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The Secret of the Bagpipes: Controlling the Bag. Techniques, Skill and Musicality.

When interviewed about the technique of the bag, bagpipe maker and award-winning Galician piper Cristobal Prieto said that. 'the handling of the bag is one of the most important things. The secret of the bagpipes is how one uses the bag [...] You need a lot of coordination: blowing, fingers [...] it depends on the arm, the pressure of the air. The [finger] technique is much simpler. Everyone blows all over the place when they start to play. It's like a car: you have to think how you are going to do all of this at the same time. The use of the bag is the most important aspect, even more than the fingers, [or] velocity'.[1]

Despite their many organological and esthetical differences, bagpipes are all played thanks to the movement of the arm on a bag, creating enough pressure to activate the reeds and produce sound. Repertoires, scales and registers vary according to the instruments and their musical cultures, going from a diatonic scale within a range of a sixth (such as the Greek *tsampouna* or the Tunisian *mizwid*) to a fully chromatic scale over two octaves (the uilleann pipes from Ireland and some Northumbrian small-pipes chanters). Bagpipes in their simplest form are composed of a bag with a blowpipe and a melodic pipe (hereafter referred to as the chanter).[2] Other pipes can then be added such as a second melodic pipe, semi-melodic pipes or drones.[3] The blowpipe is usually, but not always, fitted with a small valve in order to prevent the air from leaving the bag. In models without this system, the piper uses his/her tongue to prevent the air from escaping whilst s/he breathes in. Alternatively, the blowpipe can be fitted to bellows, thus liberating the piper from the action of blowing into the instrument.

Bagpipes can be classified into three different subgroups: single reed bagpipes, double reed bagpipes and hybrid bagpipes with a mixture of single and double reeds.[4] Single reed bagpipes are mainly found in Eastern and Northern Europe as well

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[1] Cristobal Prieto, field interview, Galicia, 16 June 2016.

[2] Jean Pierre van Hees, Cornemuses, *Un infini sonore* (Spezet: Coop Breizh, 2014). The bagpipe's 'melodic pipe' is an organological term proposed by van Hees (2014) referring to what is commonly known as the chanter in English.

[3] A semi-melodic pipe (or semi-melodic chanter) is a pipe that has less finger holes than the main melodic chanter with at least one finger hole, thus enabling the pitch to be modified during the course of a piece. Multiple chanter bagpipes such as the baroque *musette*, the *zampogna*, the *tsambouna* and the *boha* have semi-melodic chanters.

[4] van Hees (2014).

as South-Western France (*boha*, *bodega*) and a few archaic models in Spain. Double reed bagpipes are mostly Italian bagpipes and historical seventeenth- and eighteenth-century instruments from France (musette, *cabrette*). Hybrid bagpipes, such as the well-known Great Highland Bagpipes, are mostly found in Western Europe with double reeds in the chanter and single reeds in the cylindrical drones.

Bagpipes all function on the same basic principle. The bag is inflated and the arm on the bag then exerts enough pressure to activate the reeds, which drives the vibration of the air column in the different pipes. The pressure in the bag is always distributed by the added pressure of the arm, thus ensuring the flow of air into the pipes. Thanks to its mechanism, bagpipes are able to create a continuous sound, similar to the circular breathing technique used in other wind instruments.

In this research, we endeavour to understand how the bagpiper exerts control on his/her bag. Understanding this may enhance our comprehension of the importance of the arm in a musical context. Our main questions are: what role does the arm have in the control of the instrument? Is the bag controlled with musical intention? Leading from this, further questions can be asked such as how does this influence the instrument's repertoire and the musician's performance?

In 2016, the inter-institutional Geste-Acoustique-Musique project provided the perfect working environment to combine this empirical knowledge with scientific data. The creation of an interdisciplinary team including an ethnomusicologist and two acousticians led to the analysis of control and mastery in a precise and controlled environment fed by both disciplines. The ethnomusicologist brought an intimate knowledge of the instrument and its practice within a cultural framework whilst the acousticians were able to target the relevant technical aspects related to the performance and the control of the instrument, informed by prior studies on wind instruments.[5]

To answer the research questions, we will present data collected during two experiments in different cultural contexts and with musicians of different levels. Using scientific equipment, we were able to measure the airflow, the pressure in the bag, and the angle of the arm, as well as make videos and sound recordings. In order to complement our scientific data, we carried out an online questionnaire, which allowed us to gather information about respondents' subjective impressions on the control of their instrument. With acoustic measurements, qualitative data and an ethnomusicological framework, this research offers a multidimensional and interdisciplinary study of the control of the bagpipe's bag. While we concentrated on the acoustical aspects of our research in a companion paper, recently published in the *Journal of the Acoustical Society of America* (2017),[6] this article presents the findings of the first multidimensional and interdisciplinary study of the control of the bagpipe's bag, making our results available to the (ethno)musicological community.

THE TECHNIQUES OF THE BAG

An Online Bagpipe Questionnaire

Complementary to the scientific study, an online questionnaire was formulated, focusing on various bag techniques. The answers of the online questionnaire enabled us to compare the bagpipe players' comments with what was observed during the mechanical and acoustical experiments.

In order to cover the most techniques possible, the questionnaire was geared towards the international piping community, reaching pipers from different musical traditions. Our goal was to understand how pipers controlled their bag, which were their teaching methods and what, in their opinion, constituted good bagpipe practice. We asked each person about their musical background, their practice and their understanding of expert playing. 215 responses were collected, a majority of which were provided by hybrid bagpipe players (87%). Alongside these, 10% played single reed systems (*tsambouna*, *duda*, *gaida boha*), 2% played from double reed systems (baroque musette, *cabrette*) and one person played an electronic bagpipe with no reed system in place (see Table 1).

Table 2 details the 35 different bagpipes played by

[5] See for example: Camille Vauthrin, Benoît Fabre and Isabelle Cossette, 'How Does a Flute Player Adapt His Breathing and Playing to Musical Tasks?' *Acta Acustica united with Acustica* 101 (2015), pp.224–237; Vauthrin, Camille, 'Acoustique et respiration dans le jeu musical des instruments à vent: application aux flûtes', PhD Dissertation, Université Pierre et Marie Curie - Paris VI, 2015; K. Berger, 'Respiratory and articulatory function in wind instrument performance', *Journal of Applied Physiology* (1965), pp.1217–1221.

[6] Augustin Ernoult, Cassandre Balosso-Bardin, Ilya Franciosi, Patricio de la Cuadra, and Benoît Fabre. 'Music in a bag? Controlling the bag of Majorcan and Galician bagpipes', *The Journal of Acoustical Society of America* 142/3 (2017), pp.1454–1465.

Table 1. Number and percentage of different bagpipe systems used by questionnaire subjects. Online bagpipe technique questionnaire (2016).

Bagpipe system	*number*	*%*
hybrid	188	87
single	22	10
double	4	2
other	1	0
Total	**215**	**100**

the pipers. The most common bagpipes played by the respondents were the Great Highland bagpipes with 98 players (46%), the French Central bagpipes with 19 players and the UK Border pipes with 16 players.

Table 2. Types of bagpipes played by questionnaire subjects.
Online bagpipe technique questionnaire (2016).

Bagpipe origin	*number of players*	*system*	*%*
Bodega, France	1	single	0.5
Boha, France	3	single	1.4
Border Pipes, UK	16	hybrid	7.4
Cabrette, Auvergne	2	double	0.9
Chabrette, Limousin	1	hybrid	0.5
Cimpoi, Romania	1	single	0.5
Cornemuse, Central France (G and/or D)	19	hybrid	8.8
Czarny koziol, Poland	1	single	0.5
Electronic pipes (Redpipe)	1	other	0.5
Dudas, Latvia	1	single	0.5
Duda, Belarus	1	single	0.5
Dudy, Czech	1	single	0.5
Dudey, late 14th century (D)	1	single	0.5
English double pipe	1	hybrid	0.5
English Great pipe	2	hybrid	0.9
Flemish bagpipe	8	hybrid	3.7
Gaida (Greece, Thrace, Macedonia)	6	single	2.8
Gaita, Asturiana	1	hybrid	0.5
Gaita, Gallega	10	hybrid	4.7
Gaita, Portugal	2	hybrid	0.9
Gajde, Croatia	1	single	0.5
German Medieval bagpipe	6	hybrid	2.8
Great Highland bagpipe	98	hybrid	45.6
Leicestershire bagpipe	2	hybrid	0.9
Medieval bagpipes	1	hybrid	0.5
Musette (Baroque)	2	double	0.9
Northumbrian small-pipes	3	hybrid	1.4
Pibau cyrn, Wales	1	single	0.5
Piva, Italy	1	hybrid	0.5
Schaeferpfeife, Germany	2	hybrid	0.9
Scottish small-pipes	6	hybrid	2.8
Torupill, Estonia	1	hybrid	0.5
Tsambouna, Greece	4	single	1.9
Uillean pipes, Ireland	5	hybrid	2.3
Xeremies / *Sac de Gemecs*, Mallorca/Catalonia	3	hybrid	1.4
TOTAL	**215**		**100**

BLOWING STEADY

The overall consensus for a good bagpipe technique is to create an arrival of air as steady as possible. The well-known Great Highland bagpipe, for example, is taught rigorously to encourage 'steady blowing'.[7] Unsurprisingly, the most striking examples of the steady blowing technique in the online questionnaire were gathered from Highland bagpipe instructors, who used a pressure gauge or manometer in order to encourage students to maintain an extremely steady pressure. One piper wrote that, '[to make] sure [there is] constant pressure on the bag at all times, [he would use a …] manometer'. Another piper shared a similar method, which involved 'Listening [out] for steady drones, tuning [and a] manometer,' and another used a 'water manometer to observe breathing and squeezing cycles'. This self-monitoring method is advertised commercially to beginners but also to experienced players in order to 'take [their] steadiness to even greater levels which will allow to tune [their] instrument with greater precision'.[8] However, Roddy MacLeod, director of the National Piping Centre in Glasgow and one of the world's most prominent Great Highland bagpipers, nuances this by acknowledging that his particular sound is obtained by a blowing technique with 'very many variables and slight variations in pressure [which] caus[es] big changes in overall sound'.[9] MacLeod developed this skill through years of experience,

[7] Simon McKerrell, 'Sound performing: sound aesthetics among competitive pipers', *International review of the aesthetics and sociology of music* 42/1 (2011), pp.165–187, at p.182.

[8] See the website, <http://www.bagpipegauge.com/p/how-it-works.html>, last accessed 27 August 2017.

[9] McKerrell (2011), p.183.

Table 3. Percentage of responses for the question: which is the main way of controlling the following effects when you play? Percentages above 50% are highlighted in bold. For every percentage, its corresponding percentage excluding the 'Not Applicable' (N/A) answers has been added (grey columns). Online bagpipe technique questionnaire (2016).

Which is your main way of controlling the following effects when you play?	controlled with the bag		controlled with the fingers		controlled by the breath		N/A	Total
	% of total answers	*% excluding N/A*	*% of total answers*	*% excluding N/A*	*% of total answers*	*% excluding N/A*		
Attacks (start of piece)	**77**	**79**	10	10	10	10	2	100
Cut offs (end of piece)	**92**	**93**	4	4	3	3	2	100
Long notes	47	**49**	24	25	24	26	6	100
Breaks in music	41	**54**	26	34	9	12	24	100
Tuning	**62**	**69**	7	8	20	22	11	100
Register changes	25	**50**	21	43	4	7	50	100
Dynamics	14	26	35	**65**	5	9	46	100
Timbre	19	33	28	48	11	19	42	100
Phrasing	2	2	**86**	**94**	3	4	9	100
Vibrato	3	4	**67**	**95**	1	1	29	100
Glissando	1	2	**60**	**97**	1	2	39	100
Harmonics	20	41	21	44	7	14	52	100

creating his personal sound identity. Indeed, as McKerrell points out, even in Scotland where the teaching structure for the Great Highland bagpipe is highly organised and monitored, 'blowing is largely a non-verbalised skill, each player learns it individually and develops their own technique'.[10]

Despite this lack of verbalisation, bagpipe experts agreed that the breathing technique and the bag were essential elements of their playing.[11] Similarly, Tim Rice conducted a listening experience with Bulgarian bagpipe players.[12] According to his perceptive study, the main criterion for a 'master' piper was the control over the instrument, audible in the first few seconds of the recordings. When listening to a master playing, expert listeners commented on the immediacy of the control: 'What control! [...] Absolute mastery of the instrument [...] He finds the best sound and then sets the *gaida* into motion [...] From the very beginning I understand that a master is playing'.[13] The same expert commented on an amateur *gaidar*'s opening notes: 'This sound goes where it wants to, not where one wants to place it. He doesn't control the way he plays the highest tone on the *gaida*'.[14] Utter control over the instrument, as Rice points out in his concluding points, is 'the first sign of a master musician'. He then identifies six other precise aspects that underline a musician's artistry which apply to their repertoire, style, ornamentation and musicality. These are perceived by experts to an extreme level of detail, so much so that Rice did not insert any musical notation in his article and at times struggled to identify the minute differences prior to the experts pointing them out to him.

The Bag as an Expressive Tool

Although the examples given above show that the control of the bag is a subtlety mainly perceptible to fully trained ears, musicians who play single reed systems such as the Greek *tsambouna* or the Iranian *nay-anbān* use clearly identifiable bag techniques that are explicitly used in the music. Georgios-Periklis Schinas, in his PhD Dissertation

[10] Ibid.

[11] McKerrell (2011), pp.182–183.

[12] Timothy Rice, 'Evaluating artistry on the Bulgarian bagpipe', *Ethnomusicological encounters with music and musicians*, ed. Tim Rice (Farnham, USA: Ashgate Publishing Limited, 2011), pp.111–128.

[13] Kiril (pseudonym created by author) interviewed in Rice (2011), p.116.

[14] Kiril interviewed in Rice (2011), p.115.

on *tsambouna* playing in the Dodecanese islands,[15] identifies four bag techniques that depart from the more usual 'principle of steady air', described by Western pipers, especially Highland pipers.[16] These techniques include first of all the rhythmical accentuation: the rhythmical pressing of the bag to stress the beat either on long notes or during the melody. Secondly, Schinas mentions pauses in the music, a rare occurrence according to him, more to show the ability of the piper who does it 'because he can'.[17] Breaks in the music seem to be a common feature in different piping traditions: 76% of the pipers responded to its use within the questionnaire. Of these, 54% confirmed that they used the bag as the main way of controlling the pauses, 34% used their fingers and 12% used their breath (see Table 3).

Adding to this, the beginning and end of bagpipe pieces are highly controlled moments as the piper controls not only the chanter(s) but also the drones.[18] These are handled in different ways depending on the instrument and its morphology, but pipers seem to agree that these are mainly techniques controlled by the bag: 77% confirmed that they controlled the beginning of a piece with the bag and no less than 92% of the pipers answered that they controlled the cut-off of a piece with the bag. In Galicia, where the drones and chanters are supposed to start together, the piper will blow the bag as much as possible without creating any sound and then push the arm onto the bag in a quick movement so that all pipes start sounding at the same time. In Scotland, bagpipes are set into motion in a similar way with a strong blow to the bag to set all the reeds in motion together. This was illustrated by a piper who noted that he 'strike[s] [the] bag from the side to prevent a bass drone roar when starting'.[19] In order to achieve the same effect, Mallorcan pipers put their index finger on the top of the drone stock so that no air leaks while they fill the bag with air. They then let go of their index finger whilst simultaneously exerting pressure with their arm so that both drones and chanter sound together. At the end of the piece, the pipers will let go of the chanter with their right hand and block the drones again as they end the melody, creating a clear-cut end to the sound. Bulgarian single reed *gaida* players use a similar technique at the beginning of a melody. They fill the bag up with air whilst holding the end of the drone closed with their finger; they then play the introductory notes on the chanter and only then release the drone, thus bringing in the tonic musically, avoiding the groans often heard when the bag is inflated and the drone is left open. Ending the tune also demands equal skill: the piper will have to gage how much air is in the bag so that when they release the pressure of the arm, there will not be enough pressure in the bag for the drones to continue playing.

A small variation to this technique would be the management of the bag pressure by pipers who sing whilst they play. This is mainly relevant to mouth-blown pipers who have to coordinate their breathing pattern with the singing. Two pipers, a Portuguese *gaita* player using a hybrid system and a *tsambouna* player using a simple reed system, both mention that they have to anticipate their coordination when they sing, 'filling air before I sing [and being] aware of filling air immediately when a phrase ends'.[20]

Thirdly, Schinas explains how *tsambouna* players can expand the scale. The instrument has a register that spans a sixth (a fifth plus the sub-tonic). By pressing the bag on the highest note, the musician can make the reed rise a tone, adding an extra note to the scale. The expansion of the scale on the *tsambouna* can be associated with a common bag technique used in several bagpipes which is the additional pressure required to overblow the octave. Depending on the instrument, this can be achieved solely through increased pressure on the bag or through a combination of fingering and pressure. Indeed, of the 107 pipers for whom this technique was possible on their pipes, 50% answered that they controlled the register with their bag, 43% with their fingers and 7% with their breath. An English Border piper mentioned that he coordinated his breathing pattern with the music 'especially if over-blowing in octave 2'. Another Border piper commented further: 'Higher up in the register requires higher pressure which is easier to achieve on a fuller bag, so I will inflate more for sections higher in the register'.

Additionally, much like flute players adjust the

[15] Georgios-Periklis Schinas, 'Η Τσαμπούνα του Αιγαίου: Οργανολογία, ρεπερτόριο και η σύγχρονη αναβίωση', PhD Dissertation, National and Kapodistrian University of Athens, 2015.

[16] See McKerrell (2011).

[17] Periklis Schinas, personal communication, 23 May 2016.

[18] See Balosso-Bardin et al. (2016).

[19] Online bagpipe technique questionnaire (2016).

[20] Online bagpipe technique questionnaire (2016).

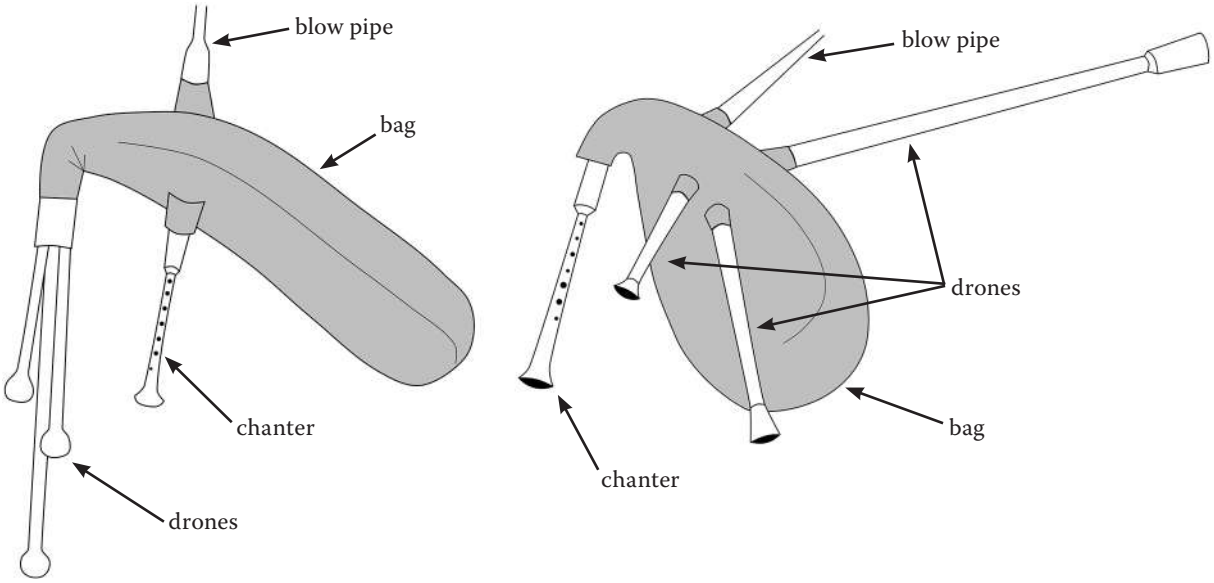

Figure 1. *Schematic diagrams of (left) the xeremies (Mallorca) and (right) the gaita (Galicia). Source: Ernoult et al. (2017), p.1455.*

air-jet speed and the position of their mouth to fine-tune their notes,[21] pipers can also adjust their tuning by slightly varying the pressure within the bag on specific notes. 'Some notes require a bit more, some less pressure' commented a central France bagpipe player in the questionnaire. In Galicia, for example, forked fingerings are well known for needing specific adjustments with the bag pressure.[22]

Finally, Schinas adds a fourth technique: stressing a particular note for expressivity. This differs from the first ornamentation as it emphasises a given note rather than accentuating the rhythm. It is also generally used on the 5th tone of the bagpipe's scale, as a stylistic ornamentation adding emphasis and volume, and slightly raising the pitch in a voluntary and controlled manner.[23] This last technique can be associated with the vibrato. Although most commonly achieved with the fingers wavering over an open tone-hole, as confirmed by 67% of the questionnaire participants (29% thought this was not applicable to their instrument), the vibrato effect can also be used with the bag by moving the chanter up and down or towards and away from the bag, thus varying the shape of the bag and its internal pressure. Only six pipers confirmed that this was a technique that was controlled by the bag including four single reed system pipers: three *tsambouna* and one Croatian *gajde*. Tim Rice also documents its use on the Bulgarian gaida for the highest note, A, where all fingers are off the chanter. For this note, good pipers produce a vibrato 'by varying slightly the pressure on the bag'.[24]

Despite McKerrell's remark that the use of the bag was a 'largely non-verbalised skill' learned over years of practice and experience,[25] it seems that in single reed bagpipe cultures, more specifically the Greek island bagpipes, the techniques are so inherent to the music and its style that they are at the very least partially verbalised by the teachers. For example, when learning the *tsambouna* in his teenage years in a folk music school, a questionnaire respondent from Greece noted that his teacher would point out

[21] Vauthrin (2015).

[22] Studies of how sound changes with blowing pressure have been carried out previously. See Ernoult et al (2017), and Sandra Carral, D. Murray Campbell and Thomas D. Rossing, 'Relationship between blowing pressure, pitch, and timbre of a Scottish bellows blown border bagpipe', *Proceedings of the Stockholm Musical Acoustics Conference* 1 (2003), pp.251–254.

[23] Schinas (2015), pp.171–174.

[24] Rice (2011), p.117. Although this may seem to affect the stability of the drone in the *gaida*'s case (the *tsambouna* does not have a drone), Ernoult et al. (2017, p.1458) show that, for the Mallorcan and the Galician bagpipes, the drones are less sensitive to pressure changes than the chanters. The sensitivity rates depend on the instrument but if such a technique is used for the vibrato, one might assume that the musician knows their instrument well enough to manage this sensitivity and therefore maintain a stable drone when relevant.

[25] McKerrell (2011), p.183.

the notes that needed specific emphasis with the bag.[26] This highlights that, at least in some musical traditions, a specific range of bag techniques are consciously used as stylistic elements within the music.

The second part of this article will detail the results of the acoustical and mechanical study carried out by the interdisciplinary team of acousticians and an ethnomusicologist along with the help of instrument makers and local musicians. Focusing on the control of the bag, these will highlight how musicians with different expertise levels manage the instrument and how they are able to create the variations detailed above.

THE EXPERIMENTAL SET-UP

The Instruments

The instruments chosen for the experimental study were two Western mouth-blown hybrid bagpipes with a double-reed chanter and single-reed drones. Although not heavily represented in the online questionnaire (2016), Galician and Mallorcan bagpipes are played by a significant number of players locally. Both instruments were also well known to the ethnomusicologist on the team, both as a performer and as a researcher, and she was able to provide in-depth cultural, musical and organological information on both instruments. Both bagpipes from the hybrid family, the Mallorcan *xeremies* and the Galician *gaita*, illustrated in Figure 1, are closely related organologically whilst presenting enough differences to be used in a cross-cultural study.

Both instruments used are products from late twentieth-century folk music revivals. This means that they are steady systems with a clear tonic, tuned with pure fifths and fourths whilst aiming towards an equally tempered scale. Both instruments use double-reed chanters and three single-reed drones. Both are mouth-blown and have synthetic bags. In addition, the two instruments are played within a dance tradition but are also used for composed instrumental music. Although the two instruments were changed throughout their revival process, the range was devised differently: while the *xeremies* remained within the register of a ninth (an octave and the subtonic), the *gaita* was developed to play into the second register, reaching up to a fifth above the octave. Most compositions that retain elements of the traditional style rarely go beyond one or two tones into the second register and the higher notes are mainly used by experienced players to display their skills.

Table 4. Technical comparison of the Galician gaita and the Mallorcan xeremies. Source: Ernoult et al. (2017), p.1460.

Bagpipe	Galician	Mallorcan
Diapason	$A_4 \approx 440$Hz	$A_4 \approx 472$Hz
Bag volume	V ≈ 9L	V ≈ 15L
Chanter pitch	[B_4, E_6]	[B_4, C_6]
Chanter reeds	double cane reed	
Drones pitch	C_3, C_4 (G_4 unplayed)	
Drones reeds	single, cane	single, plastic
Chanter onset	≈ 5kPa	
Chanter offset	≈ 4kPa	
Drone onset	≈ 4kPa	≈ 1kPa
Drone offset	≈ 2kPa	< 1kPa
Pressure range	[5, 6.5] (kPa)	
Chanter sensitivity	≈ 9cts/kPa	≈ 17cts/kPa
Drone sensitivity	≈ 4cts/kPa	≈ 15cts/kPa
Air consumption	≈ 5cL/s	≈ 7.5cL/s

Key

kPA	Kilopascal (unit of pressure)
V	Volume
L	Litres
cL/s	Centilitres/Second
cts/kPa	Cents/Kilopascal

There are a few main differences between the instruments, as shown in Table 4. The pitch of the two pipes is half a tone apart. During the revival, the *xeremies* players decided to keep the pitch at the most common frequency, which meant that the tonic was set at C# (or A_4=472Hz).[27] In Galicia, the revival period led instrument makers to choose a common pitch throughout the whole region. Previously, bagpipes were regularly found in C, C# and even D depending on the area and the bagpipe maker. The standard pitch is now C (A_4=440Hz). The difference in the size of the bags is notable, with a volume nearly twice as high for the Mallorcan *xeremies*. Finally, although both bagpipes used cane reeds for the chanter, they were fitted with different drone reeds: plastic for the *xeremies* (Seipal reeds, manufactured in Galicia by Seivane) and traditional cane for the *gaita*. The two different reed set-ups represent the different combinations present in the bagpipe world very well. According to the questionnaire, 69% of the pipers use cane reed for their chanters and 26%

[26] Thodoris Ziarkas, personal communication, March 2017.

[27] Cassandre Balosso-Bardin, 'The Mallorcan bagpipes (*xeremies*): anthropological portrait of an instrument', PhD Dissertation, SOAS, University of London, 2016a, p.90.

Table 5. Type of reeds used by pipers in percentage (number of answers in brackets). Online bagpipe technique questionnaire (2016).

What kind of reeds do you use?	Cane reed	Plastic reed	I don't know	No Answer	Total
Chanter	69% (148)	26% (55)	2% (4)	3% (7)	100%
Drone 1	21% (46)	69% (148)	3% (6)	7% (14)	100%

use plastic reeds (see Table 5). However, Table 5 also shows that only 21% pipers use cane reeds for their first drone (considered here as the main drone) whilst 69% use plastic reeds for their first drone.

When cross-examined, we can see that only 18% of the pipers use cane for both the chanter and the main drone (the set-up of the *gaita*) compared to 46% who use cane chanter reeds in combination with plastic drone reeds (the set-up of the *xeremies* used in this experiment). On the other hand, only very few pipers who use a plastic chanter reed also use cane for their main drone reed (3%). Most pipers with plastic chanter reeds also use plastic reeds for their first drone (44%). Overall, all bagpipe systems (single reed, double reed and hybrid systems) used both plastic and cane reeds. Within the single reed systems, however, only a total of three Western bagpipes (the French *boha* and the Welsh *pibau cyrn*[28]) used plastic reeds. The 14 other single reed bagpipes whose players responded to this question, used cane reeds.

The use of cane or plastic reeds is a choice made by the musicians and/or the bagpipe makers. In his article, McKerrell notes the wide variety of reeds and reed materials used by Great Highland Pipers and the tendency to prefer cane for the 'best and richest sound available' but to favour plastic for competitive piping in order to 'stabilize tuning' and increase the 'reliability of the drone reeds during extended competitive performance'.[29] A perceptive study on bagpipe drone reeds by Paquier and Moigne showed an overall preference for cane reeds, although pipe soloists and pipe band members had no systematic preference when listening to its sound.[30] This echoes competition piper Willie McCullum's words when interviewed by McKerrell in 2002: 'There is a small difference with cane, I think sometimes it's over-rated [...] One competition I played in and I hadn't told anyone [that I was playing synthetic drone reeds ...] I asked a few people [...] certainly four [...] who are absolute legends of piping and sound and they didn't know'.[31] Paquier and Moigne's study did show, however, that two musicians using in turn cane and synthetic reeds had very different reactions to the materials,[32] which suggests that it is the musician's feeling rather than the sound emitted which may lead to a preference for one material or another. The two instruments used for this study represent two common reed set-ups, both found comfortable by musicians in general.

Finally, the last main difference between the two bagpipes is the size of the bag: the volume of the Galician bag is almost half the size of the Mallorcan bag. This organological difference led us to believe

Table 6. Percentage of different combination of reeds used by pipers with at least one chanter and one drone. Only 87% of the subjects gave relevant answers to both questions. The two combinations present in the two different instruments used for the experiment are highlighted in grey. Online bagpipe technique questionnaire (2016).

Reed combinations	Cane drone 1	Plastic drone 1	Total
Cane chanter reed	18% (39)	**46**% (98)	64
Plastic chanter reed	3% (6)	20% (44)	23
Totals	21	66	87%

[28] The Welsh bagpipe may be a recent interpretation of a possibly ancient local instrument. There are no sources to prove its historical existence. However, despite its potential recent invention, it is a single reed system within the Western bagpipe world and is therefore included in this list for the purposes of this study.

[29] McKerrell (2011), p.167.

[30] Mathieu Paquier and Cédric Moign, 'Quality of bagpipe drone reeds: plastic versus cane?' *Forum Acusticum conference proceedings* (Budpest, 2005), pp.423–428.

[31] McKerrell (2011), p.180.

[32] Paquier and Moign (2011), p.425.

that the comparison between the two instruments would be relevant, as we were observing the control of the bag. Would a larger bag lead to a different control strategy?

THE SET-UP

In order to observe the activity of the pipers and their interaction with the bag, we measured four different parameters: the pressure inside the bag, the airflow of the musician, the sound and the movement of the arm (see Figure 2, colour section).

The pressure was measured by a pressure transducer (Endevco, CA), inserted into one of the drones, which gave direct access to the bag. In both instruments, this meant that only the two larger drones were functional: the tonic and the fifth. The airflow was measured by a Hans Rudolf Pneumotachometer[33] inserted between the blowpipe and the instrument. While we were able to source a shorter blowpipe for the Galician *gaita*, thus lessening the distance between the musician and the bag, this was not possible with the *xeremies*. The sound was recorded with two stereo microphones placed about 3m away from the instrument. The quality of the sound was difficult to monitor in the different field locations but the recordings were devised in order to provide an accurate pitch detection, an important parameter of the analysis Finally, a simple motion capture system was set up in order to monitor the movement of the piper's arm. Similar to the sound recording, this was to gather a point of reference and to monitor when the piper's arm was changing direction rather than a fine-tuned 3D study, which would have necessitated a laboratory setting. As shown in Figure 2 (colour section), this set-up generated four different sets of data. From the microphone recordings, pitch variations for both the chanters and the drones were extracted and displayed as a difference in cents from a tuning reference. The tuning reference was based on the mean frequency of the drone for each musical example. The chanter's tuning was then considered, with pure intervals for the tonic, fourth and fifth.

The choice of this tuning was based on the practical use of the instruments by the musicians. In Mallorca, for instance, the tonic, fourth and fifth degrees of the scale are fundamental for traditional and composed repertoire, both during the introduction when the instrument is tuned and the actual performance. The second, third, sixth and seventh degrees are used as passing notes, embellishments, but rarely as pivotal notes on which the piper will dwell. Even after the manufacturing revival of the *xeremies*, the tonic, fourth and fifth remained key notes which were, by the nature of the instrument, tuned to the drone and therefore remained closer to pure intervals than their tempered equivalent.[34] In our data, we therefore assume that the pipers are tuning the fourth, fifth and octaves in relation to the drones and are aiming for pure intervals. The data shows how the note varies around this ideal tuning. Variations of 5 cents between C_5 and C_6, the main register of both bagpipes, are very subtle and perceived with difficulty.[35]

The second data set provides information on the pressure inside the bag. Experiments both in a laboratory setting and in the field enabled the team to establish that the pressure inside both bags ranged from 5.1kPa to 6.4kPa for the Galician bagpipe and from 4.9kPa to 6.7kPa for the Majorcan bagpipe.[36] This range is similar to that already observed for Scottish bagpipes, for which the bag pressure ranges from 6kPa to 7.5kPa.[37]

The third set of data is the airflow. This allowed us to monitor when and how much the musician is blowing into the bag. This not only enabled us to visualise the temporal evolution of the musician's breaths but also to calculate how much air each bag consumed: around 5L for the Galician *gaita* and 7.5L for the Mallorcan *xeremies*.[38]

Finally, the fourth set of data refers to the movement of the arm. Figure 3 shows where the reference points for the arm movement were placed: one on the shoulder, one on the hip and one on the elbow. The shoulder-hip line provided the reference to calculate the movement of the elbow. The goal of this simplified set-up was not to create exact calculations of the angle at which the pipers moved their arms,

[33] Hans Rudolf is a manufacturer of respiratory products based in Shawnee, Kansas, USA. See <http://www.rudolphkc.com> for more information, last accessed 29 September 2017.

[34] See Balosso-Bardin (2016a), pp.90–104.

[35] See Brian C. Moore, *An Introduction to the Psychology of Hearing* (London: Academic Press, 1997).

[36] Ernoult et al. (2017), p.1458.

[37] Roger B. Dannenberg, Ben Brown, Garth Zeglin and Ron Lupish. 'McBlare: a robotic bagpipe player', *Proceedings of the 2005 conference on New interfaces for musical expression* (Singapore: National University of Singapore, 2005), pp.80–84, at p.81.

[38] Ernoult et al. (2017).

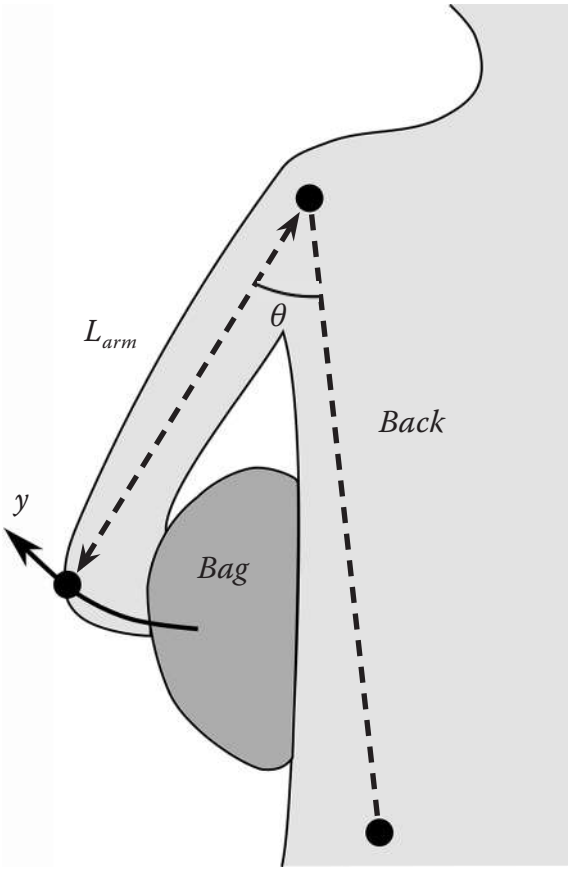

Figure 3. *Diagram of the simplified motion capture set-up. Each dot represents a reference point. Source: Ernoult et al. (2017), p.1457.*

but rather a precise understanding of when the arm was moving towards and away from the body. In Figure 2 (colour section), the data emerging from the calculations of the arm movement provides us with a line moving above and below a referential '0'. When the line is in the positives, the arm is moving away from the body. When it is in the negatives, the arm is moving towards the body.

The combination of the inflow measurements with the arm movement enables the visualisation of the synchronisation between the arm and the breathing, one of the first techniques taught to bagpipe students in order to create a steady sound. This was detailed by one of the pipers in the 2016 online questionnaire: 'Make sure [the] bag is tight with no leaks. Keep arm in contact with bag at all times. Blow regularly [...] Practice playing one note [...] until it is steady'. Looking closely at the example in Figure 2, played by an intermediate *gaita* student (piper 'A', see below), we can observe the regular breathing pattern of the piper: ten breaths within 30 seconds, each approximately three seconds long with a one second break between each break. If we now observe the arm pattern we can see that the arm moves away from the bag at the same time as the musician blows into the pipes. When the musician stops blowing, the arm moves closer to the bag. This indicates a precise synchronisation between the inflow and the arm movement. The combination of these two elements creates a stable pressure within the bag, visible on the third line of information in Figure 2. Here, the pressure is around 5.4kPa, with slight variations over the length of the notes. This stable pressure enables the musician to play steady notes. In this example, the drone is stable, providing a steady reference for the tuning of the melodic chanter. Over this drone, the musician plays three long notes of about ten seconds each: C_5, G_5 and C_6. The note C5 is in tune with the drone, G_5 is around 10 cents low and C_6 is about 5 cents below the tuning reference provided by the drone.

THE MUSICIANS AND THE MUSIC

For each bagpipe, three musicians with different levels of practice were recorded. Galician player 'A' is a young man who studied bagpipes on and off for 15 years and maintains an amateur practice. Galician piper 'B' is a proficient player, winner of a several local folk music contests with the traditional quartet formation. Galician player 'C' has an international profile and is considered as one of the best *gaita* players of his generation.

Majorcan player 'D' is an adult beginner, who has been playing for two years. The *xeremies* were his first instrument and he has no previous musical experience other than singing in an amateur choir. Majorcan player 'E' is a young player with 12 years' experience and is one of the most prominent next generation pipers on the island. Finally, Majorcan player 'F', one of the pioneers of the *xeremies* revival movement, is regarded as one of the best pipers of the island.

These musicians were asked to play several exercises: long steady notes (C_5, G_5, C_6), long notes with an intended crescendo and decrescendo (C_5, G_5, C_6) and finally diatonic scales that covered the entire range of the instrument. All these exercises were played only with the lowest drone (C_3); the other drones were muted. The musicians also played an imposed musical piece. In Mallorca, they were all asked to play the Bolero de Santa Maria, a 3/4 dance in C major composed by revivalist Pep Toni Rubio in the 1980s[39] and well known by bagpipe

[39] See Cassandre Balosso-Bardin, 'Xeremiers de sa Calatrava, from heyday to unemployment: lives dedicated to the Mallorcan bagpipes', *Yearbook for Traditional Music* 48 (2016b), pp.48–70.

Table 7. Criteria for the making of an excellent piper classified by order of importance based on the questionnaire answers of 215 pipers. Online bagpipe technique questionnaire (2016).

	Percentage of answers labelled 'very important' and 'crucial'
Tuning of chanter and drones together	84
Musicality/phrasing	80
Rhythm	79
Tuning of drones	75
Tuning of chanter	74
Stability of chanter	69
Stability of drones	69
Knowledge of style within a repertoire	46
General knowledge of ornamentation	41
Local ornamentation knowledge	36
Virtuosity	27
Quantity of repertoire known	17

players of all levels. In Galicia, the imposed piece was Loliña, a well-known 6/8 melody played in traditional contexts. The Galician musicians were then asked to play a piece of their own choice with pauses within the music as this is a musical effect used in this particular bagpipe culture. This was not required of Mallorcan pipers as their repertoire, whether traditional or more modern, does not use such stops within the music. During these musical examples, the number of drones used was chosen by the musicians. Majorcan players used the two lowest drones (C_3 and C_4) and the Galician musicians used only the lowest drone (C_3).

LEARNING THE BAGPIPES – SKILL AND TECHNIQUE

One of the questions in the online questionnaire was: 'What, in your opinion, makes an excellent piper?' The pipers were asked to rate the importance of each criterion by choosing between the following categories: not applicable, not important, somewhat important, important, very important and crucial. The most highly rated elements were first technical, then musical. Table 7 shows their percentage of responses rated as 'very important' or 'crucial' for each criterion.

The top three categories for the making of an excellent piper according to 215 pipers were: 1) the ability to tune the chanter and the drones together (84%), 2) the musician's musicality and/or phrasing (80%), and 3) the musician's rhythmical abilities (79%). The tuning of the chanter and the drones as separate entities follow immediately, demonstrating the importance of tuning. However, the first response demonstrates that it is the relative tuning of all the pipes that is important rather than the discreet tuning of each element. Indeed, the importance of tuning the chanter and the drones together is a criterion that appears in testimonies by competitive Highland pipers: 'you need to check the chanter with the drones, that's when you need to get the real test, whether the intervals are right or not. The drones will tell you if the chanter sound is any good'.[40] Returning to the questionnaire, the stability of the chanter and the drones come next (69% consider this as very important or crucial), followed by the knowledge of style within a repertoire (46%). Interestingly, the quantity of repertoire known to the musician comes last (34% rated it as 'somewhat important'), preceded by the musician's virtuosity (although 38% did rate it as 'important').

Learning the Skills: The Technical Continuum

As Cristobal Prieto pointed out in his interview, the first thing to manage when playing the bagpipes is the coordination of the many different elements that enable the instrument to sound: the breath, the arm and finally, the fingers. When asked about their teaching techniques on the online questionnaire, many teachers emphasized the necessity of gradually learning to control the instrument by playing first with the drones and then long notes on the chanter to allow the student to create a 'steady sound'. One person, for example, revealed their method in the following terms: 'Make sure bag is tight with no

[40] Greg Wilson interviewed in McKerrell (2011), p.167.

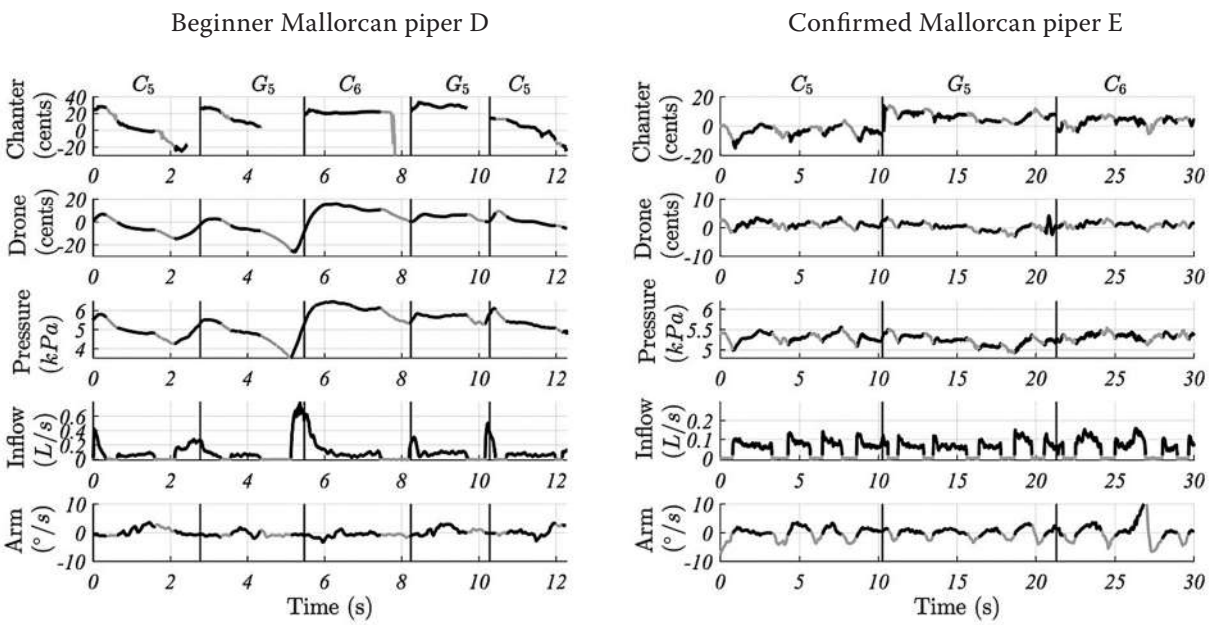

Figure 4. *Proficiency comparison between a beginner (D) and a confirmed xeremies player (E) performing an arpeggio exercise (C5, G5, C6). The black sections indicate when the arm is moving away from the body; the grey sections indicate when the arm is towards the body. Each vertical line indicates a different note. Note: the pitch, pressure and inflow scales are different for both pipers. The scale for piper 'E' is much smaller than for piper 'D'. Source: Ernoult et al. (2017), p.1460.*

leaks. Keep arm in contact with bag at all times. Blow regularly and blow from the diaphragm. Practice playing one note [...] until it is steady. Once this is accomplished, play up and down the scale slowly until you find the blowing rhythm and you can hear that the sound is reasonably steady'.[41] Another teacher has 'students sustain individual notes with drones and chanter sounding for ten seconds at a time while listening for any fluctuations in pitch'.

The techniques used to achieve this vary from one teacher to another: some, mainly Highland Scottish pipers, use pressure gauges so that the student can visualise the pressure variation within the bag. Others use digital tuners to monitor pitch variations. Some even use both: 'Control the tuning of long notes with a tuner and control pressure while playing [by] using a manometer'. Others still use more intuitive methods, such as listening, playing without drones, playing only the drones, playing long notes, playing in front of a mirror, teaching the theory of the technique, demonstrating it or even inserting a beer mat or a book between the student and the bag; if the object falls, it signifies that the student has not been exerting constant pressure on the bag.

Understanding a student's progress was one of the aims of the interdisciplinary experiments carried out in Galicia and in Mallorca. With this in mind, we asked the more experienced pipers to pick a student who would be able to participate in the experiment. In Mallorca, Piper 'D', a beginner on the pipes, played the same exercises as the more experienced pipers, which allowed us to compare the results, a common technique for the study of musical ability and instrument control. In the following exercise (Figure 4), the pipers were asked to play slow arpeggios (C_5, G_5, C_6, G_5, C_5) that would allow us to understand how they maintained long notes:

Focusing on the beginner's data, we can observe that he is unable to maintain constant notes. Indeed, each note of the arpeggio tapers out after about two seconds. If we observe the drone, we can see that although it is continuous throughout the whole exercise, it does not keep a constant pitch. The drone oscillates between 20 cents below and 20 cents above the reference pitch. This 40 cent variation equates to nearly a quarter of a tone and is clearly audible to the listener. The pressure profile is similar to that of the drone: irregular with considerable fluctuations between 4kPa and 6kPa. If we now turn our attention to the player's coordination, we can observe that he breathes into the bag just before playing the next note. The curve representing the movement of the arm is close to 0 for the whole 12 seconds. This means that the player is not using it to press on the bag, which would allow for the pressure to remain

[41] Online bagpipe technique questionnaire (2016).

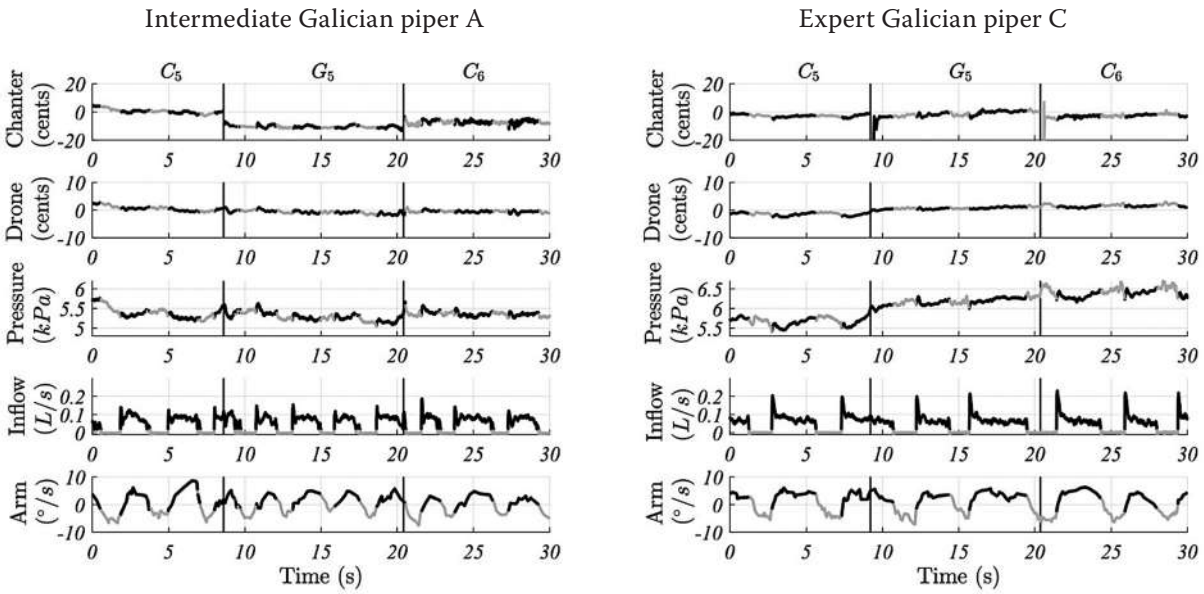

Figure 5. *Proficiency comparison between an intermediate student 'A' and a proficient gaita player 'C' performing an arpeggio exercise (C5, G5, C6). The black sections indicate when the arm is moving away from the body; the grey sections indicate when the arm is towards the body. Each vertical line indicates a different note. Source: Ernoult et al. (2017), p.1461.*

constant while he inhales.

The quasi-immobility of the arm means that the only way the piper is increasing the pressure inside the bag is by blowing air into it. Blowing afresh into the bag at the beginning of each note creates enough pressure to play that note for a couple of seconds only, before he has to pause and inhale. The player is therefore playing the bagpipes like wind instruments without a reservoir, such as the oboe or the clarinet: the sound stops when the musician pauses for breath.

Playing the bagpipe like a flute or similar wind instrument is common to all beginners. As part of the online questionnaire, a beginner on the Schaefer pipes detailed how they struggled to control their breathing pattern: 'I'm just a beginner so I'm not yet sure of what I'm exactly doing when I play. I think that, as a player, I still have a reminiscence of my flute background where you have a direct relation between blowing and sound. So, sometimes I've found myself blowing just at the end or a beginning of a phrase and not at the middle of it. This is one of my main current challenges, to be absolutely aware of my blowing and get a total control of it'.[42]

Another Highland Bagpipe player confessed that, 'Sometimes, when there is a long and complicated phrase I tend to use my breath more than my arm. I know this is not good practice but it is the result of extra concentration'.[43] Beginners seem to be aware of this practice and know what they are required to work on in order to be able to have a steady, stable sound.

If we now look at experienced piper 'E', we can observe that the arm movement is regular, and fully synchronised with the breathing. When the piper breathes into the bagpipe, the arm moves away from the bag (sections in black), and when the piper stops breathing into the bag, he immediately moves his arm towards the bag (in grey). This creates a regular pressure profile within the bag of between 5kPa and 5.5kPa, which is minimal compared to the beginner's fluctuations between <4kPa and >6kPa. The stable pressure profile is reflected in the piper's steady drone, varying less than a couple of cents above and below the tuning reference. Similarly, the three long notes emitted by the chanter are not only continuous, but also stable, varying only slightly under and above the tuning reference.

The comparison between the beginner and the experienced piper brings to light the role of the coordination between the arm and the breathing of the piper. A strict coordination of these elements creates a steady pressure in the bag, which, in turn, enables the piper to play a stable drone and a continuous melodic line. This emphasizes the remark of a Scottish small-pipe player in the questionnaire: 'Constant breathing pattern leads to

[42] Online bagpipe technique questionnaire (2016).

[43] Ibid.

constant pressure'.[44]

Whilst the previous example underlines the initial steps a beginner takes to control the bag, the following example explores the technique of two Galician *gaita* players, comparing a more advanced student and a proficient player playing the same C_5, G_5, C_6 arpeggio (see Figure 5).

Observing first the student, 'A', we note that he demonstrates a good coordination of the arm and his breathing. Like the experienced Mallorcan piper, student 'A' breathes into the pipes regularly, moving his arm away (black sections) when he inflates the bag and moving his arm towards his body when taking a breath. The pressure inside the bag is stable, fluctuating between 5.2kPa and 5.7kPa, a similar range to Mallorcan piper 'F'. This is reflected in his drone, which is extremely stable and in tune for the entire duration of the exercise. When we observe the melodic chanter, C_5 is well tuned to the drone. G_5 is slightly flat, around 10 cents below the pure interval pitch, and C_6 is around 5 cents flat. These two discrepancies, however, are very slight. Overall, piper 'A' has a good master of the coordination technique and would pass the test of the pressure gauge thanks to his stable playing.

Let us now turn to proficient player 'C', an international musician recognised both in Galicia and abroad as a talented musician. Player 'C' also coordinates his blowing with his arm movement. He has a slightly longer blowing cycle than player 'A', but the coordination is just as precise. When we turn to the pressure, however, we can observe that it is not constant. Indeed, it increases throughout the exercise, ranging from 5.5 to 5.7kPa for C_5, 6 to 6.2kPa for G_5 and 6.2 to 6.6 kPa for C_6. Unlike 'A', player 'C' changes his pressure throughout the exercise whilst keeping his coordination intact. Despite this, his drone profile does not move away from its exact pitch, similar to player 'A'. However, it is the profile of the chanter that provides evidence for the expertise of this piper. By slightly adjusting the pressure for each given note, player 'C' manages to keep the drone constant whilst fine-tuning the chanter pitches to the drone; whereas player 'A' was slightly flat, 'C' is able to play every note perfectly in tune. Referring back to the questionnaire, the most important criterion for the excellence of a piper, according to 85% of the respondents, was the tuning between the drones and the chanter. In this case, 'C' has an extremely fine understanding of the instrument. He goes beyond the coordination needed to maintain a steady pressure as he expertly controls it in order to obtain the perfect tuning between the chanter and the drone.

Of significant importance from an organological perspective, this demonstrates that the drone presents less sensitivity to pressure changes than the chanter within this specific pressure range.[45] As Ernoult et al. show in their article, the musicians are able to vary the pressure of the bag slightly, adjusting the pitch of the chanter, without impacting the pitch of the drone. Both instruments have different sensitivity levels, with the *gaita* drones presenting less than the *xeremies* drones. This means that a Galician piper will have a larger window to vary the chanter's pitch than the Mallorcan piper. Technically, experienced pipers have learned this empirically and play with the pressure range in order to fine-tune their chanter with their drones. Competitive Great Highland Piper Roddy MacLeod, for example, considers that his bagpipe sound, known for its 'note high A, which has a ringing sound to it, full of rich harmonics and interaction between the drones and the chanter',[46] is due to his blowing technique through which he creates, 'many variables and slight variations in pressure causing big changes in overall sound'.[47] The fine-tuning of the chanter to the drone is created by an extremely controlled pressure, facilitated by a high level of coordination between the piper's arm and breathing pattern.

The arpeggio exercise demonstrates the presence of a technical continuum for bagpipe players, going from learning the basic coordination skills in order to create a stable pressure and a continuous sound, to the fine tuning of the chanter to the drone. Once at this level, how does a musician manage the instrument within a musical context? The next exercise puts these skills in context as pipers were asked to play familiar melodies in order to understand how they control the bag during a musical performance.

PLAYING THE BAGPIPES – MUSIC AND PHRASING

Both in Galicia and in Mallorca, the pipers were asked to play a piece that was part of the local repertoire. In Galicia, the muiñeira *Loliña* was chosen and in Mallorca, the pipers played the *Bolero de Santa Maria*. In Figure 6 above, we compare the

[44] Online bagpipe technique questionnaire (2016).

[45] See Ernoult and al. (2017), p.1458.

[46] McKerrell (2011), p.182.

[47] McKerrell (2011), p.183.

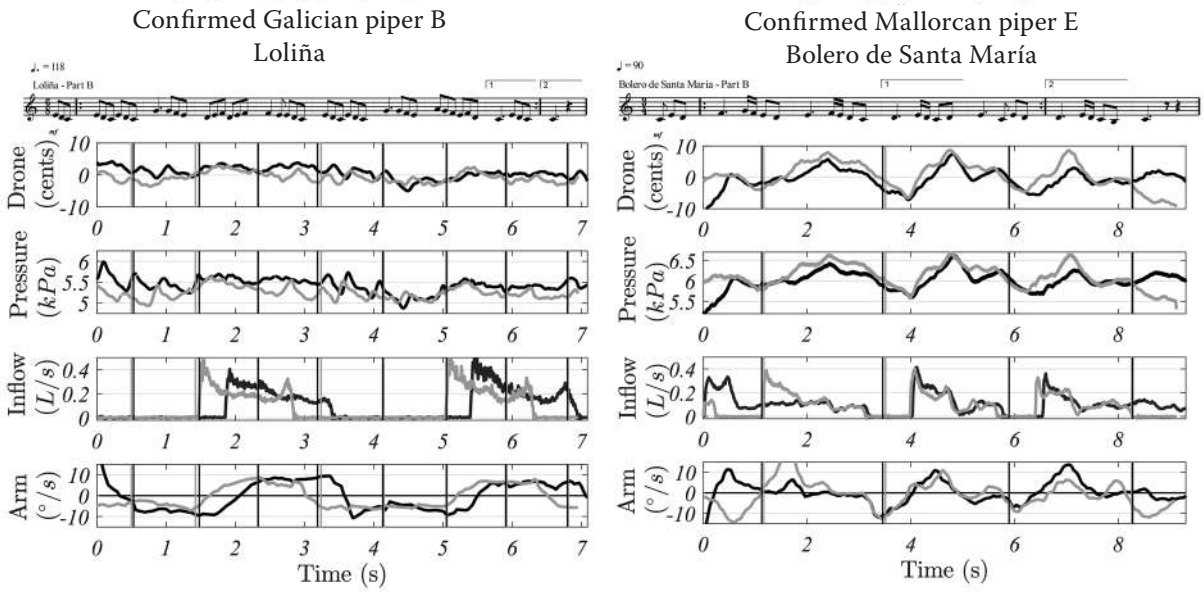

Figure 6. *Fine control comparison between a Galician piper (B) and a Mallorcan piper (E) within a musical context. Each vertical line refers to a musical bar; the black line represents the first time the melody is played, the grey represents the repetition of the melody, as indicated in the musical notation. Source: Ernoult et al. (2017), pp.1462–1463.*

musical performance of Galician piper 'B', an award-winning traditional piper with over two decades of experience and Mallorcan piper 'E', recognised as one of the most up-and-coming pipers of the island. Both play a piece that they are familiar with, which allows them to revert to their habitual reflexes.

If we first turn our attention to the Galician example, we note that, much like pipers 'A' and 'C', the musician's breathing pattern is coordinated with his arm movement. When he blows into the bag, his arm moves away from the bag and as soon as he stops blowing, the arm moves towards the body, squeezing the bag. Player 'B' has a steady cycle with overall equal length blowing and inhalations of about two seconds each. The piper blows into the bag at different moments during the repetition of the melody, demonstrating a breathing pattern that is desynchronised from the melody. Looking at the pressure profile, we immediately see that we are not in presence of the stable pressure witnessed in the exercises. Here, the pressure profile seems to follow the melodic line with slight increases at the beginning of each descending set of three quavers in bars 1 and 4 with their upbeats. Since this is repeated twice it is unlikely to be an error, but a voluntary variation of pressure created by the musician. The repeated pressure variations at a given time in the melody show musical intent, within the limits of stability of the instrument. Indeed, although the pressure varies between 5 and 6kPa, the drone remains relatively stable with a total variation of less than 10 cents (pitch reference ±5 cents).

In this example, therefore, the musician seems to create a variation in the pressure pattern whilst maintaining an overall control of the instrument with a regular breathing pattern, desynchronised from the melodic pattern. The basic control of the instrument, created by the blowing/arm coordination is not affected by the music and is maintained at a different cycle than that of the melody. This desynchronisation as well as a pressure pattern following the melody was also witnessed in the performance of the same piece by piper 'C', demonstrating the fine control ability of both musicians in a musical context, beyond their high coordination technique.[48]

The desynchronisation of the breathing cycle from the melody seems to be the preferred technique for pipers. This was evidenced in the online questionnaire where 59% of the pipers answered that they did not coordinate their breathing with their musical phrasing (see Table 8).

A Scottish small-pipe player emphasised that, 'breathing should be automatic and not linked to phrasing'. Indeed, a few pipers who answered that they sometimes coordinated their breathing with musical phrasing considered that it was bad practice to do so. One piper commented on this coordination practice: 'Actually you shouldn't! But sometimes it happens. Most of the time the/my breathing is

[48] Ernoult et al. (2017).

Table 8: Percentage of responses for the question 'when you play, do you coordinate your breathing with musical phrasing?' Online bagpipe technique questionnaire (2016).	
	%
Yes	8.4
No	*59.3*
Sometimes	22
I don't know	10.3

independent from the playing/phrasing'. Another emphasised this feeling: 'Sometimes, when there is a long and complicated phrase I tend to use my breath more than my arm. I know this is not good practice but it is the result of extra concentration'. A third piper noted that they thought that 'subconsciously this happens at times'. Contrasting with the testimonies above, a good many pipers described moments when they coordinated their breathing pattern with the phrasing. This included dynamics, playing high notes, changing register, emotion, breathing with the pulse, sustaining long notes, singing whilst playing and breaks in the music. However, despite these responses, and despite the evidence that piper 'B' controls the phrasing of the melody through the bag pressure whilst maintaining a regular, desynchronised breathing pattern, only a strikingly low percentage of pipers responded that the main way of controlling their phrasing was with the bag (2%) rather than with the fingers (86%), as shown in Table 9.

Interestingly, the four pipers who answered that they controlled their phrasing with the bag (one *gaita* player and three Highland pipers) were experienced musicians with, for three of them, a professional practice. These responses reflect what we can observe in the performance of pipers 'B' and 'E'.

If we now turn to piper 'E', the most striking aspect of his performance is the extremely high repetition rate of the pressure profile between the first statement of the melody and its repeat. This seems to indicate that the musical intention of the piper is clear. What differs noticeably from the Galicians, however, is the breathing profile. It is slightly irregular and, unlike the Galicians' performances, has a high repeatability rate between the first and second melodic iterations. This was also witnessed in the performance of piper 'F' for the same excerpt.[49] It would therefore seem that the Mallorcan musicians coordinate their blowing with the musical phrase, with inhalations during the long notes at the beginning of each bar. The difference in the blowing pattern between the first and second iteration only happens at the end where the melodic pattern changes at the repetition. Despite the fact that the inflation of the bag seems to follow the melodic pattern, the coordination between the blowing and the arm is precise, enabling a solid technical control of the instrument.[50] We can, however, observe one discrepancy within the performance of piper 'E'. In the second iteration of the melody at the beginning of the third bar, just before the six seconds mark, the piper moves his arm towards the bag whilst still blowing. This coincides with a rise in pressure, which is repeated the second time without this strategy. It would seem that piper 'E' used his arm in an unorthodox manner in order to raise the pressure and follow his musical intention. This slight discrepancy, alongside the coordination of the blowing with the melody, shows that the Mallorcan piper clearly synchronises the technical and respiratory control of the instrument with the music.

The analysis of these two examples shows how experienced pipers are able to go beyond their highly trained technical skills and vary the pressure in order to follow the melodic pattern. This clearly

Table 9: Percentage of responses for the question: which is the main way of controlling your phrasing when you play? Online bagpipe technique questionnaire (2016).					
Which is your main way of controlling the following effects when you play?	**controlled with the bag**	**controlled with the fingers**	**controlled by the breath**	**N/A**	**Total**
Phrasing	2	86	3	9	100

[49] See Ernoult et al. (2017).

[50] The measured movements of the arm are less noticeable than on the Galician bagpipe as the movement markers were place on the musician's shoulder, elbow and hip and did not measure the movement of the forearm of the piper that, due to the size of the bag, contributes in increasing the pressure by a frontal displacement.

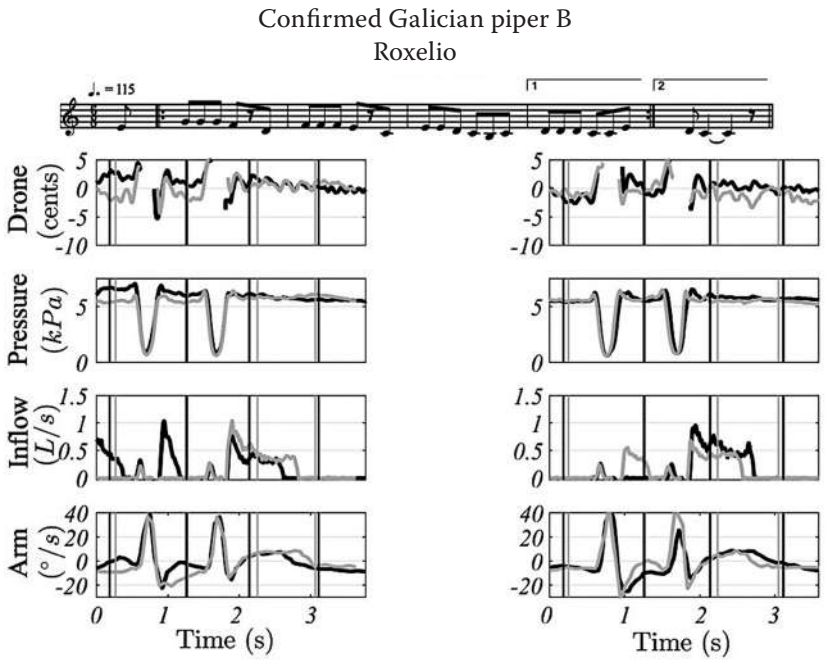

Figure 7. *Control parameters during a piece of music presenting pauses ('Roxelio', score on top) played by the Galician player 'B': the pitch variation of the drone around its mean frequency (ΔfC3), the bag pressure (P), the inflow (Qin) and the angular velocity of the arm (dθ/dt). The repeated sentence appears twice in the musical piece: at the beginning (left) and at the end (right). For both examples, the first occurrence is in black and the second in grey. The vertical lines correspond to the bars. Source: Ernoult et al. (2017), p.1465.*

demonstrates that although steady pressure is a basic requirement for a reliable continuous sound, experienced musicians are able to fine-tune it for their musical needs. The two different strategies used by the Galician and Mallorcan pipers highlights the variety of techniques possible to achieve a musical ideal. It also demonstrates that, despite what many pipers think, the pressure within the bag varies during a musical performance in order to accommodate the musician's musical intentions.

If we look at phrasing, for example, 86% of the pipers in the questionnaire replied that they controlled it through their fingers. However, experimental results show that experienced pipers use the bag to emphasize the musical intention created by the melodic line. The questionnaire responses demonstrated that only a few pipers (5%) were aware of the role of the bag for musical interpretation, with some considering that this question was not applicable to their playing (9%) (see Table 9).

Although Galician pipers de-synchronise the breathing/arm coordination and their musical intention, there are some moments within the music when the synchronisation of the instrument's control and the music is necessary. Evidence for this is provided by the following example where the music imposes a short break (see Figure 7).

In this example, the melody imposes two short breaks in the first and second bars. The topmost curve shows how the drone stops and starts. These pauses are created by sharp depressions within the bag (second line). Galician piper 'B' achieves these sharp depressions by a combination of movements. After managing his breath so that there is less air in the bag, he suddenly releases the bag of the force of his arm. The difference between the required volume of air and the lack of force leads the pressure to dive which, in turn, deprives the reeds from a source of air and stops them from vibrating. In order to start the bag again, the piper brings his arm sharply down onto the bag whilst blowing into it in order to restore pressure, and this allow the pipes to sound again.[51] This technique, solely used when demanded by the music, demonstrates that musicians who otherwise desynchronise their coordination with the music can synchronise them in order to create further

[51] These cut-off and onset techniques are also used at the beginning and the end of a piece in order to create a clear-cut start and end of the piece; see Cassandre Balosso-Bardin, Camille Vauthrin, Patricio de la Cuadra, Ilya Franciosi, Khalil Ben Mansour and Lise Ochej, 'The musical arm of the bagpipe player: a cultural and mechanical approach', *Proceedings of EuroRegio 2016, 9th Iberian Acoustics Congress, 47th Spanish Congress in Acoustic - TECNIACUSTICA* (Porto, Portugal, 2016). Online publication.

musical intention.

In contrast, the repertoire of Mallorcan pipers does not contain pauses, and it is possible that this is due to the *xeremies*' relatively large bag. As Ernoult has pointed out, the size of a bag has a significant impact on its use: it is easier for a piper with a small bag to create big variations of pressure within the bag whilst a bigger bag 'allows a more precise pressure control'.[52] A bigger bag will also feel softer than a smaller bag, which will influence how a musician responds to its control.[53] The Mallorcan bag, with its significantly larger volume, is less amenable to sudden pressure variations. This dictates musical variation as Mallorcan pipers will not be able to create breaks within the music unlike Galician pipers who, with large pressure variations created with a combination of arm and breath coordination, are able to suddenly stop both the chanters and the drones for a short amount of time during the music.

This last example demonstrates that far from being a systematic mechanical movement, the arm/breathing coordination is adapted to the musical needs of the musician. Whilst this may seem obvious, 59% of pipers in the questionnaire responded that they did not coordinate their phrasing with their breathing. Indeed, although this may be true of their overall performance as they disconnect musical phrasing, for example, from their breathing cycle (like piper 'B'), in some instances the music will lead them to coordinate their breathing with the music. These moments include among other elements, the beginning and the end of pieces, breaks within the music and, if applicable, managing playing and singing at the same time.

The experiments show that although Galician and Mallorcan pipers use different strategies during their musical performances, both use the bag beyond its mechanical use in order to support their melodic phrasing. The different strategies may be linked to the bag characteristics, which in turn determine the extent of musical variation available to the musicians. However, despite the limits of the instruments, both pipers demonstrate clear musical intention beyond the mere technical control of the bag.

CONCLUSION

In the opening quotation, Galician piper Cristobal Prieto said that, 'the secret of the bagpipes is how one uses the bag […] It's like a car: you have to think how you are going to do all of this at the same time. The use of the bag is the most important aspect, even more than the fingers, the velocity [or] playing quickly'.[54] Throughout this article, with the help of data from scholarly sources, an online questionnaire and field experiments, we have highlighted the multiple bag techniques used by pipers. While the sources and the online questionnaire focused on the pipers' discourse and their understanding of their use of the bag, the measurements demonstrate for the first time what musicians learn through years of practice and experience in a non-verbalised manner.

We were able to demonstrate the control continuum that pipers learn intuitively over the years, ranging from basic coordination skills to maintain a continuous sound to the fine control of the bag to emphasize phrasing and express musical intention whilst maintaining a regular breathing pattern desynchronised from the music. Additionally, far from being a mechanical movement, the breathing/arm coordination also often adapts to the music, fitting around the expressive and technical needs of the musicians as they interpret the music to the best of their abilities. The variety of techniques that are then developed, either with a synchronised or a desynchronised breathing pattern, are numerous and dependant not only on the musical culture but also on the morphology of the instrument, which will determine the limits of the technical palette.

Finally, although the use of the bag may be largely non-verbalised, this study demonstrates how it is a highly developed and important part of bagpipe playing in all cultures. Some musicians may exploit their bag techniques more visibly, such as in the Aegean islands, but all experienced pipers manage their bag in an intuitive and complex manner, linked to the music and their musical intention.

ACKNOWLEDGEMENTS

We would like to thank the Geste-Acoustique-Musique project, Sorbonnes Universités and CONICYT through FONDECYT Project no. 1161464 for funding the research presented in this article. We would also like to thank bagpipe players Álvaro Estévez Castro, Anxo Lorenzo, Gabriel Moyá, Cristobal Prieto, Josep Rotger, Cándid Trujillo and Miquel Tugores who agreed to participate in our field experiments in Galicia and in Mallorca. Finally, we would like to thank the 215 pipers who took the time to fill in the online questionnaire.

[52] Ernoult et al. (2017), p.1456.

[53] Ibid.

[54] Cristobal Prieto, field interview, Galicia, 16 June 2016.

Figure 12. *Luttrell Psalter, East Anglia, c1325–1335, showing two ship's trumpeters with straight instruments and central banner attached to the knob. © The British Library Board, Add. 42130, fol. 161v (detail).*

CASSANDRE BALOSSO-BARDIN et al
The Secret of the Bagpipes : Controlling the Bag

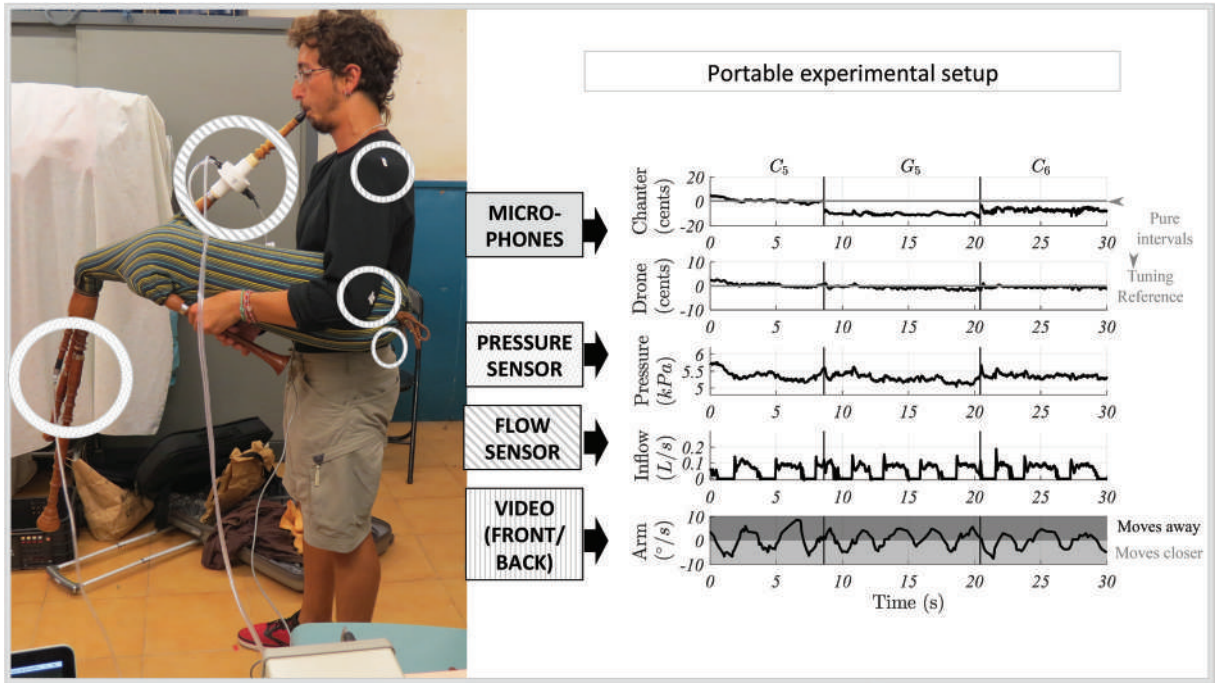

Figure 2. *Portable experimental set-up on Mallorcan xeremies with an example of the results.*