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Investigating the relationship between expressivity and synchronization in ensemble performance: An exploratory study

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We present an exploratory study on ensemble expressive performance based on the analysis of string quartet recordings. We recorded a piece with three expressive intentions: mechanical, normal, and exaggerated. We made use of bowing gesture data (bow velocity and force) acquired through a motion tracking system to devise a precise score performance alignment. Individual contact microphone audio signals allowed extraction of a set of audio descriptors for each musician and each note. We show how tempo and loudness on a macro-scale changed across expressive intentions and score sections. The score is also taken into account in the analysis by extracting contextual attributes for each note. We show that micro-deviations were affected by note contextual attributes, whereas the effect of expressive intention varied across sections. We find sections that exhibited a lower entrainment, where individual parts tended to be freer and presented more asynchronies.

Keywords: expressive timing; synchronization; ensemble performance; entrainment; motion capture

In ensemble performance the need for introducing expressive deviations and the need to maintain the dictated relationships among individual parts are in continuous competition (Keller 2008). Two types of deviations have been considered in the literature and have often been modeled separately (Widmer and Goebl 2004). The first includes modulation of tempo and dynamics happening at phrase level (macro-scale). The second (micro-scale) includes note lengthening/shortening and local loudness accentuation, which do not affect the macro-scale. In ensemble performance macro-scale deviations are collective since the musicians need to share a common reference for tempo and dynamics whereas micro-scale deviations are related to individual contributions of each musician.

One of the main methodological issues of research in music performance is separating the signal from random fluctuations (Palmer 1997). In an attempt to address this we extract contextual attributes that can explain the measured variability in different groups of notes. We are interested in studying how the synchronization among performers interacts with the micro-scale expressive deviations. In a preliminary study (Marchini *et al.* 2012) it was shown that musicians tend to introduce more micro-timing deviations when playing together than when playing alone. This supports the idea that micro-timing deviations interact with the synchronization mechanism. Here, we look for clues on how synchronization interacts with the expressive deviations in different sections of the score when musicians render the performance with different levels of expressive intentions.

METHOD

Participants and materials

We recorded a professional string quartet performing the last movement of Beethoven's *Quartet No. 4 in C minor* (Op. 19 No. 4, *allegro-prestissimo*). After the quartet had played their first version ("normal") we asked for a "mechanical" and an "exaggerated" execution. The three executions were each around five minutes long. The piece is in the classical *rondo* form and thus its sections follow a structure ABACABA. With the assistance of a professional musicologist, sections were further segmented into phrases, leading to phrases of around four bars.

Procedure: Data acquisition

For each musician, we used a contact microphone (bridge pickup) and sensors of a motion capture system (EMF, see Maestre 2009) to acquire data. Processing of motion data corresponding to the instrument's body and bow trajectories allow us to compute a number of bowing descriptors, such as bow velocity and bow force (Marchini *et al.* 2011).

We used bow velocity, bow force, audio signal intensity (RMS), and pitch to set up a score-to-performance alignment algorithm based on dynamic programming, from which we automatically segmented the performance into notes (onset/offset list) and matched it to score notes. The alignment was revised by manual inspection.

We described loudness and timing at the two temporal scales (micro and macro). For loudness, we first computed the peak intensity within each note (in dB). Then, for each musician, we obtained the *macro-scale loudness excursion* on windows of four bars by computing the difference in peak intensity between the loudest note and the softest note within the window. *Micro-scale loudness fluctuations* were computed as deviations (in dB) of each note's loudness from the weighted average peak intensity of surrounding notes in a window of four seconds.

Macro-scale timing is described as ensemble tempo fluctuations: by jointly processing note onsets and offsets of concurrent notes in the score, a phrase arc tempo curve is devised. We applied the same procedure used for loudness to compute the excursion on the tempo curve, this time also dividing it by the average tempo on the surrounding 32-bar window.

The *micro-scale timing description* provided us with three features to work with: *note duration ratio*, *participatory asynchrony* and *asynchronies among musicians*. Note duration ratio was computed as the ratio between real duration of the note in seconds and expected duration of the note in respect to the estimated local tempo. Participatory asynchrony was computed as the deviation of the onset from the macro-scale timing in beats and is defined for every note in the score. Asynchronies among musicians were instead defined only on groups of at least two simultaneous notes as the standard deviation of their onset times (in ms).

Note contextual attributes

From the symbolic information available from analysis of the score, we computed six contextual attributes for each of the notes in the performance: metrical strength quantized to three levels, melodic charge, harmonic charge quantized to two levels, Narmour group (Narmour 1990), and pairwise melodic charge: a boolean set to "yes" if the note presented the highest value among concurrent notes.

Analysis

Macro-scale analysis was carried out by studying the excursion of dynamics (loudness) and tempo fluctuations along the different sections of the three piece executions. Micro-scale analysis was performed by means of n-way ANOVA tests on loudness deviation, duration ratio, and participatory asynchrony. Factors studied in these tests were the six note contextual attributes previously described, and the expressive intention (normal, mechanical, exaggerated). We restricted the analysis to quaver notes to avoid bias on duration. This restriction left us with 2946 notes (495 from violin 1, 861 from violin 2, 861 from viola, and 729 from cello) for the ANOVA.

We complemented the analysis by looking at the average asynchrony among musicians per section. Finally we also computed an interdependence measure over participatory asynchronies using mutual information. The method was the same as reported in Papiotis *et al.* (2012) except mutual information was computed over participatory asynchronies.

RESULTS

The results can be summarized in three points. First, expressive intention affected macro-scale. Second, the micro-scale deviations were not noise, since they can be explained from contextual attributes. Third, the effect of expressive intentions on *duration ratio* and *participatory asynchrony* varied in relation with mean asynchrony of each section.

Tempo excursion (in percentage respect to section mean tempo) and loudness excursion (in dB) are shown in Table 1. A one-way ANOVA on the three expressive cases shows that the difference is significant ($p<0.05$). After the ANOVA analysis of micro-scale deviations, we found that all six score attributes affected the loudness; analogously, we also found that five out of six affected the duration ratio; finally, three out of six affected participatory asynchrony. This confirms that the introduced deviations are not noise but are rather related to contextual attributes.

We then looked at the effect of the expressive intention factor separately on each section. We found an inverse relation between the p-values of the duration ratio and p-values of participatory asynchrony as depicted in Figure 1. This means in general that when one of the two was affected the other was not and vice-versa. Although one can point out that such an inverse relation could depend on how the asynchrony and duration ratio are computed from segmented performances, we tested for correlation among the two and found a small (-0.18) correlation, which does not seem to explain this behavior. From section A to section B the mean asynchrony among musicians rose from

Table 1. Means (and standard deviations) of collective performance parameters on the three expressive cases.

	Mechanical	*Normal*	*Exaggerated*
Tempo excursion (percentage)	7.14 (2.11)	8.45 (2.05)	9.59 (2.95)
Loudness excursion (decibel)	15.31 (2.26)	17.67 (2.69)	23.43 (3.97)

19 to 24 ms (p<0.01) and then went back to 19 in section A' and section C. Correspondingly, the interdependence between asynchronies of musician pairs tended to diminish (see Figure 2). Both measures mirror the result on the effect of expressive intentions on micro-timing.

DISCUSSION

Different expressive intentions were realized modulating macro-scale tempo and loudness with different levels of excursion. We found correlations between the contextual attributes and micro-timing deviations. Our findings on synchronization and micro-timing suggest that in section B musicians were less bound one with each other and thus executed their part with more freedom in terms of timing. This supports the idea that entrainment forces the musician to shape their timing deviations differently depending on the global

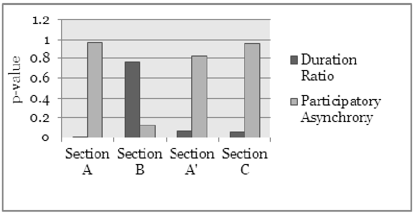

Figure 1. P-values of the factor expressive case for duration ratio and participatory asynchrony on four sections of the piece.

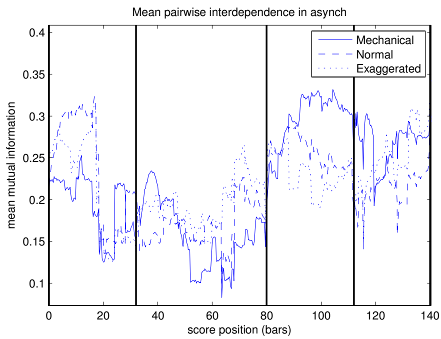

Figure 2. Interdependence among musicians in terms of asynchrony for the three expressive cases. The vertical lines mark the boundaries of score parts A, B, A', and C. (See full color version at www.performancescience.org.)

intention. By looking at the score with the musicologist we also found that in section A the main theme is given to first violin whereas in part B all the musicians contribute more equally to shape the melodic line. This aspect might also be the cause of the different entraining levels.

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