Influence of pad “resonators” on a saxophone

Pauline Eveno & René Caussé
Ircam
(UMR CNRS 9912)
1 place Igor Stranvinsky
75004 Paris, France
pauline.eveno@ircam.fr

Marthe Curtit
Itemm
Pôle d’Innovation
des Métiers de la Musique
71 avenue Olivier Messiaen
72000 Le Mans, France
marthe.curtit@itemm.fr

Jean-Pierre Dalmont
Laboratoire d’Acoustique
de l’Université du Maine
(UMR CNRS 6613)
72085 Le Mans, France
jean-pierre.dalmont@univ-lemans.fr

ABSTRACT

Toneholes have an important role in the acoustics of woodwind instruments. In the saxophone, the toneholes are surmounted by a key provided with a pad and what musicians and artisans refer as a “resonator”. They are flat disks made of metal or plastic fixed in the middle of the pad and are called with the acoustically neutral term “cover” in the article. In order to understand their role, measurements of the input impedance of a cylinder topped by a key with interchangeable pads (with and without covers) are performed. For closed holes, pads with covers have a low absorption coefficient; for open holes, effects of the covers on the radiation are highlighted when the key is at a small height. An analysis of the vibrations of the pads shows that these effects can be explained by the high mobility of the pads without a cover, which seems to act as a stiffener. Then, the input impedance measurement of an entire saxophone confirms that, when the holes are closed, the effect of a pad without a cover is to increase the damping. The effect on open holes is close to negligible. Finally, measurements in playing situations show that saxophones without covers have higher harmonic spectral centroids and require greater mouth pressure.

1. INTRODUCTION

Toneholes have an important role in the acoustics of woodwind instruments. Their opening and closing allows the musician to play different notes. Changing their position or their geometric features provides a way to modify the playing frequencies and the timbre of the instrument.

Toneholes can have a complex geometry (e.g. conical shape, undercutting) and involve several elements such as chimneys, key, pad, and finger. In his thesis, Lefebvre [1] gives a large overview of what is already known about toneholes and what remains to be investigated. The simple unflanged tonehole (i.e. a tonehole with a chimney which can be found in modern metal instruments such as concert flutes or saxophones) is now well described [1–4]. This is also the case for the tonehole directly drilled in the wall (i.e. a tonehole without a chimney which can be found in many instruments made of wood such as classical flutes or recorders) [1, 5]. Moreover, Dickens [6] provides fit-formulae that match his experimental results for closed drilled holes. Dalmont et al. [5] give an analytical formula for keys positioned above a hole with a chimney that is valid for a range of key heights excluding very small values [1, 7, p. 80-85]. Some studies have been carried out on undercut holes [8, 9, p. 321] but no models are given.

An aspect that payers find important, which is not addressed by the studies cited above, is the influence of the material properties of the pad [1] . Indeed pads of different materials are used, some with flat disks made of metal or plastic affixed in the middle. These are called pad “resonators” by makers and musicians. To our knowledge, the acoustic role of these “resonators” remains unknown, as there is no scientific literature on the subject. This paper aims at investigating the effective role of pad “resonators” and since there is no obvious reason to call them “resonators” we will use in the rest of the article the more acoustically neutral name “pad covers”. The study focuses on the saxophone, since it is the first instrument on which pad covers were introduced (likely due to its large holes).

In order to evaluate the influence of pad covers, measurements of the input impedance of a cylinder topped by a key with interchangeable pads (with and without resonators) are performed. Open and closed situations are investigated. In a second step, the vibration of these pads when submitted to sound pressure is measured. Impedance measurements of an entire saxophone are then made, and finally measurements in playing situation are taken in order to evaluate the perceptibility of the observed impedance differences.

2. INFLUENCE OF THE PAD ON THE IMPEDANCE OF THE HOLE

In order to investigate the role of a single pad, the input impedance of a tube of diameter equal to that of a side hole and surmounted by a key is measured. The tube is 100 mm long, with an inner radius of 12.8 mm and an external radius of 15 mm. Three identical keys of diameter

[1] http://forum.saxontheweb.net/showthread.php?180766-Resonators-why
http://cafesaxophone.com/showthread.php?2671-Time-to-install-resonators%85but-which-ones

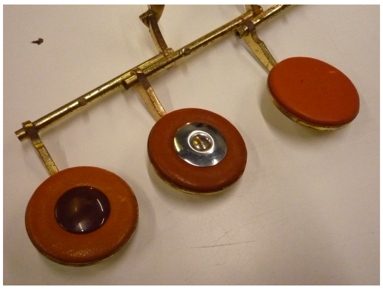


Figure 1. Three kinds of pads: with a plastic cover on the left, with a metal cover on the middle, and without cover on the right.

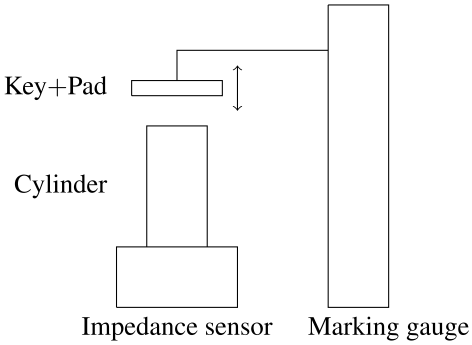


Figure 2. Technical sketch of the experimental protocol used for the measurements of the cylinder input impedance.

36 mm, provided with three different pads (see Figure 1) are measured: one with a plastic cover, one with a metal cover and one without cover. The pads consist of a cardboard covered with leather, provided or not with a cover fixed at the middle with a rivet. A marking gauge is used to move the key, whose position is measured with a tenth of a millimetre precision. Closed and open situations with different heights are investigated. A sketch of the experiment is provided in Figure 2.

2.1 Closed cylinder

The input impedance of the cylinder closed with the three types of pads is measured, from which the absorption coefficient of each type of pad can be deduced. Figure 3 shows that the pads with cover have a low absorption coefficient, circa 0.1, and that the pad without cover has a significantly higher absorption coefficient, circa 0.4. Moreover, Figure 3 shows some pad resonances. For the pad without cover a first resonance with a low Q-factor appears around 1700 Hz and a second resonance with a larger Q-factor around 2500 Hz. Pads with covers also present resonances, but they are shifted to higher frequencies. These results suggest that the input impedance of a saxophone might be significantly influenced by the presence or absence of a pad cover. This item is investigated in section 4.

2.2 Open cylinder

When the hole is open, the pad might also have an influence on the radiation impedance of the hole. Therefore, the input impedance of the tube surmounted by the pad is measured for different values of the distance between the tube and the key. Figure 4 shows the real part of the radiation impedance for the different pads and for two key heights: 1 and 5 mm. The effect of the pad is clearly visible when the key is close to the cylinder output. Indeed, Figure 4 (a) shows that the real part of the impedance is much higher for the pad without cover between 1000 and 3000 Hz, which means that the pad absorbs a lot of energy. In practice, a distance of 1 mm might only occur in a transitory state. The 5 mm case corresponds more where an open key is at rest. In that case, the difference in the radiation impedance is much more reduced but it still might be detectable. The question whether or not the effect is visible on a whole saxophone is investigated in section 4. Moreover, some peaks appear in the curves which seem to indicate a resonant behaviour of the pads. Vibration measurements are thus done to highlight this behaviour.

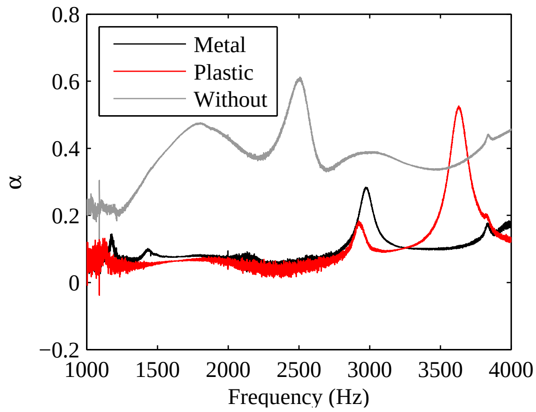
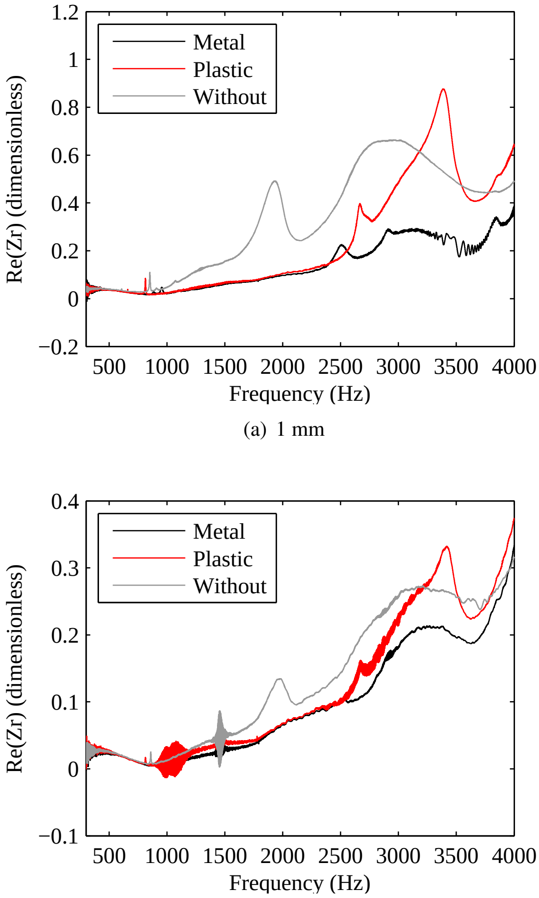


Figure 3. Absorption coefficient of the pads as function of the frequency. Pad with metal cover (in black), with plastic cover (in red) and without cover (in grey).

3. VIBRATION ANALYSIS

In order to understand why the damping induced by a pad without cover is so large, vibration analysis is carried out. For these measurements, as shown on the sketch in Figure 5, the key provided with the studied pad is fixed with a vice and excited by a loudspeaker with a sweep from 200 to 6000 Hz. The pressure is measured by a microphone placed near the pad and the pad vibrations are measured with a laser velocimeter in the middle and at the edge. The vibration of the key is measured by pointing the velocimeter at the reverse side of the pad, on the metallic part.

Figure 6 shows the mobility H=Velocity/Pressure measured at the edge and in the middle of all the pads and the key. There are more differences between the pads in the middle than at the edge. This is obviously due to the presence of the cover in the middle of the pad. The pads with a cover have a mobility about 30 dB lower than the pad without: the cover is in fact a “stiffener”. Indeed, in Figure 6 the pad without cover has a resonance around 2000 Hz. A resonance around 3500 Hz is also visible on all curves, which seems to be related to a mechanical resonance of the



(a) 1 mm

(b) 5 mm

Figure 4. Radiation impedance of the cylinder topped by the three pads (Pad with metal cover in black, with plastic cover in red and without cover in grey) at a height of (a) 1mm and (b) 5mm.

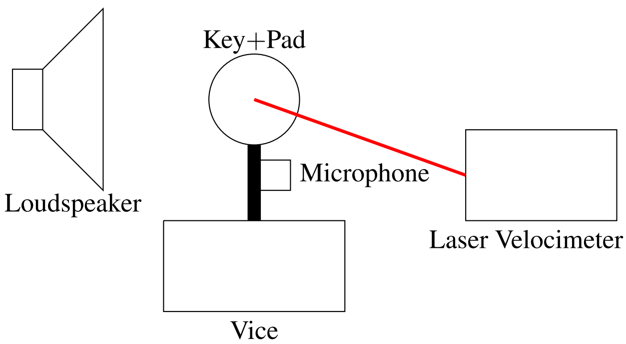
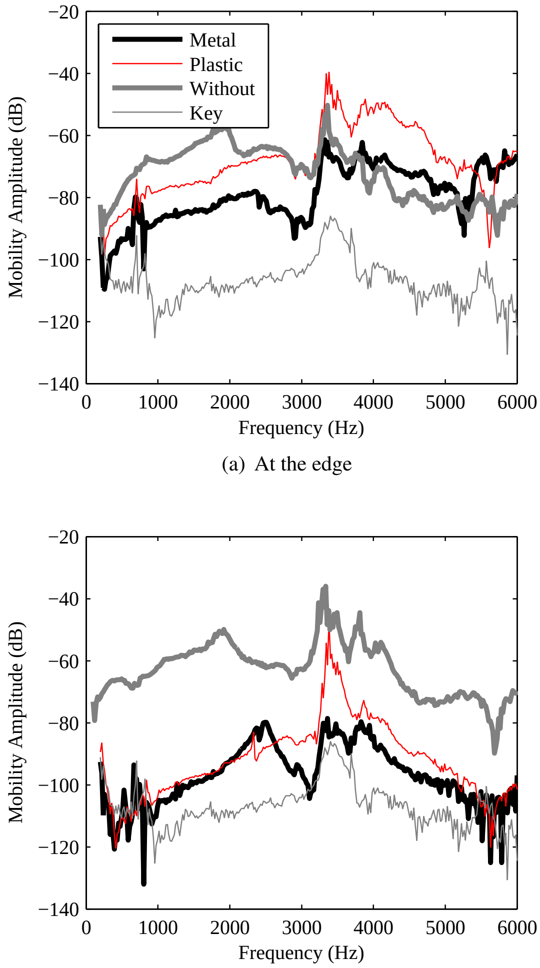


Figure 5. Technical sketch of the experimental protocol used for the vibration measurements.

key. From the curves, it appears that the cover made with metal seems to be the most efficient "stiffener".

4. INPUT IMPEDANCE MEASUREMENT OF THE WHOLE SAXOPHONE

The main effects of the pad covers have been highlighted, which leads to the conclusion that they are in fact stiffeners which reduce significantly the absorption induced by



(a) At the edge

(b) In the middle

Figure 6. Mobility measured (a) at the edge and (b) in the middle of the pad. Key mobility is given as a reference.

the pads. It is now interesting to evaluate the influence of such pad covers on a whole instrument, both for open and closed holes. The saxophone used in this study is a tenor Yamaha YTS 275. Its input impedance is measured for several fingerings of the low register: B♭, C, D, E♭, E, F♯ (played with the side key and not with the fork fingering) [2]. The F♯ fingering is particularly interesting since it requires the opening of the hole whose key has a relatively large diameter (around 30 mm) and a relatively small lift height (around 5 mm). Considering the results of the previous section, vibrations of the pad above an open hole might have a measurable influence on this fingering. The experimental set-up [10] developed jointly by the LAUM [3] and the CTTM [4] is used to measure the input impedance. This impedance sensor provides measurements with a relative error of ± 3 cents [11].

The input impedances are measured in four configurations, summarized in Figure 7: (a) the original saxophone

[2] Note names are written, so sounding notes are one tone higher.
[3] Laboratoire d'Acoustique de l'Université du Maine, Avenue Olivier Messiaen, 72085 LE MANS Cedex 9
[4] Centre de Transfert de Technologie du Mans, 20 rue Thalès de Milet, 72000 Le Mans

(fully provided with plastic covers), (b) the saxophone with pads without covers (all the pads from the original saxophone have been removed and replaced by pads without cover), (c) the "hybrid" saxophone (the smallest pads up to the last pad of the F fingering have been replaced with the original plastic covers, the larger pads remaining the one without cover) and (d) the saxophone fully repadded with its original plastic pads. The instrument has been meticulously tuned for each configuration by a skilled worker, using in particular a leaking light method.

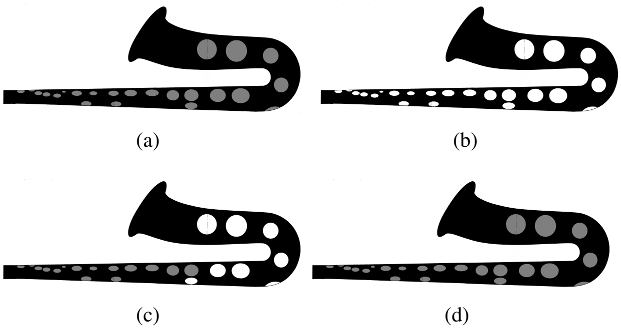


Figure 7. State of the saxophone during each series of measurements, in chronological order from (a) to (d). The pads with plastic cover are represented in grey and those without cover are given in white.

These measurements may confirm several hypothesis and effects seen on the previous sections:

- Pads without cover are more absorbent than pads with cover for closed toneholes.
- A cumulative effect on the toneholes should be observed: the absorbent effect should be more visible for the B♭ fingering, where all the toneholes are closed, and should decrease according to the number of open toneholes.
- The resonance of the pad without cover may be detected on the impedance of the F♯ since the first raised key after the closed toneholes has a small height. That is why the "hybrid" configuration is used. It allows isolating the effect of the pad without cover located on this key, by making a comparison with the "all plastic" configurations.

The saxophone input impedance is measured at the crook input, without the mouthpiece (see Figure 8). A study [7, p. 159-162] was carried out on how the pressing force on the keys can modify the input impedance of the instrument. Differences up to 8 dB were obtained on the amplitude (for the input impedance of the same saxophone but whose fingerings are performed by different persons). Consequently, in order to have repeatable measurements, pliers made of piano wire are used to press the keys with the same strength throughout the study. Each measurement is performed three times, by taking off the saxophone from the impedance sensor (and putting it back on) and removing all the pliers (and replacing them). The repeatability error is then estimated to be 4 cents for the resonance frequencies and 1 dB for the amplitude. Since measurements are performed over several days, a frequency correction is applied to take the speed of sound changes due to the temperature into account.

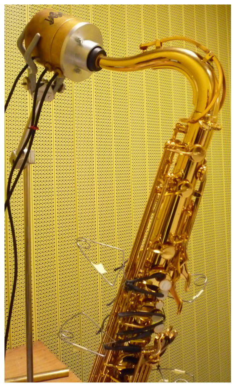
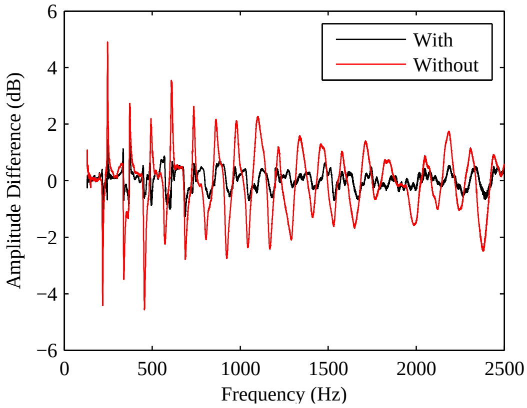


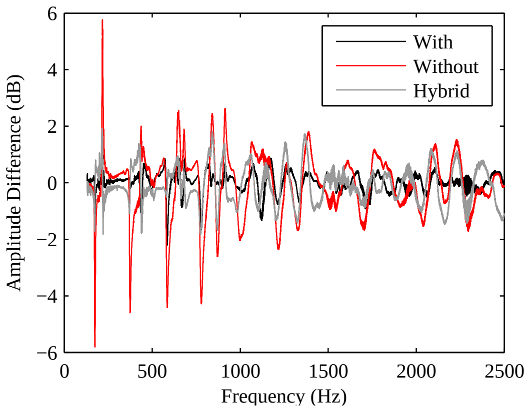
Figure 8. Photo of the saxophone input impedance measurements.

The input impedance of the saxophone with plastic covers has been measured twice: first, with the original saxophone and second, with the saxophone repadded with its original pads. These two measurements make it possible to quantify the repeatability error of the measurement combined with the effect of tuning and preparation. In the rest of the study the input impedance of the original saxophone is chosen as a reference. In Figure 9, amplitude differences between the input impedance of that reference and the input impedances of the saxophone in the other configurations are plotted for two fingerings. The black curves show that the repeatability error of the measurements is less than 1 dB and that both pad substitution and tuning do not lead to major modifications of the saxophone input impedance. Indeed, the difference between the reference and the input impedance of the saxophone without cover is much larger. This means that the pads have a visible effect on the input impedance of the whole saxophone. As predicted, this effect is cumulative, so that the difference is higher for the B♭ fingering (3 dB in average), where all the toneholes are closed, than for the F♯ fingering (2 dB in average).

Figure 10 shows that the effect of the pads without cover, when toneholes are closed, is to lower the amplitude of the impedance peaks, without changing the resonance frequency. Clearly, when it is closed, the effect of a pad without cover is to increase the damping. On the other hand, Figure 9 (b) shows that the input impedance of the "hybrid" saxophone is closer to the input impedance of the saxophone with covers. Indeed, the radiation mostly takes place at the first open tonehole, the following toneholes have practically no influence on the input impedance. So, despite the fact that the influence of the open hole without pad cover is significant, this effect is in practice negligible compared to that of the closed holes.



(a) B♭



(b) F♯

Figure 9. Difference between the input impedance (in dB) of the original saxophone and the input impedance (in dB) of the saxophone without cover (in red), of the hybrid saxophone (in grey) and of the saxophone repadded with its original pads (in black) for two fingerings: (a) B♭ and (b) F♯.

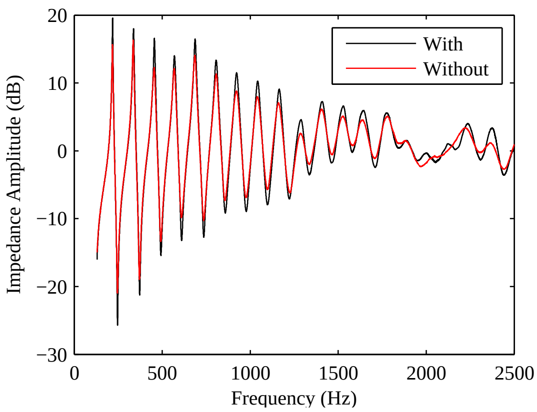


Figure 10. Comparison between the input impedance of the saxophone with plastic covers (in black) and the impedance of the saxophone without cover (in red) for the B♭ fingering.

5. PAD EFFECT IN PLAYING SITUATION

After having characterised the effect of the pads on the saxophone with an objective criterion, the input impedance, it is interesting to determine their influence in playing situation. For these measurements, two "identical" saxophones are needed so that one is kept in its original padding throughout the whole study, as a reference.

5.1 Choice of the saxophones

The choice of the two closest saxophones is first done by the musician among three saxophones of same design: tenor Buffet Crampon Evette provided with metal covers. These three saxophones are named by the last two numbers of their serial number: 65, 72 and 81. The choice is made by doing a blind pair-wise comparison: the musician plays two saxophones in a row without knowing their number and has to give a rating between 0 and 4 to quantify their difference (0 for very similar and 4 for very different). This exercise is repeated several times for all the possible pairs and the results are given by the matrix of dissimilarity on Table 1. The saxophone 65 stands out from the two others as some of its notes are difficult to play.

	65	72	81
65	0/1	3/4	3/4
72		0/1	1/2
81			1/2

Table 1. Matrix of the dissimilarity between the three saxophones.

Input impedance measurements on these saxophones confirm the musician's choice. Indeed, Figure 11 presents the difference between the input impedance amplitude of each pair of saxophone for the B♭ fingering. Differences are much bigger for the pairs involving saxophone 65 than between saxophones 72 and 81 (only 1 dB in average), which confirms the musician's choice. It was therefore decided to keep saxophones 72 and 81 for the rest of the study.

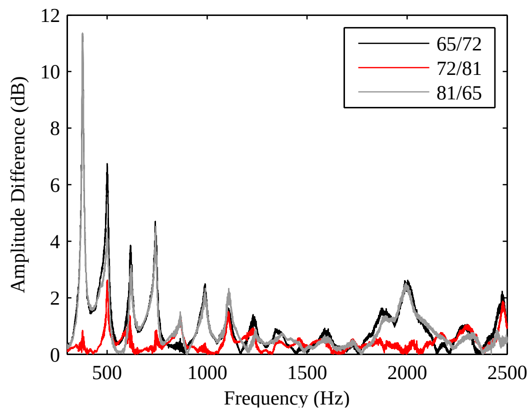


Figure 11. Differences (in absolute value) between the impedances (in dB) of each saxophone pair: 65 and 72 (in black), 72 and 81 (in red), 81 and 65 (in grey) for the B♭ fingering.

Descriptor	Description	ANOVA p-values
Attack Time (AT)	Time of the transient regime	0,37: n.s
Harmonic Spectral Centroid (HSC)	Frequency of the centroid of the harmonic spectrum	< 0,0001: sig
Odd/Even Ratio (OER)	Energy ratio of odd harmonics to even harmonics	0,79: n.s
Tristimulus, 1st coefficient (TR1)	Energy ratio of the fundamental component to the total	0,72: n.s
Tristimulus, 2nd coefficient (TR2)	Energy ratio of harmonics 2, 3 and 4 to the total	0,18: n.s
Tristimulus, 3rd coefficient (TR3)	Energy ratio of higher-order harmonics to the total	0,31: n.s
Threshold pressure (TP)	Overpressure in the mouth that makes oscillate the reed	0,53: n.s
Mouth pressure (MP)	Mean pressure in the mouth of the musician	0,004: sig
Pressure level (PL)	Level of pressure at the bell	0,40: n.s
Efficiency (E)	Ratio of the Pressure level to the Mouth pressure	0,70: n.s

Table 2. List of the descriptors and their ANOVA p-values for the effect of the pads (significant threshold: 5%, n.s : non significant, sig : significant)

5.2 In vivo measurements

The purpose of these measurements is to characterise the effect of the pads on the musician's playing parameters and on the radiated sound. The pressure in the musician's mouth and the radiated pressure at the bell are measured while 9 notes are being played (high register C♯, A, F♯, E♭ and low register C♯, A, F♯, E♭ and B♭) on the two saxophones. These recordings are realised five times in order to get a meaningful average. Then, the saxophone 72 is kept in its original shape and the 81 is provided with pads without cover for another series of recordings.

The pressure in the mouth is measured with a differential pressure transducer Endevco 8507-C2. The radiated pressure at the bell is recorded with a microphone located 10 cm from the bell in the axis of the instrument, as shown in Figure 12 (see also [12] for more photos of the experimental protocole). The data are collected using a National Instruments BNC-2110 acquisition board, with a 50 kHz sampling frequency.

Figure 12. Photo of the in vivo measurements.

Several physical descriptors characterising the timbre, the radiated sound and the musician's way of playing, have been considered. These are listed in Table 2. All these descriptors, except the attack time and the threshold pressure, are averaged on the stationary part of the signal. Then, the values of the descriptors are averaged on the five trials.

The influence of each descriptor on the distinction between the saxophones can be modeled using the analysis of variance method (ANOVA) [13]. Table 2 shows that only two descriptors can distinguish the saxophones with or without covers: the HSC and the mouth pressure. Saxophone without cover has globally a higher HSC [5] (HSC = 9.81) than a saxophone with covers (HSC = 8.63). The mouth pressure is in average 3640 Pa for a saxophone without cover and 3280 Pa for a saxophone with covers for an average pressure level at he bell around 10 Pa for both. This result is consistent with the input impedance analysis: indeed, the pads without covers tend to lower the amplitude of resonance peaks; more energy is thus needed to obtain the same output pressure provided by a saxophone with covers [6]. Nevertheless, these measurements are not sufficient to draw a conclusion regarding the influence of the pads on the radiated sound and on the playing parameters. It is only a preliminary study that need to be verified with more measurements. Moreover, since the pressure level remains the same with the two types of saxophone, it is possible that the musician compensate by adjusting his vocal tract. Therefore, measurements should be done with an artificial mouth to avoid this effect.

6. CONCLUSION

The covers have a measurable effect on the acoustical characteristics of the saxophone. Their main role is to stiffen the pad, so that the cover should in fact be called "stiffener". The reflection coefficient is increased by the presence of a cover when the tonehole is closed and the amplitude of the saxophone input impedance peaks is consequently increased of several dB. The effect appears to be greater with more closed tone holes. Measurements with a musician seem to confirm these results. Indeed, the musician needs, for obtaining a given output pressure, to produce a higher mouth pressure when the saxophone pads do not have a cover. It has been observed that pad vibrations can influence the acoustic radiation coming out of open toneholes. Nevertheless, this effect is small and is significant for small key heights only. Even if this effect has

[5] The HSC is dimensionless, divided by the fundamental frequency.

[6] $20 \log 3640/3280 = 0.9$ dB, this is a little less than the 2 or 3 dB differences found in section 4. The mouth pressure is indeed averaged for different fingerings, including particularly the C♯ fingering where all the holes are open and where the influence of the covers is therefore quite negligible.

been effectively measured in some configurations, the impact of pad vibration is negligible compared to that of pad adjustment influencing leaking and tuning. The influence of pad resonators on saxophone timbre remains questionable. A higher HSC has been measured on the radiated sound of a saxophone without cover and there is a bigger pressure in the mouth of a musician playing a saxophone without cover. In vivo measurements need to be carried on in order to confirm or deny these results. Several musicians and more saxophones are required in order to make a more reliable study. Similar preparation of the saxophones are mandatory. Measurements should also be carried out with an artificial mouth in order to avoid the effect of the musician. The future work should include a perceptive study on the timbre and the ease of playing. This might be completed by a listening test on the recorded sounds.

Acknowledgments

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