Tongue Control and Its Coordination with Blowing Pressure in Clarinet Playing

W. Li, A. Almeida, J. Smith and J. Wolfe
School of Physics, University of New South Wales, 2052 Sydney, Australia
weicong.li@student.unsw.edu.au

Articulation is one of the most important techniques of playing wind instruments, and it requires skilful control of the tongue. Clarinettists use their tongues in coordination with rapid mouth pressure changes to initiate transients. An expert player studied here produces accented and *sforzando* notes with the fastest increases in pressure, starting by releasing the tongue from the reed while the mouth pressure is low, and reaching the highest levels of mouth pressure. For *staccato* notes, the tongue was used to stop the reed vibration and thus the sound. For all others, decreasing mouth pressure terminated the note. An experiment using a playing machine investigated another use of the (mechanical) tongue under controlled conditions. Without using the tongue, the threshold mouth pressure at which notes begin with gradually rising mouth pressure is higher than that at which the notes cease under slowly falling pressures. For pressures lying in the hysteresis region between these two thresholds, transient displacement of the reed by the tongue initiates sustained notes.

1 Introduction

Musicians refer to the transients that begin and end a note as articulation, and regard good articulation as an important component of expressive and tasteful playing. On the clarinet and other reed instruments, starting a note after silence usually involves tonguing: briefly touching the reed with the tongue [1,2]. Controlling the time variation of the envelope of the sound pressure involves control of the pressure in the mouth. This paper investigates these two control parameters of articulation, and the coordination between them in clarinet playing.

Previous results from playing machines show that the region of parameters that produce a sound exhibits hysteresis. For example, consider an experiment in which mouth pressure is varied, all other parameters, including lip force, being held constant. The pressure at which a note starts when pressure is gradually increased is found to be greater than the pressure at which a note stops when pressure is gradually decreased. Similar hysteresis is observed on the high-pressure side of the playing regime and, in both cases, the range of pressures depends on the lip force [3,4,5]. A detailed report on this hysteresis and the role of the tongue will be presented at another conference [6].

Different articulations produce different amplitude envelopes. It appears likely that the times when the tongue touches and releases the reed, and their relation to the time variation of pressure in the mouth, could be important in determining the initial and final transients. To study this, measurements on human players are conducted using an instrument with a pressure sensor mounted on the mouthpiece so as to measure mouth pressure, microphones in the bore and near the bell to measure the bore pressure and radiated sound, and a sensor on the reed to determine the timing of tongue contact and release.

Players of reed instruments refer to a range of articulation classes. A smooth transition between the sound of two successive notes is called *legato* or slurring of notes. In *legato*, the player does not interrupt sound production using either the tongue or the flow of air. In *staccato*, clear gaps are left between notes, and reed instrument players usually use the tongue to start and often to stop the vibration of the reed, a process called tonguing. Other classes of articulation include *portato* (semi-*staccato* or slightly interrupted), *staccatissimo* (extreme *staccato*), accented and *marcato* (strongly accented); these are frequently used for different artistic effects.

In normal single tonguing, the tip of the tongue usually touches the reed. For rapid non-legato passages, some players use double tonguing, using the tongue in actions similar to the pronunciation of "te-ke". The tongue alternately touches the reed ("te") and the hard palate ("ke"), the latter interrupting the flow of air.

Mathematical models of single reed instruments with the tongue articulation have been published. That of Ducasse [7] includes blowing pressure, lip force and the tongue interaction with the reed. The tongue was modelled as a damped spring-mass system and the force it exerted on the reed could be varied. Sterling *et al.* [8] described how the tongue is used to interrupt the flow of air. In both, the mouth pressure and the tongue action are considered to operate independently.

Hoffman [9] used a saxophone mouthpiece equipped with a sensor of the pressure in the mouth and a reed fitted with a strain gauge. The results showed a damping effect of the tongue on the oscillating reed between two articulated tones and that the release of the tongue affects the transient of the output sound. Guillemain *et al.* [10] measured the mouth pressure, mouthpiece pressure and lip force while a saxophonist played a chromatic scale in the first and second register with a normal tongue attack. They found that the tongue's removal from the reed leads to a drop in the mouth pressure.

In this paper, the measurements investigate the action of the tongue, the blowing pressure, the barrel pressure and the radiated sound while the player is producing different kinds of articulation. Its aim is to study how tonguing and breath control are coordinated to achieve desirable transients. This is a pilot study using only one experienced player. A study comparing the techniques of different players is being conducted. A playing machine with an artificial tongue is also used to investigate, under controlled conditions, the use of the tongue to initiate notes at mouth pressures below the threshold at which pressure alone would initiate them.

2 Materials and methods

A Yamaha YCL 250 clarinet with a Yamaha CL-4C mouthpiece is used in this study, together with a Légère synthetic clarinet reed (hardness 3), chosen for its stability, hygiene and stable physical properties.

An Endevco 8507C-2 miniature pressure transducer of 2.42 mm diameter was fitted at one side of the mouthpiece for measuring the blowing pressure inside the player's mouth during playing (figure 1). A copper wire of 80 μm diameter is glued to the middle of the lower surface of the reed. One end of the wire is flush with the tip of the reed and the other end connects to a simple circuit (figure 2) using a 1.5 V battery. When the player's tongue touches or releases the reed, it also touches or releases one end of the wire and conducts a very small electrical current between the wire and the subject's body. This produces a voltage across a 40 MΩ resistor and is recorded via an optical isolator (to ensure that there is no electrical connection between the player and the apparatus). Players report that the presence of the wire increases the apparent hardness of the reed from 3 to approximately 3½, but that otherwise it played normally. (3 or 3½ are typical of reed hardness values used by 'classical' clarinetists.)

The normal barrel is replaced with a (transparent) plexiglass barrel with the same internal dimensions. A ¼-inch pressure-field microphone (Brüel & Kjær 4944A) is fitted into the wall of this barrel, 20.5 mm from the mouthpiece junction and records the pressure inside the bore via a hole of 1 mm diameter. Another microphone (Rode NT3) is positioned one bell radius from and on the axis of the bell of the clarinet to record the radiated sound.

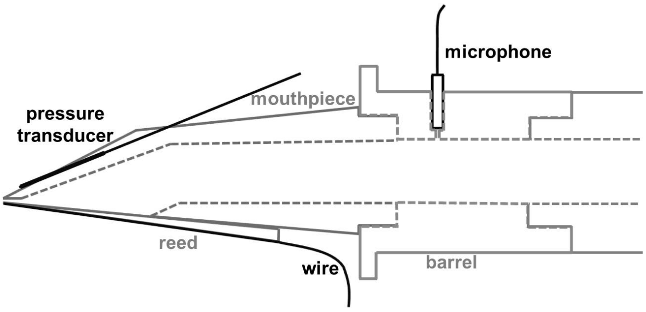

Figure 1: A schematic sketch (not to scale) of the mouthpiece and barrel used to measure tongue contact, mouth pressure (upstream) and barrel pressure (downstream).

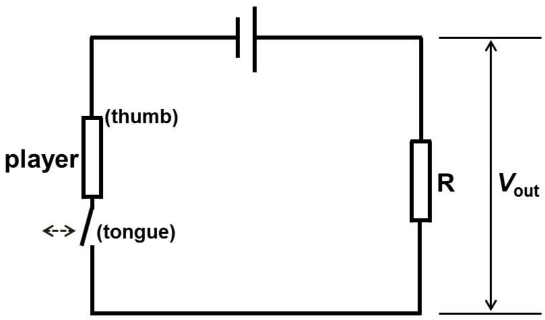

Figure 2: A circuit diagram shows how tongue contact with the reed is measured.

An expert clarinettist participated in the study. He has more than 12 years' experience, a bachelor's degree in performance and experience with recitals and chamber and orchestral music. Before the experiments began, the player was allowed to practise until he became accustomed to the clarinet, mouthpiece and reed. Then the player was asked to produce a series of notes (written C4, G4, C5, G5 and C6), each with different kinds of articulation: normal, accented, *sforzando* (*sfz*), *staccato* and starting as softly as possible, using the tongue, hereafter called minimal attack. The player was asked to play all notes with similar loudness (*mezzo-forte*) throughout the experiment. Tongue action, mouth pressure, barrel pressure and radiated sound are recorded simultaneously.

Another experiment investigated initiating notes in the hysteresis regime of the blowing pressure and lip force plane using an artificial tongue incorporated into an automated clarinet playing machine. The details of the playing machine are described elsewhere [4,6]. The hardness of the reed used in this experiment is 3.0.

3 Results and discussion

Each of the five articulations for each note was repeated 4 times for each of the five notes. The repetitions were highly reproducible, with variations in the peak mouth pressure of typically of about 0.5 to 5%, depending on the articulation. Figure 3 shows typical examples of the mouth pressure and barrel pressure when the player was playing the written C5 notes with different kinds of articulation, (a) normal, (b) accented, (c) *sfz*, (d) *staccato* and (e) minimal attack, using the tongue to start the note as softly as possible. In all the figures, the zero of the time axis is the moment when the tongue ceases contact with the reed. In the figure for *staccato*, the arrow shows the moment when the tongue touches the reed to stop the note – the only articulation for which this was done.

In all measurements, the acoustic component of the mouth pressure is much less than the DC component. The acoustic pressure in the mouth is also much less than that in the barrel. This can be explained using the model of Benade [11]: From continuity, the flow out of the mouth is close to that into the bore of the instrument. It follows that the ratio of mouth to mouthpiece acoustics pressures equals minus one times the ratio of their acoustic impedances. Usually, the magnitudes of the peaks in the mouth impedance spectra are about 10 or more times smaller than those of the bore impedance [12]. Further, if the player is not tuning the

Table 1: Peak value of the mouth pressure (P_{peak}), the values when the tongue releases (P_{tr}) and touches the reed (P_{tt}), time duration and average rate for the mouth pressure increasing from zero to P_{tr} and P_{peak} of different kinds of articulation for the written C5 note.

	P_{tr} (kPa)	P_{tt} (kPa)	P_{peak} (kPa)	t_1: P_0→ P_{tr} (s)	Rate (P_0→ P_{tr}) (kPa/s)	t_2: P_0→ P_{peak} (s)
normal	2.55±0.21	-	3.16±0.16	0.21±0.03	12.14±0.21	0.31±0.04
accented	2.43±0.29	-	4.16±0.04	0.16±0.02	15.19±0.29	0.36±0.03
sfz	1.91±0.40	-	4.32 ±0.09	0.13±0.02	14.69±0.40	0.33±0.07
staccato	2.25±0.09	2.17±0.22	3.39±0.02	0.17±0.02	13.24±0.09	0.27±0.02
minimal attack	1.77±0.25	-	2.50±0.07	0.23±0.01	7.70±0.25	0.46±0.12

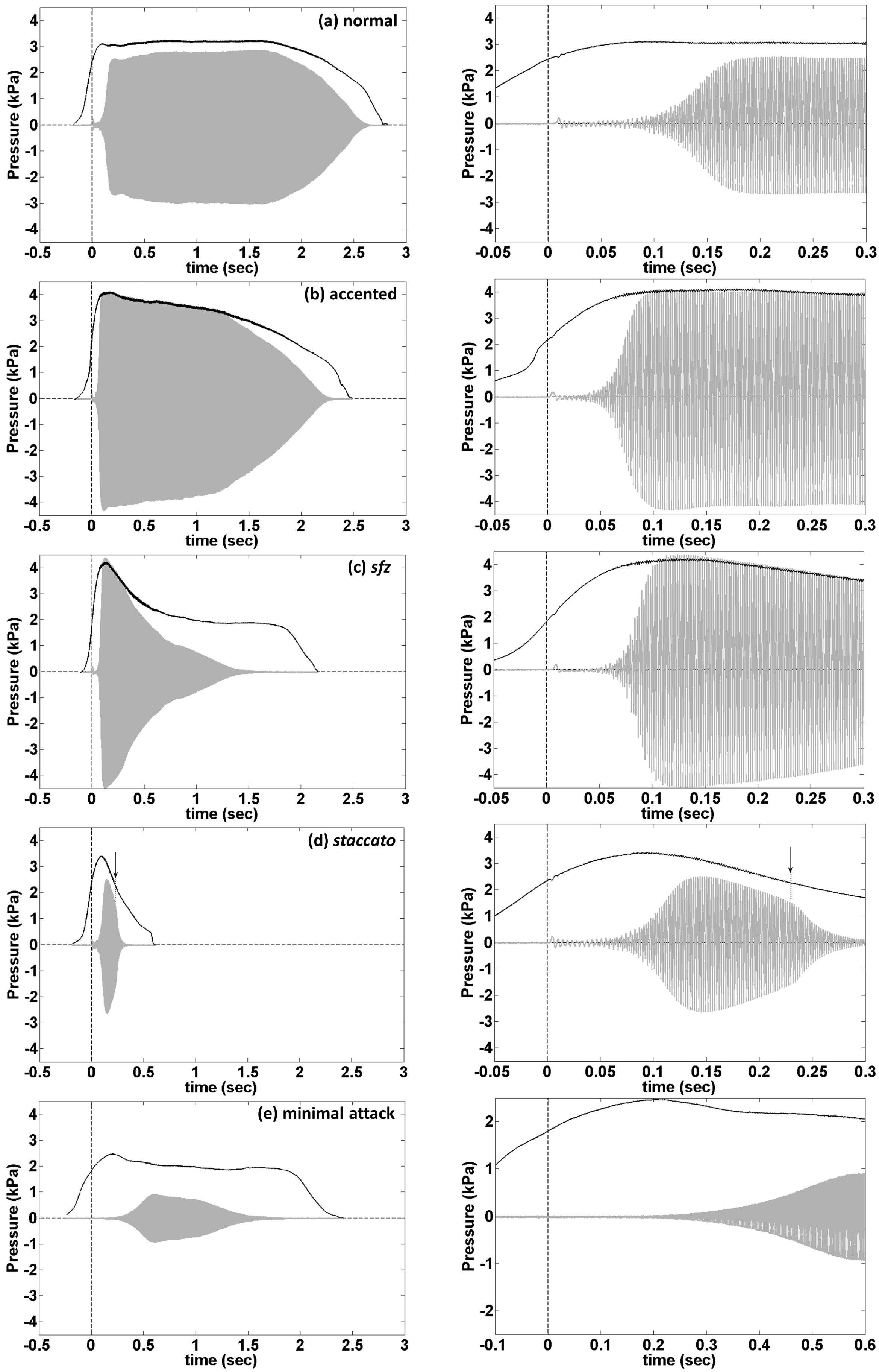

Figure 3: Mouth pressure (black) and barrel pressure (grey) of typical examples of different kinds of articulation for the written C5 notes and the attacks shown. Plots on the right show the starting transients for each articulation on an expanded time axis. In (d), the arrow shows the moment when the tongue touches the reed to stop the note.

vocal tract resonance, which is usually the case for normal playing, the frequency of the note played is not at a peak of the mouth impedance. Consequently, the magnitude ratio of mouth impedance to bore impedance is expected to be very much less than 10, as reported here.

The time course of the mouth pressure and barrel pressure of different kinds of articulation are compared in figure 3. Here we define the peak value of the mouth pressure as P_{peak}, the value when the tongue releases the reed as P_{tr}, and when the tongue first touches the reed as P_{tt}. These are compared in table 1.

For the normal note shown here, the mouth pressure increases to 2.44 kPa in 197 ms, at which time the tongue releases the reed. The mouth pressure continues increasing to 3.10 kPa and remains almost constant for about 1.5 seconds before gradually decreasing. The amplitude of the barrel pressure decreases while the mouth pressure decreases, and ceases when the mouth pressure decreases to about 1 kPa. For the simply accented note, the mouth pressure is increased more rapidly: it reaches a P_{tr} of 2.16 kPa value in 164 ms, and attains a peak of 4.11 kPa before decreasing. For the *staccato* note, P_{tr} is 2.34 kPa after a rise time of 183 ms. For this articulation only, the tongue touches the reed to stop the note (C5) shortly after the pressure decreases from the peak value of 3.40 kPa. The tongue remains out of contact with the reed for 230 ms.

Perhaps surprisingly, P_{tr} is about 1.80 kPa for both the *sfz* and minimal attack. However, the sound starts much later in the minimal attack. The explanation may be that, for the *sfz* note, the mouth pressure rises very rapidly to its peak value (P_{peak}), which is about twice that of the minimal attack note. After reaching the peak value, the profile of the mouth pressure for *sfz* and minimal attack notes also show similar features, *i.e.* the mouth pressure is decreased to about 2 kPa and maintained until the notes fade out.

The values of P_{tr}, P_{tt} and P_{peak} of different kinds of articulation for the written C5 note are shown in table 1. From the table we can see that the values of P_{tr} for normal, accented and *staccato* notes are comparable and larger than those of *sfz* and minimal attack notes.

This player stops the notes using the tongue to touch the reed when playing *staccato*, but stops the notes by decreasing the mouth pressure for all other articulations. Consequently, there are no P_{tt} values for normal, accented, *sfz* and minimal attack notes. The standard deviation of P_{tt} is larger than that of P_{tr} for *staccato*, indicating the coordination for stopping the notes may not be as important as that for starting the notes, or that the player has less control.

For the peak value of mouth pressure, the P_{peak} of *sfz* has the largest values, followed by that of accented, *staccato*, normal and minimal attack notes. In terms of the time duration for the mouth pressure increasing from zero to P_{tr} and P_{peak} (here defined as t_1 and t_2), accented, *sfz*, *staccato* and normal notes seem to have comparable t_1 and t_2 values, while minimal attack notes have the largest values. Thus, the average rate of increasing the mouth pressure for minimal attack notes is about half of that of accented notes. For *sfz*, *staccato* and normal notes, the average rate is slightly lower than that of the accented notes.

The average rate of increasing the mouth pressure for *staccato* notes is close to that for *sfz* notes. However, the standard deviation of P_{tr} for *staccato* notes is smaller than that for *sfz* notes, suggesting that playing *staccato* may require a better coordination between the tongue release and the variation in mouth pressure. For minimal attack notes, the average rate of varying the mouth pressure is lower than that for *staccato* notes, but the standard deviation is larger. Thus, the coordination for playing minimal attack may not be critical, or perhaps it is simply less called for and so less practised.

The results for the other 4 notes studied (C4, G4, G5, C6) generally present features that are qualitatively similar to those discussed above. We repeat that this is a pilot study on a single musician and caution should be used in extrapolating to other players. A study on a larger population is currently in progress.

The result of the experiment on the clarinet-playing machine presents another role of the tongue: initiating notes in the hysteresis regime of the mouth pressure and lip force plane. In figure 4, the sound level of the written C5 note is plotted against the mouth pressure at a constant lip force of 1.0 N. In one part of the experiment, the mouth pressure is gradually decreased (downward pointing triangles). In another part, it is gradually increased (upwards triangles). The oscillation thresholds for decreasing and increasing mouth pressures are about 2.2 and 2.5 kPa, respectively, as shown in the figure. The region between the two thresholds is the hysteresis regime where notes cannot be started spontaneously when increasing the mouth pressure only, so the sound level is equal to the background noise. The circles on the graph are from an experiment where the mouth pressure was maintained at a steady value, and the tongue initiated the notes. For these notes, the sound levels are close to those measured when decreasing the mouth pressure. This effect will be discussed in greater detail in a later paper [6].

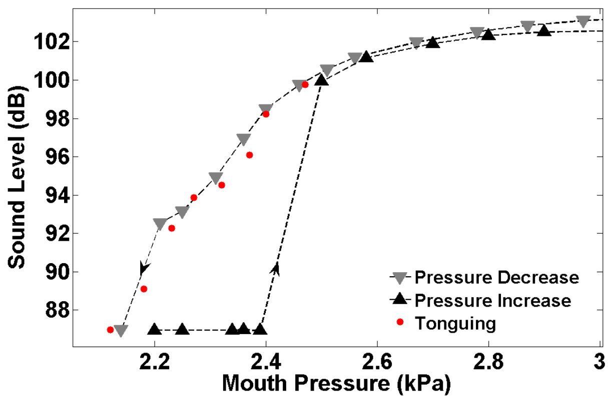

Figure 4: Measurements using a clarinet playing machine. The radiated sound level of the written C5 notes for a constant lip force of 1.0 N. They are plotted versus mouth pressure while mouth pressure is gradually decreased and increased (triangles). The circles show sound levels for steady pressures as indicated but with the tongue starting the notes.

Other factors not measured in this study may also be relevant for the attacks, including the detailed manner by which the tongue is released from the reed.

4 Conclusions

For the human subject involved in this study, the time course of the mouth pressure presents different features for different kinds of articulations: the P_{tr} values for *sfz* and minimal attack notes are smaller than those of normal, accented and *staccato* notes; the P_{peak} values of *sfz* and accented notes are larger than those of *staccato*, normal and minimal attack notes. However, *sfz* and accented notes have the fastest increases in pressure. *Staccato* notes are finished by using the tongue to stop the vibration of the reed while notes of other articulations are finished by decreasing mouth pressure. The standard deviations of P_{tr} may suggest a possible coordination between the tongue action and the variation of the blowing pressure controlled by the clarinet player. Besides its role in different articulations, the tongue can also assist in starting sustainable notes in the hysteresis region, where reed oscillation cannot be initiated by only increasing the mouth pressure.

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