A perceptual study on the effect of pad resonators on the saxophone

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There is a lot of controversy regarding the pad resonators of saxophones and their effect on the acoustical response of the instrument is not well known. The resonators, which are mounted in the middle of the pad, exist in different shapes (flat, domed, corrugated) and different materials (plastic, copper, brass, even gold!). A previous study [1] shows that pads without resonator tend to lower the impedance peaks of the saxophone, which may make the instrument more difficult to play. A perceptual study is performed with 13 musicians in order to characterize more precisely the influence of the resonators from the perspective of players. Four alto saxophones of the same model are given to the players and they are asked to blindly rate their brightness, ease of playing and evenness. Two saxophones are provided with domed plastic resonators, one with metal domed resonators and one without resonators. Results show that musicians perceive the saxophone without resonators as the least bright and least easy to play. As for the three other saxophones, they cannot distinguish them.

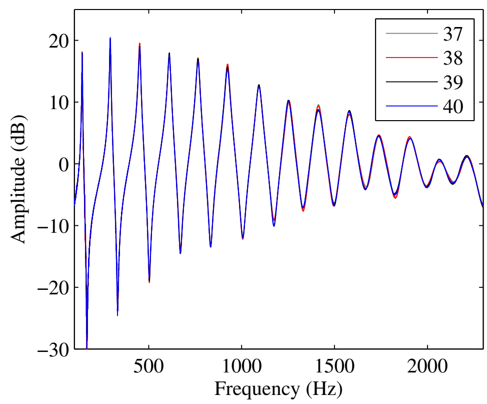
1 Introduction

Woodwind instruments are constructed with toneholes, which allow different notes to be played by varying the effective length of the air column. Since the holes are often too large or too far apart to be covered by fingers, a complex system of keys is used to allow the holes to be opened and closed. A pad, which is typically made of cardboard covered with leather, is mounted on each key to provide an air-tight seal around the tonehole. Sometimes, especially in the saxophone, a resonator is fixed in the middle of the pad. The resonators exist in different shapes (flat, domed, corrugated) and different materials (plastic, copper, brass, even gold!). Some of them are shown in Figure 1.

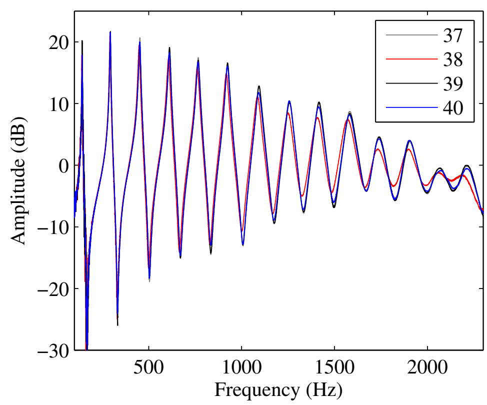
Figure 1: Different kinds of existing pad resonators: metal flat, plastic domed, gold plated wave and metal domed.

A previous study [1] showed that the resonators have a measurable effect on the acoustical characteristics of the saxophone. Their main role is in fact to stiffen the pad, and thus the resonators might be called "stiffeners." The reflection coefficient of a pad is increased by the presence of a resonator when the tonehole is closed and the amplitude of the saxophone input impedance peaks is consequently increased by several dB. The effect appears to be greater with more closed tone holes. It has also 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 been effectively measured in some configurations, the impact of pad vibration is negligible compared to that of pad adjustment influencing leaking and tuning.

Different effects of the pad resonators on the acoustic characteristics of a saxophone have thus been highlighted. It is now interesting to study how these resonators can affect the perception of musicians. Four Yamaha model YAS-480 alto saxophones with consecutive serial numbers were used in this study. In section 2, input impedance measurements were carried out in order to make sure that the four instruments could be considered as identical. Then, two saxophones (numbers 37 and 39) were kept in their original condition (provided with plastic resonators) while the pads of the other two were changed. Saxophone number 38 is mounted with pads without resonator and number 40 with metal resonators. A single neck from one of the saxophones was used for all reported measurements and the perceptual study. This helped minimize measurement discrepancies associated with slight variations of neck position on the impedance sensor. Section 3 then presents the details of participants who took part in the study and Section 4 explains the procedure. Finally, the results of the study are analyzed in Section 5.



(a) Before repadding

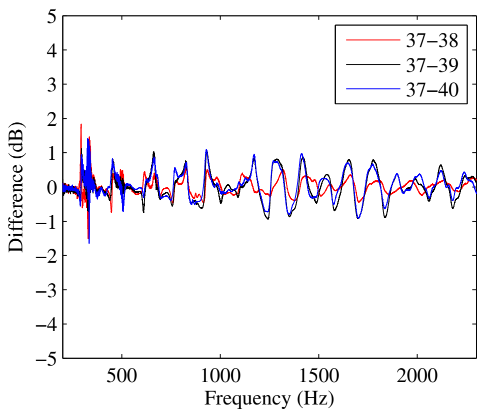


(b) After repadding

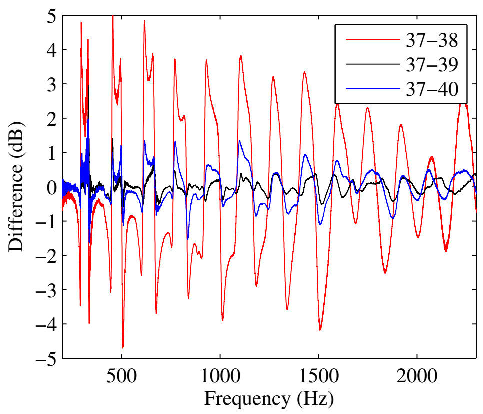
Figure 2: Input impedance of the four saxophone for the B♭3 fingering (all the toneholes closed) (a) before and (b) after the repadding.

2 Input impedance measurements

A first session of impedance measurements was made on the four new saxophones provided with plastic resonators directly from the factory and another one after the pads were changed. Several fingerings were measured. Figure 2 shows the input impedance of the four saxophones for the B♭3 fingering before and after the repadding. Differences are subtle: before the repadding the four saxophones are really close to each other and after, only the 38, which is the saxophone without resonator, can be distinguished. To have a clearer view of the results, it is possible to take saxophone 37 as a reference (since it is one of the two unmodified saxophones) and to compute the difference between the input impedance amplitudes of this saxophone and each of the three others. This is shown in Figure 3. We found that these saxophones were quite similar before the repadding as the differences were less than 1 dB in amplitude and 5 cents in frequency, which is about the accuracy limits of the measurement system in the given measurement environment. Then, their impedance was changed by providing pads with different resonators. As previously mentioned, the pads without resonator tend to lower the impedance peaks, as seen in Figure 2 (b).



(a) Before repadding



(b) After repadding

Figure 3: Differences of the impedance amplitude of saxophone 37 and each of the three others for the B♭3 fingering (all the holes closed) (a) before and (b) after the repadding.

3 Participants

Thirteen skilled saxophone players took part in this experiment (1 female, 12 males; average age=30 years, standard deviation=8 years, range=22-48 years). They had at least 10 years of saxophone experience (average years of saxophone playing=17 years, standard deviation=7 years, range=10-35 years; average hours of saxophone practice per week=15 hours, standard deviation=10 hours, range=0-35 hours). They were paid for their participation. Five participants described themselves as professional musicians and six had higher-level degrees in music performance (MMus, MA, DMus, DMA). Nine were used to playing the alto saxophone, seven the tenor, four the baritone and four the soprano. Five were playing Yamaha saxophones, three were playing Selmer, and the others were playing different brands such as Keilwerth, Phil Barone or Martin. They reported playing a wide range of musical styles: classical (60%), jazz (50%), contemporary (40%) or pop (20%).

4 Procedure

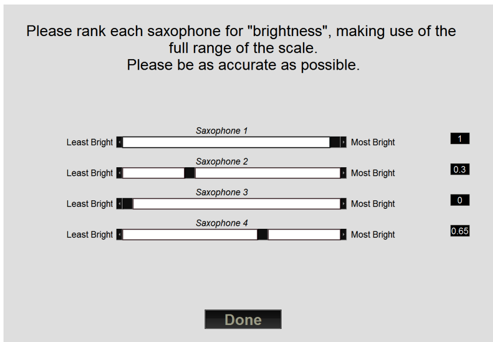


Figure 4: Matlab GUI used for the perceptual study.

The experimental session lasted between 90 and 120 minutes and the experimenter was constantly present in the room to facilitate the procedure. First, participants were presented with the four saxophones previously described randomly ordered on a table by the experimenter. They were asked to play all instruments for up to 15 minutes in order to familiarize themselves with the set. Then, for 10 minutes, the participants were asked to rate the *brightness* of the instruments using a Matlab GUI presented in Figure 4. The rating range was fixed between 0 and 1 with a step of 0.05 and the participants were obliged to use the whole scale, so they had to rate the saxophone they found the least bright at 0 and the most bright at 1. Then, they had to follow the same process and rate the *ease of playing* and the *evenness* (how similar is the timbre over the full range of the instrument) of the saxophones. Subsequently, in-vivo measurements were performed for about 20 minutes, after which the experimenter randomized the saxophones and the participants were asked to repeat the rating of the saxophones.

5 Results

Figure 5 presents the average of the two trials of ratings for the 13 participants. It is clear that saxophone 38, which is the one without pad resonators, is perceived as the least

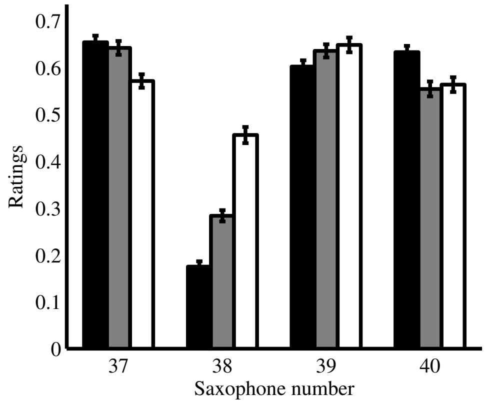


Figure 5: Average ratings of the *brightness* (in black), *ease of playing* (in grey) and *evenness* (in white) for the four saxophones. The error bars represent the standard deviation of the mean: $\sigma/\sqrt{n-1}$, where σ is the standard deviation of the data and n is the number of samples (26 here).

bright and least *easy to play*. It is also rated as the least *even*, but the difference with the other saxophones is less obvious for this criterion. The three other saxophones have quite similar ratings, so it appears that participants were not able to discriminate the saxophone mounted with metal resonators from the other two provided with plastic resonators.

We performed an analysis of variance (ANOVA) to estimate the effect of the saxophone and the repetition on the ratings of the three criteria [2, 3]. The ANOVA framework offers statistical tests to determine whether or not the means of different groups of data are equal. For this study the response corresponds to the ratings which will be modelled with two fixed factors and a factor of interaction:

$$Z = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij}, \tag{1}$$

where

- μ is a constant
- α_i is the effect of the level i of the saxophone ($i = 1...4$ since there are four saxophones)
- β_j is the effect of the level j of the repetition ($j = 1$ or 2)
- $(\alpha\beta)_{ij}$ is the factor of interaction
- ε_{ij} is the error term.

The results of the ANOVA, computed using SPSS[1], are given in Table 1 for the three criteria. The only significant results (p-value<0.05) occur with the "saxophone" factor for the criteria *brightness* and *ease of play*, indicating that there was a statistically significant variation of these two criteria across the saxophones.

In order to have more details on the impact of each saxophone, we computed a paired-samples t-test [4, 5] across all subjects between the average rating on the two trials for each possible pair of saxophones, for the two significant criteria. p-values obtained with this test are given in Table 2. The six null hypotheses (that the data in $x - y$, x and y being the ratings for the two saxophones of the pair, comes from a normal distribution with mean equal to zero and unknown variance) are tested at the 5% significance level with the Holm-Bonferroni method [6]. For the *brightness*, all the pairs involving the saxophone without pad resonators (saxophone 38) reject the null hypothesis. For the *ease of play*, only the pair 37-38 rejects it. These results show that musicians cannot distinguish between the saxophones with plastic resonators and the one with metal resonators for all the criteria. For the *ease of play*, they found some significant differences but it is less obvious than for the *brightness*. Moreover, they were not able to discriminate the saxophones in terms of *evenness*.

Table 1: Results of the ANOVA for the three criteria. Source means "the source of the variation in the data", the three sources are the saxophone, the repetition and the interaction between saxophone and repetition. dF mean "the degrees of freedom in the source", SS means "the sum of squares due to the source", MS mean "the mean sum of squares due to the source", F means "the F-statistic" and p is "the p-value".

	Source	dF	SS	MS	F	p
Brightness	Sax	3	4.06	1.35	8.08	<0.001
	Rep	1	0.01	0.01	2.09	0.17
	Sax * Rep	3	1.20	0.40	3.98	0.15
Ease of play	Sax	3	2.04	0.68	4.47	0.01
	Ren	1	0	0	0.03	0.87
	Sax * Rep	3	0.29	0.10	0.47	0.70
Evenness	Sax	3	0.49	0.16	0.66	0.58
	Rep	1	0	0	0.04	0.86
	Sax * Rep	3	0.38	0.13	0.73	0.54

We also evaluated the consistency of the subjects using the concordance correlation between the ratings from the two trials. The Pearson's correlation matrix is a good way of studying the intra- and inter-individual consistency [7]. The Pearson's coefficients range from -1 to 1, where 1 corresponds to a perfect positive correlation, 0 is when there is no correlation and -1 is for a perfect negative correlation (which means that when a variable increases, the other decreases). The first step involved computing a 26x26 symmetric matrix of Pearson's coefficients between the ratings on each of the 2 trials for each of the 13 participants. One matrix is computed for each rated criteria: *brightness*, *ease of play* and *evenness*. Across the 325 cells of the lower triangular part of this correlation matrix, there are 312 correlations between trials from different participants and 13 correlations between trials from the same participant. The distributions of these correlations is shown in Figure 6. The intra-individual distribution is highly dependent on the rated criteria. Indeed, musicians were more consistent while

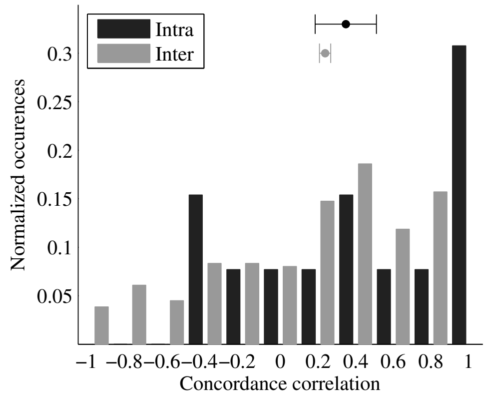
[1] `http://www-01.ibm.com/software/analytics/spss/`

Table 2: *p*-values of the paired-samples t-test.

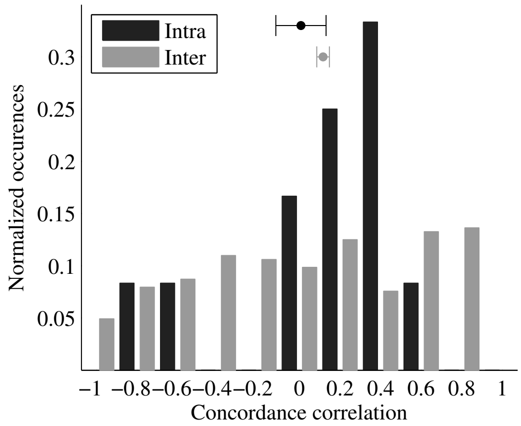
	p-value	
	Brightness	*Ease of play*
37-38	0.002	0.002
37-39	0.674	0.957
37-40	0.842	0.307
38-39	0.002	0.012
38-40	0.001	0.045
39-40	0.801	0.587

rating the *brightness* (almost all the Pearson's coefficients are positive and a lot are equal to 1, the average is equal to 0.35) than the two other criteria. The inter-individual correlation is also better for the *brightness* (average equal to 0.24). Moreover this figure shows that *evenness* was difficult to rate since participants were generally not consistent between themselves (average equal to 0.16). The inter-individual correlation is worse with a negative mean equal to -0.01.

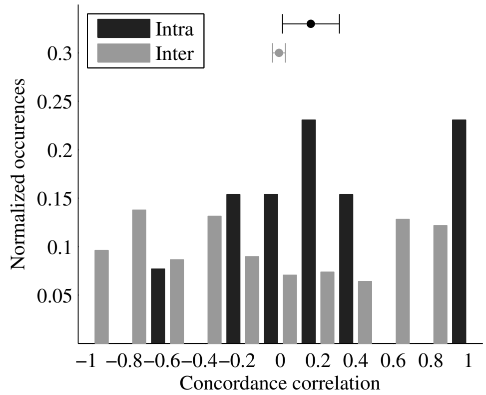
We tried to determine if some of the differences between the ratings could be explained by the level of practice of the instrument. Surprisingly, professionals (5 participants) were less repeatable than students (8 participants) with an average intra-individual consistency of only 0.04 against 0.26. As well, the "weekly hours of practice" did not explain differences in intra-individual consistency because people playing less than 10 hours had an average of 0.19 while those playing more had an average of 0.16. Nevertheless, this low consistency is not surprising because two of the saxophones were identical and a third one had metal pad resonators, which from previous results was found to be difficult to discriminate from the plastic resonators. In fact, there was essentially only one saxophone that "stood out" from the others, and thus the low consistencies.



(a) *Brightness*



(b) *Ease of play*



(c) *Evenness*

Figure 6: Distribution of intra- and inter-individual concordance correlation coefficients, computed between all the ratings from the two trials from the same and different participants, respectively, for (a) the *brightness*, (b) the *ease of play* and (c) the *evenness*. 1 corresponds to perfect consistency, 0 corresponds to no consistency and -1 corresponds to perfect anti-consistency (i.e., exactly opposite ratings given on different trials). The black and gray circles above the histograms report the across-participants average of the intra- and inter-individual consistency scores respectively and the error bar represents the 95% confidence interval of the mean (the ordinate for the symbols has been chosen arbitrarily for display purposes).

6 Conclusion

The pad resonators have been shown to have a measurable effect on the acoustics of the saxophone. A perceptual study performed on 13 musicians shows that they find a saxophone without pad resonators less *bright* and less *easy to play* than a saxophone with pad resonators. Nevertheless, they cannot distinguish a saxophone provided with metal resonators from a saxophone with plastic resonators. Results for the *evenness* were not consistent. This tends to support the hypothesis that only the rigidity of the pad matters on the acoustics of the saxophone. The material of the resonator is not important.

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References

[1] P. Eveno, M. Curtit, J.-P. Dalmont and R. Caussé, "Influence of pad "resonators" on saxophone", *Proceedings of SMAC 2013, Stockholm, Sweden*

[2] H. Scheffé, *The Analysis of Variance*, New York: Wiley (1959)

[3] R. Christensen, "Ch. 7. Multifactor Analysis of Variance", *Plane answers to complex questions: The theory of linear model*, Springer Texts in Statistics (2002)

[4] D. W. Zimmerman, "A Note on Interpretation of the Paired-Samples t Test", *Journal of Educational and Behavioral Statistics* **22**(3), 349-360 (1997)

[5] J. A. Rice, *Mathematical Statistics and Data Analysis*, Third Edition, Duxbury Advanced (2006)

[6] S. Holm, "A simple sequentially rejective multiple test procedure", *Scandinavian Journal of Statistics* **6**(2), 65-70 (1979)

[7] C. Saitis, B. Giordano, C. Fritz and G. Scavone, "Perceptual evaluation of violins: A quantitative analysis of preference judgments by experienced players", *J. Acoust. Soc. Am.* **132**, 4002-4012 (2012)