Live performance adjustments of solo trumpet players due to acoustics

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Abstract

Previous studies on musicians' adjustments to room acoustics have demonstrated an influence of room acoustics on live solo music performance. Musicians adjust different aspects of the performance, such as tempo, articulation, dynamics or level. However, this effect seems to be highly dependent on individual musicians, musical pieces and instruments. This paper studies the influence of acoustics on solo trumpet players under different acoustical conditions. By means of virtual acoustics different rooms are auralized in real-time and five trumpet students are recorded playing a set of pieces of their choice repeatedly. After the experiment the musicians are interviewed to gather their personal impression on the adjustments performed, the quality of different acoustical conditions and their personal preferences. Performance aspects such as tempo, level, articulation, and timbre are analyzed by evaluation of objective audio features i.e. length of the performance, RMS value, average-to-silence ratio, and spectral centroid, respectively. The correlation analysis of acoustic and performance parameters confirm that individualized strategies of performance adaption and the chosen repertoire seem to have an important effect on the performance adjustments. Although the effect of acoustics on tempo cannot be generalized, general trends can be observed: the RMS of the performance and the timbre brightness present a moderate inverse correlation with the strength and reverberation time of the room, while features related to articulation show a weak positive correlation with those room parameters.

Keywords: live performance, stage acoustics, auralization

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1 Introduction

The stage acoustic conditions are a key aspect in a live performance, having an influence on the comfort of musicians and their performance. In previous studies, solo musicians and ensembles have been recorded in different acoustic conditions to evaluate which aspects of the performance are affected by the acoustics and how the musicians adjusted their performance. Those studies focused on different instruments and have demonstrated common trends among musicians e.g. sound level changes [1] or tempo variations [2]. However, these changes are subject to specific music pieces and adjustments of other performance aspects are in most cases individual of each musician and instrument [2, 3]. In this paper we present a study conducted with five different trumpet players recorded while performing in a virtual acoustic environment with controllable acoustic conditions. The recordings are analyzed using signal analysis techniques and the musicians are interviewed regarding the effect of acoustics on their playing style.

2 Experimental set-up

A virtual acoustic environment has been implemented to render the acoustics of different rooms in real time. The main idea behind the implementation consists on the acquisition of spatial room impulse responses, its convolution in real time with the sound generated by a musician and the playback of the appropriate room reflections. This section presents an overview of the main steps involved in the process. A detailed explanation of the implementation is given in [4].

2.1 Auralization principle

The auralization principle is based on the Spatial Decomposition Method (SDM) [5]. A spatial room impulse response (SRIR) is captured using a microphone array composed by at least least 4 omnidirectional microphones defining a 3D space. The SRIR is then decomposed into a succession of plane waves by estimating the direction of arrival (DOA) of every acoustic event. The method has been widely used for the analysis and auralization of concert hall acoustics in the recent years [6].

The first step in the auralization process is the acquisition of a SRIR. The measured SRIR is analyzed and an associated DOA is estimated for every sample. The room response is then characterized by a set of image sources, which are rendered using Vector Base Amplitude Panning (VBAP) [7].

Since a musician is creating the direct sound, only the room reflections must be rendered, and thus the direct sound is removed from the impulse response. Finally, the impulse responses are convolved in real time with the live sound of a musician performing, picked by a close directional microphone (Schoeps CCM 4V) mounted on the trumpet bell. The result is reproduced by a 13 loudspeaker setup (Neumann KH120 A) surrounding the musician.

2.2 Measurement sound source

In order to achieve a high degree of realism in the auralization it is desirable to measure the rooms using a sound source with radiation properties similar to the target instrument. The radiation characteristics of a trumpet have been estimated using a circular microphone array of 24 microphones (Beyerdynamic MM1) in an anechoic chamber. A chromatic scale played by a musician was recorded with the microphone array and an overall radiation pattern was then computed. Then, the radiation properties of different loudspeaker models were measured using swept sine measurements and a studio monitor (Neumann KH 120 A) was found to present similar characteristics and used for SRIR measurements. The main differences between the trumpet and the loudspeaker radiation are in low frequencies, where the loudspeaker presents a higher radiated energy to the back, and in the band 4-8 kHz, with a higher lateral radiation from the loudspeaker. Overall, the trumpet presents a higher directivity towards the front.

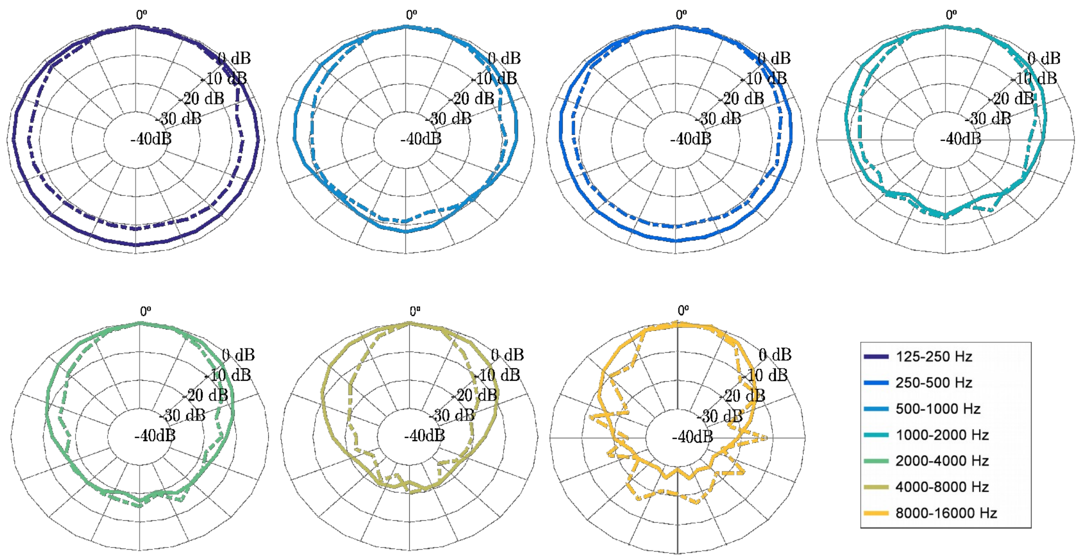

Figure 1. Radiation pattern (horizontal plane) of a trumpet (dashed lines) and a studio monitor Neumann KH 120 A (solid lines)

3 Experiment

3.1 Description

The experiment consisted of individual sessions of approximately 60 minutes in which a trumpet soloist was recorded performing the same piece in virtual rooms with different acoustics. The musician was asked to explore the sound of a room without any time limitation, in order to have an overall perception of the acoustics. After the initial exploration, an excerpt of a music piece was recorded. The procedure was then repeated with different rooms. The order of the rooms was randomized and, when possible, multiple takes per piece were recorded in every room.

The musicians freely chose the music pieces. The only imposed condition was that they must be able to perform the pieces in a relaxed way, in order to avoid learning effects after playing the piece several times during the experiment.

After the recording, interviews with the musicians were completed in order to extract their personal vision regarding the effect of acoustics on their performance and explain the adjustments in terms of tempo, dynamics, expressivity, articulation, easiness of playing, and personal taste. The information was extracted through a question-based interview with closed questions complemented with cooperative conversation.

3.2 Auralized rooms

The experiment was carried out in the WFS studio of the University of Music Detmold, a room with appropriate acoustic treatment and quasi-anechoic conditions. The reverberation time of the room is less than 0.1 seconds at mid and high frequencies and the reflections within 10 ms after direct sound have a level lower than 10 dB respect the direct sound.

Three different rooms were chosen and auralized for the experiment, in addition to the natural dry acoustics of the studio. Detailed information regarding the rooms is given in Table 1 and images of the rooms are included in Figure 2.

Table 1: Rooms general information

Room	Abbreviation	Description	Seats (approx.)	Room Volume (approx. m^3)	Stage Volume (approx. m^3)
Dry	Dry	mixing studio	-	125	-
Brahmssaal	BS	small performance room	320	750	230
Detmold Konzerthaus	KH	medium sized Concert hall	600	4600	600
Detmold Sommertheater	DST	medium sized theatre	110	2700	650

Figure 2: General view of the auralized rooms (BS, KH and DST, respectively)

3.2.1 Auralization evaluation

The auralized rooms have been measured to validate the fidelity of the auralization process in order to ensure that the virtual environment used in the experiment replicates the true acoustic properties of the measured rooms. The auralization system is fed with a swept sine and convolved with the rendered spatial impulse responses of the measured spaces (including direct sound). The same microphone array used in the real rooms is placed in the center of the listening space obtaining spatial impulse responses of the virtual rooms. Table 2 contains detailed information about the values of typical parameters i.e. T20 and C80 in both the real and the virtual rooms.

Table 2: Comparison of the estimated room acoustical parameters of the real measured rooms and the auralized rooms. The presented values are averaged over the 6 measurements microphones of the array. The background color of the cells refer to the auralization error (for T20: green = error < 0.1 s, yellow = error between 0.1 and 0.2 s, red = error > 0.2 s; for C80: green = error < 1.5 dB, yellow = error between 1.5 and 3 dB, red = error > 3 dB).

	T20 (real / auralization)						
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
BS	1.29 / 1.31	1.55 / 1.52	1.35 / 1.38	1.17 / 1.24	1.10 / 1.18	1.03 / 1.10	0.80 / 0.98
KH	1.43 / 1.02	1.20 / 1.06	1.26 / 1.21	1.38 / 1.31	1.44 / 1.38	1.31 / 1.30	0.91 / 1.12
DST	1.01 / 0.96	1.08 / 0.95	0.95 / 0.85	1.03 / 1.02	0.94 / 0.97	0.89 / 0.89	0.68 / 0.76
	C80 (real / auralization)						
BS	9.42 / 8.52	5.40 / 5.70	5.94 / 7.12	5.13 / 6.27	2.77 / 3.18	0.82 / 2.09	-0.11 / 1.98
KH	12.69 / 13.09	13.60 / 15.27	12.20 / 13.30	9.51 / 11.12	7.23 / 7.12	6.23 / 6.85	5.56 / 6.60
DST	11.08 / 13.93	12.57 / 15.86	12.31 / 15.45	10.79 / 13.03	8.59 / 9.14	7.28 / 7.09	7.13 / 7.36

Regarding the estimated reverberation time, in most of the frequency bands, the auralization error is less than 0.1 seconds. However, in the low and high end, higher divergences occur, partly due to low frequency room modes present in the listening room and the increase of high frequency in the late reverberation, which is a known feature of SDM. The clarity (C80) is in most cases overestimated but the error falls under the limen of just noticeable differences in most cases [8]. Only in the room DST there are more pronounced errors, which could be perceptually relevant.

3.3 Participants

The participants in the experiment were 5 students with trumpet as a main instrument with ages comprised between 20 and 25 years and enrolled in a bachelor degree of music in the University of Music Detmold. One of the students was focused on jazz music while the rest of them performed classical repertoire. A questionnaire completed with every musician after the experiment and Table 2 summarizes the musical experience of the musicians and the perceived realism of the auralized rooms.

Table 3: Musical experience of the participants

Player	Years playing trumpet	Concerts as soloist	Concerts with ensemble	Concerts with orchestra	Times performed in			Auralization realism (0/10)
					BS	KH	DST	
A – blue	14	>20	10-15	10-15	2	1	1	8
B – red	13	>20	>20	>20	20	10	5	9
C – yellow	15	>20	>20	>20	15	15	10	6
D – purple	11	>20	>20	>20	0	5	10	7
E - green	13	>20	>20	>20	3	1	2	8

3.4 Acoustic parameters

The selected acoustic parameters are T_{20} and G_{all} measured on stage at the receiver position. The reason of this selection is that other common parameters, such as ST_{early}, ST_{late} and EDT present high correlation with T_{20} and G_{all}. In addition, previous studies already used the chosen parameters [2] and comparison with previous results can be easily done. The parameter G_{all} is estimated using formula (1) for broadband impulse responses. The estimation of T_{20} is an average over the bands from 250 Hz to 4000 Hz.

$$G_{all}=10\log_{10}\left(\frac{\int_{0ms}^{\infty} p^2(t)\,dt}{\int_{0ms}^{10ms} p^2(t)\,dt}\right)[dB] \quad (1)$$

The values of the acoustic parameters of the different rooms are summarized in Table 4. Note that the values refer to measurements in the real rooms.

Table 4: Room acoustical parameters used for the evaluation

Room	T20 (s)	Gall (dB)
Dry	<0.1	0
BS	1.25	2.43
KH	1.41	0.74
DST	0.97	0.71

4 Signal analysis

After the experiment, recordings with noticeable performance errors are removed from the final set of files. Afterwards, the audio files are trimmed by selecting starting and ending points where the signal energy is 24 dB lower than the average energy of the recordings and a high pass filter at 150 Hz is applied to remove low frequency noise from the operation of the trumpet valves. Finally, the recorded performances are analyzed using the MIRToolbox for Matlab [9].

4.1 Extracted features

An initial list of audio features was considered for the analysis: RMS value, length of the performance, low energy ratio, average to silence ratio, spectral centroid, spectral brightness, spectral rolloff, spectral flux (mean and variance), zero crossing, envelopment variance, temporal flatness, spectral skewness, spectral spread, spectral flatness, spectral entropy, and RMS of the envelope. Detailed descriptions of these features are included in the manual of the MIRToolbox [9]. To reduce the list of features, correlation tests between all initial audio features were performed and some features were discarded. The description of the final features is presented in table 5.

The correlation (ρ) between some of the used low level audio features and the represented musical aspect has been previously studied by Friberg *et al.* in [10]. However, the rated signals were different in that study and it is necessary to carry on further research to confirm whether those and the rest of chosen features are appropriate predictors for the studied musical aspects in solo trumpet performance.

Table 5: Final list of applied audio features

Feature	Description	Abreviation	Domain	Musical aspect	ρ
Room Mean Square	RMS value of the recorded excerpt	RMS	Energy	Dynamics	-
Length	Length in seconds of the recorded excerpt	length	Time	Tempo	-
Average to Silence Ratio	Percentage of “silence” time in the recorded excerpt	lowenASR	Energy	Articulation	0.62
Spectral centroid	Spectral centroid of the recorded excerpt	centroid	Frequency	Timbre	-
Temporal flatness	Flatness of the envelope of the recorded excerpt	tempflatness	Time / Energy	Dynamics	-
Pulse clarity	Estimated strength of the beats	pulseclarity	Time / Energy	Rythmic clarity	0.73
Average spectral flux	Average difference between successive short time spectra	SFmean	Time / frequency / energy	Perceived energy	0.75

4.2 Dataset construction

Audio features for every recording were extracted and organized in a nested structure with the following levels: player, piece, and room. In order to allow comparisons between different players and pieces, the features were normalized using the average value of all the takes for each player and piece as shown in eq (2).

$$Fnorm_{pl,pi,ro}(i)=\frac{F_{pl,pi,ro}(i)}{\frac{1}{N}\sum_{n=1}^{N}F_{pl,pi}(n)} \quad (2)$$

Where F is an audio feature, *Fnorm* is the normalized value of an audio feature and *N* is the number of takes per player (*pl*), piece (*pi*) and room (*ro*).

5 Results

After obtaining the normalized values of every audio feature for all the recorded performances correlation tests between the different audio features and the acoustic parameters were done.

5.1 Individual players

The results of the correlation analysis between the audio features and the room acoustical parameters are summarized in Fig. 3. A preliminary analysis of the results suggest that G_{all} has a stronger effect on the musicians than the T_{20}. The level of the performance (RMS), timbre (centroid) and dynamics (tempflatness) present moderate correlation with the strength of the room on at least three of the musicians. This could imply that more reverberant and louder rooms lead to a quieter performance with less dynamic changes. The timbral changes are in most cases strongly correlated with the sound level of the instrument. In addition, the articulation (lowenASR) is also affected in two musicians, leading to a more *staccato* articulation in more reverberant spaces. The overall length of the performance is modified only by two players. However, this does not imply that tempo changes are not produced; in order to prove this it is necessary to complete a micro-tempo analysis at note level.

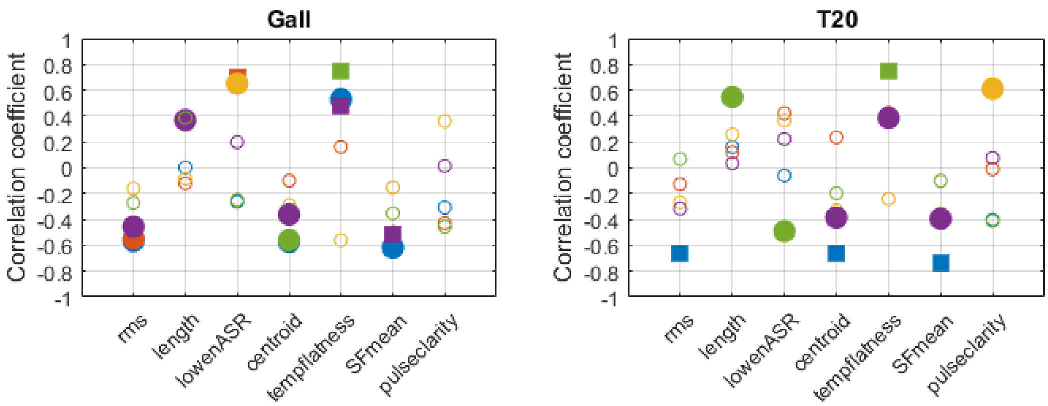

Figure 3: Results of the correlation analysis. The different colors of markers refer to the players. Circular markers denote statistical significance with p<0.05 and squared markers refer to p<0.01.

5.2 Personal interviews

A summary of the interview with the participants is presented in Table 6. Quoted text fragments refer to verbatim transcript of the musicians' own words, in some cases translated from German or Spanish to English.

Table 6: Interview with participants. Cells with green background highlight statements that have been proven by the correlation analysis presented in Section 5.1.

Player	Tempo	Dynamics	Articulation	Expressivity	Other aspects
A - blue	More reverb leads to a "lighter" performance (not necessarily related with tempo)	More reverb = softer; very dry = louder	More reverb means more staccato articulation. Dry room requires longer notes	Dry needs to be less expressive, more reverb needs more expressivity	The used trumpet is very important, playing piccolo is very important to control volume with acoustics
B - red	"The tempo is not the same. With more hall I play slower"	"With more hall I make more dynamic differences"	"with less hall I pay more attention to articulation"	"With more hall it is more fun to achieve more expressivity, but actually I always try to meet the expression"	
C - yellow	The tempo is "not much" affected	"I try to adapt the performance e.g. not too loud in a large hall"	"In more reverberant rooms the sound must be faded away faster, in dry rooms the notes should be longer"	"I think the expressivity should not depend on the acoustics"	"I feel better in a good sounding room"
D - purple	It is possible that more reverberant leads to slower performance but tries to keep the tempo. "I visualize first the music in my mind and then translate it into the room"	Not sure about the effect, it is possible that a bigger room leads to louder performance and hearing the "wind" in a dry room leads to quieter performance	With a big room there is a "loss of information" in fast passages and it is not possible to control what you play	"The room has an effect, drier is more intimate". The sound of the trumpet is different, leading to different things	Player used to play with orchestra & big band, which has an influence on the adjustments adopted
E - green	It changes depending on the room. "When the room is very dry it is easy to get faster"	More reverberation leads to a more piano performance	More reverberation leads to a more staccato articulation	More reverberation leads to a more expressive performance	The musician tries to compensate the performance according to the room auditory feedback

6 Discussion

As explained during the interviews and observed in the signal analysis, all the musicians adapt their playing style to some extent depending on the acoustics with the same tendency. However, the degree of adjustment is different in all players. In some cases effects can be observed that are not mentioned during the interviews and vice versa. This raises the question of the consciousness of the adjustments and intentionality. Although the subjective descriptions of the players concerning their own adjustments during their performances are similar to some extent (quieter performance, slower tempo, more clear articulation…) this is not always observed in the correlation analysis.

Some participants claim that acoustics could have an effect on their expressivity during performance. The analysis of expressivity of a performance is a current research topic and seems to address a mixture of tempo and dynamics variations, among other aspects. Also, it is necessary to cross-validate results from the signal analysis with those from perceptual tests of listeners to confirm whether the explained changes are perceivable by the audience.

It is important to note as well that the room parameter G_{all} seems to correlate with more performance parameters under investigation than T_{20}. This could indicate that e.g. trumpet players are more concerned about the general sound level of the hall, whereas the decay duration seems to be a secondary aspect. Nevertheless, the studied group is too small here to extrapolate this tendency to all trumpet players.

7 Conclusion

An experimental study on the effect of stage acoustics on live solo trumpet performance was presented. A virtual acoustic environment was implemented that replicates the acoustic conditions of real rooms in which the subjects usually perform. The subjective impressions of the players regarding their adjustments show significant agreement in terms of tempo variation, produced sound level, and articulation changes, indicating that a more reverberant environment generally leads to a slower tempo, quieter performance and more clear articulation. However, the analysis results of the recorded performances suggest that the adjustments implemented by the musicians vary in great extent, and in some cases the changes explained in the interviews are not supported by the results of audio features. For this reason it is required to carry on further studies to evaluate to which extent the adjustments are consciously implemented or perceivable by the audience listening to the performances. The inclusion and validation of more audio features and further experiments including more sessions with the same and new musicians are currently being implemented.

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