the timpani, decays almost monotonically. In the mouthpiece signal, however, the amplitude of the quasi-periodic signal rises smoothly from about 0.13 to 0.3 s, as more energy from the timpani is gradually stored in the standing wave in the bore. This peaks at a gain of about 26 dB, and remains near that level until about 0.5 s. In contrast, the stroke tuned away from the horn resonance receives no 'help' from the horn resonance and thus has no boost observed in the mouthpiece signal; its decay envelope is comparable with that measured at the bell.

In a large majority of orchestral scores, the timpani play the tonic (or less commonly the fifth) of the chord, which is also played by the horns. In very many cases, therefore, one or more of the horns would be using a fingering in

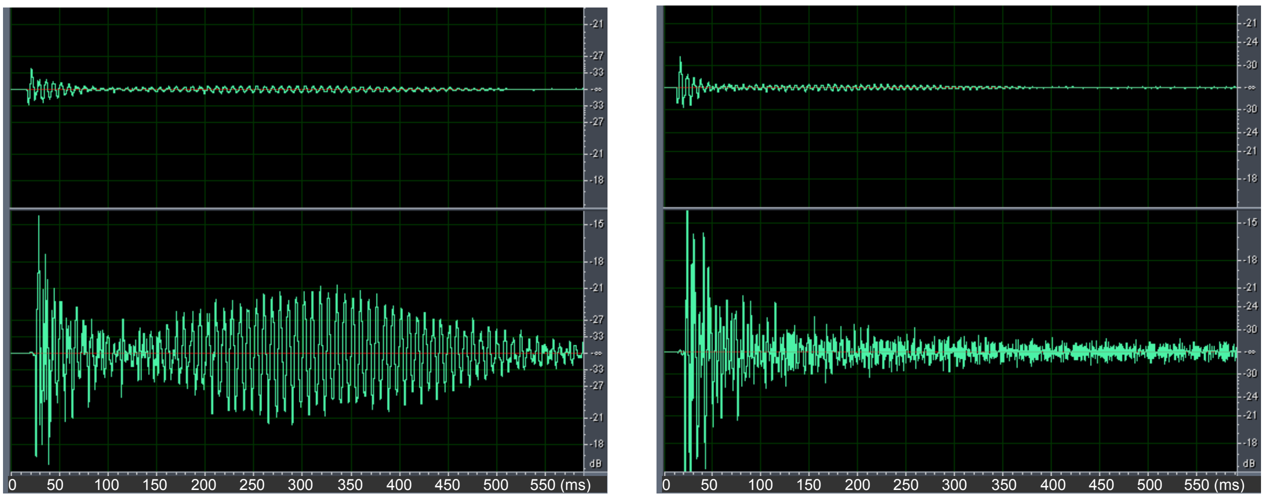

Figure 3. Two contrasting timpani strokes, measured using the B♭ horn 000 fingering, showing the microphone signal at the bell (top) and in the mouthpiece (bottom), on the same scale. *Left*: timpani tuned to A#2+25 cents to coincide with the 2nd horn resonance. *Right*: timpani tuned to D3-20 cents to coincide with the transfer function minimum between the 2nd and 3rd resonance.

which one of the resonances of the horn would be tuned close to the frequency of the timpani note.

This poses two difficulties for the horn player. First, s/he will receive a large transient, produced by the timpani, and arriving at the lips during or at best soon after the transient of the horn note. Even in the absence of the timpani, this starting transient can already be hard for the player to play cleanly, because the first several or more vibrations of the lips must be produced before the reflection from the bell has produced standing waves that stabilise the vibrations of the lips. Second, the timpani sets up a slowly increasing periodic wave that adds to the standing wave produced by the player and potentially interferes with the motion of the lips.

3.3 Timpani Strokes During Horn Playing

In many cases, the pressure impulse signal from the timpani stroke can be easily observed in the mouthpiece during horn playing at both the *p* and *mf* dynamic levels measured (~152 dB and ~158 dB respectively, measured in the mouthpiece): the arrival of the timpani stroke is indicated by a region of large-amplitude aperiodic transients (up to ~6 dB larger than the quiescent lip pressure signal) lasting several lip pressure cycles (~50 ms); alternatively, the pressure pulse might arrive at exactly the right moment to destructively interfere with and to reduce the lip pressure signal for several cycles (up to ~6 dB less than the quiescent lip pressure signal). Further, if the timpani plays at a frequency close to a horn resonance, as would often be the case, resonance-driven interactions in the horn's bore (similar to that reported earlier in §3.2) sometimes persist up to 0.5 s.

Figure 4 shows an example of a measurement made of a horn player playing at the *p* dynamic level (149 dB in the mouthpiece here), sitting in the normal concert position with his hand in the bell and the bell pointing at the timpani, which is struck 1 meter away.

Here, the pressure signal (playing at A#2+20 cents) generated by the player's lips (bottom) is quasi-periodic (quiescent) up until the arrival of the timpani stroke (seen 8 ms beforehand in the top signal, measured at the bell) where it becomes disrupted: strong irregular transients are observed in the first 50 ms (reaching 4.5 dB above the quiescent lip pressure signal here), while irregularities of amplitude and structure persist in the lip signal up to 0.5 s before the lips resume quiescent vibration.

Other perturbations are also observed in this close proximity of instruments: the player's sounding pitch can sometimes become unstable immediately following a stroke, deviating by several cents, if the timpani is tuned close to the playing pitch. However, in some instances where the timpani was tuned ~80 cents flatter than the horn sounding pitch, the lip signal was pulled similarly ~80 cents flatter for up to 0.5 s following the stroke.

A related disruptive effect is sometimes also reported when horn players are seated closely together and playing a high passage at a loud dynamic level in unison (a fairly common occurrence in an orchestral climax). Under these conditions, it is sometimes reported to be difficult for the players to sustain the notes [1]. The relative phase between the waves produced by a player and his/her neighbours has no predictable relationship, therefore potentially disruptive interference might also be possible here.

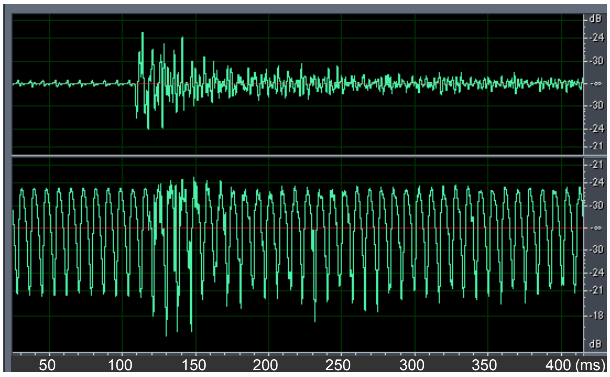

Figure 4. A typical waveform of the pressure pulse of a timpani stroke during horn playing, both sounding A#2+20 cents, measured in the bell (top) and in the mouthpiece (bottom) on the B♭ horn 000 fingering. The horn is played softly in the normal concert position (hand in the bell), with the bell pointing at the timpani, struck 1 m away. The microphones have different gains.

4. CONCLUSIONS

Transfer function measurements of the horn at various fingerings show gains of at least ~20 dB between the periodic pressure signal input at the bell and the signal which is transmitted to the mouthpiece.

Measurements of timpani strokes made near the horn reveal an overall impulse gain response of at least ~16 dB, because the horn is behaving as an acoustic impedance-matching receiver in this case. However, when the timpani is also tuned near a resonance in the horn, as would normally be the case in orchestral performance, a dramatic gain of ~26 dB can be observed once the timpani signal excites standing waves in the bore. Further, evidence of nonlinear wave propagation in the horn has been observed, allowing even greater transmission to the mouthpiece if the external impulse signal at the bell is of the order of 100 Pa or greater.

Pressure measurements in the mouthpiece made during horn playing show that both the large-amplitude aperiodic transient and the quasi-periodic decay of the timpani stroke can interact with the pressure signal from the horn player's lips to affect its amplitude (both constructively and destructively), periodicity and frequency. This interaction may be large enough to interfere with the player's control of his/her lips during musical performance.

Acknowledgments

We thank the Australian Research Council for support, our volunteer horn player and Emery Schubert for loan of his instruments.

5. REFERENCES

[1] G. Schuller, *Horn Technique*, Oxford University Press, 1962, pp. 83-84.

[2] Douglas Hill, *Collected Thoughts: On Teaching and Learning, Creativity, and Horn Performance*, Warner Bros Publications, 2001, p. 71.

[3] Martin Buckle, “The Horn and the Alphorn”, Website http://www.martinatnewton.com/page4.htm (last altered/updated on 23 March 2013).

[4] Yahoo Groups Horn Forum: http://launch.groups.yahoo.com/group/horn/message/58568 (last altered/updated 12 Feb 2012).

[5] J.R. Smith, N. Henrich, and J. Wolfe, “The acoustic impedance of the Bœhm flute: standard and some non-standard fingerings,” in *Proc. Inst. Acoustics*, 1997, vol. 19, pp. 315–320.

[6] A. Hirschberg, J. Gilbert, R. Msallam, and A.P.J. Wijnands, “Shock waves in trombones,” *J. Acoust. Soc. Am.*, 1997, vol. 99(3), pp. 1754–1758.