Experimental study of the influence of the clarinettist’s vocal tract

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This study investigates acoustical features of the vocal tracts of clarinettists, and how these features influence the frequency of the note played, its spectrum and the mouth pressure required to initiate the note. In a widely used physical model of the clarinet, a single resonator (the clarinet) is coupled non-linearly to the control oscillator (the reed). In this study, the effects of another resonator, the vocal tract (VT) are investigated. The acoustical impedances of the two resonators appear in series as a load on the reed.
From the measurements made of the impedance spectra of the VT of twenty players, two very different configurations, described by clarinettists as "ee" and "aw", were chosen for theoretical, numerical and experimental simulations. Experiments were then conducted using a blowing machine with an artificial VT. Threshold pressures, playing frequencies, spectra and transition transients were measured. The configurations ’ee’ and ’aw’ were compared for notes in different registers and for some difficult slurs. They show interesting results. In the low register, the spectral envelope, but not the playing frequency, depend strongly on the tract configuration. The difference is larger for high notes, where different mouth shapes can result in the production of different notes. An appropriate VT configuration can also make some notes start more easily (ie with shorter transients) and facilitate slurs, in good agreement with the opinion of clarinettists.

1 Introduction

Previous experimental studies on the influence of the musician’s vocal tract (Clinch [1], Benade [2], Hoekje [3], Sommerfeldt and Strong [4]) have been limited by the absence of completely quantitative measurements of the acoustical properties of the vocal tracts of players. Mooney [5] designed an artificial blowing machine based on X-rays images of musicians taken when playing and added a tongue, whose effect appeared to be important. However, the mouth cavity was not a realistic shape. Further there have been no previous attempts to use artificial playing systems to distinguish quantitatively the effects of different plausible model vocal tracts.

We have recently developed such a player (see section 3). The vocal tract is made from an area function with finite elements. The function is determined by the inversion of measurements of the impedance spectra of the vocal tracts of clarinettists (see section 2).

This artificial player allowed us to conduct a series of experiments to quantify the effects of two different configurations on the spectrum, the playing frequency and transients of a range of notes. The results are given in section 4.

Briefly, a simple model of the operation of the clarinet is as follows. The reed is modelled as an oscillator with one degree of freedom. Assuming that the air flowing in the narrow channel that passes the reed dissipates all its kinetic energy in turbulence, then the air flow into the instrument is related to the pressure difference across it by Bernoulli’s equation. The acoustic or time varying component of the pressure equals the flow times the series combination of the acoustic impedances of the instrument bore and of the vocal tract [2]. (Analytically, these two effects are usually modelled respectively in the time and frequency domains.)

2 The vocal tract of clarinettists

In previous studies of the vocal tract of clarinet players, X-rays images were used by Mooney [5] and Clinch et al.[1] but no area functions could not readily be deduced from these. Other researchers measured the input impedance (Hoekje[3], Wilson[6]). However, Hoekje did not measure the phase and Wilson measured the complex impedance under playing conditions but only at the discrete frequencies of the played spectrum.

We developed a measurement head that could be mounted in the mouthpiece of a clarinet at the position of the reed tip to measure the impedance spectrum Z(f) of the player. This allowed a player to blow and to mime realistically the configuration used when playing, a mime that professionals can perform reproducibly and reliably. Details are given in [7]. The main results are:

- The vocal tract impedance can be of same order as that of the clarinet.

- For normal playing, most musicians use a single, stable configuration throughout most of the instrument's range. However, this configuration varies considerably among musicians. Consequently, one can state that they do not tune one of the resonance frequencies of the vocal tract to the note played. Further, there is no "best configuration" to adopt for the highest sound quality.
- Clarinettists use different tract configurations for special effects, including the altissimo range.

Two extreme configurations were chosen for detailed study. Several of our clarinettist subjects referred to an "aw" configuration (large oral cavity, low tongue), which they used for lowering the pitch and "darkening" the sound and an "ee" configuration (palatal constriction, high tongue, close to the palate) for sharpening the pitch and "brightening" the sound. (With the lips closed around the mouthpiece, these configurations only approximately resemble those of the vowels for which they are named.) By mapping Z(f) to the area function of the vocal tract, two geometries were determined that yielded the two measured Z(f). These geometries, shown in Fig 1, were used in the tract of the artificial player (see section 3). Their Z(f), calculated numerically, are given on the right side of the same figure. We should note that discontinuities in the vocal tract may have aeroacoustical effects, but these are ignored here.

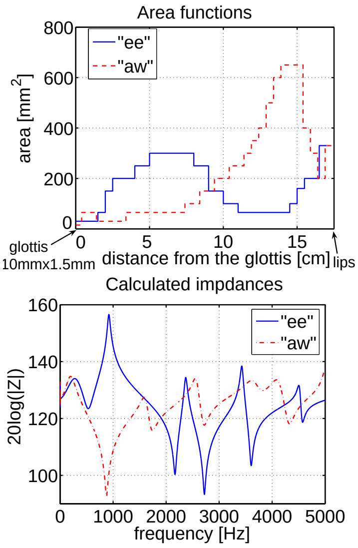


Figure 1: The two configurations "aw" and "ee" used in this study. Left: area functions. Right: Calculated impedances.

3 A blowing machine called MIAM

An artificial player with lungs and vocal tract was built at IRCAM. Full details are given in [8] and [9] so we point out here only those that are important for our study.

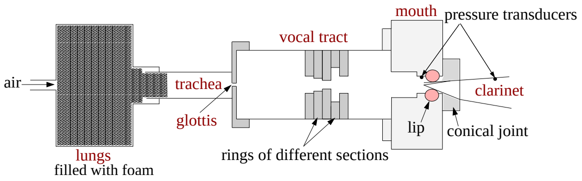


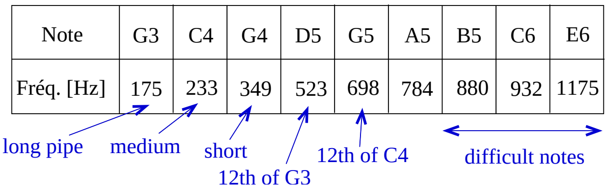
Figure 2: Scheme of the artificial player MIAM

The configurations of the vocal tract chosen for the experimental study are those described in section 2. The glottis was almost closed, i.e. as a slit of length 10mm and width 1.5mm according to Mukai's images [10].

A single reed, reed mounting and embouchure configuration (same lip pressure and lip position) were used for all results presented here. The artificial clarinet player was carefully set up by the Swiss concert soloist Pierre-André Taillard. The resulting sound is quite realistically that of a clarinettist, perhaps that of a competent debutant on the instrument. A recording of the world premiere of Mozart's clarinet concerto on an artificial blowing machine is available on the web [11].

4 Some results

The following fingerings were chosen to study different lengths of pipe, to contrast chalumeau and clarion registers, and to show notes that are difficult to play.



Note	G3	C4	G4	D5	G5	A5	B5	C6	E6
Fréq. [Hz]	175	233	349	523	698	784	880	932	1175

Figure 3: Notes that illustrate different features.

4.1 Effect on the playing frequency

4.1.1 In the chalumeau and clarion registers

Experimentation with the artificial player

We consider here the low/medium range of the clarinet. Recordings of the pressure in the barrel (on 500000 points with a sampling frequency of 48000 Hz, which allows a frequency resolution of 0.12 Hz) were made with a range of static mouth pressures, from the oscillation threshold to the extinction threshold. (For the benefit of non-clarinettists, extinction corresponds to blowing so hard that the reed closes the aperture of the instrument, which stops playing.) The playing frequency was calculated by FFT for each recording. Each measure was performed twice, for the two configurations “aw” and “ee”, the embouchure staying constant. Results are given in Figure 4.

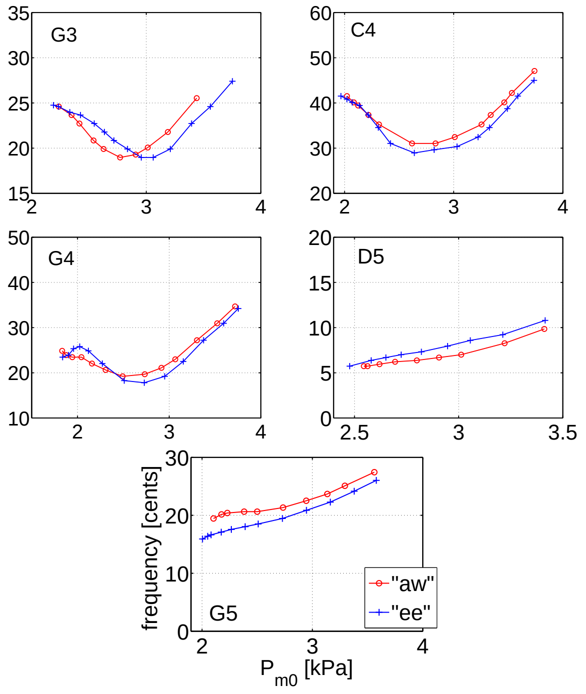


Figure 4: Difference in cents, for the notes G3, C4, G4, D5 and G5, between the playing frequency obtained with the artificial player and the corresponding reference frequency in the equal tempered scale (given in Figure 3) in function of the static mouth pressure P_{m0}, for the two vocal tract configurations “ee” and “aw”.

Comparison with a musician

We then recorded the pressure in the barrel when Pierre-André Taillard played the same clarinet, with his own mouthpiece and a reed mounted in the German style to reduce the influence of lip pressure. He tried to change his tract configuration from “ee” to “aw” without changing significantly the embouchure. Recordings were made in three steps, when Taillard blew successively harder from threshold (0) to extinction (2), (1) corresponding to an intermediate blowing pressure. Results are in Figure 5. This experiment compares qualitatively the dependence of playing frequency on pressure between a musician and an artificial player.

The same frequency scale is used in Figures 4 and 5, so we see that the “aw” configuration gives a lower frequency than the “ee” configuration for Taillard, but not for the artificial player. This may be due to differences between the geometries of the real and artificial players, or to unconscious changes in the embouchure of the former. Note, however, that in all cases the pitch difference in these ranges is modest, even for this large change in tract geometry.

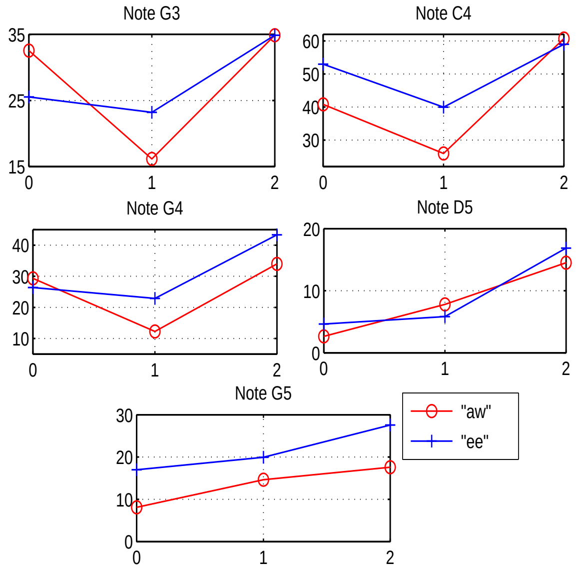


Figure 5: Difference in cents, for the notes G3, C4, G4, D5 and G5, between the playing frequency obtained by Taillard and the corresponding reference frequency in the equal tempered scale (given in Figure 3), for three regimes: oscillation threshold (0), extinction threshold (2) and an intermediate regime (1).

4.1.2 In the altissimo register

In agreement with the opinion of players, Figure 6 shows that the vocal tract configuration has considerably more influence in the altissimo register than in the lower registers. This can be easily explained by the fact that the peaks of the clarinet impedance are lower and more inharmonics in the altissimo register. Even the production of the note differs with configuration. For instance, the note C6 could only be obtained with the “aw” configuration whereas A5 could only be obtained with the configuration “ee”. For some other notes, such as B5 or E6, the playing frequency and the playing range are very different for “aw” and “ee”. Thus “aw” enlarges the range of playability for E6 but prevents a pure note production; instead there is a slight multiphonic: a weak buzzing note is heard at a resonance, a musical tenth below, that is weakened but not destroyed by opening the register key for this fingering [13].

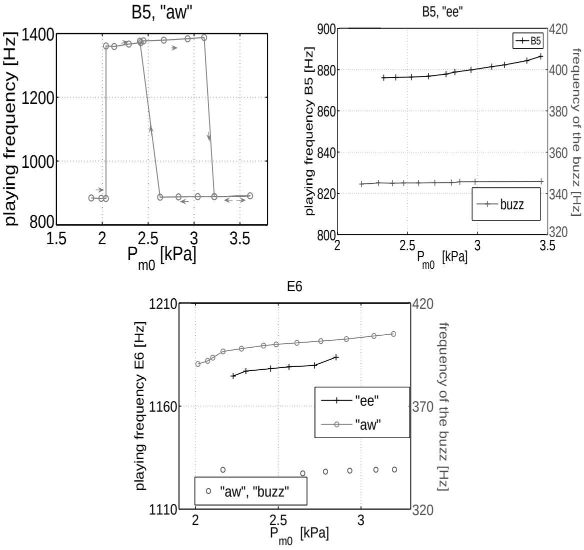


Figure 6: Playing frequencies for the notes B5 and E6.

4.2 Effect on the spectrum

The spectrum was recorded in the barrel. Figure 7 shows that, for the note A5, the configuration “ee” increases the magnitude of the third harmonic by a factor of 4 and the second harmonic by a factor of nearly 2. However, this change in the spectrum is not related to the impedance spectrum in a simple way. Near 2400 Hz, corresponding to the third harmonic, there is only a modest difference in the total impedance ($Z_m + Z_c$) between the two configurations. Measurements on other fingerings confirm this result: it is not easy to deduce qualitatively the effects on the spectrum just by looking at the graph of the total impedance. Nevertheless, this section shows that the effect on the spectrum can be important, *pace* Backus [12]. A comparison with numerical results with the software *Harmbal* [14] is in progress.

Figure 7 also shows that the range of playability varies between configurations: “ee” both lowers the oscillation threshold and increases the extinction threshold.

The effect on the spectrum was studied for the notes of figure 3: it was small for low notes but became substantial for notes above D5 (eg A5, described above).

4.3 Transitions

Clarinettists must not only produce notes with accurate intonation and appropriate timbre, but must arrive at this state rapidly. It is therefore interesting to study the transients with the artificial player.

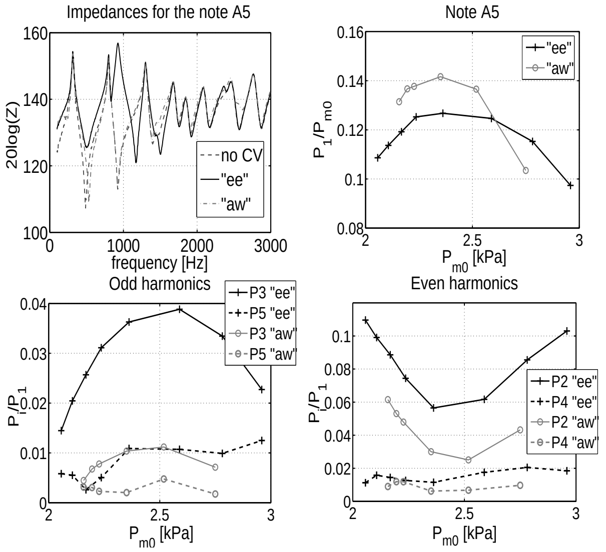


Figure 7: Left top corner: total impedance (clarinet (data from [13]) + vocal tract) for the fingering A5, for different configurations of the vocal tract. Other graphs: Evolution of the harmonics in the barrel, when P_{m0} increases.

For example, we show oscillograms for one slurred transition which is well known to be difficult: an octave jump between the clarion and chalumeau registers. Figures 8 9 and show that “ee” is better for the ascending transition C4 (238 Hz)- C5 (471 Hz) as it shortens the time to establish C5 whereas “aw” is better for the descending transition C5-C4 as “ee” does not allow to go back to C4 but favours its third harmonic (701 Hz). This effect was observed for other difficult transitions, in good agreement with the reported use of the “aw” and “ee” configurations by musicians.

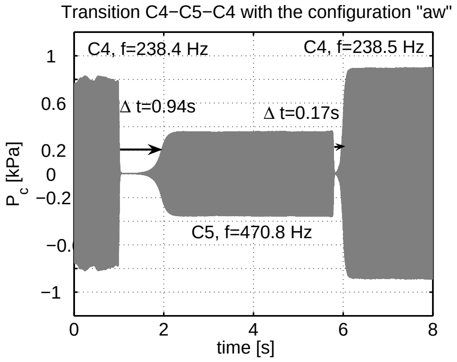


Figure 8: Transition C4-C5-C4 for the configuration “aw” recorded in the barrel with the artificial player, for a given static mouth pressure.

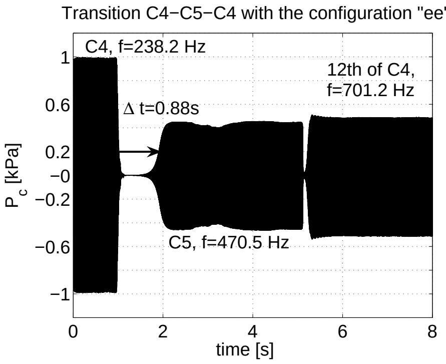


Figure 9: Transition C4-C5-C4 for the configuration “ee” recorded in the barrel with the artificial player, for the same static mouth pressure as for Figure 8.

5 Conclusion

This experimental study of the influence of the vocal tract on clarinet playing confirms the opinion of clarinettists: this influence can be large, particularly in the altissimo register. The advantage of the artificial player used in this study was to allow the independent investigation of the effect of changes of embouchure (including changes of the position and the force of the lip on the reed) and the effect on the geometry of the oral resonator. Human players cannot readily uncouple these: for instance,“aw” usually lowers the jaw and this may be the dominant effect on the pitch.

The influence of the vocal tract configuration on the pitch of notes was small in the low registers, but larger in the higher registers, where it led even to register transitions. Effects on the spectrum of different configurations were also enhanced in the higher range. However, no simple correlation was found between the vocal tract impedance spectrum and its effect on the sound.

Different configurations produced large differences in the transients of notes. In most cases, the experiments were in agreement with musician’s opinion, in particular that the “aw” aids descending leaps while “ee” aids ascents.

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