



A pocket artificial buzzing system for the trumpet

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Abstract – Artificial playing systems are very useful tools to study musical instruments, to compare experiments with simulations, develop and validate new numerical models. Indeed, by replicating the action of the player, they allow some precise control over playing parameters, while making it possible to monitor physical quantities that can be quite difficult to record on human players. They may also find other applications such as quality control, music pedagogy, or artistic applications. In this article, we present an artificial buzzing system based on two silicone-type artificial lips that enables realistic trumpet sounds to be produced with minimal adjustments from the user. It is also compact and portable, which makes it potentially versatile for different applications.

Keywords: Musical acoustics, Brass instruments, Artificial lips, Acoustic measurements, Trumpet

1 Introduction

In order to study wind instruments and voice production in the laboratory, scientists have developed over the years mechanical systems that aim to reproduce the operation of a musician on a wind instrument. In brass instruments, where the lips of the player constitute the vibrating reed, such systems have been elaborated [1–7], sometimes co-inspired with experimental benches that reproduce the action of the vocal folds for the study of voice production [9]. These systems, referred to as “artificial blowing machines”, “artificial players”, “artificial mouths”, or “automatic playing apparatus”, have been used for different research applications in order to study the excitation mechanisms itself [10–12], or as a substitute to a human musician in order to study the sound produced by the instrument [3, 13, 14] or the vibroacoustic coupling induced by wall vibrations [7, 8]. They can also be used for musical applications, through the performance of actual robotized artificial players [25], or in the perspective of developing pedagogical or playing assistance tools for brass instruments [15, 16].

Despite the complexity of the human body, four fundamental elements are usually retained to build an artificial brass instrument player: an air supply that emulates the effect of the respiratory system of the player, an upstream cavity that represents the mouth cavity of the player, artificial teeth, and artificial lips. If in woodwinds the role of the lips is primarily to impose mechanical constraints on the reed and to guarantee an appropriate sealing around the mouthpiece, in brass instruments the reed consists of the lips of the player, and therefore behave as an oscillating

valve system. The reed in brass instruments thus involves an anatomical element, as in the case of voice production where phonation arises from the oscillation of the vocal folds. Moreover, it is now well known that in brass instruments, the production of a given register requires a resonance frequency of the lips to lie in the vicinity of the resonance frequency of the corresponding acoustical resonance of the air column [17]. More precisely, depending on the underlying valve mechanism, outward or inward striking, the natural frequency of the lips should be below or above the acoustic resonance. This makes sound production in brass instruments particularly sensitive to precise adjustments of the mechanical characteristics of the lips, and the artificial lips certainly one of the most challenging element to design.

Different technical solutions for the artificial lips have been developed over the years. The patent of Brooks in 1967 [15] refers to the artificial lips as a “*resilient deformable material, such as rubber, or the like [...] of relatively yieldable consistency so it can be easily deformed, but being sufficiently elastic to readily resume its normal configuration*”. This definition provides a good summary of possible specifications for artificial lips. We propose below an overview of different methods found in the scientific literature and in patent listings:

- **Water-filled latex rubber tubes, optionally mounted on a rigid skeleton.** This solution was originally proposed by Gilbert and Petiot [2] and have subsequently been used by several researchers on the trombone and the trumpet [3–5, 8, 10–14, 18, 19]. The volume of water in the tube particularly allows the tension of the rubber to be modified, which in

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turns modifies the natural frequency of the lips. Although very realistic sounds and behaviors can be obtained with this system, it requires to manage a water circuit and potential deterioration of the rubber in contact with water. It can therefore be challenging to guarantee a good repeatability in the lip settings.

- **Silicone sheets mounted on an aluminum plates and solid-body rubber lips.** The first solution was proposed by Kaneko et al. [6] and applied to the trombone. It features a rigid skeleton in aluminum but does not include a cavity filled with water. Nevertheless it allows the lip spacing at rest to be controlled before bringing the mouthpiece in contact with the lips. A second solution proposed for the trumpet by Moore et al. [7] consists of lips made of solid rubber and formed from molds of human lips.
- **Membranes.** A solution, sometimes referred to as “membrane reed”, makes use of a viscoelastic membrane mounted on two concentric cylindrical tubes [20–22]. The inside tube is connected to the acoustic resonator (for brass instruments the inside tube may consist of the mouthpiece itself), while the external tube forms a closed upstream cavity where the quasi-static driving pressure is generated. With appropriate adjustments of the membrane properties and tension, this system can easily produce some sounds, although by construction the membrane reed follows a (+,+) mechanism in the Fletcher classification [23], while lip reeds are classified as (+,-) or (-,+) reeds [17]. Another principle, imagined by Yamaha Corporation but not tested experimentally, involves a pair of elastic membranes coupled by a small rigid cylinder, and enclosed in a cavity [16]. In this relatively sophisticated system, one of the membranes is in contact with the mouthpiece rim and the pressure in the cavity can be controlled by the player. By controlling the blowing pressure as well as the tension of the membranes through a sliding part in contact with the second membrane, both loudness and pitch can be theoretically controlled by the user. Although it is not based on the principle of a “two-lip” valve system, this original solution behaves theoretically as a (+,-) – or outward striking – reed.
- **Electroacoustic systems.** A pioneer solution was developed by Backus and Hundley in 1971 [1], where a vibrating vane, controlled by a driver designed from a commercial loudspeaker, was used in place of the lips. This system was certainly one of the first “artificial player” developed for brass instruments. A more recent solution proposed by Toyota relies on the electro-pneumatic forcing of the air-column using a membrane controlled electronically by a coil, which regulates the pulsating air flow into the instrument [24]. This approach is of course not based on the fundamental mechanisms of sound production by a human player, but this system is probably the one implemented by Toyota for its trumpet player robot [25], with quite convincing musical results.

In this short article, we present a artificial buzzing system based on two silicone-type artificial lips, that offers an alternative to the existing solutions listed above, and that enables very realistic sounds to be produced in the trumpet with minimal adjustments and supervision from the user. We also made it small enough so that it is portable and can be easily carried in your gig bag or in your pocket!

2 Objectives and requirements

We aim at designing a system that is compact and portable, with simple design, relatively easy to use, and that can easily guarantee repeatable settings. We would like the system to be based on the physics of sound production in brass instruments through an oscillating valve reed, we then discard the solutions based on electro-acoustic systems such as a compression driver. We also intend to use artificial lips that may be modeled numerically, and therefore with geometrical features and material properties that can be conveniently integrated into a finite element model for instance. We then wish to focus our choice towards artificial lips with the most simple structure, that preferably make use of a single material with isotropic properties. We then discard the solutions based on water-filled latex tubes, sophisticated lip geometries, and silicone sheets mounted on aluminum plates that consist of relatively complex systems. We also want our system to reproduce as much as possible a human embouchure: we want to keep a layout based on one or two lips in contact with the mouthpiece rim. We then discard the solution based on the pair of elastic membranes.

3 Technical specifications

3.1 General description

A sketch of the system proposed is represented in [Figure 1](#) and based on the assembly of five fundamental elements:

- **A mouth unit:** it consists of a cylindrical part that includes the mouth or upstream cavity which is open on the back side through a small cylindrical port that can be connected to an air supply system, and which is open downstream to the lips through an “inter dental” oblong hole. The cylindrical wall that hosts the inter-dental hole is referred to as the “teeth plate”.
- **The artificial lips:** they consist of two half disks made of silicone material and inserted on the downstream side of the mouth unit against the teeth plate. The two lips are mounted so that the two straight lip edges are facing each other, centered on the oblong inter-dental hole, and parallel to the longest axis of the oblong hole. The lip opening at rest can be controlled by adjusting the distance between the lip edges. In our experience, better sound quality and lower threshold blowing pressures are obtained when

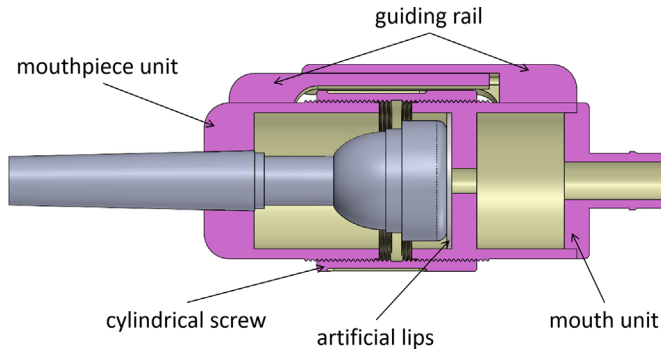


Figure 1. (Color online) Sketch of the pocket artificial buzzing system (PAB system) with a trumpet mouthpiece.

the lips are in contact in the resting position, which means with a quasi-null lip opening at rest. More details about the material used for the artificial lips are provided in the next section.

- **A mouthpiece unit:** it consists of a cylindrical part on which the mouthpiece back bore can be inserted to guarantee a perfect alignment of the mouthpiece with the central axis of the system.
- **A cylindrical screw:** it allows the mouth and mouthpiece units to be connected and to modify their relative distance through two threads in opposite directions. This part is required to bring the mouthpiece in contact with the lips, as well as to control the force applied by the mouthpiece on the lips.
- **A guiding rail:** it guarantees no rotation of one unit with respect to the other when the screw is rotated, and especially when the mouthpiece is in contact with the lips.

A 3D printed version of the system, mounted on a B♭ trumpet (Yamaha 8335S) is shown in Figure 2. This copy was printed from resin using high-resolution 3D printer (Agilista-3000, Keyence) with 15 μm print resolution. In order to make this device available to the research community, the CAD files of the PAB system can be shared by the authors upon request.¹

3.2 Artificial lips

As it was discussed in previous section, the artificial lips are a key element in this type of device. The choice of the geometry and material has significant effects on the ability of the system to produce perceptually realistic sounds, generated with reasonable amplitudes of the blowing pressure. For the lip material, we use Toughsilon®, a silicone-type material developed and commercialized by Tanac Corporation. Several variations of the material properties and thickness of the sheets were evaluated. We eventually came up with the selection listed in Table 1, that allows at least three registers (registers 3, 4 and 5) to be excited on several B♭ trumpets. These registers correspond to the tones F4 (349 Hz), B♭4 (466 Hz) and D5 (587 Hz) in open fingering.

Three variations of thickness for the silicone sheets were evaluated (2.5 mm, 2 mm, 1.5 mm). For all variations of material properties, the 1.5 mm thickness was always selected as it induced the lowest minimum blowing pressures, and the most perceptually convincing sounds. A view of the artificial lips mounted on the teeth plate of the mouth cavity is shown in Figure 2. In this picture, the lips are mounted so that the lip spacing at rest is close to zero (lips in contact at rest), which is what we expect to happen in a human player (the lips are most likely closed before the player increases the mouth pressure). Depending on the force applied by the mouthpiece on the lips, which is controlled using the cylindrical screw, two different registers can be obtained for a same lip type. This is likely to be due to the mechanical constraints induced by the mouthpiece, that locally modify the mechanical properties of the lips. Small variations of the lip natural frequency may then allow two registers to be excited.

We can also mention that cases of multi-stability where two periodic regimes co-exist for a same blowing pressure, were also observed for a given mouthpiece force: varying the blowing conditions (slow or fast mouth pressure rise) allows one or the other register to be selected. Although the analysis of this phenomenon is beyond the scope of this paper, we may explain this observation by the change in the initial conditions caused by the different mouth pressure profiles.

4 Basic assessment of the performance of the system

In order to illustrate the performances of the pocket artificial buzzing (PAB) system, two sequences were recorded in two conditions: first by a trumpet player in normal playing conditions (baseline condition), and then using the PAB system where the blowing pressure is generated by a brass player with no trumpet training, through a flexible tube connected to the upstream cavity. The sound produced outside the instrument was recorded using a microphone in the axis of the bell, about one meter from the bell end. The first sequence consists in a single-pitch (B♭4 around 470 Hz) musical phrase where the player is allowed to articulate the notes using appropriate tonguing technique, and the second sequence consists in a crescendo-decrescendo maneuver of the same note. The associated sound files are available online.²

The waveform of the normalized recorded signals of the first sequence, and the associated spectrograms are represented in Figure 3. By looking at the spectrograms and listening to the audio files, one can notice that the sound produced by the PAB system is perceptually very close to a trumpet sound. Articulations (through tonguing) are also quite well reproduced with the PAB system.

The waveform of the normalized recorded signals of the second sequence, and the associated spectrograms are represented in Figure 4. This result first demonstrates the ability

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² <https://hal.science/hal-04672616>.



Figure 2. (Color online) A 3D printed version of the pocket artificial buzzing system mounted on a B♭ trumpet, a keyboard-harmonica flexible pipe allows the user to control the pressure in the mouth cavity (left). Front view of the artificial lips mounted on the teeth plate of the mouth unit, with quasi null lip spacing at rest (right).

Table 1. Some proposals for the artificial lips for different registers obtained on B♭ trumpets. More information about the physical properties of Toughsilon® material can be found on Tanac Corp. website.

Product	Hardness (Type A/Type E)	Tensile strength	Thickness	Registers obtained	Corresponding tone in open fingering
TSG-E50	A1/E20	1.7 MPa	1.5 mm	3	F4
TSG-A10	A10/E33	3.1 MPa	1.5 mm	3 and 4	F4 and B♭4
TSG-A20	A21/E43	3.7 MPa	1.5 mm	4 and 5	B♭4 and D5

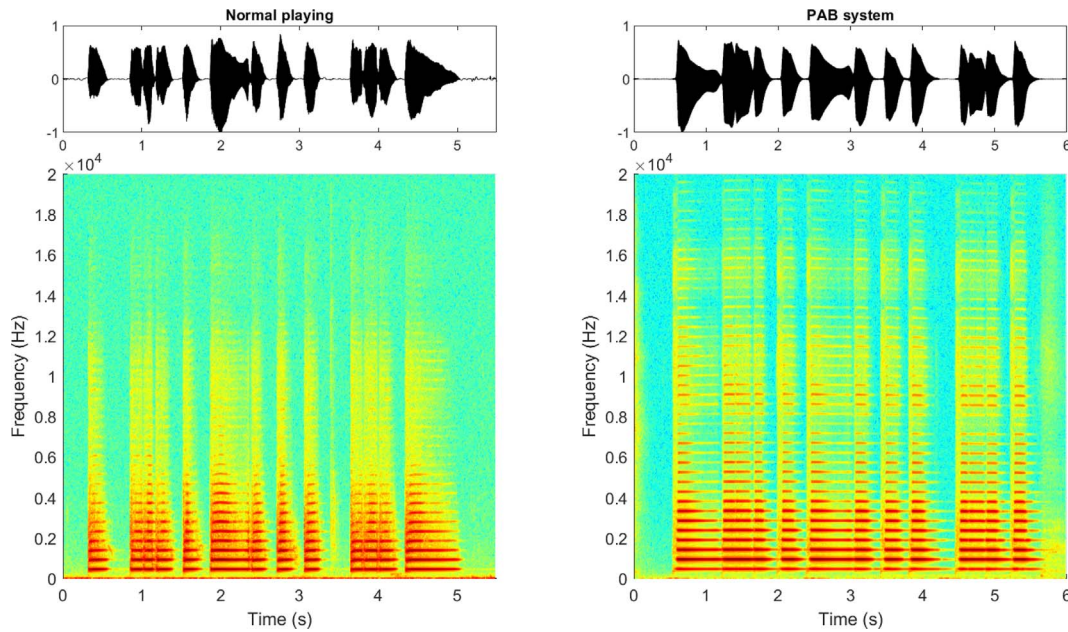


Figure 3. (Color online) Time-domain data and spectrogram of the recordings of a musical phrase performed by a trumpet player in normal conditions (left), and by a brass player using the PAB system (right).

of the PAB system to undergo large blowing pressures and to generate large sound amplitudes. The nonlinear distortion of the acoustic wave at high amplitudes results into a significant spectral enrichment as the blowing pressure increases. The pressure in the cavity of the mouth unit (blowing pressure) was measured using a pressure sensor, and reached 5 kPa at the loudest level, which seems coherent with mouth pressure levels observed in trumpet playing [26]. It then demonstrates the ability of the PAB system to

produce the typical “brassy” sound of brass instruments. Furthermore, as it can be seen on Figure 5, despite some differences potentially due to the lip dynamics, or to less wave distortion in the performance with the PAB system, the waveforms of the radiated sound at loud sound level show some relatively similar patterns, where each period features a phase of rapid rise and drop of the pressure, followed by a phase of smoother pressure variations. Although nonlinear acoustic propagation could be induced using other sources

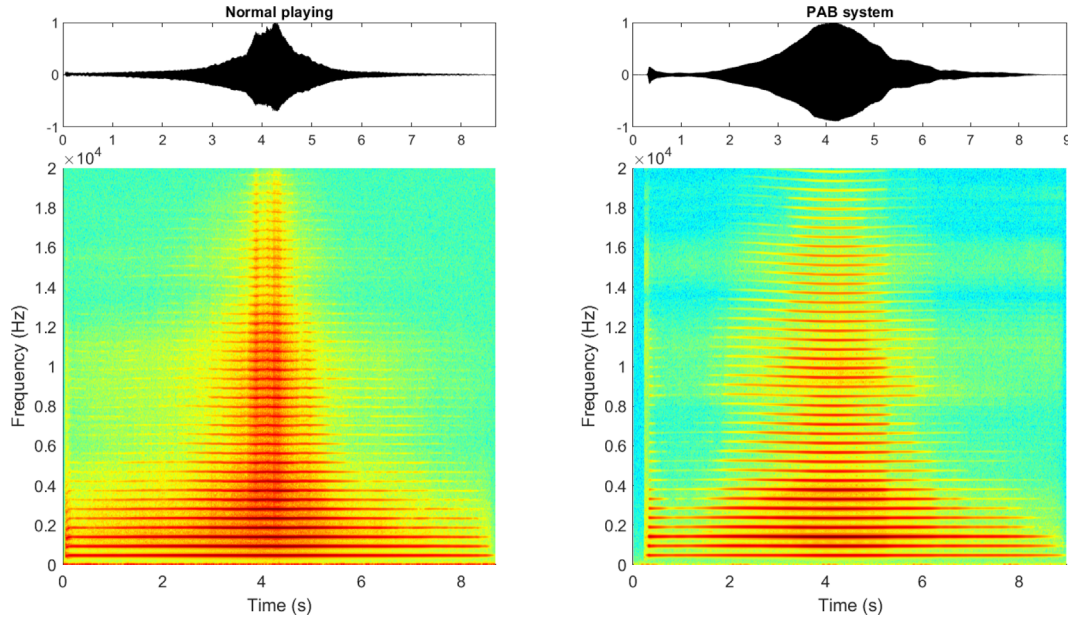


Figure 4. (Color online) Time-domain data and spectrogram of the recordings of a *crescendo – decrescendo* performed by a trumpet player in normal conditions (left), and by a brass player using the PAB system (right).

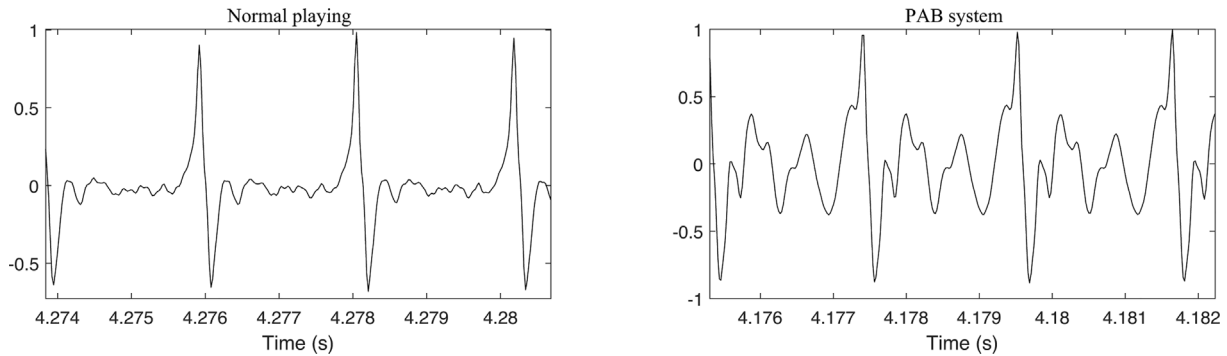


Figure 5. Zoom on the waveform at loud sound level performed by a trumpet player in normal conditions (left), and by a brass player using the PAB system (right).

such as compression drivers or other types of artificial lips, our former experiments with water-filled latex lips for instance showed less stable behaviours, notably through the emergence of quasi-periodic regimes, as the blowing pressure was increased. This new solution for the artificial lips, allowing high amplitude sounds to be obtained without particular adjustments of the lips, can thus be suitable to excite and compare instruments across a large dynamic range.

5 Conclusions and perspectives

We introduced a pocket artificial buzzing (PAB) system that enables realistic sounds to be easily produced on the trumpet. By generating a quasi-static pressure in the upstream cavity (by human or artificial blowing), artificial lips made of a silicone-type material are excited and allows sound to be produced without any former experience play-

ing brass instruments. Different notes can be obtained depending on the properties of the silicone and on the blowing conditions. Some comparisons between normal and artificial blowing using the device, demonstrate the capabilities of this system in producing very realistic trumpet sounds. It then offers some exciting perspectives in terms of research on brass instruments, such as playing tests for instrument comparisons or sound recordings in repeatable control conditions using a stable air supply. For research purposes, a laboratory version of this artificial player system was developed, allowing a more accurate control using micro positioning stages as well as pressure and optical measurements, although the presentation of this device is beyond the scope of this article. It may also find applications for product testing, or for other applications (music education, artistic projects, etc.). It also shows some potential in music performance pedagogy, allowing for instance to work on the respiratory control independently from the control of the embouchure. Finally, it can also be used for sci-

entific pedagogy, as a simple way to illustrate the principle of sound production in brass instruments, or to illustrate the influence of the blowing pressure on the characteristics of the sound for instance. In order to make this system easily reproduced outside our laboratory, information about the lip material is provided in this article, and the CAD files of the device can be shared by contacting the authors.

Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The data are available from the corresponding author on request.

References

1. J. Backus, T.C. Hundley: Harmonic generation in the trumpet, *Journal of the Acoustical Society of America* 49 (1971) 509–519.
2. J. Gilbert, J.-F. Petiot: Brass instruments, some theoretical and experimental results. In: *Proceedings of the International Symposium on Musical Acoustics*, Edinburgh, UK, 1997, pp. 391–400.
3. C. Vergez, X. Rodet: Model of the trumpet functioning: real time simulation and experiments with an artificial mouth. In: *Proceedings of the International Symposium on Musical Acoustics*, Edinburgh, UK, 1997.
4. J.S. Cullen, J. Gilbert, D.M. Campbell: Brass instruments: linear stability analysis and experiments with an artificial mouth, *Acta Acustica* 86 (2000) 704–724.
5. F. Ehara, K. Nagai, K. Mizutani: Relationships between vibration of artificial lips and sound frequency of a trumpet. In: *Proceedings of the International Symposium on Musical Acoustics*, Perugia, Italy, 2001, pp. 513–516.
6. Y. Kaneko, S. Mizuhara, K. Mizutani, K. Nagai: Artificial lips for automatic trombone blower. In: *Proceedings of the First Asian Pacific Conference on Biomechanics*, Osaka, Japan, 2004, pp. 23–24.
7. T. Moore, E. Shirley, I. Codrey, A. Daniels: The effects of bell vibrations on the sound of the modern trumpet, *Acta Acustica United with Acustica* 91 (2005) 578–589.
8. M. Secail-Geraud, L. Leblanc, J. Gilbert, F. Gautier, P. Hoekje: Analyse des couplages vibroacoustiques sur un double pavillon de trombone en situation de jeu. In: *Proceedings of the Congrès Français d'Acoustique*, Le Havre, France, 2018, pp. 1279–1283.
9. S. Kniesburges, S.L. Thomson, A. Barney, M. Triep, P. Sidlof, J. Horacek, C. Brücker, S. Becker: In vitro experimental investigation of voice production, *Current Bioinformatics* 6 (2011) 305–322.
10. M.A. Neal, O. Richards, D.M. Campbell, J. Gilbert: Study of the reed mechanism of brass instruments using an artificial mouth. In: *Proceedings of the International Symposium on Musical Acoustics*, Perugia, Italy, 2001, pp. 99–102.
11. M.J. Newton, M. Campbell, J. Gilbert: Mechanical response measurements of real and artificial brass player lips, *Journal of the Acoustical Society of America* 123, 1 (2008) EL14–EL20.
12. V. Fréour, N. Lopes, T. Hélie, R. Caussé, G.P. Scavone: In-vitro and numerical investigations of the influence of a vocal tract resonance on lip auto-oscillations in trombone performance, *Acta Acustica United with Acustica* 101 (2015) 256–269.
13. J.-F. Petiot, F. Teissier, J. Gilbert, M. Campbell: Comparative analysis of brass wind instruments with an artificial mouth: first results, *Acta Acustica United with Acustica* 89 (2003) 974–979.
14. N. Lopes, T. Hélie, R. Caussé: Control of an artificial mouth playing a trombone and analysis of sound descriptors on experimental data. In: *Proceedings of the Stockholm Music Acoustics Conference*, 2013, pp. 521–528.
15. J.R. Brooks: Trumpet embouchure (US Patent US3339444), Gainesville, TX, USA, 1967.
16. R. Hashimoto: Musical instrument playing actuator, play assisting mouthpiece, brass instrument, automatic playing apparatus, and play assisting apparatus (European Patent EP1998316A1), European Patent Office, Hamamatsu, Japan, 2012.
17. M. Campbell: Brass instruments as we know them today, *Acta Acustica United with Acustica* 90 (2004) 600–610.
18. J. Gilbert, S. Ponthus, J.-F. Petiot: Artificial buzzing lips and brass instruments: experimental results, *Journal of the Acoustical Society of America* 104 (1998) 1627–1632.
19. S.R. Bromage, O.F. Richards, D.M. Campbell: Reproducibility and control of the embouchure of an artificial mouth for playing brass instruments. In: *Proceedings of the Stockholm Music Acoustics Conference*, 2003, pp. 197–200.
20. B. Hopkin: Musical instrument design: practical information for instrument making, See Sharp Press, 1996.
21. J.-F. Laporte: <https://totemcontemporain.com/fr/instruments/membranes-vibrantes>. Accessed: 2024-05-14.
22. N. Bras: https://youtu.be/Jk7J4_bneZo?si=fndTiPsf8JQe2RH. Accessed: 2024-05-14.
23. N.H. Fletcher: Autonomous vibration of simple pressure-controlled valve in gas flows, *Journal of the Acoustical Society of America* 93, 4 (1993) 2172–2180.
24. T. Goto, T. Niwa: Japanese Patent JP 2004258443A, Japan, 2003.
25. M. Doi, Y. Nakajima: Toyota partner robots. In: A. Goswami, P. Vadakkepat, Eds., *Humanoid robotics: a reference*. Springer, Dordrecht, 2019, pp. 215–264.
26. T. Bianco, V. Fréour, I. Cossette, F. Bevilacqua, R. Caussé: Measures of facial muscle activation, intra-oral pressure and mouthpiece force in trumpet playing, *Journal of New Music Research* 41, 1 (2012) 49–65.