How does posture influence flute player's breathing and playing ?

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This study focuses on the influence of musical task and position on the preparatory gesture, respiratory patterns and the associated respiratory muscle recruitment used in flute playing. The study was triggered by the flute players and teachers claiming that the control of the playing starts during these preparatory phases. We present the experimental setup used to record simultaneously the lip positions, the activity of a few selected respiratory muscles, the chest wall compartment displacements and the associated volumes, the blowing pressure in the mouth of the player and finally, the radiated sound. Thus, the flautist plays two musical tasks, which present different complexities in two different postures (seated and standing position). The analysis of respiratory and hydrodynamical parameters show the strategy developed by the player in the case of different complex musical tasks. The data indicates a strong correlation between the duration of the musical phrase, the register at which it is played and the preparatory gesture. To play a demanding musical task, the flautist has to take into account all the difficulties before playing. Furthermore, the flute player needs to adapt his respiratory strategy to the physiologic changes due to the position changes. However these respiratory control variations do not influence the hydrodynamical parameter control, which is thus independent of the change of position. Finally, our results on the respiratory control in the seated position are consistent with the observations in the literature on forced respiratory maneuvers.

1 Introduction

The sound production of music instruments has significantly been studied from the physical characteristics of the instrument perspective. However, the sound produced by flute depends not only on the physical characteristics of the instrument but also on the control exerted by the musician. This is especially important when the air jet is shaped by the lips of the player (as is the case for the flute). Indeed, music performance requires the instrumentalist to develop an expert control, acquired during training. For the flautist, the control of fingerings, lips and respiratory parameters allows to play the requested pitch, amplitude and timbre associated to musical pieces.

This study focuses on the influence of a flautist's posture on the hydrodynamical and respiratory controls during two musical tasks. As explained by Vellody at al., [1], thoraco-abdominal movements may change because of compliance variations induced by the change of posture, but these variations may also influence the respiratory control and bring the musician to develop a different strategy to play the musical task. Furthermore, if a change in respiratory control occurs, it may influence the hydrodynamical control. This needs to be verified. In brief, the first objective is to understand how the flautist's respiratory activity and control parameters are linked together but also to the musical tasks and then, to observe the influence of posture on the respiratory and hydrodynamical controls. Simultaneous measurements of the hydrodynamical and respiratory parameters were conducted during two musical tasks that present different complexities. In a first section, we briefly present the acoustic and respiratory control parameters. The next sections present the measurements and the protocol with a brief presentation of the two musical tasks and the flautist, the results of acoustical and respiratory measurements, and a brief discussion and conclusion.

2 Control parameters

2.1 Acoustical parameters

Flute operation can globally be described as a coupling between the hydrodynamic modes of a jet and the acoustic modes of a resonator. This passive element, coupled to the jet, provides the necessary energy to sustain the oscillation. The description commonly used in the literature, [2], [3] describes the flute as three independent blocks, figure 1. The three different elements (jet, sources and resonator) are

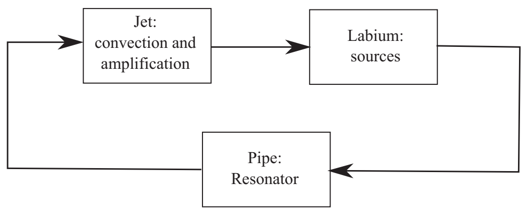

Figure 1: General description of flute operation as three independant blocks coupled together.

supposed to interact locally. The analysis of each block is done separately and then concatenated to produce a caricature of flute operation. The acoustic resonance of the resonator has been studied by Kergomard [2], Wolfe [4] and Nederveen [5] amongst others. The importance of labium geometry and its influence on the jet or on the sound production has been studied by Coltman [3, 6], Nolle [7] and Dequand [8].

To describe the parameters of the control by the player, we focus on the jet-labium configuration. Indeed, the flute player controls both the jet characteristics and the lip to labium distance W. The jet can be described by the flow Q and the velocity U, which are both linked to the opening area A between the lips $Q = AU$. With Bernoulli's equation, $U = \sqrt{2P_m/\rho_0}$, the velocity can be estimated from the mouth pressure P_m, where ρ_0 is the air density.

These parameters can be described using dimensionless numbers: the dimensionless velocity θ, ($\theta = U/fW$, where f is the fundamental frequency of the radiated sound), the Strouhal number Str_h, ($Str_h = fh/U$, where h is the height of the flue from where the jet flows) and the Reynolds number Re, ($Re = UD/\nu$, where D is the hydraulic diameter and ν the kinematic viscosity of the fluid). The structure of the jet is directly related to the Reynolds number Re. For more detailed information, refer to Verge's [9] or Howe's [10] studies. The Strouhal number informs us on the stability of the jet, following Mattingly [11], Drazin [12], Rayleigh [13] and Nolle [7]. In the literature, a few studies by Coltman [3], and Auvray [15], discuss the importance of using the dimensionless velocity θ as a describer of hydrodynamic operations. Playing the flute requires adjustments of these different parameters in order to guarantee the oscillation at the requested frequency and to achieve expressive intentions.

2.2 Respiratory parameters

Although all components of the respiratory system are essential to its good functioning, we limit our description to the main respiratory concepts and mechanisms relevant to flute playing and to the understanding of our data analysis and results. The different parameters described below include the pulmonary volumes, the main respiratory muscles and the pressure-volume curve of the respiratory system. For further information on respiratory mechanics, please see [16, 17, 18]. Figure 2 shows the spirometric tracings of static pulmonary volume subdivisions: Vital Capacity (VC), Residual Volume (RV), Functional Residual Capacity (FRC) and Tidal Volume (TV). Vital Capacity

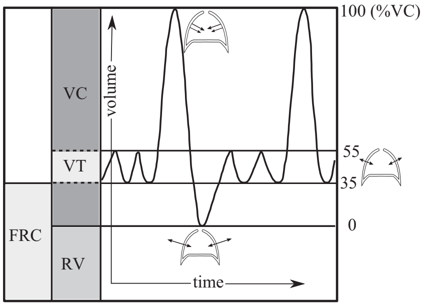

Figure 2: Spirometric tracings of static pulmonary volume subdivisions, [19], [20]. The arrows in the small side drawings indicate the static forces exerted by the lung and the chest wall at different volumes.

(VC), which corresponds to the air comprised between a maximum inspiration and a maximum expiration, is the air available to play flute. At 100 % of VC, passive forces exerted on the system are strong enough so that, if respiratory muscles are relaxed, air naturally tends to go out. FRC volume represents the resting volume, at this volume passive forces of the lungs are equal and opposite. At 0% of VC, the volume of air that remains in the lungs is the residual volume (RV). At that volume, when muscles are relaxed, passive forces are oriented outwards. Tidal Volume (TV) commonly refers to the air used during quiet breathing. During the inspiratory phase of quiet breathing, only inspiratory muscles are activated to enlarge the chest-wall cavity and during the expiratory phase, the thorax passively returns to its resting state. During forced breathing, air displacement is considerable and requires more effort. The action of the inspiratory muscles is greater and the expiration is forced by the expiratory muscles.

3 Measurements and protocol

3.1 Measurements

One of our goals was to measure simultaneously the acoustical and the respiratory parameters. The set-up used in this experiment is the same as the one described in de la Cuadra's study, [14]. The camera device used to film the lips of the flautist was slightly modified in order to make it compatible with the OptoElectronic Plethysmography (OEP). The camera was attached to the head extremity of the flute to catch a transverse view of the lips. To catch the frontal view, a mirror was placed near the embouchure forming an angle of approximately 45 degrees with the flute. To measure the pressure in the mouth, a soft tube was connected to a calibrated differential pressure sensor. The radiated sound was measured with an external microphone placed 1 meter away from the flautist.

The respiratory set-up is the same that the one described in Cossette's study, [21]. Volumes of the chest-wall compartments are measured by the OEP system, which consists of 9 infrared video cameras tracking 89 hemispherical markers apposed to the chest wall. For the analysis of the chest-wall displacements, the chest wall is divided in three compartments: the pulmonary rib-cage compartment, the abdominal rib-cage compartment and the abdomen compartment, see figure 3.

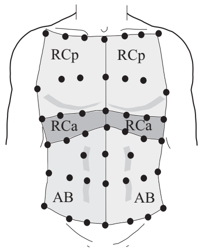

Figure 3: Three chest-wall compartments and positions of the markers.

Selected surface respiratory muscles are measured: scalene, sternocleidomastoidian, rectus abdominus and lateral abdominal muscles (internal and external obliques and transverse combined). For information on muscles measurements, see [21]. In order to simplify data representation and comparison, respiratory volumes and muscular activity are expressed against time as a percentage of the maximal volume or the maximal activation reached during a vital capacity manoeuvre (% max activity). Our flautist has a Vital Capacity of 3.8 liters.

3.2 Musical tasks and presentation of the flautist

As mentioned previously, the objective is to study the control of the flautist during two musical tasks with different musical and/or respiratory complexities and, more specifically, to observe how the flautist adapts breathing and playing to the standing and seated positions. The flute player performs two musical tasks: a) a G major scale on two octaves which constitutes a practice routine for which does not require any special musical or respiratory effort and, b) a piece from the flute repertoire, Debussy's *Prélude à l'après-midi d'un faune*, which is a demanding piece in terms of breathing. Indeed, this flute solo at the beginning of an orchestral piece is traditionally expected to be played in one breath even though its tempo is moderate and the excerpt is long. The time duration is the principal challenge, made even more demanding by the crescendo-decrescendo indicated at the end. As the flautist plays solo, a high quality and musical sound is sought. The figure 4 represents the score of the two musical tasks. The flautist studied is a woman who was 47 years old at the moment of the measurements. She was trained as a professional flute player and had an extensive playing experience (over 250 public concerts) and played daily over 20 years.

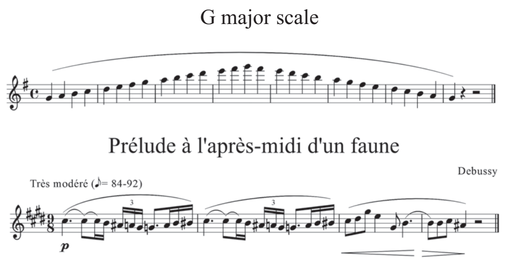

Figure 4: Scores of the two musical tasks

4 Results

Hydrodynamical and respiratory data are synchronized and represented together. The right graphs of figures 5 and 6 show measurements of radiated sound, mouth pressure P_m, area of the lips A, distance of the lips to the labium W, jet-flow Q, total volume and muscular activity, Reynolds number and dimensionless velocity θ respectively for the G scale and Debussy's excerpt played in the standing position. The left graphs of figures 5 and 6 respectively represents the same parameters for the G scale and Debussy's excerpt played in the seated position. On figure 5, the vertical lines represent the beginning of sound production and the limits between each register. The dashed horizontal line on the total volume indicates the FRC volume.

G scale: Figure 5 shows a consistent repeatability in the hydrodynamical control parameters (P_m, Q, Re, A, θ, W) during G major scale playing in the two positions. Indeed, in both positions, mouth pressure increases by the same factor $\approx$ 3.6) while pitch increases by a factor 4 and inversely when pitch decreases. Area between the lips decreases in the high register to counterbalance the increase of jet velocity, and in order to keep low flow variations and to prevent an extreme increment of loudness. We also observe that W decreases in the high register (from 4 mm) to keep $\theta = U/fW$ relatively constant. A slight variation of θ is observed between the two positions, between the vertical lines 3 and 4, that may be due to the fast retreat of the lips in the standing position at the end of the play. In the two positions, a strong correlation between the flow and the Reynolds number is also noted. Finally, the activation of the inspiratory muscles seems to be similar in the two positions. Conversely, we can note a higher expiratory activity in the standing position. At the end of the G scale, the total volume is higher in the standing position (3.4 %VC) than in the seated one (12.3 %VC), which may explain the higher expiratory activity as more effort is required for a larger expiration.

Debussy's excerpt: On figure 6, the vertical lines represent the beginning of the sound production and the transition between the musical structures. As for the G scale, mouth pressure varies with pitch. Indeed, the two first musical bars of the excerpt are clearly different from the third one. The player seems to play the crescendo by increasing jet velocity rather than by an increase of flow. It seems that this long excerpt requires the flautist to keep (save) her air. This is clearly reflected on the flow data, which is approximately 2.8 times smaller than the one used during the G scale. The Reynolds number also follows pitch, and is smaller than for the G scale, which directly results from the smaller values of the lip area. W is kept very stable during the excerpt and θ has approximately the same pattern for the two positions. The principal difference between the two positions occurs between the vertical lines 2 and 3. During that section in the standing position, the muscular activity is minimal, thus the flautist controls the air exhaust and the flow for the decrescendo by a diminution of the lips area. In the seated position, the muscular activity is slightly higher between the vertical lines 2 and 3. The air exhaust is then controlled by the muscular activity and not by a diminution of the lips area. In the two positions, the flow is controlled by the muscular activity in the rest of the excerpt. Furthermore, the maxima of muscles activation are higher during the Debussy's excerpt than during the G scale, which correlates with higher inspiratory and expiratory volumes. Finally, even if the maximum activation of the laterals are similar for the two positions, we remark that in the standing position the activity is more present than in the seated position, where the lateral activation quickly increases at the end of playing. The mean of lateral activation is higher in the standing position (26%) than in the seated position (23%), from the vertical line 3 to the end of the excerpt.

Chest-wall compartment contribution:
We use a Konno-Mead diagram, [22], to show the contribution of each chest-wall compartment during inspiratory and expiratory phases of the musical tasks. Figure 7 represents the volume variations of the upper thorax compartment (VRC_p) versus the variations of the abdominal compartment (V_{AB}) for the two musical excerpts played in the two positions. The beginning of sound production is represented by crosses for each musical task and time evolution is noted by arrows and t indication. The oblique dotted line represents the linear function corresponding to an equal contribution of each compartment. On figure 7,

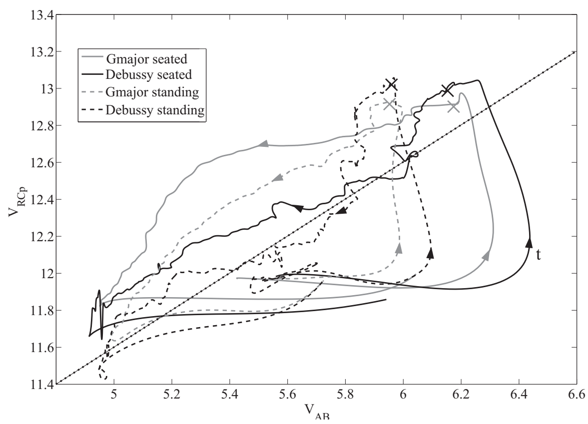

Figure 7: Konno-Mead diagram for all the excerpts

we notice that inspiration occurs in two phases: first the Abdomen Volume increases and, second, chest-wall volume increases. Furthermore, for each musical task played in the seated position, we remark a higher inspiration, $\approx +300mL$, in V_{AB}, while the same volume is taken in VRC_p during inspiration respectively for the two postures and the same musical task. At the end of the expiration of each musical task in the seated position, the remaining pulmonary volume is higher ($\approx +300mL$ in the VRC_p) than the one for the same musical task in the standing position. Thus, the same total volume is used to perform the same musical task in the two postures. We could suppose that it is easier to play at a high Abdomen Volume in seated position. And at contrary, it should be easier to play at low VRC_p in standing position.

The higher contribution of the Abdomen Volume in

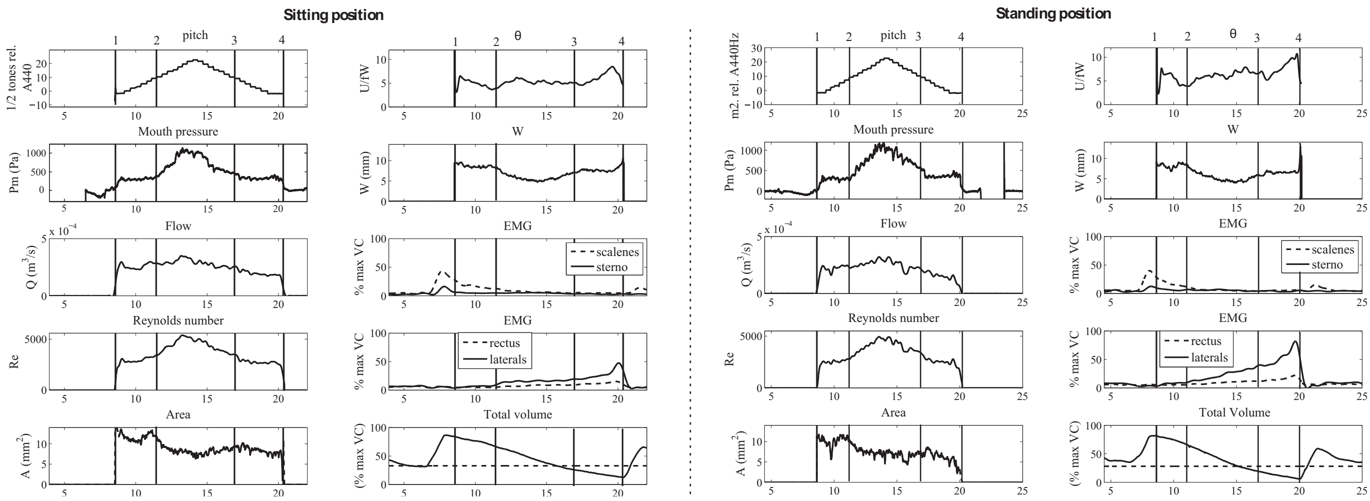

Figure 5: Hydrodynamical and respiratory parameters for the G scale played in the seated (left) and in the standing positions (right).

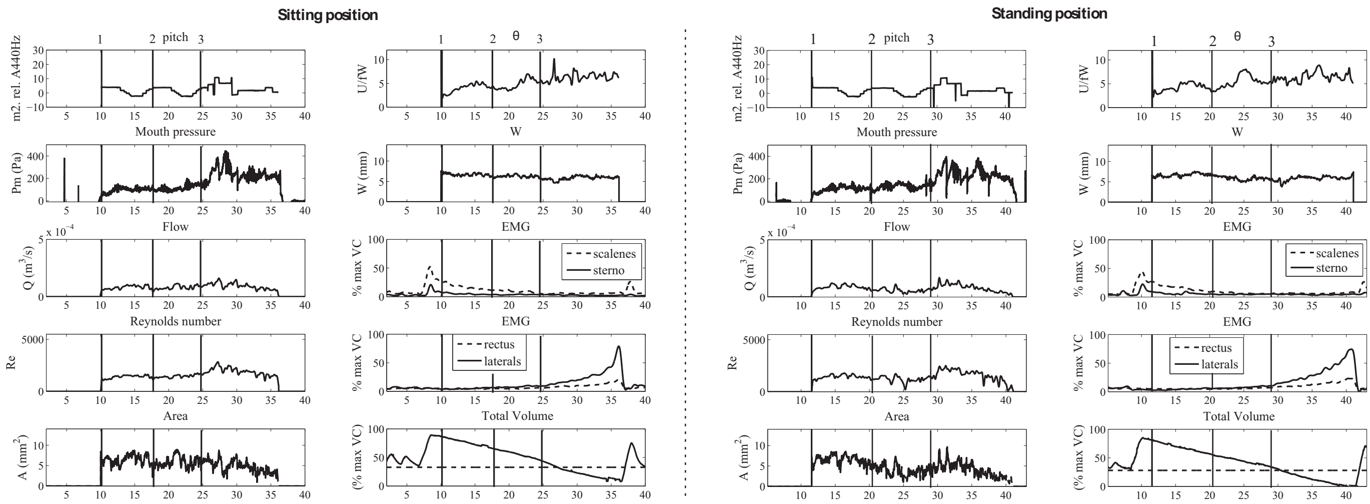

Figure 6: Hydrodynamical and respiratory parameters for the Debussy's excerpt played in the seated (left) and in the standing positions (right).

the seated position decreases the slope of the curves during the expiration. However, we distinguish some resemblances between the expiratory pattern for the Debussy's excerpt played in the two postures: the beginning of the excerpt displays a faster diminution of the upper thorax compartment. The rest of this excerpt displays a contribution of the two compartments. For the G scale played in the two postures, the resemblance is not so clear, however, the expiration is globally due to the contribution of the two compartments.

5 Discussion and conclusion

The combined experimental set-up is used in order to have persistent understanding of the respiratory and hydrodynamical parameters of a flautist's performance during two musical tasks played in two different postures. Firstly, we show how the flautist needs to adapt the control parameters to perform different complexities. Indeed, a long musical excerpt requires inspiration of high air volume and a highly active control of the muscles during playing . To keep a certain stability of the dimensionless velocity, the flautist controls the distance of the lips to the labium according to the pitch and the velocity. During the expiration, the flautist also involves her respiratory muscles to perform flow control in correlation with the lip area. All of the results are consistent with the previous studies by Cossette [23, 24, 21], de la Cuadra [14], Fletcher [25] and Montgermont [26].

The analysis of the two excerpts in the two positions show that the hydrodynamical is independent of the posture and clearly repeatable. Indeed, despite the variation of posture and despite an utilization slightly different of the respiratory system, the flautist controls her mouth in the same way. Moreover, the respiratory analysis of the two excerpts played in the two positions shows a glaring similarity: the flautist uses a larger contribution of the abdomen volume during the seated playing than during the standing one. However, the total volume commitment remains unchanged. These observations are already mentioned in the literature, especially in Johny's study [27], which shows the influence of the posture on the thoracoabdominal movements. Indeed, the results of this study indicate a greater contribution of the abdomen volume in seated position than in standing position, especially in forced breathing (as vital capacity maneuver). Vellody et al., [1] explains that during a change of position, the gravitational forces and the force distribution of the respiratory muscles, change the compliance in the different parts of the thorax which may influence the contributions of the thoracic and abdominal volumes. This is aligned with our results.

Finally, further studies are required to further compare the hydrodynamical and respiratory parameters for musical tasks with other difficulties (register, dynamic,...) in the two different positions. As an example, high register playing requires high pressure. It would therefore be interesting to compare the different strategies used while playing in the third register of the flute.

Acknowledgments

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