Analysis of Piano Duo Tempo Changes in Varying Convolution Reverberation Conditions

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Analysis of Piano Duo Tempo Changes in Varying Convolution Reverberation Conditions

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ABSTRACT

Acoustic design of performance spaces typically places the performers' needs relatively low in the hierarchy of requirements in comparison to the quality of sound for an audience. While there are a number of studies relating to solo performers' and symphony orchestras' preferred acoustic environments, there is a paucity of literature on objective measurements of the impact of acoustic spaces on smaller ensembles. This study aims to bridge this gap by building a methodology for the analysis of changes in ensemble musical expression caused by different acoustic environments. The study finds that there is an association between reverberation time and global tempo for a co-located piano duo and provides a basis for future studies in this area. This work extends previous research in the area of acoustics and musical performance.

1 Introduction

In acoustic design of performance spaces, the majority of research focusses on the audience's experience. Existing work that examines the impact of acoustic environments on performers offers only subjective viewpoints on this impact, and focuses on solo instrumentalists [1]–[4].

Bolzinger et al. [4] looked at seven solo pianists playing on a Disklavier in variable acoustics at IRCAM's '*Espace de Projection*' and found global tempo was not impacted by reverberation time (RT), with each pianist playing different pieces of music and over a long duration; however, the pianists almost unanimously identified a preferred room acoustic. Looking at RT, Gade [2] investigated subjectively the room acoustic needs of performers and the objective properties of the sound field used for orchestra performances. This research provided an early overview of the perceptual issues affecting musical performance and presented two objective parameters of Support (ST) and Early Ensemble Level (EEL) to quantify the performers' abilities to hearing oneself and to hear others in the acoustic environment.

In the literature, existing acoustic studies generally only analyse the performance of solo musicians in a subjective manner. For example, Barthet et.al [5] presented subjective analysis of the perceptual effects of variations in acoustical properties of timbre, timing, and dynamics on musical preference. Larger ensembles were analysed through reflective analysis in Jeon et al. [1], which correlated subjective measures on preference of stage position with acoustic measurements defined by Gade [2].

Key studies in performance analysis related to acoustic properties include Kato, Ueno et al. [6]–[8]. These studies investigated the playing of soloists in a range of simulated acoustic environments and the impact of these acoustic environments on the adjustment of tone, tempo, note lengths, silence between notes, articulation, dynamic level, dynamic range, harmonics strength, pitch tuning, and vibrato extent. The study correlated quantitative measurements to subjective opinion, with the quantified audio variations showing considerable agreement with statements from the performers. All the measured parameters were found to vary with statistical significance with room acoustic conditions.

A recent study of a duo conducted by Kato et al. [7] showed a reduction in tempo for short and long reverberation times. This resonates with the idea of 'comfort reverb' used in recording studios, which use a small quantity of reverberation to support a performer's expressive capabilities. Here, we ask the question of whether the same holds true in extreme reverberation environments, such as spaces with reverberation times outside those suitable for musical performance?

However, there are limitations with the previously mentioned study, along with others by Kalkiandjiev [9], [10] and Amengual Garí [11]. The main one is the focus on soloists rather than ensembles. While solo performance is widely covered, music often relies on successful artistic collaboration for its performance. Ensemble performance has not been subjected to the same level of investigation in the fields of acoustics and performance analysis. Our current investigation examines, for one piano duo, whether the work of previous studies in the domain of tempo variation hold true so as to prepare for extending such work to other quantifiable areas of audio variation, and to more kinds of duos and more duo participants.

2 Methodology

Our study involves two piano players playing in convolution reverberation conditions based on Room Impulse Responses (RIR) of real spatial environments.

Two experienced pianists, Edward Hall and the last author, were recruited from the Centre for Digital Music at Queen Mary University of London to produce the recordings for this study. It was agreed between the pianists and the lead author that Mozart's *Sonata for 2 Pianos in D Major, K.448 / 375a* [12] would be a suitable piece of music to learn for the study, and would also provide suitable variation and detail for analysis of tempo changes. The participants and investigator agreed that Bars 0-33 were to be used.

Two rehearsal sessions served as preparation for the study where the participants played through the score and discussed the approach to their playing (e.g. who was to play which part). This was to ensure adequate familiarity with the piece and sufficient proficiency with the notes to enable tempo variation at will to suit different reverberant conditions and ensemble communication so as to not impact the performance and confound the data.

In order to make the study replicable, easily available commercial equipment was sourced. Two Digital Pianos—a *Yamaha CP300* and a *Yamaha P80* keyboard—were used. These were patched through a *Focusrite Scarlett* audio interface and a *Samson S-Amp* to ensure participants and investigator could hear the proceedings, and the recordings were made using the *Ableton 9 (Suite)* Digital Audio Workstation. This DAW was chosen due to the freely available Convolution Pro Reverb Device developed in *MAX/MSP* [13]. The experimental set up is represented in Figure 1 (below).

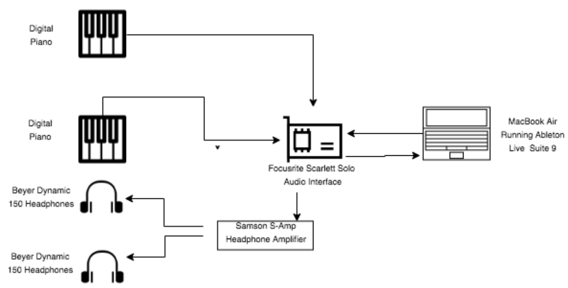

Figure 1 - Technical Drawing of Experimental Set up.

The participants were presented with ten convolution reverberation conditions, and a dry condition presented through two pairs of *Beyer Dynamic Headphones (Model DT150)*. The Room Impulse Responses were selected from the *OpenAIR Library* [14] and were chosen to represent a wide range of acoustic conditions. The list of locations are presented in Figure 2 with their associated Reverberation Times (RT) for tones at 500Hz and at 1kHz, respectively. The chosen frequencies were selected to cover the range of a typical musical performance; the reverberation conditions are arranged in ascending order based on the RT times for the 500Hz tone.

Location	Reverberation Time at 500hz	Reverberation Time at 1kHz
Live Room, Sound Studio Laboratory, University of Athens	0.60	0.59
York Guildhall Council Chamber	0.93	0.93
Hoffman Lime Kiln	0.93	0.71
Dixon Studio Theatres	1.09	1.14
Central Hall, University of York	1.11	1.12
St Andrew's Church	1.22	1.45
Underground Car Park	1.94	2.15
Disused Nuclear Reactor	5.43	4.78
Sports Centre	6.81	6.52
York Minster	8.40	7.71
Terry's Factory Warehouse	10.22	10.52

Figure 2 - Reverberation Times Used in Study Adapted from OpenAIR[14].

The conditions were presented in a randomised order, excluding the dry condition at the start which was used as a baseline in each run through of the conditions. The randomised order mitigated against performance improvements due to order-based learning confounding the results if, say, the conditions were presented from no reverberation time progressively to full reverberation time.

The participants played the piece in randomised conditions through all 10 reverberation conditions a total of four times, with small breaks in between, and a larger break (of one hour) between the third and fourth run at which point the performers swapped piano lines.

At the end of the study, after all four runs through the reverberation conditions, participants were asked to rate, on a Likert scale, the 'ease of playing' in each condition and their general thoughts in a free text box. This was used to validate the objective measures against the experience of the performers in each reverberant condition.

3 Results

The data was analysed using two methods to ascertain the tempo variation in the performances. The first method used manually-derived beat information annotated using Sonic Visualiser [15]. This beat information was then processed using MATLAB, to compute the tempo for each performance in beats per minute in score time.

In this section, we present the results from the first to fourth cycle through the ten experimental conditions.

Figure 3 shows the mean tempo for each reverberation condition, presented in ascending RT for 500Hz. The graph supports a strong association between short and long reverberation times and lower tempo.

While outlying tempi exist from one cycle to the next, the mean tempo graphs form similar shaped curves with the tempo for each increasing toward the median condition and dropping from this point.

An exception to this observation occurs in the first cycle where the conditions of Dry, and Nuclear Reactor resulted in outlying tempi, with the performance in Dry being much slower than in subsequent cycles, and the performance in Nuclear Reactor being significantly faster than others in the cycle. This could be explained by time for human adaptation to the reverberant conditions. The effect of learning can be observed in the data. As the stimulus became more familiar, in subsequent cycles, and as the participants learned to adjust to the different reverberant conditions, they developed a wider range of tempi. See the wider range of tempos in the fourth cycle in Figure 3.

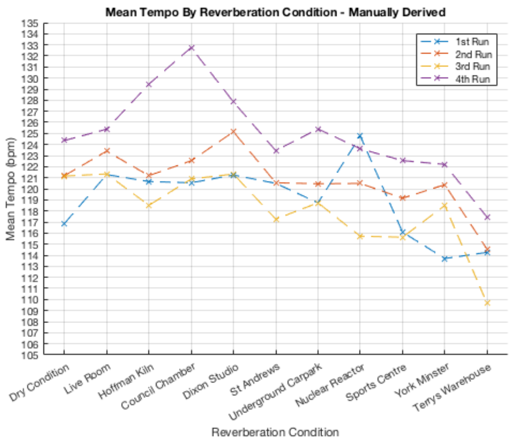

Figure 3 - – Mean Tempos (computed from manually-derived beat information) for each of the four recorded performances in each Reverberation Condition.

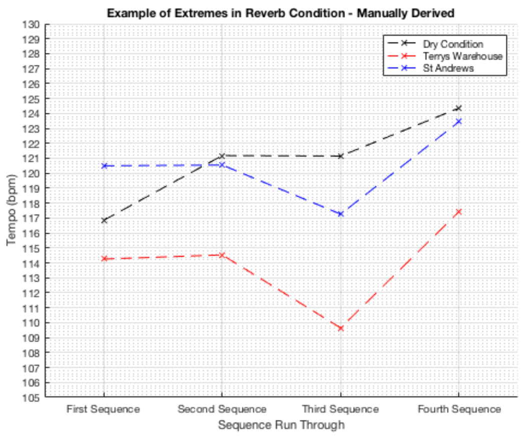

Figure 4 - Mean Tempo (computed from manually-derived beat information) for each of the four performances recorded in Extreme and Median Reverberation Conditions.

Figure 4 shows the mean tempo for the four recordings in the most extreme reverberant conditions - the Dry Condition and Terry's Warehouse - and the median condition—St. Andrew's. The graphs show an association between the longest reverberation time - Terry's Warehouse -and a generally slower mean tempo.

In order to mitigate against human bias in the manually-derived beat information a second method for tempo analysis was obtained using the *MiningSuite Toolbox* [16] for MATLAB using, in particular, the Aud.Tempo function which provides analysis directly from the audio file.

This analysis, detailed in Figure 5, verified the previous results, with the tempo for each performance broadly in agreement with the analysis obtained from human beat analysis, but with a markedly narrower range of tempi per condition. The narrower tempo range is likely due to lower machine adaptability to regions of high tempo variability in the recorded performances.

We next repeat the analysis of the most extreme reverberant conditions as with the previous analysis which used the tempi derived from manual tapping. The results for the MiningSuite tempi are presented in Figure 6. There is an association between the longest reverberation time (Terry's Warehouse) and generally lower tempi, between the optimal median reverberation time (St. Andrew's) and faster tempi, but only in the third and fourth cycles. This again suggests that learning and familiarity with the reverberant conditions may have played a part in the results, which fit with the literature post-learning. The Dry Condition performance was slowest in the first two cycles, and became middling (between Terry's Warehouse and St. Andrew's) and closely matching Terry's Warehouse in the final run.

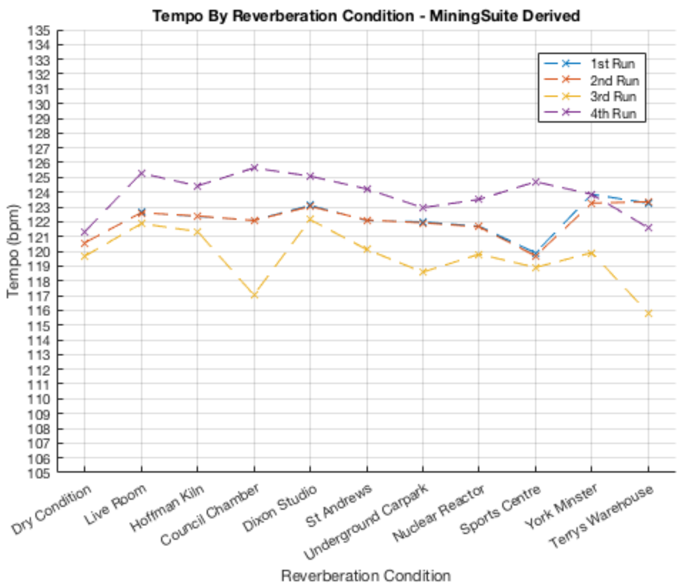

Figure 5 - Tempos (obtained from beat information provided by MiningSuite) for each of the four recorded performances in each reverberation condition.

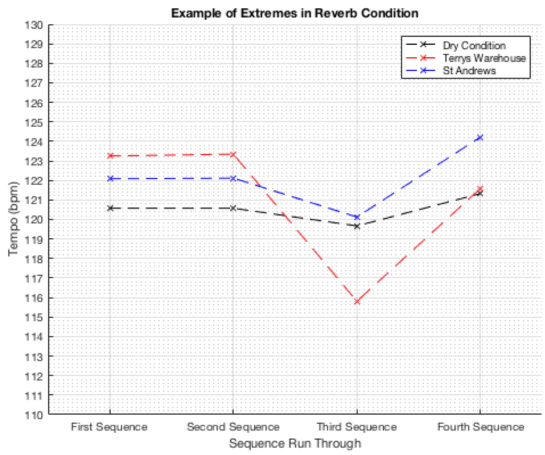

Figure 6 - Tempo (obtained from beat information provided by MiningSuite) for each of the four recorded performances in extreme and median reverberation conditions

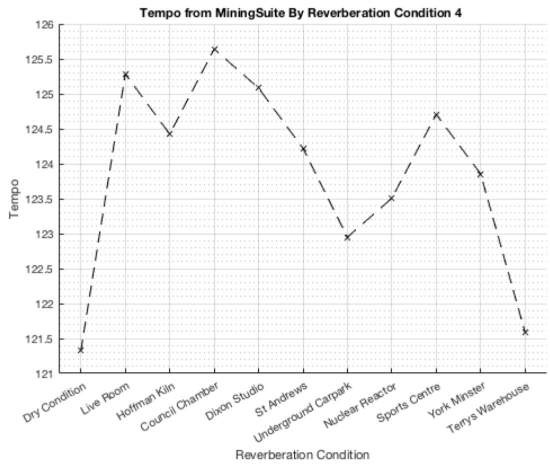

Figure 7 – Tempi from Cycle 4 (obtained from beat information provided by MiningSuite).

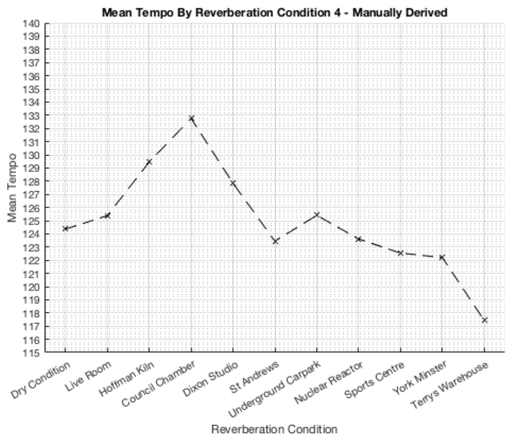

Figure 8- – Tempi from Cycle 4 (computed from manually-derived beat information).

The tempo adopted by the performers in the final cycle of performances broadly follows a bell shape for both the MiningSuite (Figure 7) and manually derived (Figure 8) analysis, with slower tempi associated with the no reverberation time and highly reverberant conditions. The fastest tempi were recorded in the Live Room, Council Chamber, and Dixon Studio conditions, each having what is known as 'comfort reverb' (1-2 seconds RT). There is another interesting association between these conditions: The Impulse Responses for these conditions were obtained from spaces that were designed for performance.

As an additional validation analysis, the participants were asked after the final series of performances to rate if they perceived their performance to be faster or slower than in the baseline Dry Condition. These ratings are reported in Figure 9.

Broadly the two participants agree with each other, with one exception: Sports Centre. In this condition, one participant judged the performance to be slower while the other thought it was faster. This may be explained by re-visiting the narrative documentary. Both participants stated in their feedback that this condition led to a larger range of tempi in their playing, this implies that it may be harder to pin down an actual global tempo in this case. For this situation, it may be more appropriate to examine the tempi in smaller sections of music. The responses do however validate the 'St Andrews' results, as it appears this reverberation condition sits at the median of the set, and also serves as an optimal reverberant condition for performance.

Condition	Participant 1	Participant 2
Live Room	Slower	Slower
Hoffman Kiln	Same	Same
Council Chamber	Faster	Faster
Dixon Studio	Same	Faster
St Andrews Church	Same	Same
Underground Carpark	Faster	Same
Nuclear Reactor	Slower	Slower
Sports Centre	Slower	Faster
Minster	Slower	Slower
Terrys Warehouse (a disused warehouse space	Slower	Slower

Figure 9 - Subjective Analysis on Tempo (presented in order from short to long RT).

4 Discussion

This study extends previous studies of solo music performance in different acoustic environments to duet performance. It placed two musicians in the same physical space and investigated tempo changes in a range of acoustic environments. The study provides a basis on which to build future work drawing upon objective expressivity measures for duo performance in different reverberant spaces.

The data was analysed using manually-derived beat annotations as well as an automated tempo extraction function to determine associations between the tempi of recorded performances and the associated acoustic conditions.

Both analysis methods show an association between tempo and acoustics under the experimental conditions, taking into consideration the relatively quick adaptation to the different reverberant conditions.

The data is supported by subjective evaluation of the conditions, through a Likert Scale representing ease of playing in the condition and a rating of whether the performance was faster or slower than the baseline.

There were several limitations in the current study. The participants, while expert pianists, were not an established duo, which required greater adaptation and learning in collaborative performance. Future studies will seek to recruit established duos with significant experience performing together.

The study design can also be further improved. The Impulse Responses used in this study, while covering a good range of locations, could number more, allowing for analysis covering a more comprehensive collection of spaces. On the other hand, future studies could also focus on a more limited range of conditions, with larger numbers of recordings per condition in order to create a dataset with greater effect size and to enable more robust statistical analysis.

Realism is one of the key challenges in simulating acoustic environments in studies such as these. Presentation of the acoustic conditions was done via headphones in the current study. Going forward, a speaker array will be employed in order to create more realistic and immersive performance environments.

The analysis presented reported global tempi of the combined duo performance. Further refinements will examine tempo at change points, individual tempi (as they are not necessarily the same at the micro scale) as well as the usual combined and global tempi so as to better understand the impact of the reverberation conditions on duo performance.

5 Conclusions

In this study we have shown an association between tempo changes and reverberation conditions for a piano duo co-located in a single room. The acoustic environments were simulated artificially using convolution reverberation and delivered through headphones. This protocol is in line with previous studies conducted for soloists, and duos in separate rooms.

The tempi adopted by the performers in the final ten performances broadly follows a bell curve with the slower tempi associated with the no reverberation time and highly reverberant conditions, and with the fastest tempi detected in simulated conditions having ‘comfort reverb’ (1-2 seconds RT). Interestingly, these simulated spaces in the ‘comfort reverb’ zone are also the ones with Impulse Responses drawn from locations which were designed for performance.

Further work will examine associations between audio parameters such as tone, note length, silence between notes, articulation, dynamic level, dynamic range, harmonics strength, timbre, pitch tuning, and vibrato extent, as described by Kato et al. [7] for experienced duos in a wider range of conditions. In addition, there is work to be done comparing performances in a series of varied and actual physical spaces, and performances of the same music in virtual spaces that simulate these same environments.

6 Acknowledgments

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