STUDY ON THE INFLUENCE OF ACOUSTICS ON ORGAN PLAYING USING ROOM ENHANCEMENT

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ABSTRACT

A pilot study on the influence of different reverberation on the musical performance of organ players is presented. Using an organ with MIDI output, three different organ players are recorded performing the same pieces while a room acoustics enhancement system is used to modify the acoustic conditions of the Detmold concert hall in real time.

Since the dynamics and tuning properties of the organ remain constant, the analysis focuses mainly on tempo features such as total duration, rests duration and tempo variability, as extracted from the MIDI files. A set of binaural recordings is obtained for future studies on the relation of performance variations and the acoustic feedback received by the musicians. Finally, the participants are interviewed individually after the experiment to obtain their impressions of the influence of the acoustics.

The results show that the reverberation has a direct influence on the musicians, leading to slower tempo and longer breaks between consecutive notes. However, this relation is conditioned by other factors such as the character of the piece, the level, the global tempo and the individual players.

1. INTRODUCTION

Organ music is usually played in very reverberant spaces such as churches or cathedrals, resulting in challenging conditions to achieve a good synchronization with other musicians such as choirs or ensembles. Moreover, in many cases, the organ console is located far away from the organ stops, increasing the performance difficulty due to the sound travel time. This implies that organ players in particular need to adapt to the environment, in order to achieve a good music performance in a variety of different spaces.

Organ music was originally composed to be played in churches or religious spaces, thus room acoustics are an inherent characteristic of organ music. However, nowadays organ music is also played or practiced in concert hall environments, with noticeably different conditions. The goal of this preliminary study is to find out in what way the performance is affected.

By means of a room acoustics enhancement system it is possible to modify the room acoustics in real time, in order to study the performance adjustments adopted by the musicians. In addition, using a concert organ equipped with a MIDI output the performance can be easily recorded to extract a set of features related with the properties of the musical performance.

2. STATE OF THE ART

The authors know of no formal studies specifically on the influence of acoustics on organ playing. Nevertheless, the study of musicians' performance adjustments to room acoustics is a topic under investigation and similar experiments have been completed focusing on piano performance, cello and other soloist instruments.

In [1, 2] Bolzinger et al. presented a series of experiments on the influence of acoustics on piano performance. The main finding of that study is the relation between intensity of the performance and reverberation, meaning that more reverberant environments lead to softer performances. However, they found no conclusive relation between acoustic conditions and tempo variations.

A similar experiment focusing on piano performance was presented by Kawai et al. in [3]. In this experiment, the authors present links between the musicians' adjustments and three room acoustic parameters - T_{30}, ST_{early} and ST_{late}. The main effect of reverberation is reported to be on the *full pedal time ratio*, meaning that longer reverberation time leads to a shorter use of the piano pedal, as the remaining room energy acts in a similar way to the pedal. From the perspective of stage support, the main effect is reported to be on the dynamics of the performance, agreeing with the results presented previously by Bolzinger et al. Nevertheless, in this case the analysis of the tempo features show that the tempo variations are highly piece dependent: The musical characteristics of the piece are a variable that have impact on the influence and depending on the character of the piece the musicians may or may not be affected by the acoustics.

Although the acoustic properties of organ and piano are quite different, the playing technique presents several overlaps and similar results could be expected. However, it is clear that the feet and pedals have a completely different role in organ playing (yet, special attention has to be given to pedal melodies). Moreover, the organ dynamic cannot be influenced as directly.

When investigating the influence of room acoustics on cello players, Schärer et al. [4, 5] conclude that musicians are affected individually and relates the reverberation time with the tempo. In this case, it is shown that very dry and very reverberant rooms lead to lower tempos.

3. SET-UP

To conduct an analysis on the influence of the acoustics during a music performance it is necessary to be able to generate dif-

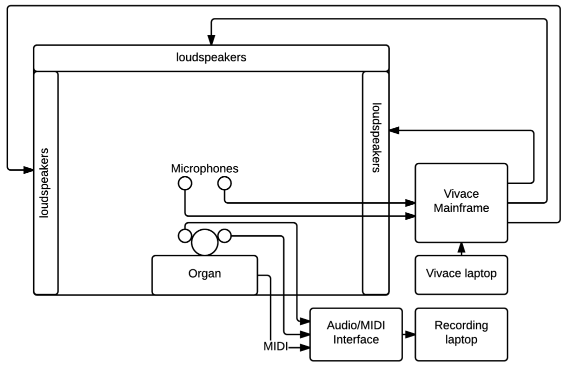


Figure 1: Schematic view of the implemented setup

ferent acoustic situations in real time and record the musician's reaction by means of acoustic and/or visual feedback. In this study, the acoustic conditions are generated using the electronic enhancement system *Vivace*, distributed by Müller-BBM ASG. The performance is captured using a MIDI connection implemented on the organ with respect to the instances at note on/off, and the acoustic signal at the musician's position is recorded by means of binaural recording.

3.1. Variable acoustics

To implement an electronic enhancement (or variable acoustics) system it is necessary to create a signal path: (1) capturing the signal from the instrument, (2) processing it by means of convolution with different spatial impulse responses and (3) playing back the generated reverb using a surrounding loudspeaker setup (see Fig. 1 & 2).
The Detmold Konzerthaus is equipped with a *Vivace* system, which is a convolution engine that allows the user to define a set of desired room acoustic parameters as well as manipulation of the convolved impulse response. To feed the convolution engine, a pair of microphones in the ceiling and a pair placed close to the organ is used, in order to capture more direct sound of the instrument. After processing the signal, the artificial reverberation is played back through a virtual loudspeaker array (Iosono WFS with approximately 300 real loudspeakers) resulting in 56 virtual output channels.

3.2. MIDI recording

The most effective way to analyze the interaction between a musician and an organ is encoding all the keys and pedals pressed during the experiment. During this experiment the performance was encoded using a MIDI interface built on the organ and recording the data stream with a digital audio workstation (DAW).

The MIDI recording ensures that the recorded data matches completely with the action of the musician, avoiding errors that could occur in audio signal analysis. In addition, in this case, the keyboards and the pedal are encoded in different channels, allowing an easy separation and analysis of the pedal and hand notes.

Moreover, since the dynamics of the organ are constant – i.e. the MIDI velocity values are all maximum – the performance analysis is limited to temporal features.

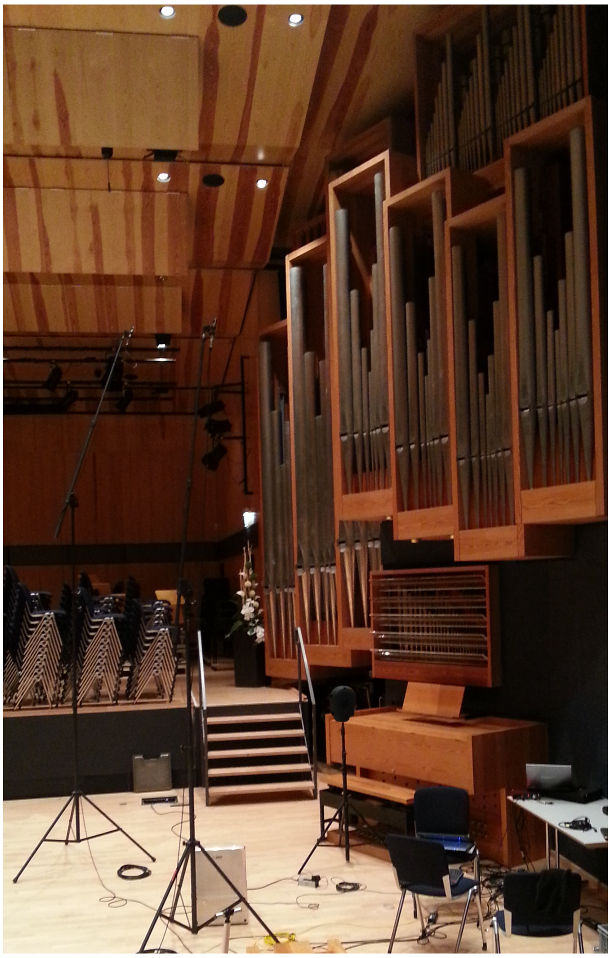


Figure 2: General view of the set-up in the concert hall

4. EXPERIMENT

4.1. Procedure overview

In the experiment the musician plays the same excerpt repeatedly while the acoustic conditions of the room are changed between iterations. Every excerpt is played in two variations (blind and non-blind) and it is played at least five times for each of the acoustic conditions:

- Blind test: In this variation, the musicians are not explicitely notified about the changes in the acoustics, which are randomly switched after each take. This allows the study of the ”natural” adaptation of the playstyle.
- Non-blind test: After the blind test, several iterations are completed with explicit notifications on the acoustic changes. All the iterations of every different acoustic scenario are completed consecutively and a short training period is given before the trials/recordings. The data from this variation is used to quantify wether a bias is introduced in the playstyle by the *a priori* knowledge.

As the participant musicians are told about the general topic of the investigation (to study possible effect of the room on organ playing) and the conditions are briefly demonstrated in the beginning, there could be some bias involved i.e. that participants would play differently on purpose or subconsciously when a certain acoustic condition is active. Nevertheless it is not discussed *how* different acoustic settings could alter the playing or articulation and the subjective opinions are the musicians' own vocabulary.

4.2. Acoustic conditions

Three different acoustic conditions are designed for the experiment:

- Natural reverb: Natural room reverberation without enhancement. The RT_{60} of the room is approximately 1.6 seconds.
- Soft increase: The reverberation is increased by approximately 0.5 seconds between 250 and 1500 Hz.
- Strong increase: The reverberation time is strongly increased at low and mid frequencies, between 5 seconds at 250 Hz to 1.5 seconds at 5 kHz.

In Figure 3 the different reverberation times are shown as a function of the frequency. The measurements are performed using the organ itself as an excitation source: by pressing all keys simultaneously most frequencies of the spectrum are covered. With releasing the keys, the decay is measured using an NTi XL2 Sound Level Meter and repeated a few times if single bands do not fulfill the signal-to-noise ratio requirement for the measurement. Possibly due to low frequency noise caused by the ventilation system or the organ itself, the results at 63/125 Hz are not reliable and therefore not included in the graph. Moreover, since the measurements are performed using the organ for exciting, it is not possible to achieve a sufficient dynamic range over 5 kHz, hence the reverberation is measured until 4 kHz only. However, the depicted frequency range contains most of the acoustic energy radiated by the organ and it is measured using the same radiation characteristics present during the real performances.

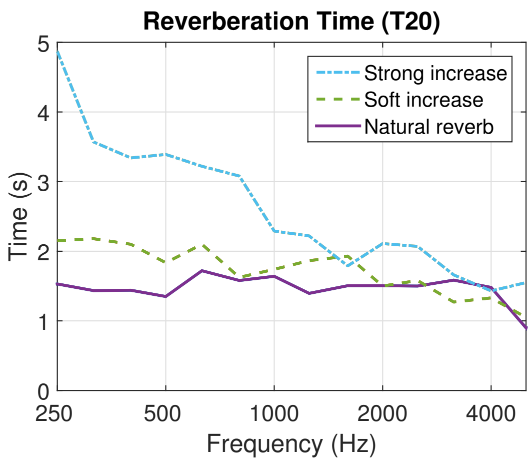


Figure 3: Reverberation times for the different acoustic conditions.

4.3. Participants

The participants in the experiment are three organ students from the Hochschule für Musik Detmold. The study level of the musicians is different, yet all of them are at a comparably high professional level.

Player Green is the first participant and only plays in two of the three conditions, "natural reverb" and "soft increase" (not in "strong increase" setting). The organ registration of this initial player then stays constant for the other two performers. As all musicians are given the same pieces and since two of them have to commemorate the piece, they are asked about any difficulties or insecurities that would inflict on their natural flow of playing. This is not the case, as everybody had studied the pieces before and refreshed it with some rehearsing.

4.4. Music pieces

The music pieces played during the experiment are two excerpts of a composition for organ solo:

- Mendelssohn A: Felix Mendelssohn Bartholdy, *Organ Sonate Op.65 No.2, Grave*, bars 1-4 (Fig. 4).
- Mendelssohn B: Felix Mendelssohn Bartholdy, *Organ Sonate Op.65 No.2, Adagio*, bars 24-30 (Fig. 5).

As mentioned before, the registration used by the musicians stays the same per piece, ensuring equal conditions for all players. One player suggested possible modifications regarding the registration and a take is recorded with this personal registration after completion of the tests. Table 1 contains supplementary information regarding the two pieces.

Piece	LAeq (dB)	Character	Avg. duration (s)
Mendelssohn A	78.2	Grave, lots of chords	13.5
Mendelssohn B	67.5	Pianissimo, legato	22.4

Table 1: Characteristics of the pieces used in the study.

5. ANALYSIS

This section describes in detail the different steps implemented to analyse the recorded performances.

5.1. Procedure

After completing the experiment, every recorded session results in a single MIDI file. The next steps are executed for each individual musician:

- Split & sort
- Importing the MIDI database
- Features extraction
- Analysis of the results

5.2. Split & sort

The files are split and sorted by acoustic condition, piece and musician, in order to build a database. "Defective" recordings with performance or technical errors are deleted.

5.3. Importing the MIDI dataset

The main tool used for the analysis is the MIDI Toolbox for Matlab [6]. Once the files are imported into the program the MIDI stream is represented as a Nx7 matrix, where N is the number of notes of the stream. Table 2 shows an example of the imported data stream corresponding to one take of the performance of *Mendelssohn A*.

Note that the onset and duration expressed in beats do not contain valuable information, since it is extracted from the encoded tempo embedded in the MIDI file, which is an arbitrary value. There are two channels containing information – channel 1 and 7 – which correspond to the keyboard and pedal notes respectively. The velocity of all the notes is the same as the keys are only quantized as "pressed" or "not pressed" (analog to an open or closed organ stop).

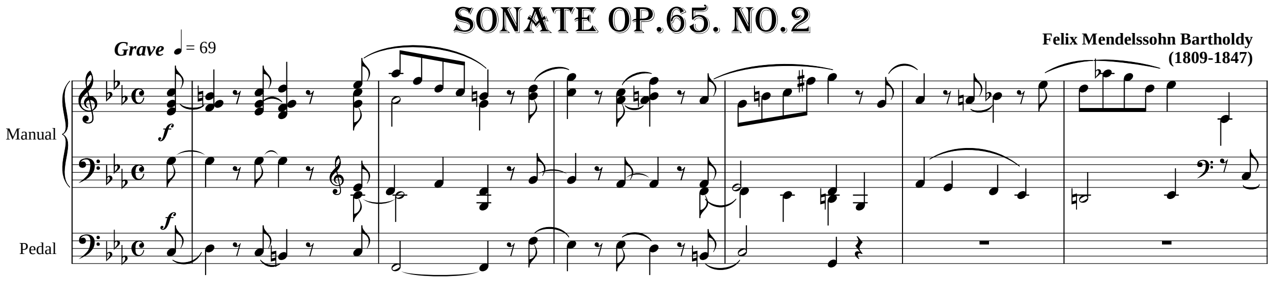


Figure 4: Music score of *Mendelssohn A*.

Figure 5: Music score of *Mendelssohn B*.

Onset (beats)	Duration (beats)	MIDI channel	MIDI pitch	Velocity	Onset (sec)	Duration (sec)
0	1.2250	7.00	48.00	127.000	0	0.6125
0.0333	0.6354	1.00	63.00	127.00	0.0167	0.3177
0.0490	0.9073	1.00	72.00	127.00	0.0245	0.4536
0.0781	2.0750	1.00	67.00	127.00	0.0391	1.0375
0.1063	1.9458	1.00	55.00	127.00	0.0531	0.9729
1.0240	1.1542	7.00	50.00	127.00	0.5120	0.5771
1.0281	1.0958	1.00	65.00	127.00	0.5141	0.5479
1.0427	1.1396	1.00	71.00	127.00	0.5214	0.5698
3.1719	1.0948	7.00	48.00	127.00	1.5859	0.5474
3.2031	0.4490	1.00	63.00	127.00	1.6016	0.2245
3.2469	1.7719	1.00	55.00	127.00	1.6234	0.8859
3.2490	0.8198	1.00	72.00	127.00	1.6245	0.4099

Table 2: Decoded MIDI stream of an excerpt of *Mendelssohn A*.

5.4. Features extraction

5.4.1. Average Tempo

The tempo related features are *total duration of the excerpt* (T_{time}) in seconds and *average tempo of the excerpt* (T_{tempo}) in beats per minute. They are extracted using the following expressions

$$T_{time}(s) = t_{last} - t_1 \tag{1}$$

$$T_{tempo}(bpm) = 60 \cdot \frac{N_{beats}}{T_{time}} \tag{2}$$

where t_{last} and t_1 are the onset times of the last and first notes of the excerpt, respectively, and N_{beats} is the number of beats of the excerpt. Note that the duration of the last note is not included in this feature.

5.4.2. Duration of rests

Since the most audible effect of the increased reverberation is produced after the offsets, a useful feature to analyze the influence of reverberation on the performance is the duration of the rests in the excerpts. The extracted features are *total time of rests* (T_{rest}) and *average duration of rests* ($T_{\mu rest}$), both computed in seconds.

$$T_{rest}(s) = \sum_{i=1}^{N} t_{rest}(i) \tag{3}$$

$$T_{\mu rest}(s) = \frac{T_{rest}}{N} \tag{4}$$

where t_{rest}(i) is the duration of every individual rest and N is the total number of analyzed rests.

5.4.3. Phrasing

The phrasing characteristics can be extracted following different methods, most of them based on beats histogram or distribution of strong beats. However, in this case all the beats have the same strength and different approaches have to be considered. Due to the character of the pieces used in this study, the following approaches can be implemented:

- Analysis of the duration of consecutive rests: In case of having rests in all the voices, the duration of consecutive rests can be measured, obtaining an estimation of the start/opening and stop/closing of different musical phrases.
- Analysis of a single voice: The analysis of a melodic voice allows the representation of the evolution in the duration of consecutive notes.
- Analysis of the pedal: Due to the easy extraction of the pedal voice the single voice analysis can be effortlessly implemented on the low notes.

6. INTERVIEWS AND SUBJECTIVE IMPRESSIONS

To gain insight in the musicians' impressions on the acoustic situations, short interviews are collected for the preceding set of trials (i. e. after a block of 10-15 repetitions of one music piece), to 1) gather information and hints on what the musicians had experienced, heard or got affected by in a certain way and 2) analyze later if these impressions are truly resulting in a change of playing and could be measured through extracted features, or are possibly just imagined/random. The interviews are conducted in German and translated into English.

6.1. Organ players

Detailed interview content can be seen in tables 4 and 5 of the Appendix. To summarize, for *Mendelssohn A*, the effect of additional reverberation is supposedly heard by all three participants, reporting changes of playing mostly in terms of shorter articulation and longer breaks. Preference tends towards the ”soft increase” reverberation setting. For *Mendelssohn B*, less dynamic and rather fluent, nobody reports to be significantly affected. By the most experienced player (Blue) there are a few remarks towards altering the registration depending on the acoustics.

6.2. Authors’ impressions

The authors are trained in music and partly in audio production and therefore consider themselves expert listeners. During pretests consisting of the selection of appropriate music it quickly appears that an effect of the acoustics on the organ playing seems very dependent on the musical material and its character. With some pieces, the additional acoustics appear negligible (e. g. soft, fluent passages) while others seemed very prominent, both for player and audience (e. g. parts with big dynamic and breaks). Overall, the configuration ”soft increase” seems to enhance the natural acoustics in the hall well, although depending on the music it is sometimes rather subtle.

The biggest immediate difference between the players seems to be the chosen overall tempo since this is not fixed but left to the musicians choice. This can be seen in the results and might be kept fixed by means of a metronom/click for further studies.

Player Blue (BL) appears to play a rather constant tempo regardless of the acoustics, Player Yellow (YE) on the other hand seems not as consistent in their behavior in general. In Mendelssohn A the musicians appear to notice the acoustic changes after the first 2-4 chords and then alter their playing, if at all. Overall, a slight difference in tempo and articulation and a noticeable difference in rest duration seems to happen. There is no big difference in behavior heard between blind and non-blind trials.

7. RESULTS

The results of the study seem to be highly dependent on the individual players and nature of the piece. While the results for *Mendelssohn A* show a tendency to play slower, with longer rests and notes, in the case of *Mendelssohn B* the performance is not affected by the acoustics (see Fig. 6 and 7). This corresponds to what the musicians reported.

The following subsections give a close view to the different analyzed features of *Mendelssohn A*.

7.1. Tempo

In *Mendelssohn A* the players tend to play slower when the reverberation is increased (Fig. 6a). However, the analysis of variance shows significance only for player OR. Player BL reports being affected - this is not visible here. Nevertheless, player BL shows the reported tendency in the non-blind case, meaning that the previous knowledge about the acoustic conditions seems to lead to an overrating of the effect of the acoustics.

7.2. Quaver rests

The duration of the first five quaver rests of *Mendelssohn A* has been measured and averaged in every take (Fig. 6b). The behavior of the players follows a similar tendency in this case, with longer rest duration when the effects of the reverberation are more evident. In this case, the statistical significance shows similar results (only player OR is significantly affected).

7.3. Notes duration

The duration of all the notes has been averaged in every take, using the same approach as in the quaver rests. By combining the effects on rests and notes duration, the origin of the tempo variations can be deduced (Fig. 6).

On one hand, player YE is playing longer rests (Fig. 6b) but the duration of the notes remain constant (Fig. 6c), which means that all the effect in the tempo variations is due to longer rests. On the other hand, players BL and OR tend to play longer notes with increased reverberation, and their tempo variations are made up from both longer notes and rests.

One way ANOVA					
		P-value			
		Mendelssohn A		Mendelssohn B	
Player	Test	Tempo	Rests	Tempo	Rests
BL	Blind	0.459	0.302	0.779	0.7957
OR	Blind	<0.01	<0.01	0.572	0.6413
YE	Blind	0.087	0.054	0.97	0.3485
BL	Non Blind	0.046	0.176	/	/
OR	Non Blind	<0.01	<0.01	/	/

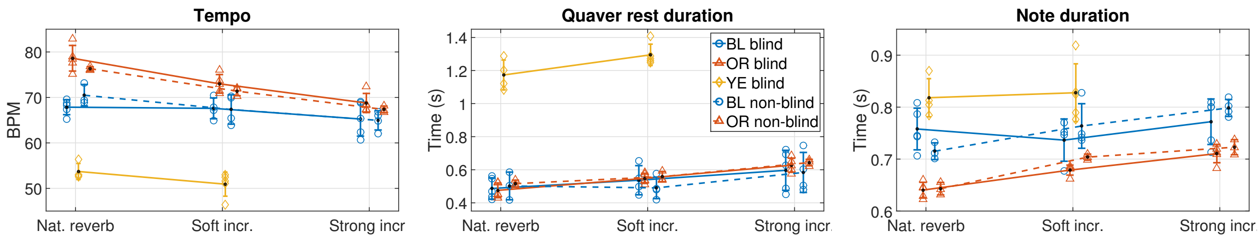
Table 3: Resuts of the one way ANOVA analysis on the analyzed features. Abreviations BL, OR and YE stand for players blue, orange and yellow, respectively.

7.4. *A priori* knowledge

Although there are only two players which are recorded in blind and non-blind conditions, the results show a very different individual behavior. Player OR shows the same behavior and results with and without previous knowledge about the acoustic conditions. However, as mentioned previously, player BL shows a different behavior when having previous information about the acoustics and a detailed analysis is necessary to understand this situation: As shown in Fig. 3 in the acoustic condition ”Strong increase” the reverberation is much more drastically lengthened than in ”Soft increase”. Therefore, player BL seems to naturally change the performance in the ”Strong increase” scene, but in the case of ”Soft increase”, the changes are originated by the *a priori* knowledge on the acoustics, leading to an overrating of the effect of the reverberation, which is not present in the blind experiment.

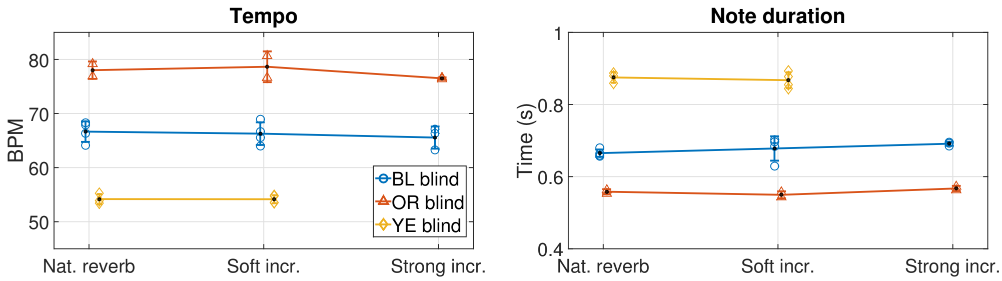
8. CONCLUSIONS

This paper presents a pilot study on influence of acoustics on music performance. The proposed set-up using acoustic room enhancement in a concert hall and MIDI analysis has been



(a) (b) (c)

Figure 6: Performance results of *Mendelssohn A*, bars 1-4. Every color stands for a different player, solid and dashed lines represent blind and non-blind conditions, respectively. Point markers represent results of single takes.



(a) (b)

Figure 7: Performance results of *Mendelssohn B*, bars 24-30. Every color stands for a different player, solid and dashed lines represent blind and non-blind conditions, respectively. Point markers represent results of single takes.

proven to be suitable in this experiments, in which all the information related to the performance can be encoded in a data stream. Results show different influence of acoustics depending on individual players and musical context. In some cases, there is no noticeable influence, and when a given musical and acoustic circumstances are met, increased reverberation time results in lower tempo and longer rests.

8.1. Further work

Further experiments are planned with a larger number of participants and musical pieces in order to create a representative categorization of musicians, classifying them according to the influence of acoustics on their playstyle. In addition, it is necessary to perform an extended study on the musical features that make a piece susceptible to performance adjustments.

The inclusion of a delay between pressing a key and sound generation is a variable that can be taken into account in order to increase the effect of the acoustics and approximate them to performance spaces such as churches or cathedrals. The delay can be implemented by using a digital organ synthesizer and playing back the synthesized sound through an electroacoustic system placed in a remote position, thus using the organ merely as a console. First experiments using this approach have been already implemented and the results are under analysis.

9. ACKNOWLEDGEMENTS

The authors wish to thank all the participants in the experiments for their collaboration. The research work presented in this article has been funded by the European Commission within the ITN Marie Curie Action project BATWOMAN under the 7th Framework Programme (EC grant agreement no. 605867).

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11. APPENDIX: MUSICIANS INTERVIEWS

Table 4: Musicians interview for *Mendelssohn A*

Player	Experience Level	Articulation	Rests/Tempo	Preference	Other
Blue	Completed so called concert exam studies in organ playing (additional 2-year degree after Master), therefore quite advanced.	The same phrases are played stronger or softer depending on the acoustics. The key releases are shorter with much reverb.	Hears when ”the room comes” and it of course affects the playing, e. g. if there is more reverb, one waits longer in breaks. When much reverb is there, the player waits longer after the break(s).	With the given registration, ”soft increase” was preferred over the other two. The setting ”strong increase” would require another registration (e. g. more 8-feet pipes to make it less transparent and give it a more romantic sound).	Sometimes the registration sounds better and fuller with more reverb, otherwise the mixture is too ”squeeky”. The player would put in more ground voice registers to create a fuller sound.
Orange	Last semesters of Bachelor studies.	With more reverb, there is no legato but instead more staccato articulation in the lower voice.	In the frame of the possibilities of the piece, the playing is changed to longer breaks and slower tempos when there is more reverb.	The ”soft increase” setting fits the best, with longer reverb (”strong increase”), it is too much and gets muddled up. Also, an acoustic feedback tone was heard.	Changes between acoustics are not confusing, one hears well in the breaks what is happening. After the first two chords, the player listens for what happens acoustically and reacts spontaneously and to musical taste.
Yellow	Half way through Bachelor studies, initial participant with lower experience level than the other players.	The reverb makes the ”impact” so the player lets the reverb do the impact – if present, otherwise one has to do it by playing.	If extra reverb is not present, the note before the break is played longer than one would usually – to make up for the missing reverb and to get overall the same desired expression.	Clearly better with extra reverb than without for this romantic (period) piece.	/

Table 5: Musicians interview for *Mendelssohn B*

Player	Experience Level	Articulation	Rests/Tempo	Preference	Other
Blue	Completed so called concert exam studies in organ playing (additional 2-year degree after Master), therefore quite advanced.	Left hand sounds stronger when there is more reverb. Regarding the registration the player would change the swell	In the right hand no big changes are noticable.	Overall it sounds nicer and more ”airy” with the setting ”strong increase”, so this was the preferred configuration	With the ”big acoustics” it sounds like a ”sound carpet / wash”.
Orange	Last semesters of Bachelor studies.	Player notices a difference when there is lots of reverb (”strong increase”). Then, the left hand gets ”mixed up” and one must play more transparent, e. g. smaller phrasing.	/	”Soft increase” sounds a bit more organic, but overall no big sonic difference.	The difference is suspected to be smaller because there are less breaks.
Yellow	Half way through Bachelor studies, initial participant with lower experience level than the other players.	Not much difference was noticed while playing due to nature and little dynamic of piece, maybe a small effect in the melody voice.	/	With artificial reverb is preferred ”a little better” when listening back to the own MIDI recording played back with and without extra reverb.	/