18TH INTERNATIONAL CONGRESS ON SOUND & VIBRATION
ICSV18
RIO DE JANEIRO
BRAZIL
10–14 JULY 2011

MEASURING THE INFLUENCE OF THE VOCAL TRACT IN THE TIMBRE OF THE FLUTE: PRELIMINARY ASPECTS

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Flute players apply changes to the timbre of the sound produced by their instrument by changing the configuration of their vocal tract, based on the mental images they create of it. However, this alteration is difficult to measure due to the large number of involved variables (e.g., the movements of lips and jaw) that prevent an immediate and objective perception. Therefore, we conducted an experiment whose main goal was to demonstrate the existence of vocal tract influence on the timbre of the flute. For this purpose we built an artificial blower that enables the elimination of the influence caused by modifications in the shape and position of lips and jaw. The theoretical frameworks of this experiment can be found in the works of Quantz, in *On Playing the Flute: the Classic of Barroque Music Instruction*. and Kent & Read, in T*he Acoustic Analysis of Speech*. The results of this experiment indicate the existence of a considerable influence of the position of the vocal tract on the timber of the flute. The aim of our current research is to conduct the experiment under a new paradigm that would allow measuring this influence in different registers of the flute. This deepening of the research will focus on building new structures representing the lips and modelling a vocal tract in a way that reflects the positions of the tongue during the execution of the instrument. In a future stage this research we will investigate the application of these techniques to enhance the instrument playability, improving its technique and facilitating the performance in the most problematic registers of the flute. We also seek to apply these results on new didactical methods, renewing interest in studying and teaching the instrument.

1. Introduction

The flute is one of the most popular wind instruments played all over the world (WOLFE et al, 2001, p. 127). Its operation has been studied by several researchers, including physicists, engineers and musicians (FLETCHER and ROSSING, 1998; NEDERVEEN, 1998, SCAVONE, 1997). It consists of a cylindrical tube open at both ends (differently from the oboe, clarinet or French horn, in which one end is closed by a blade or by the lips of the instrument player) and the sound production occurs from the incidence of a air jet against the edge of the mouth hole.

Verge (1995) defines the production of sounds of the flute as an acoustic system in which the sound is the result of the connection between a dynamically unstable jet and a resonant sound field created in a tube (standing waves). Thus, the jet of air the player inserts in the flute as well as the shape and distance from the lips to the mouth can be both adjusted while s/he plays, providing a significant control over timbre and tuning (BAKUS, 1969, p. 223). To understand how the adjustment of this air jet is produced and what is the influence of the vocal tract over this adjustment are the main objectives of the experiments reported in this article.

The research starts from the hypothesis that the changes of timbre are a fundamental element to musical performance, surpassing simple technical mastery of the instrument. Control of timbre changes by the musician becomes an integrating item of the music creation process, and contributes to the expressiveness of the performance. Such changes in the timbre of the flute can be widely applied in various types of composition. Our proposal includes theoretical and practical objectives capable to, on one hand, deepen the knowledge about the sound production of the flute and, on the other hand, to enable such knowledge to be immediately applied in the performance and teaching of the instrument.

The research focuses on aesthetic concepts related to musical performance, from an analytical procedure that integrates technical and technological aspects involved in interpretive practice. It also considers the musician a creative and transformative agent, as much as the composer. This musician, imbued with an interactionist perspective (MANZOLLI, 1996), positions itself in the musical process in a particularly active way, in which his choices, actions and/or musical gestures (IAZZETTA, 1997) serve as the substrate, making him an interface of the sound production process (BOULEZ, 1986).

2. The influence of the vocal tract

The vocal tract consists of the upper respiratory system, including the entire structure limited by the vocal chords in its base and by the lips and nostrils in its upper part. This is a continuous tube with average diameter of 3 cm and 17 cm in length (PINHO, 1998; FRITZ, 2004). The vocal tract is critical for the understanding of speech, functioning as a filter capable of changing the original signal emitted by the vocal chords, regardless of the fundamental frequency of emission (SUNDBERG, 1979).

In a study on the resonances of the vocal tract in speech, song and wind instruments, Wolfe et al. (2009) demonstrate the filtering effect caused by the vocal tract and claims that the resonances of the vocal tract can influence the timbre of the woodwinds. (WOLFE et al., 2009, p. 7). Wolfe et al. (2003) examine the effect of two positions of the vocal tract in the production of sound in the didgeridoo (an Australian typical instrument) and in the trombone. The authors point out two reasons for using experimental apparatus to explain the effects of the changes being studied: first, when a player changes the shape of the mouth, he/she may also unconsciously change the pressure and geometry of the lip. Secondly, due to the large number of variables, it is difficult to explain the effect. (WOLFE et al., 2003, p.307). The modeling of a geometrically simple vocal tract is also presented, from two positions usually used by the musicians: the first representing the tongue entirely down; and the second representing the tongue raised.

Lamkin (2005) suggests that articulation and sound production in the flute are influenced by the flutist's native language as well as by any other language s/he is able to speak. According to the author, the culture of a language can cause subtle influences in choices related to sound production.

3. Preliminary experiments

Aiming at revealing the relations between the configuration of the vocal tract and the production of sounds on the flute, an empirical experimental model was created to search for any evidence of the influence of the vocal tract on the flute's timbre. For this purpose we tried to isolate the variables which could define the sound of the flute, such as movements of lips and jaw. Thus, a dummy mouth was built in fiberglass, using an average opening and angle found in real flutes. First we made a mold of plaster bandage placed directly on the lips. These molds, which allow greater similarity to the regular instrument, were then covered with fiberglass. After drying, the fiberglass was detached from the original mold providing a model quite similar to the real flute.

Figure 1. **Model embouchure in fiberglass**

The fiberglass model of the embouchure is attached to the nozzle of the flute according to the model developed by Quantz (2001) and is capable of producing tones around the middle range of the instrument.

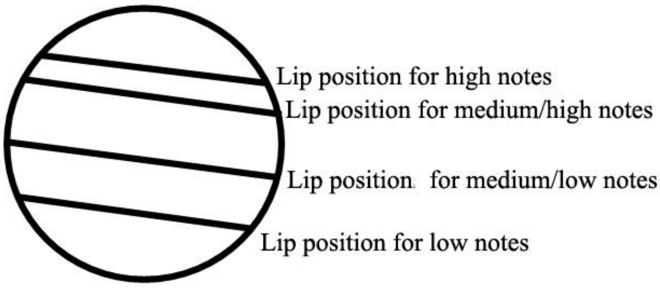

Figure 2. **Position of mouthpiece covered by lips for different records in the flute (Quantz, 2001. P. 521).**

Part of the mouthpiece opening was covered with plastic tape, as suggested by Coltman (1966): *"To simulate the coverage of the lips, a curved plastic tape 3 mm thick was fixed to the mouthpiece as a way to replicate the human model"*. It was necessary to use a carbon fiber mouthpiece, less susceptible to damage as a result of the assembly process of the experiment. This piece was developed by the acoustician and musician Leonardo Fuks, and reproduces quite closely the sound characteristics of a metal mouthpiece. Later, the fiberglass embouchure was coupled to an artificial vocal tract made of PVC. A metallic ring was built to simulate the vocal tract constriction. This ring moves inside the vocal tract model by sliding a magnet placed on the outside of the tube. These details can be better visualized in Fig 3.

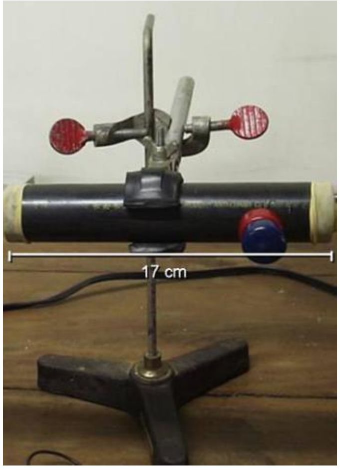

Figure 3. V**ocal tract made of PVC**

This vocal tract model is commonly used in researches on speech, as Kent and Read (2001) assert: "*To introduce the acoustic theory of speech production, we use an apparatus that does not look much like a human vocal tract. (...) To make this example relevant to the study of human speech production, one must observe two things: (1) a vocal tract of an average man is 17.5 cm from the glottis to the lips and (2) a vocal tract has approximately the same frequency of resonance of a straight tube of the same length and diameter. That is (...) a satisfactory model for a particular vowel in human speech. (...) To have this model representing other vowels, the constriction area should be diversified along the length of the tube in order to approximate the vocal tract configuration to that of a desired vowel. (...) All vowels in English can be shaped, even if rudimentary, by appropriate modification of the configuration of such straight tube*."

The artificial vocal tract is connected to a compressed air system. The flow, which is manually adjusted, was monitored with a flowmeter for compressed air, 0/15 L/min, with a long cylinder, and the airflow kept constant during measurements. This process removed any possibilities of variation of the air flow. The experiment was performed in the Experimental Physics Laboratory, in the Department of Physics of the Institute of Mathematical Sciences (ICEX), at the Universidade Federal de Minas Gerais (UFMG).

The results of this experiment were recorded with a microphone AKG D60S positioned about 20 cm from the mouthpiece and pointed to the area between the mouthpiece and the keys, according to the suggestion made by Garcia (2000). Samples were recorded in three different situations: the first, using only the mouthpiece of the flute, generated a 1000Hz tone; the second one, using the entire flute, had the keys positioned to the issuance of the note "B", produced a 480Hz tone; and finally, the third, also using the entire flute, with the keys positioned to the issuance of the note "A", generated a 430 Hz tone.

The results obtained using the entire flute, with the keys positioned to the issuance of the note "A" are presented. Having the keys in this position, we obtained a fundamental in 430 Hz. Four samples were recorded. The flow by means of which an adequate sound response was obtained from the instrument was 13 L/min. The first sample was recorded by making a sweep of the vocal tract model using a constrictor element that was moved, with a magnet, between (1.0 ± 0.5) cm and (15.0 ± 0.5) cm of the model. The initial position represents the constriction closer to the mouthpiece of the flute.

On the sonogram obtained from this recording, one can see the remarkable changes occurred. Observe the three distinctive sections, as indicated in Figure 4.

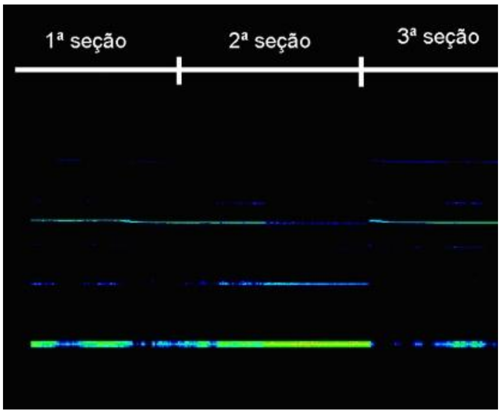

Figure 4. **Sonogram obtained in the recording of the experiment**

From the results generated by the experiment it was possible to observe that the sound changes were considerable, indicating an evident influence of the position of the vocal tract on the quality of sound of the flute. This influence was noticed both aurally and through spectral analysis of the configuration of the sound, as shown in Figure 4. There were noticeable changes in the corresponding fundamental and harmonics, according to the constrictor element's position on the tube of the vocal tract model in all the three cases researched.

It is necessary to observe that, in practice, the interference of the vocal tract on the timbre of a flute is less obvious than it was shown in the model. This is due to the large number of variables to which the flutist submits his performance, for example, the position of the lips and jaw, and variations in pressure and flow. The function of the model, by isolating variables, is to highlight the changes due to the position of the vocal tract.

4. Future prospects

Given the evidence of existence of influence of the vocal tract position on the flute sound, a series of events will be held, such as building a device that enables the explanation of the mechanism of control of timbre from different configurations of the vocal tract, and the creation of interviews with semi-structured questionnaires for flutists who use this mechanism.

From the preparation of the preliminary experiment, some features should be observed for new experiment. Particularly, our model needs to take both the instrument and the vocal tract impedance into consideration. The acoustic impedance allows an objective approach to the instrument, regardless the particularities of any individual performance or the changes in the vocal tract in comparison with the instrument. The flute, according to Wolfe et al. (2003), would be the only instrument played with its input flow open to the atmosphere. As a result, the flute operates with maximum impedance levels, unlike, for example, the clarinet, which has a blade that is fitted in the mouth of the performer, delivering great pressure variation in its input device. Also according to the author, this would explain the relative small number of experiments (especially if compared to those on the clarinet) on linear acoustics of the flute. Nevertheless, there are interesting studies on the impedance of the flute in Wolfe et al. (2000) and Wolfe (undated). In Fritz (2004) the impedance of the vocal tract in clarinet players was measured in a situation classified as "quasi-performance". Her findings report that musicians who took part in the survey, though unanimous in asserting the importance of the vocal tract, did not agree about the better way of using it.

Another aspect that needs further improvement is the development of a mouth model that simulates, even though in a simplified form, the mouthpiece of the flute. The model previously developed does not have the ability to fit to the mouthpiece of the flute, and of being adjusted to different registers of the instrument. Fritz (2004) carries out his experiment with two latex tubes filled with water and with pressure regulation. Although effective in the empirical clarinet mouthpiece model, the free mouthpiece of the flute demands further study. Thus we designed a mouthpiece model made of galvanized latex and odontological materials which still are in the testing phase.

On the other hand, it is expected that the questionnaire that is going to be conducted with flutists is able to bring new data to the construction of the new model, by getting information regarding the vocal tract configurations they use during the study and performance of the instrument. Fritz (2004) successfully uses a similar method in his research with clarinetists. It is expected that from the semi-structured questionnaire with flutists, the most commonly used and recommended positions of the vocal tract can be reproduced in the experiment.

After completing his experiments, Fritz (2004) states that the influence of the vocal tract would not be only acoustic, but also affects the aerodynamics of the air column. The modifications of the resulting sound would be a consequence of both causes. However, considering the specificities of the flute, with the production of sound from a free embouchure, in which the air jet is blown directly over the edge of the mouthpiece, not being influenced by the vibration of the blade and running in maximum impedance levels, it is expected that the vocal tract configuration has greater influence on the sound and, particularly, in the timbre of the instrument.

5. Acknowledgements

This research has been supported by FAPESP - São Paulo Research Foundation (grant 2008/08632-8 and 2010/06510-2).

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