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A PHYSIOLOGICAL EVALUATION OF THE EFFICIENCY OF PLAYING THE WIND INSTRUMENTS – AN AERODYNAMIC STUDY

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The purpose of this study was to present mean values of particular aerodynamic parameters to determine the physiological standard of playing. The authors applied the aerodynamic method in examinations of musicians playing the orchestral wind instruments. Direct results of the measurements for each person were the following quantities: the pressure before the instrument inlet (SP), the mean air flow rate (MFR) through the mouthpiece or the reed, and the play time (MPT). On the basis of these quantities, the lips or reed resistance (GR), the expiration power (EP) and the work performed during playing (S) were calculated. The measured results were so elaborated that the measured results were calculated separately for those persons for whom the play time was no less than the mean time of persons playing the same instrument. For such a division of the examined persons, the mean values of the aerodynamic parameters were calculated. The efficiency of playing is essentially affected by the value of the lips or reed resistance (GR).

1. Introduction

This paper is concerned with the set of the values of aerodynamic parameters occurring for musicians as they play the wind instruments. In 1981–1985, the present authors carried out clinical studies, using a purpose-modified aerodynamic method [3, 4]. This method made it possible to register and then calculate the occurring parameter values, namely the maximum play time (MPT), the air pressure before the instrument inlet (SP), the mean air flow rate (MFR) through lips or the reed, the lip or reed resistance (GR), the expiration power (EP) and the work performed in the course of the play (S).

In previous publications, the present authors described the aerodynamic method [3, 4], chosen problems related to the aerodynamics of playing [5] and the phenomenon of initiation, i.e. the sound formation [6]. These papers also considered the hyperbaric phenomenon significant for the activity and efficiency of the

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musicians' respiratory organ. It has been shown that there is a defensive automatism of the respiratory organ during playing, consisting in the compensation of the large value (100 cm H_2O) of the air pressure during playing in forte and at a high frequency (trumpet). Therefore, we should believe that, apart from other factors, such as age, allergy, nicotinism [2], the compensation phenomenon makes it possible to continue the long-term work of musicians without the occurrence of symptoms of emphysema.

The present authors believe that the presented mean values of the aerodynamic parameters should serve in elaborating physiological standards for playing the wind instruments, within the limits assumed for the population in Poland. Because of lack of literature on the subject, the present study may contribute to the undertaking of further research.

2. Selected literature review

Results of spirometric examinations carried out on instrumentalists [2], collected from various points of view, are uniform for the group of those who play the same instrument. No characteristic changes were found in terms of age groups or the number of years of playing.

It is interesting to note ventilation changes. A large percentage of the examined persons exhibit obstructive ventilation changes characteristic of increased resistance of the respiratory tract. On the other hand, no changes of restrictive type were found, which would result from increased resistance of lung tissue.

Obstructive changes occur in 80% of the examined young and middle-aged persons aged between 20 and 40. On the other hand, in elder persons, aged between 40 and 60, ventilation changes occurred in 58% of cases. This is probably caused by the fact that professional instrumentalists in whom, when they were still young, large ventilation changes occurred, had to abandon their profession. Apart from other factors, such as nicotinism or chronic catarrh of bronchi, the symptoms of ventilation insufficiency are to a deciding degree caused by the way of playing a given wind instrument. It seems that the age of the examined persons is of greater significance than the duration of professional work.

Problems related to the technique of hyperbaric breathing [7, 8] have been the object of numerous studies. In hyperbaric condition the lung pressure is greater than that in normal conditions and depends on the diver's submersion depth under water, the gas flow intensity and the kind of used respiration mixture. Respiratory hyperpressure consists in supplying a mixture of respiratory gases to the respiratory tract under increased pressure, i.e., one greater than that of the ambient atmosphere, to increase the molecular pressure of oxygen.

It follows from studies carried out by A. Muras [1] that an increase in pressure in musicians' lungs during playing the wind instruments occurs only in the expiratory phase as it is considerable but short compared with hyperpressure occurring in divers. Hyperpressure in divers' lungs in hyperbaric conditions occurs in two respiration phases, and has a long-term effect, because of changes of respiratory gas distribution which it causes.

It follows from the results obtained by the authors [5] for the values of aerodynamic parameters concerned with the technique of hyperbaric respiration that there is a compensation for a rapid increase in the lung pressure. This pressure is necessary for the intonation of a sound with given pitch and intensity.

3. Assumptions and purpose of the study

Because of some operational mechanisms have not been determined in detail, it is necessary to analyze the cooperation between the respiratory and articulatory organs, namely the actions of the tongue and lips in playing the wind instruments. The results obtained from both experimental and clinical researches would provide the basis for elaborating the optimum standards (physiological standards of playing). These standards would make it easier to ensure diagnosis in considering cases of insufficiency of the respiratory and articulatory organs in the teaching process. The characteristics of playing the wind instruments have been presented in the literature above all from the points of view of aesthetics, playing technique, educational problems, choice of repertoire in the course of education etc.

Phoniatric problems are related above all to the explanation of the physiological mechanism of sound formation, i.e., the cooperation of the functions of the respiratory and articulatory organs. Quite purposefully, the authors do not consider the problem of cooperation between playing and the functions of the central nervous system and the hearing organ – as it will be the object of further studies.

The purpose of this study is to analyze the mutual dependence of aerodynamic parameters. An ideal vibrating system, i.e., one exciting vibrations, which would be characterized by constant resistance independent of the pitch and intensity of sound, would require constant pressure to excite vibrations. Pressure changes would determine those in the vibration amplitude, i.e., in the sound intensity. To change the sound pitch, it would not be necessary to change the pressure before the instrument inlet. A real vibrating system, such as the reed or the mouthpiece of the instrument, varies its resistance, depending on the sound pitch and intensity.

The authors' intention was to determine the values of aerodynamic parameters and the correlations between them in the course of playing.

The purpose of this paper is to present mean values of particular aerodynamic parameters and gain data for determining the physiological standard of playing.

4. Selection of the examined persons and the research method

The study was carried out on a group of students and teachers of the Academy of Music in Warsaw. Moreover, they were performed on professional musicians who applied for medical treatment. In all, 87 persons were examined. The study used the results for 66. Because of the poor technical quality, resulting from insufficient cooperation with the examined persons, 21 cases were not interpreted.

Prior to the study, general otolaryngological examinations were performed, whose results showed no deviations from normal in the range of interest.

The study was carried out according to the method elaborated and published by the authors [5]. The direct measured results for each person were the quantities: – the pressure before the instrument inlet (SP), the flow rate (MFR) through the mouthpiece or reed, and the play time (MPT). On the basis of these quantities, the lip or reed resistance (GR), the expiration power (EP) and work (S) were calculated.

Apart from theses aerodynamic parameters, sound signals were recorded for further studies. The results of aerodynamic measurements and mean values were computed on a RIAD computer.

5. Results of the study and their interpretation

The results of aerodynamic measurements were elaborated in such a way that the results of measurements for those persons for whom the duration of playing sounds from the lower and upper frequency scale was equal to or longer than the mean play time for persons playing the same instrument were included in the group of persons with normal play time. For such a division of the examined persons, into groups with normal or shorter play times, mean values of aerodynamic parameters were calculated. Quite purposefully, the authors did not include in this publication the standard deviations (SD), on the assumption that the number of persons playing the

Table 1. Mean values of aerodynamic parameters obtained for instrumentalists with normal play time

		flute		clarinet		oboe		bassoon		trumpet		trombone		French horn		tuba	
frequency of play. soun.		c_1	c_4	e	b_3	c_1	c_3	c	c_2	c_1	c_3	F	c_2	c	c_3	F	b_1
MPT [s]	P	31,0	12,2	37,4	27,6	32,0	28,0	19,1	28,6	40,0	21,3	17,4	17,0	32,0	23,0	21,0	21,0
	F	20,3	8,2	32,5	24,0	31,0	30,0	16,5	18,6	11,2	11,3	15,0	8,5	14,2	0,5	10,5	7,0
SP [cmH_2O]	P	4,8	15,7	37,5	24,0	53,4	55,0	39,5	69,8	60,0	82,1	21,2	38,1	22,2	70,8	14,8	74,0
	F	9,0	26,9	51,5	37,0	57,3	68,5	50,2	87,1	48,0	153,8	24,7	53,5	37,5	118,5	40,0	103,0
MFR [1/s]	P	0,18	0,53	0,18	0,23	0,19	0,27	0,30	0,20	0,13	0,25	0,44	0,58	0,17	0,25	0,29	0,29
	F	0,26	0,85	0,21	0,26	0,18	0,20	0,36	0,30	0,47	0,63	0,77	0,91	0,40	0,55	0,59	0,29
GR $\left[\frac{cmH_2O}{1/s}\right]$	P	25,4	40,5	228,0	112,5	326,0	272,0	140,0	388,0	536,0	488,0	48,0	99,6	136,0	299,0	50,0	250,8
	F	34,6	36,0	278,0	154,0	336,0	390,5	160,6	305,0	93,0	282,0	59,8	58,8	101,0	235,0	67,4	116,4
EP [W]	P	0,10	0,65	0,67	0,54	0,99	1,54	1,13	1,29	0,69	1,51	0,93	2,04	0,37	1,73	0,42	2,14
	F	0,23	2,80	1,11	0,93	1,02	1,32	1,67	2,5	2,49	9,35	1,69	4,77	1,43	6,15	2,30	8,95
S [kGm]	P	0,30	1,00	2,13	1,74	3,53	3,63	2,75	4,92	3,77	4,36	1,97	3,46	1,57	4,91	1,18	5,92
	F	0,56	1,87	3,16	2,66	3,81	4,48	3,55	6,12	2,43	8,03	2,24	4,76	2,61	8,24	3,18	8,24

parameters   P = piano , F = forte

Table 2. Mean values of aerodynamic parameters obtained for instrumentalists with reduced play time

		flute		clarinet		oboe		bassoon		trumpet		trombone		French horn		tuba	
frequency of play. soun.		c_1	c_4	e	b_3	c_1	c_3	c	c_2	c_1	c_3	F	c_2	c	c_3	F	b_1
MPT [s]	P	14,9	8,6	27,8	16,3	11,7	16,7	13,5	13,8	15,9	19,5	15,2	9,5	19,2	3,1	5,0	5,0
	F	12,2	6,2	17,6	10,6	13,1	14,2	11,3	14,5	8,0	8,15	4,6	5,9	8,0	6,2	2,5	12,0
SP [cmH_2O]	P	4,0	7,0	27,7	25,2	54,0	41,8	21,0	34,2	37,5	64,7	30,3	53,3	49,0	70,0	17,4	42,2
	F	6,7	14,0	29,5	37,3	45,7	60,8	26,3	55,0	60,8	109,7	42,4	87,9	18,8	69,3	26,5	69,3
MFR [l/s]	P	0,39	0,68	0,31	0,41	0,48	0,35	0,50	0,49	0,42	0,29	0,47	0,62	0,30	3,00	1,10	1,10
	F	0,52	0,93	0,49	0,66	0,42	0,44	0,55	0,51	0,70	0,81	1,33	0,93	0,71	1,16	2,20	0,46
GR $\left[\frac{cmH_2O}{l/s}\right]$	P	10,0	10,0	132,0	64,3	96,3	120,0	48,3	78,3	111,0	214,0	76,0	93,4	147,0	52,0	15,8	38,4
	F	18,0	15,0	88,5	57,6	118,0	165,0	53,0	127,0	83,0	159,0	29,0	88,8	24,5	95,0	34,8	151,0
EP [W]	P	0,17	0,53	0,85	1,03	2,27	1,58	0,97	1,57	1,57	2,07	1,35	3,28	1,68	15,50	1,87	4,55
	F	0,28	0,47	1,19	2,90	1,85	2,64	1,66	2,69	4,54	9,90	7,40	8,73	1,42	6,60	16,5	3,11
S [kGm]	P	0,27	0,48	1,94	1,81	2,70	3,51	1,58	2,58	2,46	4,55	2,00	3,53	3,49	4,59	1,20	2,91
	F	0,40	0,95	2,09	2,61	2,86	3,72	1,95	4,19	4,23	7,40	2,78	5,76	1,23	4,57	5,28	4,78
parameters																	

P = piano , F = forte

particular instruments (4 persons on average) could not be considered a full basis for determining the value of scatter. The results are shown in two tables. Table 1 lists value for the normal play time whereas Table 2 does so for those with shorter play time (pathology).

To illustrate better the results and the mutual relations between particular aerodynamic parameters, Fig. 1 lists graphically the results obtained for persons with normal play time and the values with reduces play time (MPT), mean flow rate (MFR) of air through the reed or lips and expiration power (EP).

Interpreting the relations between these three parameters one should pay attention to the following dependencies. It is known that the power (EP) is the product of strength (here, SP) and the flow rate (MFR). Moreover it should be recognized that the person playing an instrument has a limited air volume in his lungs – so an increase in the flow rate (MFR) must be accompanied by a decrease in the play time (MPT). An increase in the expiration power (EP) corresponds to an increase in the air flow rate. Considered for particular instruments and ways of playing in piano and forte, thes dependencies usually provide a logical justification for the increase in the expiration power (EP) and the flow rate (MFR), and the decrease in the time (MPT) of playing sounds in forte. The results listed in Fig. 2 include the values of pressure before the instrument inlet (SP), the lips or reed resistance (GR) and the performed work (S).

The work (S) is proportional to the flow rate and the lips or reed resistance. It is also known that for decreased resistance the keeping of continuous flow would require the corresponding drop of pressure before the instrument inlet (SP). The person playing the instrument can decrease this pressure only to a small degree, to

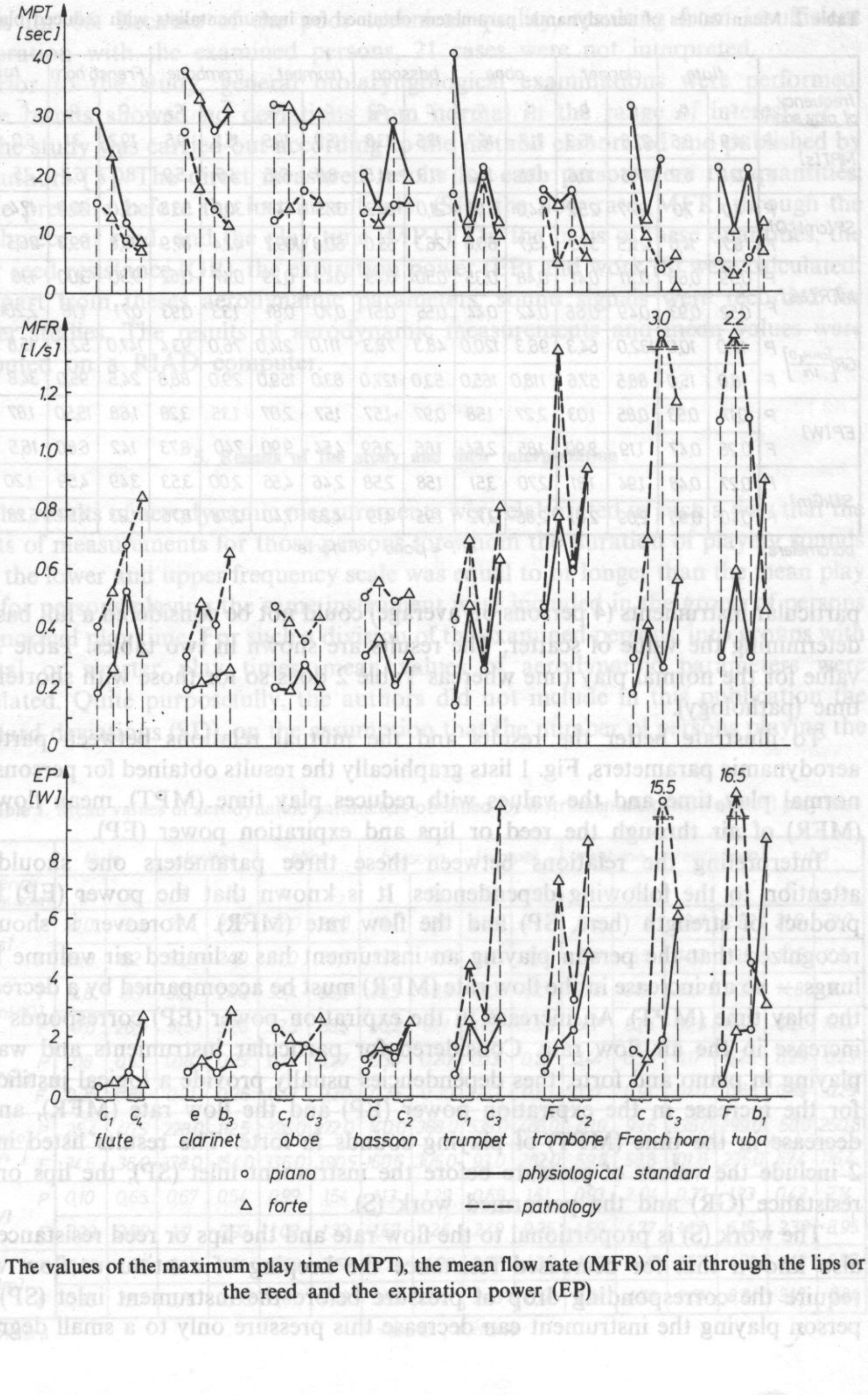

Fig. 1. The values of the maximum play time (MPT), the mean flow rate (MFR) of air through the lips or the reed and the expiration power (EP)

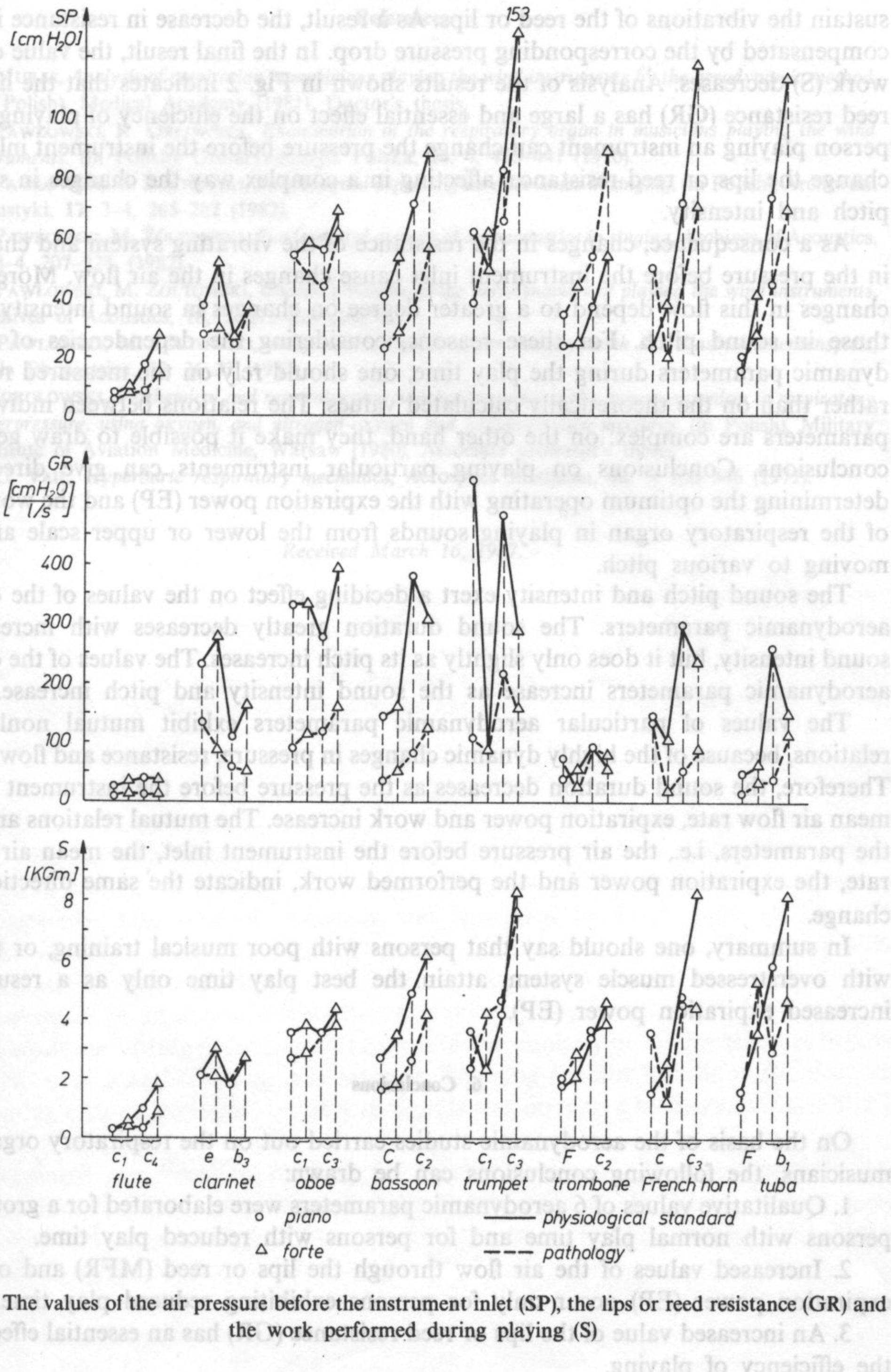

Fig. 2. The values of the air pressure before the instrument inlet (SP), the lips or reed resistance (GR) and the work performed during playing (S)

sustain the vibrations of the reed or lips. As a result, the decrease in resistance is not compensated by the corresponding pressure drop. In the final result, the value of the work (S) decreases. Analysis of the results shown in Fig. 2 indicates that the lips or reed resistance (GR) has a large and essential effect on the efficiency of playing. The person playing an instrument can change the pressure before the instrument inlet, or change the lips or reed resistance, affecting in a complex way the changes in sound pitch and intensity.

As a consequence, changes in the resistance of the vibrating system and changes in the pressure before the instrument inlet cause changes in the air flow. Moreover, changes in this flow depend to a greater degree on changes in sound intensity than those in sound pitch. For these reasons, considering the dependencies of aerodynamic parameters during the play time, one should rely on the measured results rather than on the theoretically calculated values. The relations between individual parameters are complex: on the other hand, they make it possible to draw general conclusions. Conclusions on playing particular instruments can give directives determining the optimum operating with the expiration power (EP) and the work (S) of the respiratory organ in playing sounds from the lower or upper scale and in moving to various pitch.

The sound pitch and intensity exert a deciding effect on the values of the other aerodynamic parameters. The sound duration greatly decreases with increasing sound intensity, but it does only slightly as its pitch increases. The values of the other aerodynamic parameters increase as the sound intensity and pitch increase.

The values of particular aerodynamic parameters exhibit mutual nonlinear relations, because of the highly dynamic changes in pressure, resistance and flow rate. Therefore, the sound duration decreases as the pressure before the instrument inlet, mean air flow rate, expiration power and work increase. The mutual relations among the parameters, i.e., the air pressure before the instrument inlet, the mean air flow rate, the expiration power and the performed work, indicate the same direction of change.

In summary, one should say that persons with poor musical training, or those with overstressed muscle system, attain the best play time only as a result of increased expiration power (EP).

6. Conclusions

On the basis of the aerodynamic studies carried out on the respiratory organ of musicians, the following conclusions can be drawn:

1. Qualitative values of 6 aerodynamic parameters were elaborated for a group of persons with normal play time and for persons with reduced play time.

2. Increased values of the air flow through the lips or reed (MFR) and of the expiration power (EP) occur only for persons exhibiting reduced play time.

3. An increased value of the lips or reed resistance (GR) has an essential effect on the efficiency of playing.

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