Proceedings of the Institute of Acoustics

BLOWING PRESSURES IN REED WOODWINDS

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1. INTRODUCTION

Blowing pressures in wind instruments, which range between 10 and 120 cm H_2O in reed woodwinds, have been a matter of interest in different fields such as respiratory physiology and pathology, occupational health, music acoustics, sound synthesis based on physical models and musical playing practice (Bouhuys [1], [2]; Navrátil and Rejsek [3]; Worman [4]; Pawlovski and Zoltowski [5], [6]; Bak and Doemler [7]; Fuks [8]; Cossette [9]).

In music acoustics, pressure data are required for comprehension of how the system consisting of player/instrument converts aerodynamic energy into sound. The complex relationship between input parameters (mouth pressure, air flow, and the embouchure, i.e. the constellation of forces and positions in the lip and mouth regions) and the resulting sound properties (pitch variations, loudness and sound quality) represent a challenging issue in the physics of instruments. In musical practice and education, objective facts regarding playing are valuable for the music teacher/performer and sometimes also for the composer, as such information may have important consequences in playing techniques. However, the data available on blowing pressures in wind instruments are scarce, particularly with respect to dependence on pitch and dynamic levels and confined to sustained tones, lacking a musical context. The purpose of the present investigation was to measure blowing pressures in wind instrument players at four different dynamic levels and at pitches covering the normal range of the instruments, initially focusing on four reed instruments, clarinet, alto saxophone, oboe and bassoon.

2. MATERIAL AND METHOD

Mouth pressure was captured by means of a thin pressure transducer (Gaeltec 7Sb), inserted in the player's mouth corner, connected to an amplifier and one track of a multichannel TEAC (RD-200T) PCM DATA recorder, in which the audio signals were also recorded. The experimental protocol consisted of the following tasks:

i) Sustained tones (Table 1) in a series of ascending fifths, played four times at each of four different dynamic levels: *forte*, *f*, *pianissimo*, *pp*, *mezzopiano*, *mp*, and *mezzoforte*, *mf*, duration of about 2 seconds each. This task was performed 3 times. These data will be referred to as f_s, mf_s , mp_s and pp_s .
ii) The same sequence of pitches as in the previous item, in ascending and descending order, played *crescendo-diminuendo* from *pp* to *mf* to *pp*. Each tone had a duration of 3 seconds, approximately. This series was played three times. Therefore, three pressures were measured for each tone, at the onset, at peak and at the termination. These pressures will be referred to as b_o , b_p and b_t.
iii) Ascending and descending *arpeggi* (see table 1), tones of 1s duration, approximately, covering the typical pitch range of the instrument. These *arpeggi* were played *legato* at four dynamic levels (*fortissimo*, *ff*, *pianissimo*, *pp*, *mezzopiano*, *mp*, and *mezzoforte*, *mf*). Each level was played four times in succession. Henceforth, the data from this task will be referred to as ff_a , pp_a , mp_a and mf_a.

One of the pitches played in these tasks was common (marked with bold characters in Table 1). As can be seen in the table, this tone was located in the middle range of the instrument. For all tasks, subjects were instructed to play as uniformly as possible with respect to tempo, sound quality and loudness. In task 3, the players were instructed that *ff* and *pp* referred to the maximum and minimum possible loudness that could be produced, keeping acceptable tone quality. The intermediate dynamic levels (*mf* and *mp*), were left to the musician to decide. They were also asked to avoid vibrato, as it might be associated with a modulation of the blowing pressure. Players were aware only of the fact that the experiment was related to blowing pressures and that it would take from 40 to 50 minutes. No other information was given until the entire recording protocol was completed. The subjects, two oboists, two bassoonists, two clarinettists and two saxophonists, were all professionals, and represented the western classical music tradition. All subjects had at least 15 years of experience of playing in symphony orchestras. Only one of them was female (clarinettist Cl1). The age range was 32 to 54 years. The musicians played on their own instruments and mouthpieces/reeds, that they used as their everyday working tools.

Table 1. *Tones used for the various tasks for the different instruments. Bold characters represent pitches common to all three procedures. The note names refer to actual pitches, rather than transposed notation.*

A4= 442 Hz

Instrument	Series of Fifths - tasks 1 & 2	*Arpeggio* - task 3
Bb Clarinet	F_3 C_4 **G_4** **D_5** A_5 E_6	Eb_3 G_3 Bb_3 Eb_4 **G_4** Bb_4 Eb_5 G_5 Bb_5 Eb_6
AltoSax (Eb)	F_3 C_4 **G_4** **D_5** A_5	Eb_3 G_3 Bb_3 Eb_4 **G_4** Bb_4 Eb_5 G_5
Oboe	C_4 G_4 **D_5** A_5 E_6	Bb_3 D_4 F_4 Bb_4 **D_5** F_5 Bb_5 $D6_6$
Bassoon	C_2 G_2 **D_3** A_3 E_4 B_4	Bb_1 D_2 F_2 Bb_2 **D_3** F_3 Bb_3 $D6_4$ F_4 Bb_4

3. RESULTS

For each instrument, mean pressures (in cm H_2O) for *sustained tones* and for *crescendo-diminuendo* tasks are presented in Table 2, for both subjects in each instrument. These data show the pressures used under quasi-neutral conditions. The pressures observed in the *arpeggio* task are displayed in graphs where the abscissa represents the tone's position in the musical score.

Table 2. *Mouth pressures [cm H_2O] for sustained (pp_s, mp_s, mf_s, f_s) and crescendo-diminuendo tones (b_o, b_p, b_f)*

		Subject 1 in each instrument							Subject 2						
Instrument	tone	pp_s1	mp_s1	mf_s1	f_s1	b_o1	b_p1	b_f1	pp_s2	mp_s2	mf_s2	f_s2	b_o2	b_p2	b_f2
clarinet (Cl)	F3	26	34	39	49	24	48	22	32	34	39	44	26	48	25
	C4	24	33	39	49	23	48	21	27	33	38	45	25	50	23
	G4	24	31	37	47	21	46	21	23	29	35	42	23	48	23
	D5	25	32	41	56	23	52	21	28	34	41	49	26	54	24
	A5	22	25	29	46	23	38	21	26	32	35	41	25	41	24
	E6	21	24	32	46	21	39	26	23	26	31	36	25	44	24
alto sax (Sx)	F3	24	29	27	30	20	30	18	22	21	21	25	19	23	14
	C4	16	19	26	49	17	35	14	16	18	21	25	14	21	11
	G4	19	27	48	82	19	52	17	24	28	31	36	18	32	14
	D5	16	25	35	79	18	43	15	21	25	29	38	16	31	13
	A5	16	22	34	45	17	37	15	23	27	29	35	17	31	14
oboe (Ob)	C4	36	39	44	48	38	44	38	41	50	57	57	42	48	42
	G4	38	43	53	60	37	54	41	44	47	57	66	43	51	42
	D5	43	47	59	67	43	66	40	43	54	71	84	44	65	42
	A5	47	50	75	90	43	72	41	59	64	90	117	47	83	44
	E6	54	64	79	95	52	77	50	54	80	102	126	53	80	52
bassoon (Bn)	C2	13	18	23	27	12	26	15	15	19	22	24	14	20	14
	G2	15	29	34	43	16	39	15	16	18	24	30	16	25	15
	D3	17	26	36	48	18	40	16	17	21	29	33	17	29	16
	A3	21	36	50	64	20	59	19	17	24	30	37	19	32	17
	E4	27	43	59	86	30	77	21	20	30	37	47	24	43	19
	B4	37	58	80	90	35	85	23	26	31	40	51	28	47	20

3.1 Clarinet (Figure 1, a and b)

In general, the data are quite systematic and reasonably similar for both players. Also, the b_o pressures (Table 2) observed at the start of the *crescendo-diminuendo* tones were very similar to the pp_s values from the sustained tones. The b_p pressures at the peak of the *crescendo* tones are generally close to the mf_s or f_s slightly lower than the b_o at the onset. The pressures range from 20 to 55 cm H_2O, and player Cl1 tended to use slightly lower pressures than player Cl2. The loudness increases between the dynamic levels *pp*, *mp* and *mf* correspond to pressure increments. For player Cl1, they range from 3 to 9 cm H_2O for the *pp*, *mp*, and *mf* levels, while for the *ff* level it was up to 15 cm H_2O. Player Cl2 used more even steps, ranging from 3 to 9 cm H_2O.

The blowing pressures measured in the sustained tones agree reasonably well with those observed in the ascending *arpeggio*, the maximum discrepancy being up to 3.0 cm H_2O in *pp* , *mp* and *mf*. In *ff* larger differences were observed. Also, both subjects played sustained tones with pressures quite similar to those they used for the neighbouring tones in the *arpeggio* tasks. There was a quite close agreement between the lowest pressures used for G_4, the common pitch to all three tasks. Thus, the *pp* pressure used in the *arpeggio* (pp_a) was quite similar to the b_0 in the *crescendo-diminuendo* tones and also to the p_s in the sustained tones.

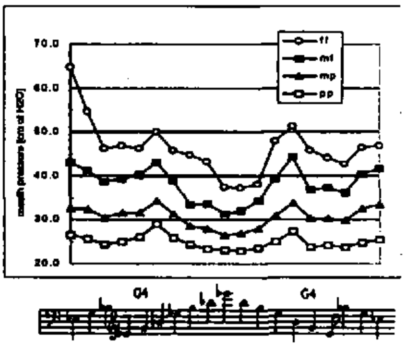

Figure 1 a.. *Arpeggio task , player Cl1*

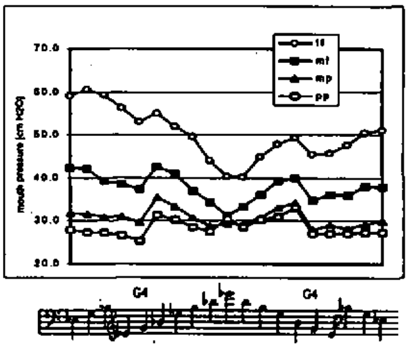

Figure 1 b.. *Arpeggio task , player Cl2*

Another striking characteristic is the fact that the pressure curves in Figure 1 exhibit a maximum at Bb_4 for all dynamic levels of the *arpeggio*. This probably due to the fact that overblowing starts at this point along the pitch scale. Thus, the fingering for Bb_4 is identical to that for the lowest pitch Eb_3, except for the opening of the register key, which produces the overblowing effect.

3.2 Saxophone (Figure 2, a and b)

The low standard deviations found in the *arpeggio* task indicate a good intra-subject consistency. For player Sx1, the pressure ranged from 15 to 80 cm H_2O, approximately. The highest pressure used by player Sx2 was 55 cm H_2O. In general, both players used similar pressures at low dynamic levels.

Both players increased pressures when they shifted to a louder dynamic level, except for the lowest pitch, F_3. The pressures for Sx1's sustained tones do not agree well with those observed in the *arpeggio* task. However, listening to the recordings and inspecting the SPL values revealed that the sustained tones were played louder than the *arpeggio* tones. The pressures used for mf_s, sustained tones (Table 2), agreed closely with the b_0 values for all tested tones as played by player Sx2. Pressure steps between sustained tones played at adjacent dynamic levels are also very regular, ranging approximately from 4 to 6 cm H_2O. Player Sx1 tended to use higher pressures in all tasks.

For both players the blowing pressures seem to increase with pitch in the lowest octave, reaching a peak in the region between Eb_4 and G_4, and decreasing with pitch above this pitch region. It may be relevant that in the alto saxophone overblowing starts in this pitch range, viz. at F_4.

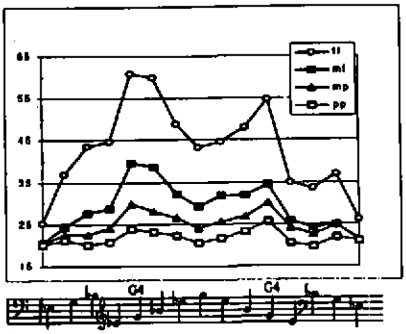

Figure 2 a.. *Arpeggio task , playerSx1*

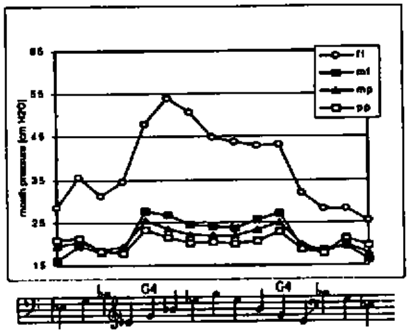

Figure 2 b.. *Arpeggio task , player Sx2*

3.3 Oboe (Figure 3,a and b)

The two players' pressures ranged from 35 to 95 cm H_2O and from 41 to 124 cm H_2O, respectively. Pressures increased not only with loudness but also with pitch. Player Ob2 used a wider range and also tended to use considerably higher pressures than player Ob1.

In both subjects, the values used for the sustained tones agree quite well with those observed both in the *crescendo-diminuendo* and *arpeggio* tasks (Table 2). For both players, the onset pressures, b_o, in the *crescendo-diminuendo* task were very close to the pp_s values in the sustained tones. Also, the b_p pressures in the *crescendo* tones were generally close to the mf_s values while the termination pressures b_t were mostly somewhat lower than the b_o. There was a quite close agreement between the lowest pressures used for D_5, the pitch common to all three tasks, but the pressure steps between dynamic levels were usually smaller in the *arpeggio* task than in the sustained tones.

In the arpeggio task, the pressures used for pp and mp were rather similar, especially for the five lowest tones, Figure 3. This suggests that at low dynamic levels, the loudness control is mainly realized with other factors than pressure, such as the embouchure. In both subjects, the pressures used for *pp* at the lowest pitches are slightly higher than the ones used for *mp*. The lowest tones of the oboe are particularly difficult to start. As opposed to the clarinet and the saxophone, the changing of register and the presence of the overblowing effect did not correspond to peaks in the pressure curves.

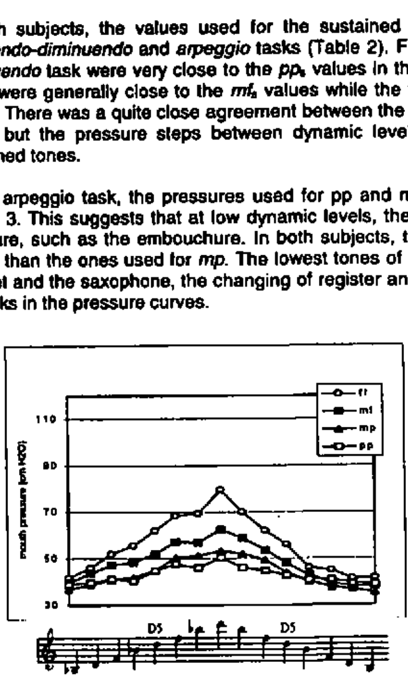

Figure 3 a.. *Arpeggio task , playerOb1*

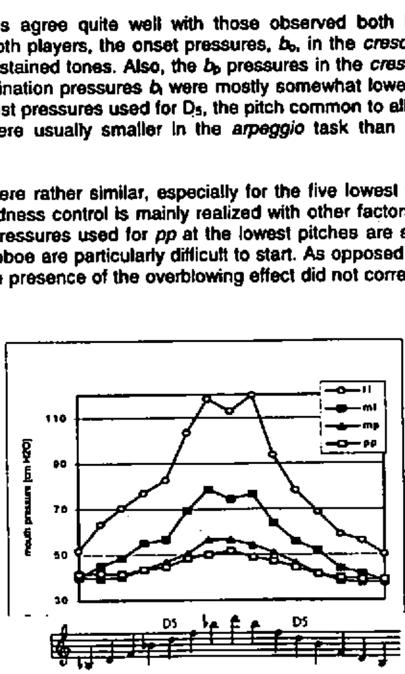

Figure 3 b.. *Arpeggio task , player Ob2*

3.4 Bassoon (Figure 4, a and b)

For players Bn1 and Bn2, the pressure ranged from 12 to 90 cm H_2O and from 13 to 52 cm H_2O, respectively. The variability of both players' pressures was small in *pp-mp-mf* although player Bn2 showed increased variability in the *mf* production of sustained tones. Still, all takes from both players sounded musically quite acceptable. Pressure increased continuously with both loudness and pitch. The pressure steps between adjacent dynamic levels showed some variation in the sustained tones (Table 2). In the *arpeggio*, pressures for *pp* and *mp* were rather similar throughout the pitch range, while slightly higher pressures were sometimes used for *pp* than for *mp*. For both players' sustained tones and *crescendo-diminuendo* tasks, the b_o pressures observed at the start of the *crescendo-diminuendo* tones were very similar to the pp_s values for the sustained tones. In a similar way, the b_p pressures at the peak of the *crescendo* tones were generally close to the mf_s or f_s values of the sustained tones. The termination pressures b_t of the *crescendo-diminuendo* tones were generally lower than the b_o at the onset, and the difference between b_o and b_t clearly increased with pitch.

At dynamic levels above *pp* both subjects played sustained tones with pressures systematically higher than those used for neighbouring tones in the *arpeggio*. Similarly, pressures used by both subjects for D_3, the pitch common to all three tasks, differed between the musical arpeggio context and the musically more neutral sustained tone context. On the other hand, the *pp* pressures in the *arpeggio* (pp_a) were quite similar to the b_o in the *crescendo-diminuendo* tones and also to the p_s in the sustained tones.
As with the oboe, no peculiar characteristic was found relative to the overblowing phenomenon.

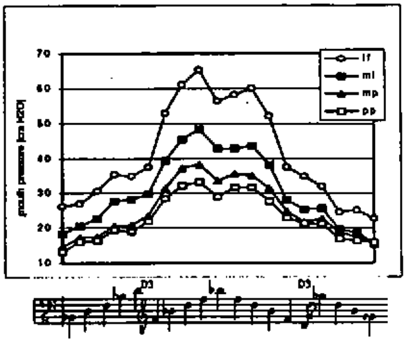

Figure 4 a.. *Arpeggio task, playerBn1*

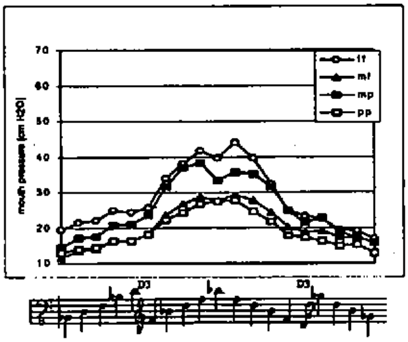

Figure 4 b.. *Arpeggio task, player Bn2*

4. DISCUSSION

The present investigation concerned the blowing pressures. These pressures obviously represent a limited aspect of the overall blowing mechanism. The airflow through the reed and the embouchure conditions are other important factors, which we plan to examine in future investigations.

The blowing pressures are important to the understanding of the player's work and the instrument behaviour. The airflow is a function of the blowing pressure and the resistance offered by the vibrating reed and by the acoustic properties of the air column. The reed system, in turn, is characterized by the geometry and physical properties of the reed, the mouthpiece design and the embouchure.

The data only partly agree with the previously reported results mentioned in the introduction. Interestingly, the systematic dependence on pitch and dynamic level found for the oboe and the bassoon is quite similar to that previously found in singers (Leanderson & al [10]). although the pressures used in these woodwind instruments are much higher.

We tested only two players for each instrument. Mostly both players' pressure data exhibited similar pitch and loudness dependences, but in some cases, noticeably in the oboe and the bassoon, one player tended to consistently use higher pressures than the other. These interindividual differences may be due to different reed properties and/or different blowing techniques and personal preferences.

Clarinets on the one hand and the double reeds oboe and bassoon on the other, showed clearly contrasting features as illustrated particularly by the *arpeggio* curves. In the double reed instruments, pressure tends to be increased continuously with pitch. In the clarinet, pressure tended to decrease with pitch but peaked at the lowest point of overblowing. These pressure characteristics would be due to the acoustical properties of the instruments, that respond differently depending on their input impedance curves and the reed-instrument interaction. Interestingly, the pressure curves in the lowest octave of the saxophone showed a pattern similar to that of the double reed instruments. However, at higher pitches, where the tones are produced by overblowing, the curves were more similar to those of a clarinet. The saxophone has a conical bore like oboe and bassoon whilst the reed and mouthpiece are similar to those of the clarinet.

In the *arpeggi*, the pressure curves differed between the ascending and descending parts. Generally, higher pressures were used for the ascending part, particularly at the highest dynamic levels. Probably the reason for this was musical; the players tended to make a *crescendo* during the ascending part and a *diminuendo* during the descending part.

5. CONCLUSION

Our data revealed characteristic dependences of the pressure on pitch and on dynamic level in clarinet, saxophone, oboe and basson. For each of these instruments, these dependencies seemed consistent within as well as between players, although some players tended to use higher pressures than others. In the double reed instruments, oboe and bassoon, pressure tends to be increased continuously with pitch. In the clarinet, pressure tended to decrease with pitch, but overblowing was produced with higher pressures than the corresponding lower tones. The pressure curves in the lowest octave of the saxophone showed a pattern similar to that of the double reed instruments. However, at higher pitches, where the tones are produced by overblowing, the curves were more similar to those of a clarinet

6. ACKNOWLEDGEMENTS

This study is supported by the Brazilian Ministry of Education (**CAPES** Foundation), by Escola de Música da Universidade Federal do Rio de Janeiro and by the KTH (Royal Institute of Technology), Department of Speech, Music and Hearing. The authors are indebted to the kind cooperation of the players.

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