Performing music with delayed auditory feedback

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ABSTRACT

This paper presents a study where the effect of a delayed acoustic feedback is researched with 10 professional musicians performing four different pieces of piano music. The influence of a delayed auditory feedback on the performance is quantified using both MIDI information and the measurement of the movement of the upper body of the pianists. Four conditions were examined namely: a normal piano performance, a performance without acoustic feedback and two conditions with a delayed acoustic feedback of 300ms and 200ms respectively.

The analysis of the MIDI data shows a significant increase in both the velocity of the keystrokes and the duration of the performance in the delayed conditions. An asynchrony measure of notes, notated on the same time point in the score, shows this same effect for three out of four musical pieces. We observed a large movement of the head of the performers comparable to the movement of the elbows but larger than the neck, shoulders and hip. This head movement shows a significant increase in the delayed conditions in three of the pieces played. Both for the MIDI and the movement analysis there is no difference between the normal performance and the one without any acoustic feedback.

In short we can say that the role of body movement becomes more prominent in situations where an alteration in the delay of the acoustic feedback is most disturbing.

I. INTRODUCTION

In most music performances on classical music instruments, the musicians' actions lead to a direct sound result. One notable exception concerns the performance on church organs, which, due to the mechanics of these instruments, produce a noticeable delayed acoustic feedback (DAF) between the player's action and the generated sound. Similar problems may occur in networked performances, where due to large distances in communication, performers may have to deal with considerable acoustic delays of transmitted sounds (Bartlette, Headlam, Bocko & Velikic, 2006). The fact that some musicians can cope with a DAF raises questions about the role of auditory and motor strategies in music performance.

As described by Leman (2007) there is a process of action-reaction coupling involved in music making. This process describes the action of a player, a sound that is generated, a judgment of this output and an adaptation of the action performed. This circular process is distorted in the case of a delayed acoustic feedback. It is therefore relevant to research the effect of a delayed or even a complete absence of acoustic feedback from the viewpoint of embodiment.

The role of a DAF in a music performance task has been studied since 1974 (Gates, 1974) where the maximally disruptive DAF interval was found to be 270ms. However, most studies on DAF include tests with only simple key sequences, often performed with only one hand (Pfordresher & Palmer, 2002; Pfordresher, 2005) or a very short fragment of a single musical piece (Finney, 1997). Furthermore, the analysis is mostly only restricted to the timing of the keystrokes on a piano.

To better understand how musicians cope with DAF, it is necessary to study 'real' performance settings where professional keyboard players play musical pieces in a controlled experimental setting. In addition, it will be instructive to look at how musicians involve their body in the time-keeping process. Playing a music instrument can be conceived from an embodied perspective, in which the coupling of perception and action is mediated through the instrument. In the case of a DAF, the circular action-reaction process, which involves (i) the action of a player, (ii) the sound that is generated, (iii) the judgment of this output and (iv) the adaptation of the action performed, is distorted. Given the fact that the DAF is embedded in action patterns, it is therefore relevant to study the effect of a delayed or even a complete absence of acoustic feedback by considering the effects of corporeal articulations (Leman, 2007).

In this paper we will describe an experiment where the effect of a DAF on the performance of a number of musical pieces for piano is studied. The subjects included in this study are all professional keyboard players (including piano, organ and harpsichord). Different multimodal measurements were made including MIDI, audio and movement of the body of the players.

II. EXPERIMENTAL SETUP

10 professional keyboard players played four short, easy pieces with different rhythmic characteristics. They performed with normal acoustic feedback, without any acoustic feedback and twice with a delayed feedback. The time of delay was chosen to be 300ms and 200ms based on the original findings of (Gates, 1974) where a delay of 270ms was found to be the most disturbing.

A. Subjects

10 subjects participated in the experiment, aged 23-48 (mean 33.8), 6 male and 4 female. Five of them indicated the piano as their main instrument, three the organ and two the harpsichord, but only three (piano players) played only one type of keyboard instrument. Six subjects indicated to play classical music in a broad sense, three specialized in early music and one in contemporary music. On average they played 14.3 hours a week and had 14.3 concerts a year. Only three of the subjects indicated to have experience in playing with delay, two of the organists and the contemporary pianist (who has experience with networked keyboard performances).

B. Musical Pieces

The subjects were asked to play four (excerpts from) relatively simple keyboard pieces (see Table 1), each taking about one minute to play. Each of the four pieces has a different meter and texture, which allows to test the effect of delay in a variety of tasks.

Table 1. List of musical pieces played in the experiment

Name	Composer	Meter & tempo
Für Elise	L. van Beethoven	3/8 'poco moto'
Sonatina op.36/1	M. Clementi	4/4 'allegro'
Bulgarian Rhythm (Microcosmos 113)	B. Bartók	7/8 'allegro molto'
Sarabande in g-minor	G.F. Händel	3/2

C. Technical Setup

The performers played on a digital piano with fully weighted keys (Yamaha P60) without the use of a foot pedal. The audio and MIDI was routed to an external soundcard (Tascam US122) connected to an iMac computer running a Max/MSP patch. This patch enabled the recording of the audio and MIDI data from the piano. Furthermore, the data of a Nintendo Wii Balance Board was collected. This board was connected via Bluetooth to the computer and was placed underneath the piano monitoring the pressure exerted by the feet of the performer. The Max/MSP patch logged these three data streams (MIDI, audio and pressure data) to files on the computer using the time of the audio recording as a common timestamp for the multimodal dataset.

By routing the MIDI output of the piano back to the MIDI input and switching the local control of the piano off it was possible to introduce a delay in the MIDI stream.

Furthermore, the movement of the upper body of the performers was monitored using an OptiTrack (NaturalPoint) motion capture system (MoCap) (Figure 1). In the setup described 8 IR sensitive cameras were used enabling a 3D positional readout if IR-reflective markers at a sampling rate of 100Hz.

All performances were videotaped using a Canon HV30 camera for further reference.

D. Procedure

Keyboard players were invited by email to participate in an experiment on delayed auditory feedback. Musicians who agreed to take part received the scores of the four pieces to be performed and made an appointment to visit the lab for the experiment. Upon arrival they were asked to put on a jacket and a hat to which markers for the MoCap system were attached. Then they were instructed about the procedure: "You will have to perform each of the pieces in four conditions: a normal performance, a performance without auditory feedback and two conditions with a delayed auditory feedback". They were also given a form on which they had to rate every performance in each of the four conditions on a scale from 0 to 10, after finishing each piece. This time was also used by the experimentalists to store the recordings and open new files for the next piece. The pianists could then go to the digital piano, adapt the seat to their preferred position and got some time to get accommodated to the setting. After finishing the whole experiment they were asked to fill out a questionnaire about their personal background and general experience of the experiment.

Figure 1. Experimental setup showing a performer playing, where MIDI and audio are recorded together with the pressure exerted by the feet using a Nintendo Wii Balance Board. The movement of the upper body was recorded using a MoCap system.

III. ANALYSIS AND RESULTS

To synchronize the data streams recorded in the Max/MSP patch with the MoCap measurements, the performer was asked to strike a single key on the piano, thus generating a MIDI note event, with a pronounced vertical movement. The minimal position of this movement was then traced back in the movement data and synchronized to the time of the MIDI event.

After the synchronization of the data streams the different multimodal data sets were segmented starting from the time of the first note of the piece up to the time of release of the last note. This segmentation was done for each of the four conditions and for each music piece resulting in a total of 16 performances per player.

The analysis of the MIDI data and the MoCap recordings will be discussed below. The analysis of the foot pressure will not be discussed in this paper.

In what follows condition 1 refers to the normal performance, condition 2 to the performance without acoustic feedback, condition 3 to the performance with a delay of 300ms and condition 4 to a delay of 200ms in the acoustic feedback.

A. MIDI Analysis

Four aspects of the performance were analyzed using the MIDI recordings from the keyboard: dynamics (loudness), tempo, coordination and accuracy. The dynamics were analyzed using the MIDI velocity data, and normalized by the average velocity for each subject and each piece played over the four conditions, so that the average of one performer in one piece over the four conditions always equals 100. ANOVA shows a highly significant effect of condition on the MIDI velocity for each of the four pieces ($F(3,39) = 17.97 - 19.24 - 15.62 - 7.8$, $p < 0.001$). Post-hoc tests show a contrast between the first two conditions and the delayed conditions, with no significant differences between normal and silent conditions nor between the longer and the shorter delay conditions (Figure 2).

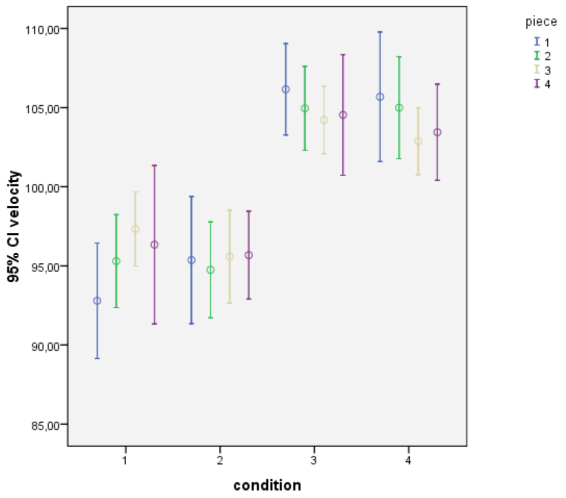

Figure 2. Comparison of the normalized velocity data for the four pieces in four conditions, error bars represent the 95% confidence of the mean.

The tempo was analyzed by annotating the start of each measure in the onset time data of the MIDI recordings. In those (rare) cases were the first note of the measure was omitted, the first played note of the measure was used. In order to exclude the basic differences in tempo between the performers, and to concentrate on the effect of the four conditions, these data were normalized in a similar way as the velocity data, namely, that the average for each performer in each piece played over the four conditions equals 100. The ANOVA shows a highly significant effect of condition in each of the four pieces ($F(3,39) = 16.06 – 12.34 – 6.96 – 9.72$, $p < 0.001$), again with a strong contrast between the first two and the two delayed conditions (figure 3). In addition, there is a significant effect of condition on the standard deviations of the normalized measure length, at least in the first three pieces. This indicates that the variability becomes larger in the delayed versions. However there is a strong interaction here with the insertion and deletion of notes (cf. infra).

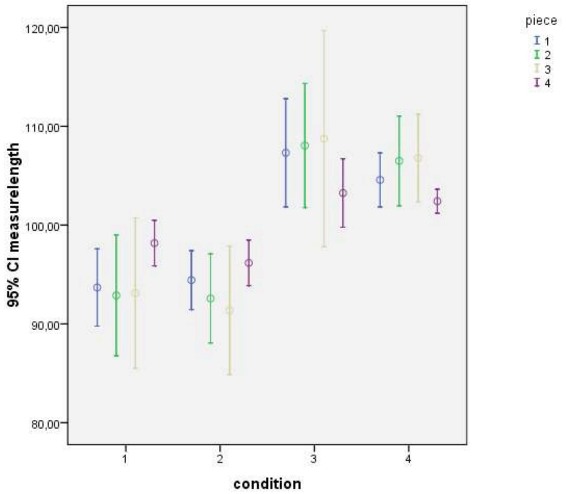

Figure 3. Comparison of the normalized measure length for the four pieces in four conditions, error bars represent the 95% confidence of the mean.

A third parameter that has been analyzed is the amount of asynchrony between notes notated on the same time point in the score. To measure this we used the time distance between the notes from low to high (if the chord contained more than two tones, only the distances between successive tones were used), the total sum of squares was taken to exclude the effect of sign and this was divided by the number of intervals measured, again the results were normalized. We find a strong effect of condition, at least for the first three pieces ($F(3,39) = 123.37$ (!) – 31.41 – 20.72, $p < 0.001$). Again a contrast between the first two and the delayed conditions is found, but in this case the post-hoc tests also show a significant difference between the long and the short delay, with a larger asynchrony in the long delay (Figure 4) In the Händel Sarabande, however, no effect at all was found ($F(3,39) = .21$, $p = .89$). This can be explained by two factors, first the piece has a very slow rhythm, so the players should have enough time to plan the next chord, without introducing asynchrony between both hands. Second, this is also the only piece that consisted mainly of full chords with three or four notes, and some players had a tendency to arpeggiate some of the chords already in performances without delay. This is reflected in the clearly higher variance seen in the 'normal' condition.

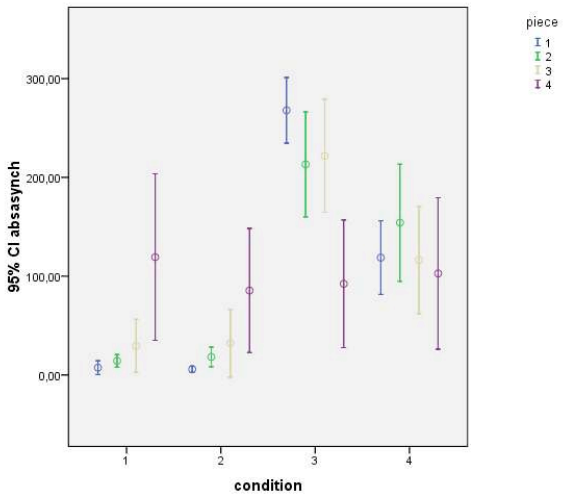

Figure 4. Comparison of the normalized asynchrony for the four pieces in four conditions, error bars represent the 95% confidence of the mean.

Finally, the MIDI data from the performances were compared with the score data, in order to indicate the errors. A distinction was made between four basic types of errors: 1. 'Order errors', playing two notes in the wrong order, 2. 'Deletions', omitting one or more notes, 3. 'Wrong notes', replacing the notated tone by another, and 4. 'Insertions', playing extra, not-notated notes. A summary of the results is given in Table 2. This shows that the silent version shows no strong effect compared to the normal version, actually most types of errors decrease, except the number of wrong notes. In the delayed versions we see an increase for each type of error, but especially for the insertions. It is however striking that no effect at all is seen for the Händel Sarabande. The comparison of the long and the short delay is somewhat puzzling. In the Beethoven piece, the number of errors is clearly higher for the short delay, but in the Clementi and the Bartók the opposite is seen. Also we see that only one type of error occurs more often with the shorter delay, namely the deletions. More detailed analysis is necessary to clarify these effects.

Table 2. Summary of the error analysis. Above: the increase or decrease of errors compared to the 'normal' performance, for the three other conditions, in each of the four pieces. Below: the same analysis for the four types of errors.

	silent	long delay	short delay
Beethoven	3	85	172
Clementi	-6	167	125
Bartok	-11	295	226
Händel	-3	2	-2

	silent	long delay	short delay
order errors	-3	69	28
deletions	-10	64	92
wrong notes	23	79	64
insertions	-27	334	255

B. Motion Capture Analysis

The upper body of all performers was measured using an optical motion capture system (MoCap). In total 19 IR-reflective markers were positioned on the upper body of the performer, namely, on the head (4), on both hands (2x3), on the upper arms (2x3) and on the back (3) as shown in Figure 5 on the left. Furthermore there were 3 markers positioned on the piano as a reference. In the first step of the analysis after the synchronization of the MoCap data these 19 markers were merged into 9 locations on the body representing the head, neck, hip, left shoulder, right shoulder, left elbow, right elbow, left hand and right hand as shown in Figure 5 on the right.

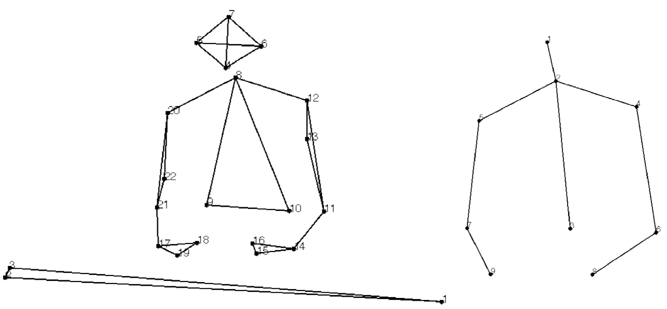

Figure 5. The positions of the markers placed on the upper body of the players. On the left all original markers, on the right the reduction to 9 body parts.

To quantify the movement of the players the total Euclidian distance traveled in the (x,y,z) coordinate system was calculated for the 9 locations. Because each performance had a different duration the Euclidian distance values were averaged over the number of data points of each performance. This results in what can be called an average speed of each body part for a certain performance. The result of this calculation can be seen in Table 3 where the mean and standard deviation of the average speed is shown over all players for all the different performances.

Table 3. The mean and standard deviation of the average speed over all the players and performances.

Body part	Mean of the average speed [cm/s]	Standard Deviation of the average speed [cm]
head	8.3	4.4
neck	3.7	1.7
hip	1.6	0.7
left shoulder	4.7	2.2
right shoulder	5.0	2.2
left elbow	8.4	3.5
right elbow	12.3	6.7
left hand	12.5	3.8
right hand	15.6	6.2

It is possible to make a distinction between functional movements and non-functional movements of piano playing (Thompson & Luck, 2008). The functional movements are related to the action of playing the piano, that is, by moving the hands and elbows. The non-functional movements are those performed with the head, neck, hip and shoulders because these movements are not directly related to the action of playing the piano. When we refer back to Table 3 we can see that the functional movements have the highest average speed and also the highest standard deviation over the different players and musical pieces. Furthermore, the right hand and elbow have a higher value, which corresponds with the action of playing a melody rather than the bass that requires less movement. Looking at the non-functional movements, the head has the highest mean and standard deviation. It is therefore useful to make a more detailed analysis of the movement of the head when we want to study the role of the body in a delayed feedback condition.

In order to compare the movement of the head for the different conditions, the data was first normalized over the average of the movement during a single musical piece for each player (played over the four conditions). As in the previous normalizations, this normalization compensates for the amount of movement related to the player and makes a comparison over the different conditions possible. The result of this analysis is shown in Figure 6. ANOVA shows that there is a significant difference in song 1 ($F(3,39) = 4.36, p = 0.01$), song 3 ($F(3,39) = 15.8, p < 0.001$) and song 4 ($F(3,39) = 4.15, p < 0.05$) but no effect in song 2 ($F(3,39) = 0.29, p = 0.83$). Furthermore, the post hoc test shows that there is a significant difference between the first two conditions and the delayed performances for song 1 and 3, but in song 4 there is only a significant difference between the shorter delay condition and the other conditions.

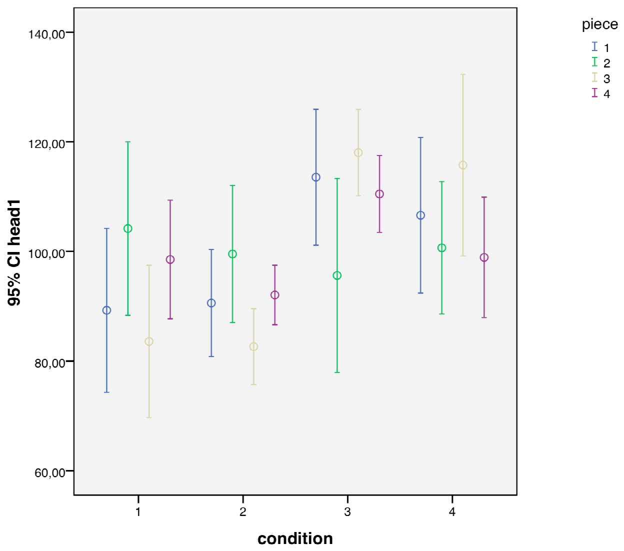

Figure 6. The mean and 95% confidence interval of the normalized average speed of the head movement of the players for the 4 conditions and 4 musical pieces.

The absence of an effect in the second piece can be explained by the fact that there are different types of playing, according to the amount of movement. The first type of playing is characterized by a low average speed of movement. These players have a tendency to move less in the delayed condition compared to the normal and silent performance. The majority of the players, however, belong to a second type of playing, which is characterized by a moderate to high average speed. These players have the tendency to increase their movement in the delayed conditions. The combination of these opposite tendencies leads to a disappearance of the effect in the Clementi.

IV. DISCUSSION AND CONCLUSION

The results show that playing without acoustic feedback has almost no effect on the performance. Delayed acoustic feedback however, causes strong impairment and changes the behavior of the performer. Thus our results can confirm the findings of Finney (1997), who found the same effects using short musical sequences. The effect of delayed acoustic feedback is reflected in an increase of dynamics (velocity), a slower tempo, a larger asynchrony between left and right hand, a considerable increase in the number of errors played and larger body movements. The difference between the longer and the shorter delay is not always apparent, but the asynchrony, number of errors and to some extend the movement analysis, shows that playing with the longer delay causes a bigger impairment.

An important issue in this study is the use of real musical pieces instead of simple sequences of notes, thus simulating a concert performance using an organ with a long delay time or a keyboard with delay caused by computer software. Therefore it is interesting to look at the effect of the different pieces. The only piece that shows significantly different effects is the Händel Sarabande. This is not surprising, as it is a very slow piece, which allows the performers to take the time to prepare their chords, despite the auditory feedback. Nevertheless, dynamics and measure length are still increased. From the other three pieces, the Bartók seems to be the most difficult, as reflected by the error analysis. Also this is not surprising, as it is written in a 7/8-meter, which is not that familiar to most players and has a very high tempo. This difference is also reflected in the participants' self-evaluation, where the Händel is considered to be performed best, especially in the delayed conditions, while the Bartók gets the lowest marks of the other three pieces.

In the future we will do more measurements with more subjects to confirm our statistics. Also an analysis of the periodicities, timings and strategies will be performed on the motion data. Further analysis of the movement data needs to be done in order to figure out the possible role of movement on keeping track of the meter.

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