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Accordion acoustics: A study on pitch bending

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ABSTRACT

The sounds of a Pigini Sirius free-bass concert accordion have been recorded and data have been obtained in the time and frequency domains. The accordion free reeds are suitable to obtain the descendent glissando (pitch bending). The frequency of the sounds is reduced by approximately 25 cents (bellows-and-finger glissando) and 15 cents (only-finger glissando), with similar drops for the harmonics. The decrease in the sound pressure level is greater with an only-finger glissando. The different harmonics experience a different change in sound pressure levels according to a characteristic pattern. Two factors seem to control the modelling of pitch bending: on the one hand, the increase in pressure on the bellows; on the other hand, the narrowing or almost choking of the pass of the air through the chamber of the reed plate. This study may benefit accordion players, teachers and students, and acousticians working on free reed instruments.

1. INTRODUCTION

The accordion is a generic term suitable for the members of a family of diverse handheld aerophones that have free reeds. Accordion sound generators are free reeds activated by an airflow provided by the bellows. Reference [1] includes a detailed description of a concert accordion.

The characteristic of free reed is a stable frequency for a certain range of pressure values [2]. The accordion tuning provides notes of the twelve-tone equal temperament scale. There exist specific interpretation techniques involving a continuous reduction of the frequency, and there are studies for several free reed instruments [3-8]. The primary objective of pitch bending is the change of the frequency.

Pitch bending can be carried out in different ways on the accordion [9]. The usual method to bend a pitch downwards involves a combination of increased pressure on the bellows and a partially opened pallet valve (bellows-and-finger method). A second method consists in releasing the button or key while maintaining the pressure on the bellows constant (only-finger method). This method is less efficient and it is mainly applied when only a note of a double note played in the same manual is intended to be bent.

According to literature and musicians' experience, the distinctive characteristics of the pitch bending for the interpretation allowed in the accordion are the following [9,10]:

- It is not possible to force a higher pitch.
- As the pitch is bent, the sound intensity drops.
- 8' (with or without cassotto) or 16' registers from the right manual are the best for pitch bending. The 4' register should not be used. The pitch bending is more easily performed with the right keyboard. That is, while the left hand is free to move the bellows, the right hand is tilted over the edge of the keyboard.

- There is no regularity between different keys or even instruments regarding the degree of response to distortion techniques.

The first accordion score in which the pitch-bending effect was explicitly demanded was "Anatomic Safari", written by Norwegian composer Per Nørgård in 1967. Composer Sophia Gubaidulina (De Profundis, 1978) made this effect popular among composers and accordionists.

The distribution of energy over frequency is one of the major determinants of the quality of a sound or its timbre. Timbre is defined as the auditory sensation attribute in terms of which a listener can judge that two steady complex tones with the same loudness, pitch and duration are dissimilar [11]. Timbre defined in this way depends mainly on the relative magnitudes of the tone partials.

This work is part of a research that deepens in the understanding of which factors are important in a good quality accordion that began with the study of the different types of attacks [1]. We study the perception of small changes in the sound when a pitch bend is made. We focus on the evolution of the frequency and the level reached by the acoustic pressure for the first twenty harmonics of different musical sounds. The effects of register and tessitura, the direction of movement of the bellows and the cassotto are characterized for the two types of pitch bending.

2. EXPERIMENTAL

We used an accordion for concert, of Pigini Sirius brand, that has free bass [1]. The musician played an original sound (mezzo forte) and bent the pitch. The sounds were recorded and data in the time and frequency domains were obtained. For sound recording, we used a Brüel&Kjær 4189-A-021 microphone placed 50 cm away from the sound source and a PULSE analyser. For sound dynamic control, we used an Extech Instruments 407727" sound level meter placed 50 cm in front of the sound source. The mezzo forte dynamics correspond to about 70 dBA. The value displayed by the sound level meter allows the player to check that he is playing mezzo forte. This value is not used in any calculation.

One round of experiments have been conducted using both bellows and finger simultaneously, and then, the second round of experiments has been conducted using only the fingers. The accordion is an instrument with a broad spectrum and the highest harmonics are likely to depend on the relative position of the accordion to the microphone. However, all the measurements were carried out without varying this relative position, which was chosen because it offered a well-balanced sound [12]. Finally, the results have been compared for this position, the same for the complete series of measurements.

In a previous work [13], some notes for the 16-foot register and the 8-foot registers (in and out of cassotto chamber) were studied. An important experimental result shows that there is no possibility to bend the pitch with tones from C6 to C#8. For the rest of the notes, the results showed that the cassotto (chamber that lowers the intensity of higher harmonics of a note), the register and the direction of the movement of the bellows have no influence on pitch bending. For this reason, none of these three elements has been considered. Taking into account the results of [13] and the accordionist literature, all the notes from A#2 to A3 have been played, always opening the bellows, for the 8' register outside the cassotto. Each measurement was repeated fifteen times. Each time, the original and final sound were recorded. The final sound recording was made five seconds after the original sound (when the pitch bending was reached). For the first twenty harmonics in the sound, the frequencies and the level of their sound pressure were determined. All results are average values for fifteen measurements. All measurements that the player did not considered good were rejected before data analysis.

In order to compare the different drops in the original frequencies, we used the unit of pitch named cent: twelve-tone equal temperament divides the octave into 12 semitones of 100 cents each. Hence, the number of cents measuring the frequency drop interval from f_{or} to f_{fin} is:

$$f\,drop = 1200\log_2 \frac{f_{or}}{f_{fin}}(cent), \quad (1)$$

where f_{or} is the frequency of the original sound, and f_{fin} the final frequency of the sound. Being a logarithmic ratio between frequencies, the cents are independent on the involved octave.

In order to study sound pressure level variation of each harmonic, the "sound pressure level" shift function was defined as:

$$L_p shift = L_{por} - L_{pfin}\ (dB), \quad (2)$$

where L_{por} is the sound pressure level of the original sound, and L_{pfin} the final level of sound acoustic pressure.

For the study of the variation of the frequency and the shift of the sound pressure level, we have calculated two types of mean values of the “fdrop” and “Lpshift” magnitudes. On the one hand, for each of the twelve notes A#2-A3, we have obtained the mean value of “fdrop” and “Lpshift”, averaged over the first twenty harmonics of the note. On the other hand, for each of the first twenty harmonics of each note, we have obtained the mean value of “fdrop” and “Lpshift”, averaged over the twelve notes A#2-A3.

3. RESULTS

Figure 1 shows the spectrogram of the A4 note played mezzo forte on an 8’ out-of-cassotto register: there are harmonics approximately up to 10000 Hz. Up to 10000 Hz, the sound pressure level of the harmonics decays with the frequency. From 10000 Hz upwards, the energy of the harmonics is negligible. This is a typical spectrogram of a mezzo forte low or medium pitched note of the accordion.

When the pitch-bending technique is applied to a note, the frequency and intensity of the different harmonics of its spectrogram can be transformed in a different way. In principle, each harmonic could undergo a different change in frequency and intensity when submitted to pitch bending. Figure 2 shows an example of the evolution of the first harmonic of a note.

3.1. Variation of the frequency

In general, if we compare the nth order harmonics of the different notes, we see that the first twenty harmonics of each note experience a similar behaviour when subjected to the pitch-bending technique. Under a bellows-and-finger pitch bending the frequency of the studied notes drops about 25 cents; under an only-finger pitch bending the frequency is lowered approximately 15 cents. Figure 3 shows the frequency drop, measured in cents and averaged over the studied twelve notes experimented by each harmonic. These averaged harmonics undergo a similar drop in frequency, so that the harmonicity is conserved, regardless of the type of pitch bending [14].

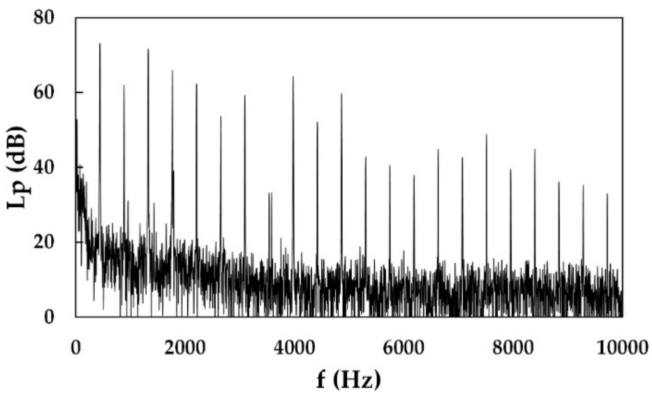

Figure 1. *Spectrogram of an A4 note played mezzo forte on an 8’ out-of-cassotto register.*

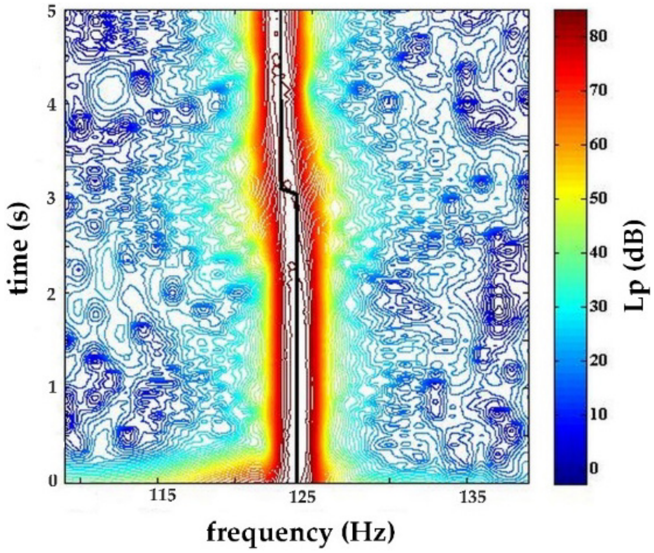

Figure 2. *Spectrogram during pitch bending for the fundamental mode of a B2 note played mezzo forte on an 8’ out-of-cassotto register.*

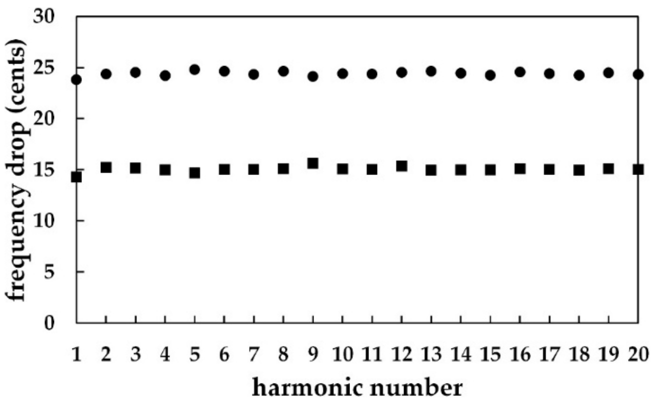

Figure 3. *Frequency drop (averaged over the studied twelve notes) experimented by each harmonic. Circles correspond to pitch bending carried out with bellows and fingers. Squares indicate the pitch bending accomplished with fingers only. The maximum cent error is 0.1 (standard error of the mean, SEM).*

Table 1 shows the frequency drop (now averaged on the first twenty harmonics of each note) on the note for both methods of pitch bending. Table 1 also shows the average values of the frequency shift, as well as their maximum and minimum values for both types of pitch bending.

All notes have a frequency decrease of 10 to 35 cents, that is, the maximum change is less than a semitone. A greater pitch bending could have been achieved if the player had not been asked to achieve the maximum frequency drop after a fixed time (five seconds after the attack of the note). In actual performance, if the goal is the greatest pitch bending possible at the same time

Table 1. Frequency drop (averaged over the first twenty harmonics of each note) for each of the measured notes. The maximum cent error is 0.1 (SEM).

Note	f (Hz)	Bellows-finger		Only finger	
		fdrop (cents)	Max-min (cents)	fdrop (cents)	Max-min (cents)
A#2	117.0	27.0		22.1	
B2	124.0	28.6		15.7	
C3	131.3	29.2		23.7	23.7
C#3	139.0	33.7	33.7	17.4	
D3	148.0	21.2		18.2	
D#3	156.0	20.7		13.6	
E3	166.0	25.3		17.6	
F3	175.7	27.7		15.3	
F#3	186.0	16.0	16.0	9.0	9.0
G3	197.0	27.6		17.7	
G#3	209.0	18.4		9.5	
A3	221.0	16.9		13.4	
Average value		**24.4**		**16.1**	

that controlled (that is, the lowering of the frequency must be well perceived) the time (meter) is not usually fixed. On the other hand, there are other times when the player has to play pitch bending on time; in these cases, he/she can choose freely the range of the pitch bending.

If both methods are compared, it can be seen that the shift in frequency is greater (about 8 cents greater on average) when pitch bending is carried out with the bellows and the finger at the same time (first method).

The average values of the frequency shift for odd and even harmonics can be examined separately. This will be interesting when dealing with the sound pressure level shift. The obtained results for the frequency drop averaged separately over the first 10 odd and first 10 even harmonics show that the decrease of the frequency does not depend on the evenness of the harmonics.

Summarizing this section, the two methods of pitch bending give rise to different results. The frequency of all the harmonics drops in a similar way, so harmonicity is maintained (odd and even harmonics are indistinguishable from one another) and the change in timbre is not due to the shift in frequency.

3.2. Sound pressure level shift

Table 2 shows the sound pressure level of the original sound, the sound pressure level of the final sound, and the "sound pressure level" shift averaged on the first twenty harmonics of each note, for both methods of pitch bending. Data include the twelve notes of the scale going from A#2 to A3. It can be seen that the initial sonority is very similar in both cases; otherwise, both kinds of measurements could not be compared without some kind of normalization [15].

Both types of pitch bending lead to a decrease in sound pressure level, but all the notes suffer a greater lowering when pitch bending is carried out with only

Table 2. Sound pressure level obtained values (averaged over the first twenty harmonics of each note) and L_p shift for both methods of pitch bending. The maximum L_p error is 0.5 dB (SEM).

Note	f (Hz)	Bellows-finger			Only finger		
		L_{por} (dB)	L_{pfin} (dB)	$L_p$shift (dB)	L_{por} (dB)	L_{pfin} (dB)	$L_p$shift (dB)
A#2	117.0	62.0	55.3	6.7	67.4	55.1	12.3
B2	124.0	61.2	54.3	6.9	66.4	57.1	9.3
C3	131.3	63.2	55.0	8.2	68.1	54.2	13.9
C#3	139.0	60.8	53.4	7.4	67.7	55.5	12.2
D3	148.0	61.0	52.5	8.5	65.8	54.7	11.1
D#3	156.0	65.3	56.2	9.1	65.2	54.4	10.8
E3	166.0	66.0	55.9	10.1	66.9	54.3	12.6
F3	175.7	68.8	58.1	10.7	52.0	41.8	10.2
F#3	186.0	66.1	58.7	7.4	66.2	55.4	10.8
G3	197.0	68.0	59.6	8.6	68.7	56.6	12.1
G#3	209.0	69.3	62.5	6.8	70.1	61.8	8.3
A3	221.0	67.1	62.0	5.1	67.6	57.6	10.0
Average value				**7.9**			**11.1**

fingers, instead of being accomplished with both bellows and fingers.

In fact, considering that the free reed is a flow-controlled device, an easy explanation can be given for this phenomenon [16-18]. When gradually closing a valve (by releasing the corresponding button), less and less air reaches the reed, which implies a decrease in energy and a lowering of its frequency and amplitude. In the case of bellows-and-finger pitch bending, this loss of energy is somewhat offset by the action on the bellows. With finger-only pitch bending this compensation does not exist, and hence the consequent larger drop in sound pressure level.

Likewise, the greater decrease in frequency associated with bellows-and-finger pitch bending should be explained by the additional contribution of the bellows. This extra input of energy would allow the reed to vibrate at lower frequencies, avoiding the complete weakening of the harmonics.

Another aspect that we have analysed is the variation of the sound pressure level in both the initial (before pitch bending) and final (after pitch bending) states, in each kind of pitch bending. Figure 4 shows the value of the acoustic pressure level for the first twenty harmonics, an average of twelve notes going from A#2 to A3, before and after pitch bending, for (a) the bellows and finger method, and (b) the only finger method.

Regardless of the kind of pitch bending, the loudness of the original sound is always higher than the loudness of the final sound. The variability of L_{pfin} is greater than that of L_{por}. As it was pointed out, this effect is related to the body's difficulty in making the pitch bending, and the player feels instability in reaching the final pitch [13].

The same pattern of change in the harmonic structure is observed regardless of the type of pitch bending. For the first six harmonics, the even harmonics (2-4-6) experiment a larger descent in their sound pressure level than their corresponding odd harmonics (1-3-5); for the seventh to the twentieth harmonics, the even harmonics suffer a lesser lowering of L_p than their corresponding odd harmonics.

Finally, the interpreter has verified that there is no possibility to bend the pitch with tones from C6 to C#8.

4. DISCUSSION

The pitch-bending fact has been studied with a concert accordion right manual. The bending of the pitch of a note leads to a decrease in loudness and a decrease in frequency.

With respect to changes in the frequency, the results indicate that the differences in the decrease in frequency are not significant throughout the tessitura studied, with a maximum change of less than half a tone. The first twenty harmonics show very similar amounts of frequency variation of each note, and this maintains the harmonicity of the bent note. The lowering of the frequency is greater in the bellows-and-finger pitch bending.

As far as the sound pressure level is concerned, the variability in acoustic pressure levels is higher for the end state than for the initial state, because of the ergonomic difficulties to bend the pitch. Both kinds of pitch bending lead to a decrease in sound pressure level, but the lowering is greater when pitch bending is carried out with fingers only. This fact, along with the greater lowering in frequency when the pitch bending is performed with both bellows and fingers, can be explained in terms of the extra input of energy supplied by the bellows in the bellows-and-finger pitch bending.

The different harmonics experience a different change in sound pressure levels according to a characteristic

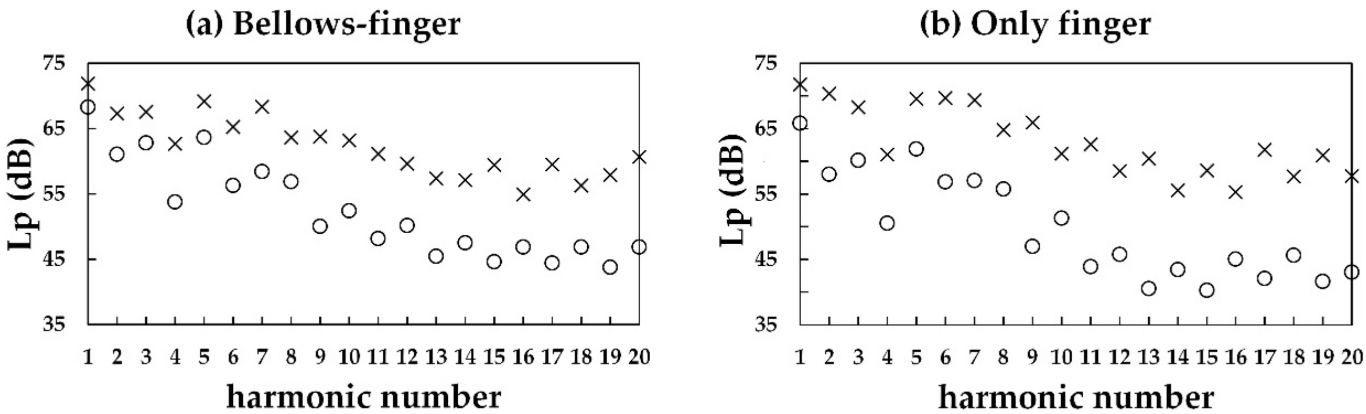

Figure 4. Sound pressure level of the original sound (L_{por} crosses), and sound pressure level of the final sound (L_{pfin} circles) for the first twenty harmonics averaged over the A#2-A3 twelve notes, pitch bending being carried out according to (a) the bellows and finger method, and (b) the only finger method. The maximum L_p error is 0.5 dB (SEM).

pattern similar for all the notes included in these experiments, and independent of the kind of pitch bending.

Two factors seem to control the modelling of pitch bending: on the one hand, the increase in pressure on the bellows; on the other hand, the narrowing or almost choking of the pass of the air through the chamber of the reed plate. To manage the first factor, the performer exerts a greater pressure on the bellows. When dealing with the second factor, the accordionist can release up the button gradually. In some laboratory experiments, Coyle et al. have achieved similar results reducing the volume of the reed chamber; however, this method is not usable in actual performance [19]. Plitnik carried out similar experiments on pipe organ reed tongues [20].

It should be pointed out an important result obtained experimentally: there is no possibility to bend the pitch with tones from C6 to C#8. These notes involve the tongues without a strip (the leather or plastic strip that prevents airflow through the opening of the inactivated tongue), no matter the kind of pitch bending method tested. With these tongues, the interpreter increases the tension of the bellows, while the lack of the strip filters the airflow through the opening of the tongue plate. This is coherent with the recommendations given by Macerollo about avoiding the use of the 4' register when it comes to performing pitch bending [10].

All this suggests that the viscosity of the air has an important role in the drop in frequency. In general, the Reynolds number (Re) characterizes the ratio of the convective inertia forces to the viscosity ones:

$$Re = \frac{V_0 D_0}{\nu_0} \qquad (3)$$

where V_0 is a characteristic or mean velocity of the stream, ν_0 the kinematic viscosity of the air, and D_0 a characteristic longitude of the tube. For a fluid moving through a slot in which the width of the slot (that is, the separation between the walls of the slot) is much greater than its length, the characteristic dimension is twice the width of the slot. This is the case of the duct formed by the gap between the lateral wall of the reed and the internal wall of the slot carved in the reed plate. Taking D_0 as the width of the reed plate, we have $D_0 \approx 2 \cdot 0.0001$m, $\nu_0 \approx 1.5 \cdot 10^{-5}$m^{-2}s (at about 20 °C), $V_0 \approx 10$ms^{-1} (calculated from the stationary Bernoulli equation for a supply pressure of about 40 Pa), the resulting Reynolds number is Re ≈ 133 [17,21].

This approximated calculation means that the viscosity should play an important role when the narrow gap between the reed and the reed plate is considered. On the contrary, the absence of some leather or plastic strip in the highest pitched reeds allows the air to pass through the wider gap between the non-active reed and the metal plate (coming air over a non-active reed moves the reed away from the metal plate), where the effect of the viscosity can be disregarded. Consequently, no pitch bending is produced.

Miklós et al. [22,23] have developed some models in which viscosity is taken into account for the lingual organ pipes. There a Poiseuille flow was introduced to explain the balance between elastic restoring forces and the aerodynamic ones. The authors explain that the main problem is the modelling of the flow in the slit between the reed and the shallot (analogous to the gap between the reed and the reed plate in the case of the accordion). The slit (essentially the thickness of the shallot wall) is not long enough to allow the full development of a laminar flow. Something similar could happen in the case of the reeds of the accordion. In fact, some free reed models show that any subtle change in the modelling of the gap can drastically change the results [24].

T. Tonon took a different approach [18]. He studied the conditions under which the resonances of the chamber of the reed (either as a Helmholtz resonance or as a quarter-wave or even full-wave resonance) can match the resonance frequencies (fundamental or higher harmonics) of the reed itself. In these cases, both resonances interfere causing the reed to lower its frequency. Tonon has patented an ingenious system that allows the performer to bend pitch thanks to a special resonating chamber added to the standard reed chamber [25]. The extra pressure of the fingers on the keys or buttons activates this additional chamber. Cottingham [7] described the whole process.

5. CONCLUSION

Our study has shown how pitch-bending effect leads to both a decrease in volume and a frequency drop. All notes suffer a greater decrease in the level of sound pressure when the musician performs the pitch-bending effect only with the fingers, instead of achieving it with bellows and fingers. The decrease of the frequency undergoes a maximum change of less than half tone in the whole tessitura. Moreover, under an only-finger pitch bending the frequency is reduced by approximately 15 cents, while under a bellows-and-finger pitch bending the frequency of the notes studied falls to around 25 cents.

In regards to pitch-bending effect modelling, previous studies to the conditions for pitch bending-effect suggest that both resonances, the resonances of the chamber of the reed and the resonance frequencies of the reed itself, interfere causing the reed to lower its frequency. Another approach establishes that the control of the effect seems to be due to both, the increase in pressure on the bellows and the narrowing of the passage of air through the reed plate chamber. Consistent with the important role of the viscosity of air in the frequency drop, in the accordion there is no experimental possibility of bending the pitch with the smallest and highest pitched reeds, without a strip covering the slot of the non-sounding reed in the metal plate. In this case, the air passes through the wider gap between the non-active reed and the metal plate and the effect of the viscosity is negligible.

This study may be interesting for experienced or debuting accordionists and their teachers. They can better understand how to activate their instrument, especially in the case of wanting to execute a pitch bending. The specialists in acoustics of free-reed instruments can extend the current knowledge of the aerodynamic modelling of the reed behaviour and the characterization of the accordion timbre.

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