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Structuring music in recorder playing: a hydrodynamical analysis of blowing control parameters

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ABSTRACT

For musical instruments producing sustained tones, the sound of the instrument can be interpreted as a sounding transposition of the player's gesture over the duration of each tone. By shaping individual tones, the player may create a musical structure such as a melody. The playing of wind instruments requires an expert control of one's blowing. In the case of flutes and recorders, the player's control can be efficiently analyzed in the framework of the knowledge on sound production of flute-like instruments. The time evolution of the hydrodynamical parameters that determine the sound production conveys the player's intention. We present analyses of the control exerted by a recorder player playing written musical excerpts, varying the performer's musical engagement by means such as rewriting the score with a different time signature. The basic control parameters measured during playing are analyzed in terms of the player's hydrodynamic jet of air. The different tones can then be classified according to the time shaping of each tone. The structure emerging from this analysis is finally compared to the written structure of the music. Results show that the same parameters that are used to produce the basic balance necessary for sound production are also finely tuned to shape the time structure of the playing, turning the sound into music.

CONTEXT

The playing of a musical instrument requires years of practice. During the first years of practice, the player learns first to control the basic technique necessary for sound production. Later, once this basic balance becomes a reflex, the player can concentrate on how to play more efficiently when close to the points where the instrument's regime changes, thereby allowing him to enhance the expressivity of his playing. Ten years of practice is considered to be a minimum in order to reach the expertise required for a professional musician [1]. For instruments producing sustained tones, such as the violin family and the wind instruments, the time shaping of the sound is the result of the control gesture of the player. Indeed, the sound can be seen as a transposition of the control gesture. Furthermore, the control by the player is highly adapted to the oscillating behavior of the instrument. Therefore, the analysis of the control gesture, within the frame of the oscillating response of the instrument, may exhibit the player's musical intention, in a very explicit way.

Blowing indicator : the hydrodynamical framework

In the present paper, we analyse the control in the case of recorder playing. Together with the correct fingering, the recorder player needs to adjust his blowing pressure in order to produce the desired tone. The blowing pressure is the main parameter that the player uses to shape each note. The analysis of blowing pressure is here presented within the framework of the current knowledge on the physics of flute-like instruments. The main points are summarized below. For a detailed discussion, see [2, 3]. The excitation mechanism of a flute relies on the interaction between an unstable air jet and the acoustic field from the resonator. Perturbations are convected and amplified along the jet, and acoustic sources are created by the interaction between the jet and the labium. The pipe acts as a resonator and accumulates energy at specific frequencies, resulting in a self sustained oscillation. Figure 1 shows a schematics of a recorder, defining the relevant dimensions we will use later in the article: the jet with velocity U_j, the distance W from the channel exit to the labium. The jet is formed at the end of the channel and is directed towards the labium. The travel time of the jet from flow exit to labium is essential to the oscillation : by adjusting the blowing pressure, the player controls the jet velocity that determines this travel time. This is the main reason why the blowing pressure is analysed in terms of the dimensionless jet velocity : the dimensionless velocity θ is calculated as the ratio of the jet velocity to the velocity that would be necessary to travel the distance W from flow exit to labium in one sound period $1/f$, where f is the oscillating frequency :

$$\theta = \frac{U_j}{fW} \tag{1}$$

The jet velocity U_j can be reasonnably estimated [4, 2] from the blowing pressure p_m in the mouth of the player using Bernoulli's equation $U_j = \sqrt{2p_m/\rho_0}$ if ρ_0 is the air density. The dimensionless velocity appears to be a blowing indicator, independantly from the note played : in playing conditions, standard values are $7 < \theta < 17$, while θ may be as low as 3 for overblowing on the first oscillating regime. For high θ values, the jet velocity is of high relevance to the regime played. This eventually leads to a jump to the higher regime. On the other hand, for low values of θ, the oscillation can jump to the lower regime or even stop. Furthermore, the dimensionless velocity θ is highly correlated with the spectral content of the sound produced : the spectral content shows a strong increase in higher harmonics for values over 10 while the harmonic content is very poor for values under 8. De la Cuadra [5] and Blanc [2] have shown that the dimensionless jet velocity θ is a significant blowing indicator.

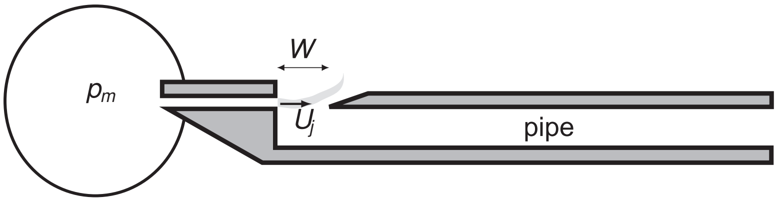


Figure 1: Simplified representation of a recorder, showing the pressure p_m in the mouth of the player and the jet velocity U_j.

Musical examples

The musical excerpts that were played for the present study were composed by Marin Marais (1656-1728), Telemann (1681-1767), Vivaldi (1678-1741) and Quantz (1697-1773), from different countries during the baroque period. For the present study, a recorder player at the end of her formal conservatory training was asked to perform original and rewritten music of the composers cited above. Said performer had received training in this style, and as the reader will see in the following section, the intersection of the musician's technique and the use of blow pressure is at the heart of this study's main results. Various rewrites of the score allowed us change its agogics, even going so far as to change time signature of the original scores. For some of the original scores, the player was asked to perform with varying musical "commitment" (*debutant*, passionate, disinterested, etc...).

The aim of the work is to study the way the player translates a baroque score into blowing, in order to give the music its audible structure. We therefore assume that the player does not experience any difficulty with fingerings.

DATA

An Aesthé alto recorder was used for the experiments. The recorder has two extra holes added by the maker, in order to measure both the blowing pressure in the mouth of the player and the acoustic internal pressure in the recorder. A small tube with 1mm internal diameter measuring about 10cm long is inserted into a hole drilled along the flow channel of the instrument. One end of this tube goies into the mouth of the player while the other end is connected to a calibrated differential pressure sensor Honeywell 176PC14HG1 allowing to measure the mouth pressure p_m. The radiated sound is also recorded stereo using two Schoeps MK6 sound recording microphones on omni-directionnal mode in AB configuration, and positionned about 80cm from the recorder, at the level of the eyes of the player. Fig shows typical data from the recording sessions. Several parameters are estimated from the raw data : the pitch, the onset time and the offset time of each note. The frequency is estimated from the inner acoustic pressure using Yin's algorithm [] and plotted as pitch deviation relative to A 440Hz. The onset time and offset time of each note are estimated using both the blowing pressure onset and offset as well as the pitch changes.

The figure 3 compares the dimensionless jet velocity estimated for two playings with contrasted musical intentions : the top part of the figure corresponds to an interpretation without musical investment while the bottom part corresponds to expressive playing. Listening to the first playing, although it sounds rather flat and boring, one does not hear any errors that would inhibits one's ability to discern the piece's musical structure. Both examples are played approximately at the same tempo, but show differences in the detail of the timing, in the dynamics of each note and in the global contrast of the dimensionless velocity within the range from 4 to 10. The time shaping of each note is amplified in the second version compared to the first, and the silence between successive notes is used for longer groupings in the second case : the first note is separated from the the second note by a short silence, then three groups of six notes appear (note 2 to 7, 8 to 13 and 14 to 19). Aurally, this is made manifest by one's perception of more attention to phrasing in the second playing than in the first.

In order to synthesize the data and allow for a higher level analysis, five parameters are calculated for each note of a melody. These parameters are constructed from an *a priori* of the expressive possibilities the recorder player uses. To simplify the problem, we first suppose that the fingering does not play an important role in time shaping as related to expressivity. We then focus on the blowing : at the level of each note, the player can adjust the blowing pressure, its timewise evolution during the note and the precise timing of the note (attack time and duration). Assuming that the playing technique can be reduced to these blowing properties, we define the following parameters :

- a *mean* value of the dimensionless jet velocity during the note,
- a *slope* of the dimensionless velocity during the note, indicating the global tendancy (increasing/decreasing) during the note ,
- the *fluctuations* of the dimensionless velocity during the note, increasing when the fluctuations get faster and when their amplitude grows. For example, a very fast vibrato with a wide amplitude would give a high value of the fluctuation parameter,
- the *silence* between the actual note and the next one,
- the *deviation* from the written rythm, defined as a time deviation from the value expected following the mean tempo played.

These five parameters are then used to group together notes that are played in a similar way. Groups of notes are generated by Gaussian mixture models [8]. The number of groups is increased until the new group include notes that show highly different values of their characteristic parameters, or that include only very few notes. The number of groups obtained ranges from 3 to 5. A close look at the groups obtained show that the mean value of the dimensionless velocity is a significant factor, since the mean value and standard deviation of this parameter is about the same for each group. Another global characteristic of the groups obtained is that groups with no fluctuations correspond to notes with a large slope (positive or negative). It is important to note that, *a priori*, these groups do not correspond to any inherent musical phenomena. Rather, it is the goal of the section below to corroborate these results with technical and interpretive aspects of the performer's playing. In the study presented below, the algorithm generated four blowing-parameter groups that are identified by green, yellow, orange, and red.

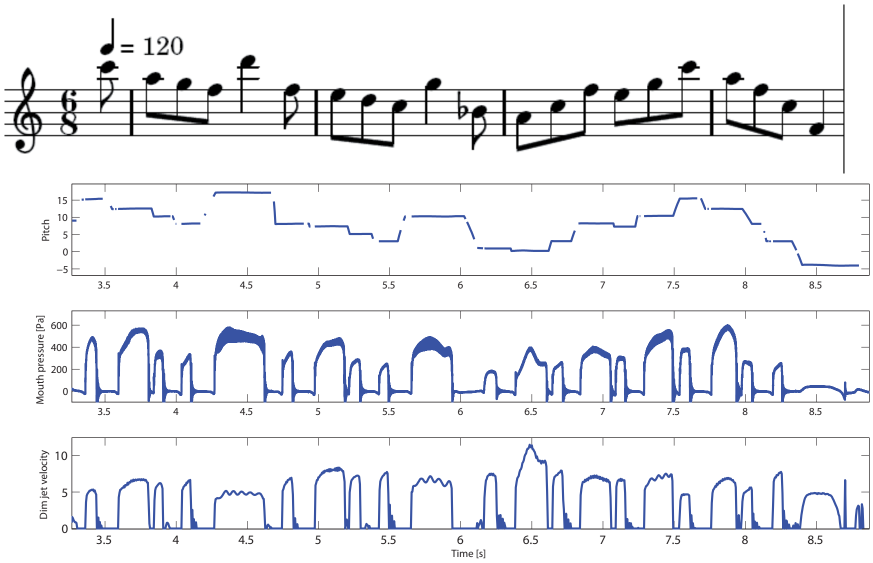


Figure 2: Score and raw data recorded while playing Teleman excerpt on an alto recorder.The pitch detected is plotted in semitones relative to A 440 Hz. The dimensionless jet velocity is calculated using the detected pitch and the distance W from the channel exit to the labium.

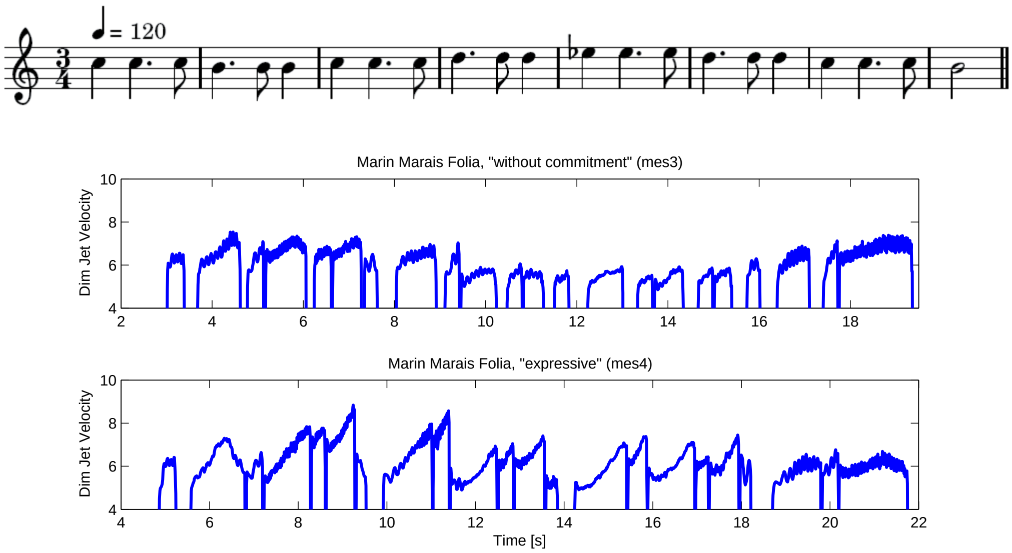


Figure 3: Comparing the dimensionless velocity estimated for two playings of the beginning of Marin Marais' Folia, played without commitment (top) and with expression (bottom).

TECHNICAL AND INTERPRETIVE CONTEXTUALIZATION OF BLOWING CONTROL

Having shown through hydrodynamic analysis that blowing control is a salient interpretive parameter along which the performer can effectuate a wide range of aural variability independent of "musicality", the next motivating question behind our research is to contextualize said variability in a musical style, showing the manners in which performers vary control in order to address traditional musicotechnical, and even musicoaffective, issues in interpretation. In order to do so, several questions must be addressed, both with respect to the general manner by which such an inquiry should be conducted and the specific limitations that arise in our body of data.

Regarding the first, it is outside of the scope of this paper to find a parsimonious relationship between the manifold styles in which the flute is musically meaningful and the way in which a performer, through blowing control, can shape this meaning. Rather, we favor a bottom-up approach: looking at one style in which the flute's performance practice is well documented, we seek to establish that blowing control has a degree of orthogonality with respect to the other parameters by which a performer makes an interpretive statement. Or, in other words, we seek to show that blowing control is not completely correlated with other parameters (dynamics, pitch, etc...) and can be considered in and of itself as musically important. However, for the task to be limited in this manner, it is important to define with clarity the intersection between flute performance practice and the musical style upon which our studies will be built: the late-baroque / proto-classical work for flute solo. This will be the motivating question of the next subsection.

After having done this, we must turn to the specifics of our study, which is also bottom-up in approach. That is, rather than surveying the interpretive choices of a variety of flautists on a variety of works from this era, we instead concentrate on one recording session as a case study in hopes that said study will not only show the ways in which blowing control *is* meaningful, but the way that said parameter can *becomes* meaningful as a player becomes familiar with a piece. This is the subject of the last subsection in this analysis.

Flute Solo in the Baroque - Trends and Tendencies

The late Baroque is an important junction in the history of music for solo-instrument works: musical literacy had permeated class strata to the point where these works could be printed and diffused for a wide audience, and the piano had not yet become the solo instrument *par excellence* that it was to become during the 19th century. As a result, a wide range of solo literature exists in this era, many of which forms the basalt of contemporary primers and textbooks on these instruments. The flute was no exception to this rule. The Oxford Dictionary of Music lists over 100 known composers writing for flute solo in Italy, France, and the Teutonic countries. Additionally, in spite of the heterogeneity of styles across various national traditions, a continental style emerged that was based on popular dance rhythms as well as the rhythm of speech. In this confluence of musical abundance and a shard musical language, one finds a landmark treaty on the subject, written during (if not slightly after) the high baroque era by Quantz. Two of the most important themes recurring through this treaty: the uniformity of tone and the articulation of temporal nuance, are two of the most important observations made below.

Blowing pressure as seen in one work

To focus on one specific work, take the following excerpt from our data by Telemann:

In spite of the lack of a continuo to provide a clear harmonic context for the flute part, we can use Larson's idea of the trace to develop a harmonic context for said work. This trace uses strong beats and arpeggiations to extract harmonic information. Often times, said information yields only one meaningful contextualization. However, ambiguities do arise, and they have been duly noted in the analysis below: Figure 5 uses colours to present the classes to which the notes of the excerpt belong. Only four groups are represented in the excerpt, out of the five groups generated by the Gaussian Mixture Models using the complete data base. Interestingly, the principal passage of harmonic ambiguity falls precisely at the occurrence of the hemiola, which in all of the recordings we have analyzed is classified in a similar manner with respect to the blowing parameters:

Although the reason for this similarity is unclear, it is reasonable to assume that the uniqueness of this passage with respect to the rest of the work demands a sort of interpretive memory that results in recurrent breathing control. Thus, while it is difficult to make a link between the musical result and blowing pressure in this particular case, the muscle memory used to achieve such pressure is certainly an aspect present in the present player (if not all flute players with a certain expertise). This reinforces one of the key claims of our research: namely, that a performer's training reinforces psychokinetic habits that are necessarily brought into play during the interpretive process, and that by shedding light on these links, we can illuminate how and where the player integrates their technique into the creative sphere.

Any particular musical result they yield is impossible to predict from the data without making musically-motivated observations that link the recordings and scores to the classification. There are, for example, a higher incidence of green-classified notes on strong beats and red-classified notes on weak beats. Orange notes, which are comparatively rare in the data set, fall principally on final beats of phrases. Of course, causality cannot be inferred from the presence of these phenomena: it is difficult to say how blowing pressure factors into the cognitive recognition, let alone production, of a "weak beat" versus a "strong beat". What is interesting is that, independent of the way this actually factors into identification of salient musical phenomena, the player feels compelled to engage in this behavior, which means that at the very least it is a cognitive landmark that has been integrated into the player's musical vocabulary. The permenance of these landmarks is particularly reinforced by the yellow-classified notes, which have in our study a 7% chance of being independent from intervallic leaps in the Telemann (where intervallic leaps are defined as anything over a major second). While we were not able to ascertain if this method of using the breath has a causal relationship with the arrival of intervallic leaps, there are many reasons that such control could be useful — the tone of the flute being heterogeneous as a function of its register, it becomes necessary to make certain adaptations in order to standardize one's tone over large leaps. Whether or not said standardization is a result of blowing pressure or whether this is simply a "trace" of a cognitive process (fear, anticipation, commitment, etc...) is outside the scope of this study. What is important, as in the previous data, is the regularity with which it repeats, confirming again the extent to which breathing control is systematically integrated into technique.

DISCUSSION

Analysing the dimensionless jet velocity shows in a very salient way the control by the player. The time shaping allows to understand the strategy used by the player to produce notes with different roles in the musical structure. This is illustrated by the

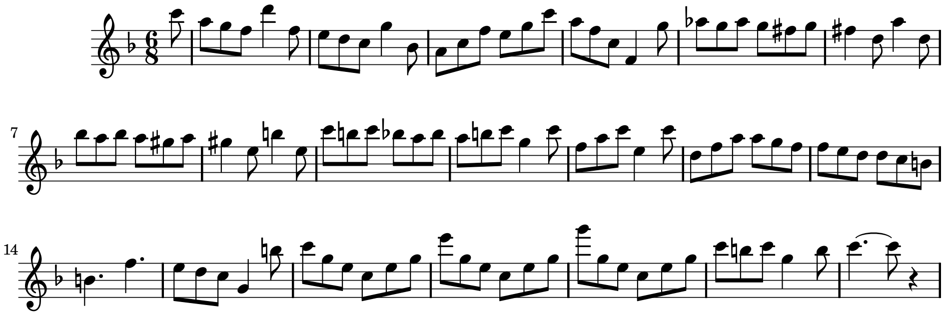
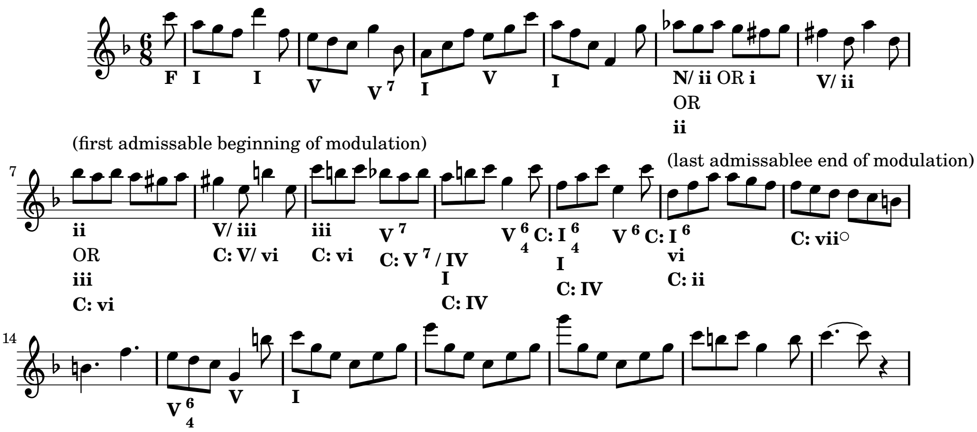


Figure 4: Telemann sonata for solo flute



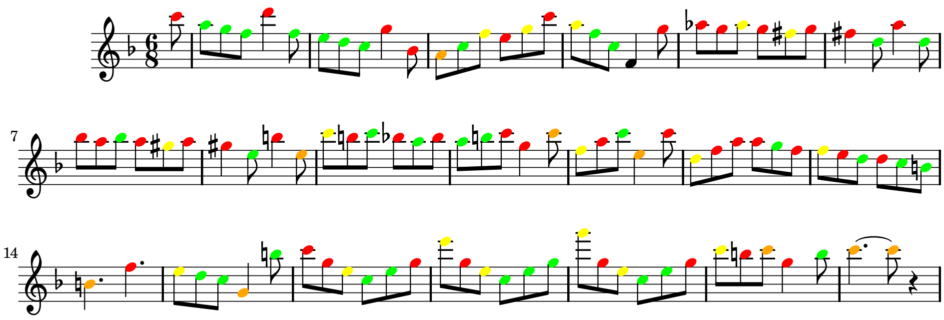


Figure 5: The groupings obtained through the Gaussian Mixture Models are presented here as colours. The groupings were obtained using a wide data base. Only four of the five groups obtained are found in this excerpt.

comparison between two successive playings of the Teleman excerpt discussed above. Figure 6 shows the dimensionless velocity measured from measure 5 (including the up beat) to measure 8. The player is sightreading during the first playing, and does not succeed in playing the first hemiola (measure 5) : the time structure clearly indicates a grouping of notes three by three. The second hemiola (measure 7) is well played even during the first playing, as shown by three groups of two notes. The second playing shows a higher command : both hemiolas are played with success, the player uses a wider range of dimensionless velocities, and the timing structure is also more developped (the long notes are longer).
While the reading of the dimensionless velocity gives a clear understanding of the player's intention, the groups of notes obtained in our analysis are more difficult to interpret. Indeed the analysis presented in the previous section shows that the groupings may give an interesting insight in some specific cases. However, a general survey of the groupings obtained through all our data base does not give a general information on the player's strategy.
On purpose, the input data used for grouping are very restricted : the time duration and the pitch of the notes are not included in the data. By doing so, our analysis can be summarized as an attempt to identify the musical structure independantly of rythmic and pitch information. In a way, our study takes a complementary point of view from studies of perceptual groupings from rythmic and pitch informations as written on a musical score [10, 11, 12].

CONCLUSION

We analysed data from a recording session with one recorder player, playing several excerpts from the baroque musical period. The blowing parameters were analysed in terms of the dimensionless jet velocity. The analysis of our data show how the interpretation structures the music, shedding light on some aspects of the player's strategy to break a succession of notes into coherent and articulated segments. Compared to the structures derived from the musicological analysis of the score, our data show how the player makes the interpretation sensible from a musical point of view. Furthermore, the blowing control also gives insight in the expressivity of the interpretation, allowing to differentiate performances with different musical comitment.
Analysis through Gaussian Mixture Model shows that a set of descriptors of the control parameters not including rythmic and pitch information does not convey the musical structure: indeed rythm and pitch are necessray parts of solo recorder music from the baroque period. However, the musicality of a flute player, and specifically the technical aspects of said musicality, are meaningfully linked to blowing parameters as a separate phenomenon from other musical parameters.

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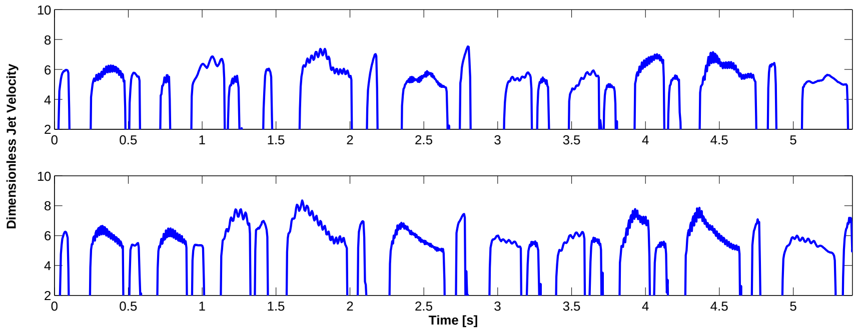

Figure 6: Dimensionless velocity measured during two successive playings of the Teleman excerpt analyzed. The data plotted correspond to measures 5 to 8. In the first playing (actually sightreading), the player does not succed in playing the first hemiola but only the second.