Performance analysis of solo baroque music played in a period and modern hall

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Research into historical instruments, repertoire, playing technique, and compositional styles has formed the basis of the historically informed performance (HIP) movement, however, the importance of the venue/space has not been widely studied. This paper presents a preliminary analysis of the effect of the room and its acoustics on the performance of musicians specializing in baroque music. Ten solo musicians, playing period instruments (or facsimiles), performed in two small chamber halls, one from the Baroque era (the Salon des Nobles at the Château de Versailles) and the other contemporary (the amphitheater at Cité de la Musique). The effect of these halls was analyzed through objective musical performance parameters extracted from recordings and on-site subjective questionnaires.

1 Introduction

Performances of a musical composition can vary widely even though they are derived from the same underlying musical score. These differences can be the result of many factors, including training and experience, psychological state, the environment—both visual and acoustic, and cultural factors such as performance conventions. These conventions that guide stylistic decisions made by the performer are not static but evolve over time. When it comes to early music, some musicians aim to perform while following conventions appropriate to the era during which the piece was composed. This school of performance philosophy is known as historically informed performance (HIP) and is generally accomplished by reviving historical performance practices and instruments as documented in primary sources.

Despite its documented importance in music performance, the impact of acoustics has not taken a prominent role in the field of HIP. In his defense of using period instruments for HIP, musicologist Robert Donington argues that the ability to perform in Baroque style is "very largely dependent on the sound" [1]. It is valid to extend this idea beyond the instrument to the room in which the sound is produced since composition, performance styles, and instrument design are developed within, and are therefore influenced by, certain architectural spaces and their acoustics. Accordingly, it follows that certain performance styles and instruments may be better suited to the types of performance spaces in which they were conceived.

Of interest in this study is an examination of the interaction between HIP musicians and two different performance spaces, one modern and one from the Baroque period, with an aim towards investigating whether Baroque music may be better supported by a performance space of that era compared with a modern performance space. The study also intends to shed light on the role of acoustics in the evolution of stylistic conventions and performance practice. Ten musicians specializing in Baroque music and playing period instruments (or facsimiles) performed multiple repetitions of several pieces of music in two rooms. The musicians' subjective experiences were examined through questionnaires while differences in their playing were investigated through features extracted from recordings of their performances.

2 Background

2.1 Acoustics—Performance Interaction

The connection between acoustics and the composition, performance, and perception of music has been observed and documented for centuries [2]. Historically, the interaction between acoustics and performance practice has taken a minor but meaningful role in music pedagogy where performance strategies for different acoustic situations are passed down from teacher to pupil. However, the number of serious scientific investigations into the matter has been increasing in recent decades, seeking to find which acoustic qualities affect musicians and to what extent [3].

One important takeaway from many of these studies is that musicians demonstrated consistent but individual responses to changes in acoustics [4, 5, 6]. Additionally, Schärer Kalkandjiev and Weinzierl [7] found that the prevalence of certain trends was somewhat dependent on tempo, indicating that the musical content plays an important role when measuring the effect of acoustics on performance.

2.2 Description of Rooms

Two spaces were chosen for this study, one from the same era of focus (early 18th century) as the music and another small modern hall to serve as a contrast. The Baroque space is the Salon des Nobles at the Château de Versailles in which numerous musical performances have been documented [8]; the modern hall is the amphitheater which is a part of the Cité de la Musique in Paris (see Figure 1). The Salon des Nobles is roughly cubic in shape with a width and length of approximately $9\,\mathrm{m}$ and a height of approximately $7\,\mathrm{m}$ for a total volume of around $567\,\mathrm{m}^3$. The amphitheater is a roughly fan-shaped, asymmetrical chamber music hall with an approximate volume of $1430\,\mathrm{m}^3$.

Acoustic measurements were taken of both rooms with multiple source and receiver positions in the performer and audience areas, respectively. Figure 2 shows a comparison of the reverberation time (T_{30}) and clarity (C_{80}) for these two rooms. The amphitheater shows a moderate reverb time of around $1\,\mathrm{s}$ across all analyzed frequency bands. This lack of distinct acoustical signature renders the room somewhat transparent and allows it the flexibility of hosting a variety of music which is an essential function for many modern halls. By contrast, while the Salon des Nobles was not specifically designed to host concerts, its reverberance may serve to support Baroque instruments which are typically less resonant than their modern counterparts.

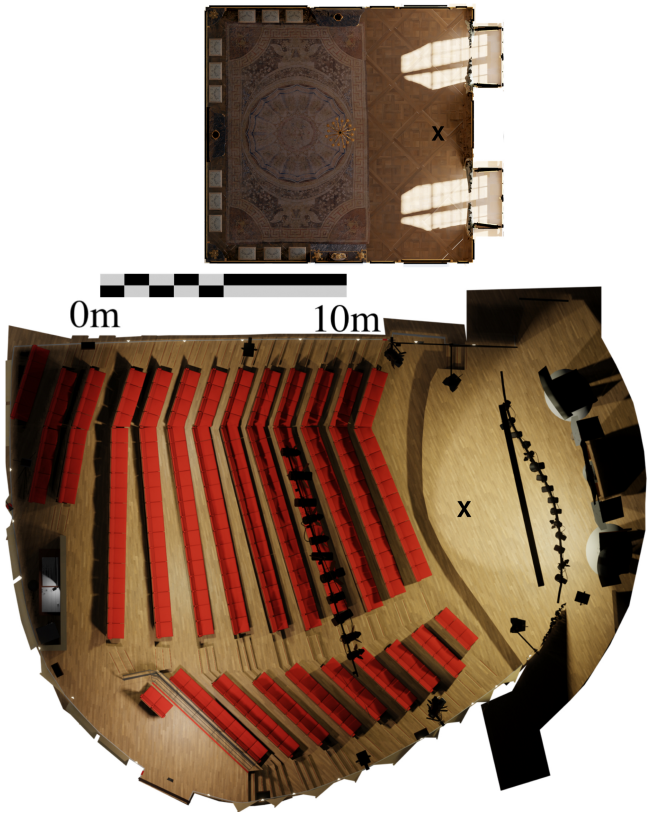
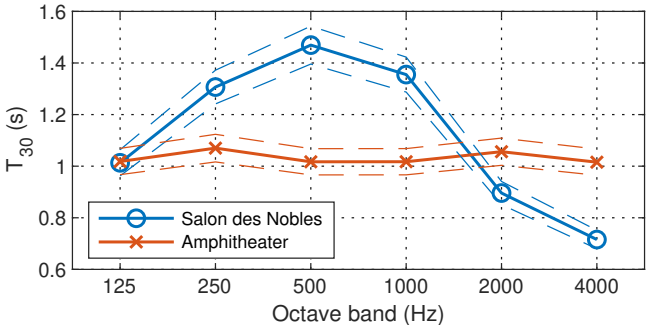
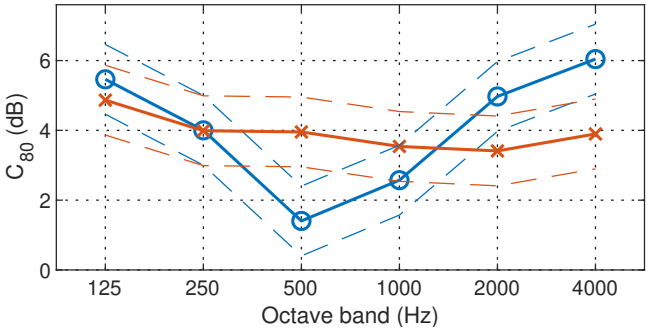


Figure 1: Plan view of 3D models of the two performance spaces. Musician positions indicated by **X**.



(a) T_{30}



(b) C_{80}

Figure 2: The measured reverberation time (T_{30}) and clarity (C_{80}) of the rooms used in this study. The dotted lines represent the range of JNDs.

3 Experimental Overview

3.1 Experimental Design

As stated earlier, the strategies used by musicians to adapt to changes in acoustics are individual and also depend on the musical content and instrument. It is therefore important that the experimental design accounts for this by employing multiple musicians playing the same pieces of music. This study was done with 10 professional musicians trained in HIP playing three different instruments: 4 violists da gamba, 3 transverse flutists, and 3 theorbists. They were compensated for participating in the study. These instruments were chosen because of the availability of solo repertoire, which is somewhat rare in Baroque music, and their suitability to French Baroque musical contexts. A set of compositions was chosen for each instrument with input from musicologists and musicians (see Table 1). Music was selected which would be appropriate in a French Baroque setting while also showcasing a variety of playing styles and tempos. The couplets for viol are from *Les Folies d'Espagne* by Marin Marais (1701), the flute selections are from Jacques Hotteterre's *L'Art de Préluder* (1719), and the selections for the theorbo were written by Robert de Visée (1716).

Each musician performed their repertoire several times, interleaved between performances of the other participants, in the two different rooms. Sessions were separated by a period of eight days and scheduled so that half of the musicians would experience the rooms in a different order than the other half. Performances were recorded with a cardioid microphone (AKG C414) positioned 1 m away, directed towards the instrument. The microphone was positioned slightly to the left of the musician to avoid reflections from the music stand. After each session, participants responded to questionnaires regarding their impression of the acoustics and its potential influence on their performance (see Section 3.2). Additionally, objective performance parameters were extracted from recordings of each performance for further analysis (see Section 3.3).

Table 1: List of musical pieces chosen for the experiment along with a few basic attributes. *Tempo* is a rough approximation of the average tempo across all performances.

Inst.	Title	Time Sig.	Tempo	# Bars
Viol	Couplet 12	3/4	♩ = 70	16
	Couplet 13	6/8	♩. = 60	16
	Couplet 18	3/4	♩ = 100	16
Flute	Animé	2/2	𝅗𝅥 = 80	14
	Gravement	4/4	♩ = 60	13
	Lentement	4/4	♩ = 100	9
Theorbo	Gigue A	3/4	♩ = 120	8
	Gigue B	3/4	♩ = 120	16

3.2 Questionnaire

The questionnaire that was administered to each musician after each session was adapted from the Stage Acoustic Quality Inventory (STAQI) [9] which is a tool designed for subjective evaluations of stage acoustics by musicians. Each of the terms were presented in a semantic differential format on a 5-point line with their extremes (i.e. dry—reverberant) labeled. Additionally, there were open-ended questions about the performers' experience including any conscious adjustments they may have made to their performance.

3.3 Music Performance Analysis

A number of low-level features were extracted from the recordings of the performances as time-series vectors. The recordings were peak-normalized to reduce inter-file loudness differences while retaining dynamic difference within recordings. The features, which are listed in Table 2, can broadly be grouped into three categories: timbre, intensity, and tempo.

While the microphone choice and position were intended to emphasize the sound of the instrument while minimizing the sound of the room, it is possible that the room response may unduly influence the extracted features. In order to investigate this, mean-centered histograms were produced for each feature of each instrument and piece, separated by room. These histograms were examined to search for common room trends that extended beyond instrument and composition. No such trend was observed.

Each of the time-series feature vectors were synchronized to a 32nd note grid via linear interpolation using the note-onset information used to calculate the note-level tempo. These synchronized data were then subject to principal component analysis (PCA) in order to reduce the dimensionality of the datset due to their high number of correlated features. Principal components with an eigenvalue below 1 were discarded. PCA was performed for each subset of the data rather than globally since it was anticipated that the adjustment strategy would be different for each musician or composition. Prior to performing PCA, each feature was normalized to have a mean of 0 and standard deviation of 1. This was then run through a logistic regression classifier, which is a simple binary classifier that uses a logistic function to model the dependent variable, in this case, the room in which the performance occurred. A number of classification schemes were used including individual musicians and pieces within each instrument, and all repetitions were grouped together. Each classification scheme utilized 10-fold cross-validation where 90% of the data were used as training data while 10% were used as testing data; this was repeated 10 times until all of the data had been used as either training data or testing data. Assuming the extracted features capture a robust picture of the performance, the classifier could serve as a tool to indicate how different one set of musical performances was from another. Of course, more in-depth analysis would be needed to explain precisely what those differences are.

4 Results

4.1 Questionnaire Results

The questionnaire results are shown in Figure 3. The terms are organized into four different category groups, which are the result of the factor analysis done by Schärer Kalkandjiev and Weinzierl [9]. The groups are: *reverberance*, *quality*, *support*, and *ease of playing*.

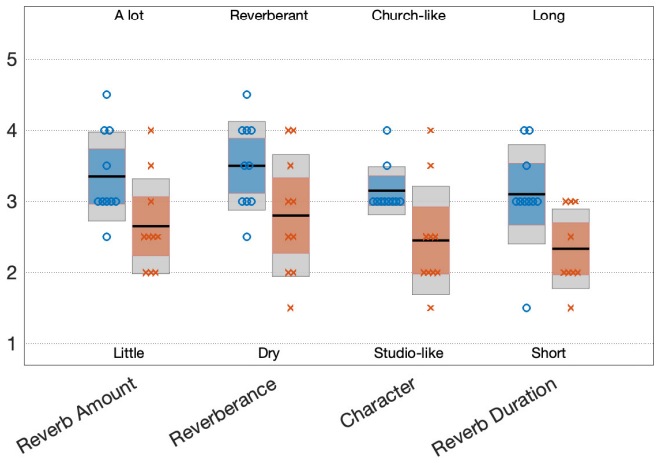
Within the "reverberance" group (Figure 3a), the responses to three out of four categories (reverb amount, character, and reverb duration) showed a significant difference between the two rooms. More specifically, the Salon des Nobles was judged to be more reverberant and to have a more "church-like" character (as opposed to "studio-like"). These judgments by the participants align with the reverberation times found in the measurements shown in Figure 2a. The ratings within the "quality" group (Figure 3b) demonstrated the clearest differences between the two rooms with four out of the five categories showing significantly higher ratings for the Salon des Nobles. The remaining category in this group, timbre, showed little difference between the ratings of the two rooms. Within the "support" group (Figure 3c), ratings for three out of five of the categories (resonance, envelopment, and room response) demonstrated a significant difference in the responses. Specifically, the Salon des Nobles was rated as more resonant, more enveloping, and more lively than the amphitheater. And finally, within the "playing" group (Figure 3d), only "ease of hearing self" showed a significant difference between the two rooms with Salon des Nobles rated as being easier to hear oneself in.

Answers to the open-ended questions revealed somewhat mixed opinions on the acoustics of the amphitheater, with about half describing the acoustics as "unflattering", "empty", and "dry", causing their performance to sound "exposed". Two participants had a fairly neutral opinion of the acoustics. Meanwhile, the remaining participants, a violist and theorbist, seemed to have a favorable opinion on the acoustics with the violist saying it had a "positive impact on my performance," and the theorbist saying the room had a "very good projection" there being "no need to force the instrument." By contrast, the acoustics of the Salon des Nobles were almost universally praised. "This space is made for playing the viol ... the acoustics are absolutely perfect," one participant wrote. Other participants described the room response as "very pleasing", "very suitable" for the music and instrument, "very pleasant" to play in, and "adapted to my instrument".

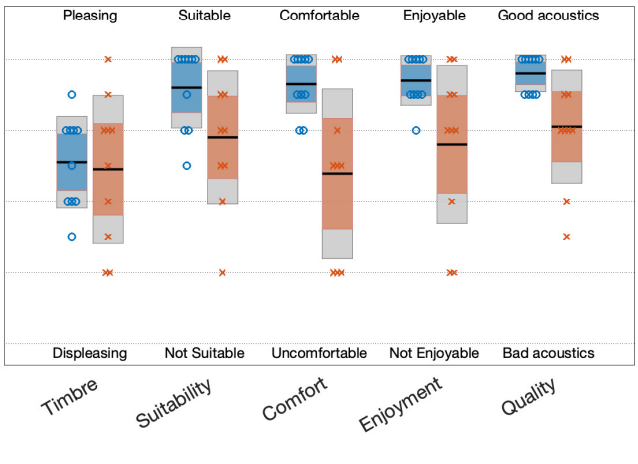
In regards to the acoustics' effect on their performance, the musicians did not describe a single adjustment strategy, however, most participants generally felt that due to the resonance and support of the acoustics in the Salon des Nobles, the musicians were more at ease, allowing them to perform better. By contrast, some described difficulties adapting to the amphitheater's lack of resonance, feeling compelled to compensate for this by playing notes longer or by adjusting their tone to compensate for the lack of support. While the question of preference between the two rooms was

Table 2: List of features extracted from recordings of performances.

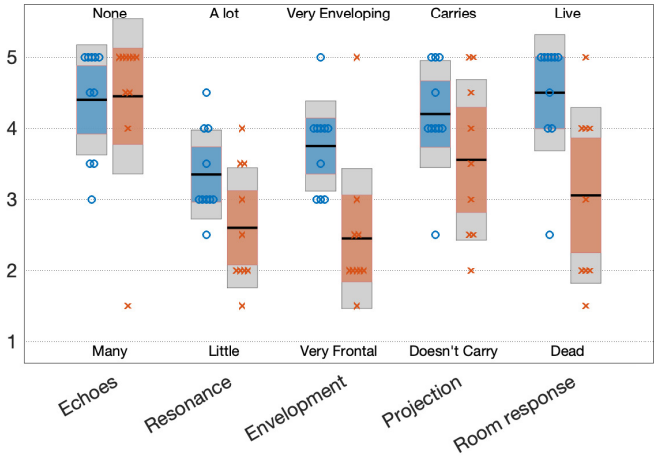
Timbre		Intensity	Tempo
Spectral Skewness	Spectral Centroid	Zwicker ISO	Note-level tempo
Spectral Kurtosis	Spectral Spread	Zwicker ITU	
Spectral Rolloff	Spectral Slope	ITU 1770	
Spectral Flux	Spectral Flatness	VU Meter	
Spectral Crest Factor	MFCCs 0-12	A-weighted RMS	
Spectral Decrease			



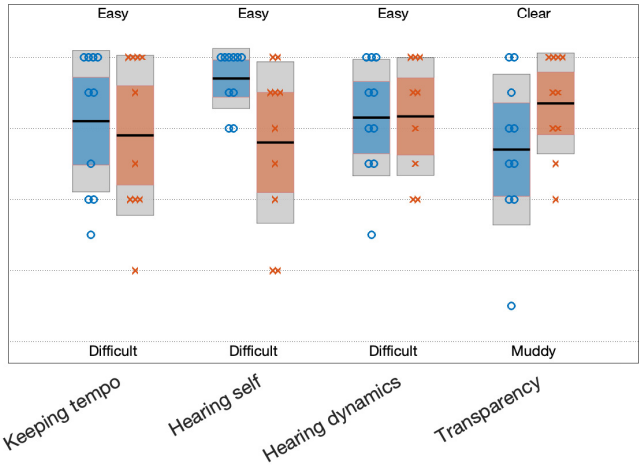
(a) Reverberance



(b) Quality



(c) Support



(d) Ease of playing

Figure 3: Mean (—), 95% confidence interval (colored area), and standard deviation (gray area) of results to the questionnaire for (○) Salon des Nobles and (×) the amphitheater.

not explicitly asked, comments from the participants as well as significantly higher ratings in most "quality" categories indicate that the Salon des Nobles was generally preferred and better suited for the given music selection.

4.2 Music Performance Analysis Results

While the results of the classifier (shown in Table 3) do not indicate precisely how performances differed from room to room, some broad trends can be observed. Overall, the classifier showed a fairly high success rate in predicting which room the performance occurred in. In every case but one the accuracy was greater than 70%, reaching greater

Table 3: Results of logistic regression classifier for each musician, instrument, and composition.

Musician	Viol		Flute		Theorbo	
1st	Couplet 12	87.08	Animé	96.97	Gigue A	80.99
	Couplet 13	90.06	Lentement	98.07	Gigue B	79.20
	Couplet 18	92.12	Gravement	99.30		
	All	88.65	All	97.68	All	79.17
2nd	Couplet 12	93.13	Animé	81.85	Gigue A	83.30
	Couplet 13	98.79	Lentement	89.60	Gigue B	79.10
	Couplet 18	94.33	Gravement	88.13		
	All	94.55	All	86.41	All	79.60
3rd	Couplet 12	90.08	Animé	96.36	Gigue A	77.44
	Couplet 13	90.81	Lentement	93.14	Gigue B	73.22
	Couplet 18	90.22	Gravement	96.77		
	All	90.42	All	94.66	All	75.44
4th	Couplet 12	87.08				
	Couplet 13	90.81				
	Couplet 18	90.22				
	All	88.65				
All	Couplet 12	74.12	Animé	82.80	Gigue A	72.39
	Couplet 13	75.34	Lentement	73.36	Gigue B	70.94
	Couplet 18	69.81	Gravement	78.79		
	All	72.00	All	78.00	All	70.87

than 99% in one case. The accuracy tended to be higher for individual musicians and pieces, supporting findings from earlier studies which showed that adaptation can be individual and also influenced by musical content. The theorbo instrument class showed the lowest results overall which can be at least partially explained by the fact that the chosen repertoire was difficult and the musicians were generally not able to perform it without any errors. The musicians were therefore less able to be consistent from one repetition to another, resulting in greater variability within a single room. Furthermore, the theorbists were likely concentrating primarily on the technical demands of the music rather than on optimizing their interpretation for the environment.

While a full accounting of each musicians' performance adjustments is out of the scope of this article, the classification scheme with the highest accuracy, flutist 1 performing *Gravement*, was chosen in order to demonstrate the explanatory power of the collected data. First, the top principal components resulting from this set of performances were examined. PCA maximizes variance, and an examination of the data separated by room can indicate whether this variance is primarily inter-class (across rooms) or intra-class (within room). In the case of this example, the top principal component, which is responsible for approximately 30% of the variance shows a significant difference between the rooms ($p < 0.001$). If the top principal components did not exhibit a meaningful difference between rooms this would be an indication that the musician's performance did not vary as a function of the room.

Next, the top loadings of this principal component were examined to see which underlying features are correlated most strongly with this principal component. In this case, the top five loadings of this principal component are the five intensity features. The top loading, with a coefficient of 0.44 is a model of loudness proposed by Eberhard Zwicker and standardized in ISO 532 [10]. Examining the individual feature curves (see Figure 4) of each of these performances reveals that the dynamic range of the flutist was greater in the amphitheater.

This participant's questionnaire responses suggest that these differences were intentional. The flutist stated that in the amphitheater their playing felt exposed and that, subsequently, they "had to project further" while in the Salon des Nobles the acoustics gave them the impression of a "full space", implying that the added projection which was necessary in the amphitheater was not necessary in the Salon des Nobles.

While this added projection certainly had an effect on the overall loudness (see Figure 4) it also likely affected the tone. Research has suggested that "lightness of tone" is a major indicator of "baroque expressiveness" [11]. In this case, the lack of forced projection in the Salon des Nobles likely allowed the flutist to maintain this lightness of tone, something which was likely more difficult in the amphitheater which required more projection.

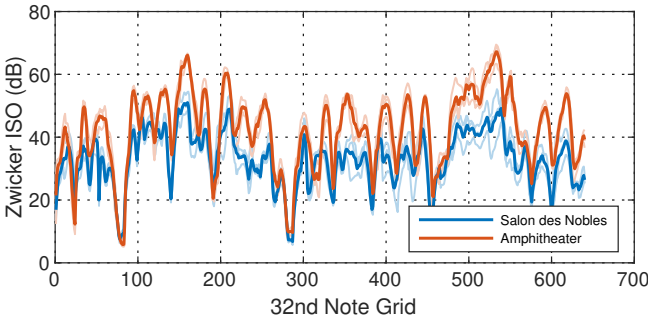


Figure 4: Synchronized feature curve of the Zwicker ISO loudness of the performance in question, flutist 1 playing *Gravement*. The thick lines show the mean of the three performances while the color of the line indicates the room.

5 Conclusion

The results of a logistic regression classifier suggest that there was generally a significant measured difference in the performances between the two rooms. The accuracy tended to be higher for individual musicians and pieces, supporting previous findings. Because the classifier does not provide insight into the qualities which make a set of performances different, a methodology was proposed which does this. An example set of performances was examined in detail and revealed an intentional strategy by the flutist to adjust to the acoustic differences in the room, a strategy which was borne out in the objective analysis of their performances. Without supporting data from the questionnaire responses, it would be difficult to understand the relevance of any measured changes as there are a number of non-acoustic influencing factors which could be responsible for any observed changes, from the natural day-to-day variations of a musician's playing to the the novelty of playing in a visually compelling and historic space such as the Château de Versailles.

Because only two performance spaces were used in this study, larger trends as a function of acoustics cannot be observed. However, the general response from the musicians is that they tended to feel less support from the acoustics of the amphitheater and that they adopted a number of strategies to compensate for these acoustical shortcomings, including projecting more. By contrast, the participants generally felt that the acoustics of the Salon des Nobles reinforced their playing, supporting the original premise of the study that the acoustics of the performance space are an important component of HIP. While the relatively high reverb time in the mid-frequencies in the Salon des Nobles is likely a part of why the musicians felt acoustic support in this room, without a larger acoustical variety presented to the participants, it is difficult to say with certainty.

Future work should investigate precisely which acoustical properties support the performance of HIP musicians. Furthermore, one aspect which is missing from this analysis framework is the perspective of the listener. A listening test could help to identify the saliency of measured features in terms of baroque HIP context and to examine whether and to what extent listeners are able to perceive a qualitative difference in the performances between the two rooms.

Acknowledgements

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