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Influence of Expressive Coupling in Ensemble Performance on Musicians' Body Movement

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ABSTRACT

This study aims at investigating if movements executed by musicians during musical performances are related to their expressive intentions. We tested the hypothesis by identifying information patterns on body movement data collected in performances of clarinet duos under different experimental conditions. First, we identified information patterns recurrent enough for the recognition of musicians who performed the excerpts. Then, we found evidence for a change in the "gestural signature" of the instrumentalist follower imposed by the leader, across the different performance conditions.

1. INTRODUCTION

Several empirical studies in music performance have shown evidences that musicians manipulate note durations, articulations, intensity, pitch and timbre, in order to convey musical intentions of a particular interpretation [1]. Notable differences may arise between interpretations of distinct performers or even between the same performer in different situations [2]. Constancy on such manipulations may be acknowledged as a style or a signature of the interpreter.

It is also well known that body movements in music performance also communicate interpretative intentions. In recent years, great efforts have been devoted to the study of these movements. Wanderley and colleagues proposed to differentiate body movements directly related to the production of sound (instrumental gestures) from those that are not (ancillary gestures), suggesting that the latter present tighter relations to the performer's expressive intentions [3, 4]. Attempts have been made to characterize and quantify physical gestures involved in musical performance, in order to identify their musical significance [5, 6, 7].

In order to identify how the information contained in body movements relates to the music structure and consequently to the musician's intention, some authors seek for models for segmenting these data [8, 9]. Teixeira and colleagues investigated musical significance of instrumentalists' gestures in clarinet performances of excerpts from classical and romantic repertoire. They were able to detect high recurrence of movement activity correlated to relevant harmonic and melodic changes, which they considered as objective evidence of musical significance of musician's body movement [10].

1.1 Ensemble performance

In instrumental ensemble performances, musicians have to coordinate their actions in order to converge to a musical concept that enables the accomplishment of a consistent performance, in which not only the notes are synchronized, but also the musical ideas are coordinated. To do so, musicians have to anticipate the expressive manipulations of the notes played by other members of the group. The burden of this coordination is shared among all musicians engaged in the musical task, either as a leader serving as reference for other players, such as a conductor, a *spalla*, or *Clarinet I*, or as a follower of the musical interpretation proposed by the leader. As pointed out by Gabrielsson [1], the goal of the movement performed by a musician, in addition to giving relevant information for the coordination with others, may also be used for communicating expressive intentions, which provide information about the artist's personality or simply entertain the audience.

1.2 Goals of the present study

Even though, as we discuss above, the ancillary movements in music performance have important roles in the transmission of expressiveness and in the synchronization of ensemble performances, the precise way in which instrumentists adjust their movements when playing with others is still an open research question. The present study is aimed at an empirical investigation of this issue.

More precisely, we sought to determine whether the body movement of musicians contains information related to the interpretative intention in a performance. To test this hypothesis, we attempt to demonstrate: (i) that body movement data contain sufficient information to identify "gestural signatures" of musicians from recurrent kinematic patterns; and (ii) whether "gestural signatures" of different musicians could be influenced by different interpretive situations, for example in instrumental duet performances, where it is necessary to follow the musical conception of the leader.

Although musicians take advantage of visual information conveyed by body movements of other members of the ensemble, in order to improve their synchronization and overall musical coordination, they are able to follow other musicians solely by listening to what they play, without any visual contact. This facilitates the methodological design for approaching the question proposed by this study: does musicians change their gestural signature when playing with others?

2. MATERIALS AND METHODS

2.1 Experiment

We analyzed the performances of six professional clarinetists in a simulated orchestral environment. All the musicians were recruited in Belo Horizonte, Brazil, had previous experience in orchestra and knew each other. The choice of the instrument facilitated the focusing on body movement not related to music production, since sound production on wind instruments is limited to low-amplitude movements, such as those of the fingers, the lips and the jaw, liberating the engagement in broader body movements, which have higher chance to be related to the intended musical interpretation.

The music performed in the experiment was a short excerpt of the "Dance of the Peasant and the Bear" from the ballet *Petrushka* by Igor Stravinsky, taken from the *Quatrième tableau* N$^{\text{o}}$ 100, first three bars (Figure 1), where "the peasant plays the pipe and the bear walks on his hind feet". This excerpt, in which first and second clarinets play solo in unison (*soli a 2*), presents a real duo performance situation, that requires synchronization of every single note and optimize similarity of conditions in both performances.

The recordings were done in two sessions separated by a period of two or three days. In the first session, musicians were instructed to play four times a musical excerpt as first clarinetist, i.e., following their own interpretative intentions. They were asked to choose one out of the four recordings, considered the best performance. This recording was later used for the second session, in which the musicians were instructed to play as second clarinet, following all chosen recordings of the first session, including those executed by themselves. The only instruction given was to accompany the first clarinet the best they could. After listening to the each first clarinet performance, each one played the excerpt four times, while listening to each execution of the first session through a earphone in their right ear, randomly presented. Three metronome beats were included at the beginning of each recording to be followed, whose tempo was estimated from the duration of the first complete pulse measured between the onsets of notes 5 and 9, F# and C, respectively (Figure 1).

2.2 Data acquisition

An *Optotrak Certus* (Northern Digital Inc.) was used to track the three-dimensional position of the clarinet and the head of the player, at a sampling rate of 100Hz. Three markers were placed on the bell of the clarinet to define a rigid body (represented by its spatial and angular positions) associated to it and other three for the player's head, as used in [5], [11] and [12].

Previous studies have shown that most of the movement in clarinet performance is focused on the bell of the instrument [13, 14], hence the restriction we adopted.

2.3 Parametrization

The magnitude of the resultant velocity of each three-dimensional position, estimated by Euclidean distance between two subsequent samples (1), was used to parameterize the motion of the clarinet bell, which we named the *velocity profile*:

$$v_i = \frac{1}{sf}\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2} \quad (1)$$

where x, y e z represent spatial coordinates, and i the sample number. A low-pass, linear-phase Butterworth filter of the sixth order and cutoff frequency of 5 Hz was used for discarding movements of low amplitude, such as those caused by the impact of the fingers on the instrument, or adjustments to the embouchure.

In order to preserve information that may be relevant, such as preparation and finalization gestures, we consider the movement to be analyzed starting at a metrical pulse before the first note and ending at a metric pulse after the end of the last note.

The difference between body weights, heights and ages of the participants seem to have influenced the amplitude and speed of movement, resulting in greater variability of absolute speed values across the subjects. In order to minimize the variability related to individual body characteristics and optimize the detection of "gestural signatures" due to temporal details that emerge from the interpretive intentions of the musicians, the amplitude of the *velocity profile* of each performance was normalized by its root mean square value, defined as 2.

$$v_Q = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^2} \quad (2)$$

where v_i is the amplitude of each of the N samples.

Due to the variability of tempi of each performance, the velocity curves were adjusted to the same number of samples, using the technique of time warping, as suggested by [13] and [5], which ensures the same approximate tempo for all performances. The mean values for each note onset of all performances was used as a timing model. This procedure aimed at minimizing the misalignment of the velocity curves with the musical structure. The superposition of *velocity profiles* of two performances by the same musician is shown in Figure 2. It can be observed that the misalignment of the two curves intensifies over time, resulting in a total duration difference of ca. 400ms. The bottom panel of Figure 2 shows the result of the time warping adjustment. This procedure was applied to each *velocity profile*, allowing performances of different tempi to be compared.

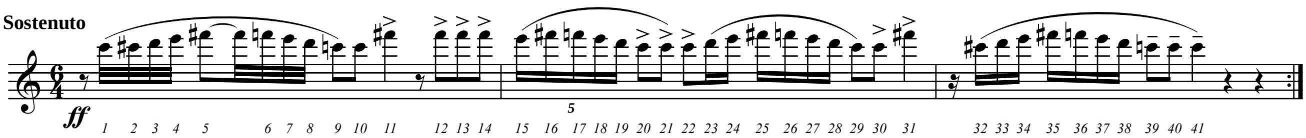

Figure 1. Excerpt from the "Dance of the Peasant and the Bear" from the ballet Petrushka by Igor Stravinsky, taken from the *Quatrième tableau* N^o 100 (first three bars).

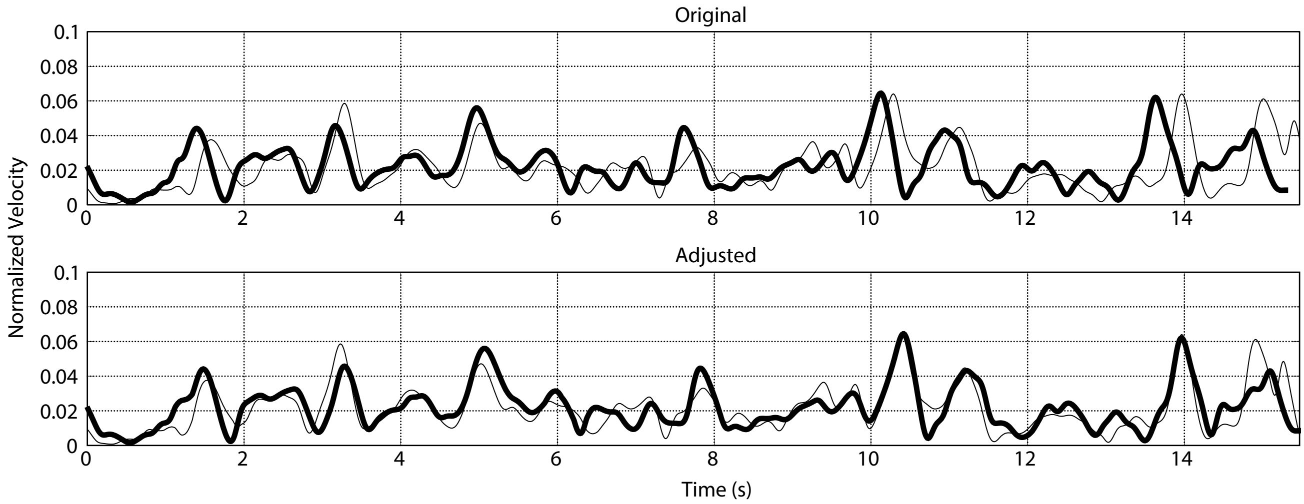

Figure 2. Temporal adjustment of *velocity profiles*. The curves correspond to the low-pass filtered velocity profiles obtained from two performances of a given subject. Top panel: original profiles. Lower panel: adjusted curves.

3. ANALYSIS

3.1 Musical gesture recognition

Results of previous studies with clarinet duets, in the same conditions, suggested that musicians have a "musical signature", observed upon acoustic parameters that describe characteristics of tempi, *rubatos* and articulation of notes. A significant decrease in mean asynchrony between the onsets of the notes, measured over 4 subsequent takes, was also observed in these studies, suggesting that musicians have the ability to quickly learn to better predict the expressive intentions of their partner, which may indicate evidence of interpretive coupling in ensemble performance.

The existence of consistency in gestural patterns of musicians, while performing similar musical content, observed by different studies, suggests that musicians might also present "gesture signatures" in different performances [13, 5, 15]. In fact, "gesture signatures" in everyday task performances were demonstrated by several studies, such as [16, 17]. Several patents of different applications of such investigations have been already filed, such as [18, 19].

In this study, the existence of individual "gesture signature" of musicians in different performances of the same musical material was evaluated with pattern recognition techniques applied to the *velocity profiles* of all solo performances of the subjects. K-means Cluster Analysis was applied to identify the 6 players of all solo executions, combined with Principal Component Analysis (PCA) for reducing data dimensionality (> 1500).

3.2 Gestural coupling

Having demonstrated that body movements in different performances of the same musician contain sufficient patterns of recurrence that can be identified as individual "gestural signatures", we sought to verify if musicians would change their "gestural signatures" by influence of different interpretive situations imposed by the musical conception of a leader.

The adaptation of the followers' gestures to those of the leaders was evaluated by projecting their *velocity profiles*, while playing as second clarinetist, onto the dimension that separate the leaders apart. This was done as follows. First, we represent the leader performances of these two clarinetists in the space of velocity profiles (points $\boldsymbol{A}$ and $\boldsymbol{B}$ in Figure 3). The vector that connects the point $\boldsymbol{A}$ to the point $\boldsymbol{B}$ is denoted $\boldsymbol{v_l}$. We consider then the performance of the first clarinetist when playing with her- or himself (point $\boldsymbol{A_a}$) and when playing with the second clarinetist (point $\boldsymbol{A_b}$). The amount of change in the kinematic pattern is evaluated by computing the projections of the vector $\boldsymbol{A}$–$\boldsymbol{A_a}$ ($\boldsymbol{v_s}$, the "self" condition) and the vector $\boldsymbol{A}$–$\boldsymbol{A_b}$ ($\boldsymbol{v_o}$, the "other" condition) onto the vector $\boldsymbol{v_l}$. These are the vectors represented as $proj_{\boldsymbol{v_l}}\boldsymbol{v_s}$ and $proj_{\boldsymbol{v_l}}\boldsymbol{v_o}$, respectively, according to equations 3 and 4.

$$proj_{\boldsymbol{v_l}}\boldsymbol{v_s} = \frac{\boldsymbol{v_s} \cdot \boldsymbol{v_l}}{||\boldsymbol{v_l}||} \qquad proj_{\boldsymbol{v_l}}\boldsymbol{v_o} = \frac{\boldsymbol{v_o} \cdot \boldsymbol{v_l}}{||\boldsymbol{v_l}||} \qquad (3, 4)$$

The length of the projected vectors were adopted as a metric to differentiate executions where musicians follow themselves from those where they follow others. Small

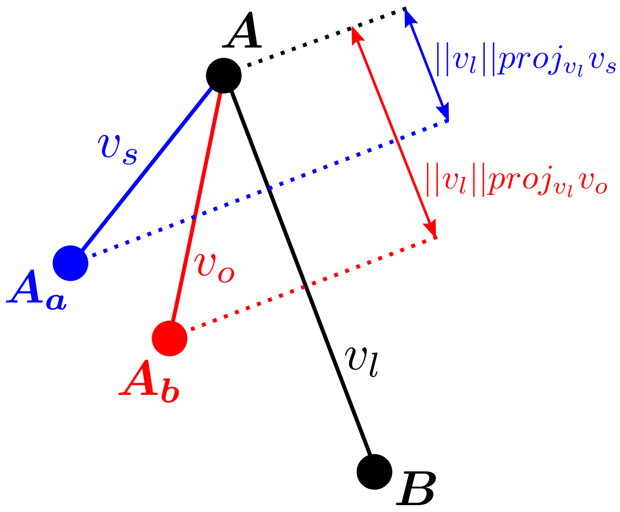

Figure 3. Geometric illustration of the vector projection procedure. The points in the *velocity profile* space corresponding to the solo performances of the first and the second clarinetists are indicated by $\boldsymbol{A}$ and $\boldsymbol{B}$, respectively. The performance of the first clarinetist when playing with himself and when playing with the second one are represented by $\boldsymbol{A_a}$ and $\boldsymbol{A_b}$, respectively.

values of $proj_{\boldsymbol{v_l}}\boldsymbol{v_s}$ indicate that musicians maintain their gestural signature when accompany his own recordings, while increased values of $proj_{\boldsymbol{v_l}}\boldsymbol{v_o}$ indicate that they would abandon their own gestural signature to adjust to that of the other.

4. RESULTS

Principal Component Analysis (PCA) was able to explain over 90% of the variance with the first 13 principal components. Note that the goal of PCA here is not really to find a reduced space for the representation of the data, even though there was an enormous reduction of dimensionality from over 1500 to 13. Actually, reducing the number of explanatory components is a necessary step for avoiding the“high dimensional low sample size data” problem [20]. Without this, any attempt to classify the data using a small amount of groups would be meaningless.

K-means Cluster Analysis, applied to the 13 first PCs was able to classify all *solo* executions into 6 groups, corresponding to the 6 players with 100% accuracy. This may indicate that each performer have a consistent way of moving, which appears to be distinct from the others. This suggests the existence of individual “gesture signatures”, corroborating the findings of previous studies. Figure 4 shows the partition of the first two principal components into 6 players with 100% accuracy.

A two-tailed t-test with Welch’s correction was applied to the *self* and *other* conditions of the 240 vector projections, corresponding to four takes of the two projections in each of the 30 pairs of clarinetists ordered without repetition $(n(n-1))$, which were obtained as mentioned in section 3.2. Results indicated significant mean difference between $proj_{\boldsymbol{v_l}}\boldsymbol{v_s}$ $(M = 0.338, SD = 0.118)$ and $proj_{\boldsymbol{v_l}}\boldsymbol{v_o}$

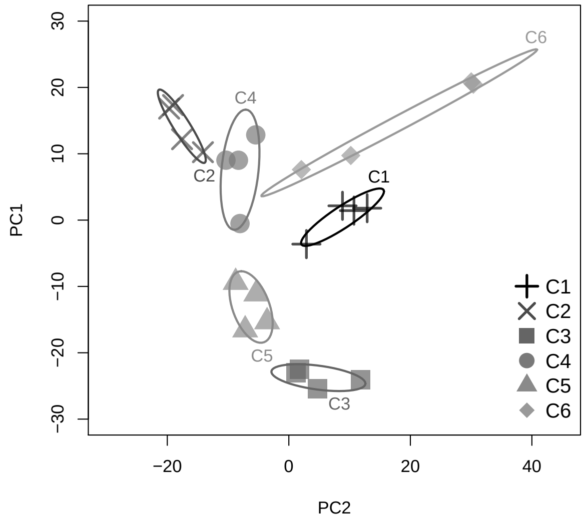

Figure 4. K-means clustering of the solo executions. The *velocity profiles* of the four solo executions of each six instrumentists are shown with points, with different shapes across subjects. The points are represented in the subspace composed by the first and the second PCs. The ellipses show the result of the k-means algorithm when six classes are required.

$(M = 0.438, SD = 0.173)$; $t(184.3) = 4.91$, $p < .0001$, suggesting that musicians tended to maintain their original gestural profile while following their own executions, but shifted towards others’ gestures profiles when following them (Figure 5).

A one-way ANOVA performed separately on subgroups *self* and *other* exhibits significant decrease of distance from original profile along subsequent takes, indicating adaptation towards the original “solo” velocity profile, $F(3, 108) = 5.054, p < .01$, as shown in Figure 6 left panel, while no significant differences related to takes, $F(3, 102) = 0.097, p > .96$ was observed for the subgroup *other* (right panel). This might additionally argue towards the existence of individual “gesture signature” in musical performances.

5. DISCUSSION

This study aimed at determining whether body movement of musicians contains information related to the interpretative intention during a performance, by verifying the occurrence of gestural coupling in clarinet duos. Our experiments enabled us to investigate the influence of different interpretive situations on individual patterns of body movement. The procedures used sought first to identify gestural pattern recurrence of the players, which we considered as individual “gesture signatures”, then to verify if these "signatures" would be affected when the performance situation were influenced by interactions within ensemble performance.

The *self-other* effect, as discussed in several previous studies focused on synchronization of music ensemble perfor-

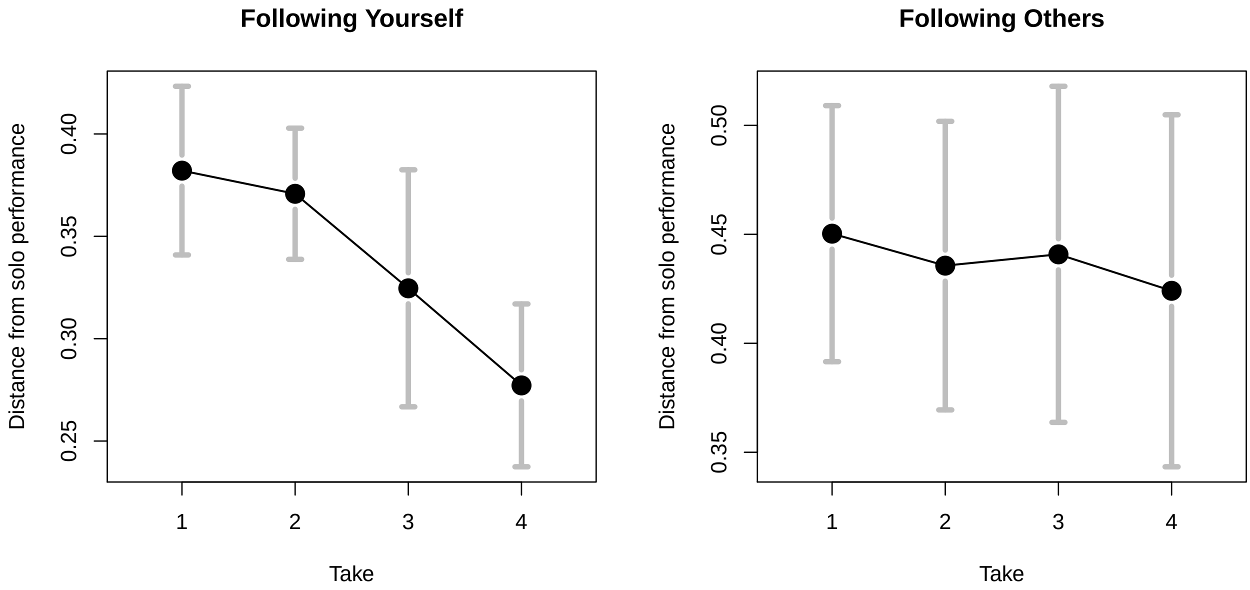

Figure 6. Projections of the duo performances across takes. The mean value of the duo-to-solo vector into the follower-leader vector are shown with dots. The standard error bars are indicated with gray bars.

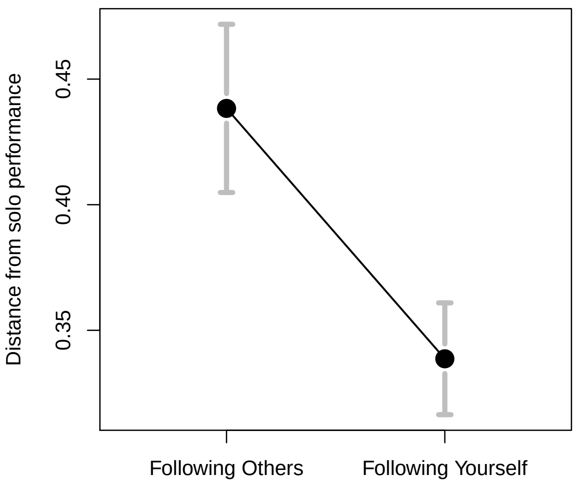

Figure 5. Projections of the duo performances. Results are show for the Self and Other conditions. The mean value of the duo-to-solo vector into the follower-leader vector are shown with dots. The standard error bars are indicated with gray bars.

mance, was adopted as a framework for our experiments design [21, 11, 12, 22]. The most accepted hypothesis for explaining *self-other* effect suggests that coordination between musicians is achieved by each interpreter internally simulating the actions of other members of the group, initially relying on how they would perform the music excerpt, hence when following themselves, they would recognize the musical actions of the first clarinetist as self-produced and would more easily adapt to them. In recent studies, we suggested the existence of a *self-other* effect also in gestural coupling in clarinet duo performance [23, 24].

In the present experiment, we tested the existence of gesture communication between two clarinetist playing duets in unison, without any visual contact. First, we were able to recognize the player using the solo performances with 0% error rate. Afterwards, we were also able to observe that clarinetists, when following themselves, tend to retain their "original" gestural profile, as recorded in solo performances, while when following others, they tend to deviate from the "original" profile. Moreover, our results indicate a tendency of the gesture profile of the second clarinetists (followers) to robustly adapt to that of the first clarinetists (leaders), even without seeing the partner.

These results suggest that the observed variations of gestural patterns are an indication of the involuntary attempt of the musician to anticipate the interpretive intentions of the leader, only by hearing his or her acoustical parameters manipulations. Therefore, these results are favorable to the hypothesis of close relationship between ancillary gesture and music performance, corroborating what has been demonstrated by several studies, such as the experiments carried by [25], which showed that parameters extracted from the gestures of listeners, such as position, velocity module, normal and tangential accelerations, curvature, radius and torsion, were correlated with acoustic parameters, such as loudness and sharpness. Goebl [26] showed that, when playing in ensemble, musicians with reduced auditory feedback moved more than the others, which influences the overall synchronization of the group.

6. CONCLUSION

We propose a multimodal analysis framework intended to access the interactions between gesture and music in ensemble performances. Human communication is not limited to the use of only one way of sensory information. Just as in verbal communication, music makes use of various mechanisms not directly associated with the production of sound, such as the movements of the body, or the facial and gesture expressions of a conductor, as a mean of maintaining the desired interpretation imaginary. We believe that the recurrence of body movement patterns observed between performances of the same musician is a strong indication of gesture encoding of the planned, desired, imagined interpretation to be realized. On the other hand, when we verify that musicians tend to bend their gestures towards the gesture patterns of the leader, we might hypothesize that such gestural adjustments reflect his or her ability of musically "fitting". As musicians in an orchestra commonly "get used" to the gestures of a conductor very quickly, it might be possible to assume that musicians are able to learn to "read" the movement of their partners.

Further multimodal investigations of musical performances may facilitate the comprehension of the creative process underlying musical interpretation, which could shed light on questions such as: why some musicians feel more comfortable playing with a particular partner? Would gestural information contribute to this? We think that the framework proposed in this paper would contribute to answer these questions.

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