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# Evaluation of virtual acoustic stage support for musical performance

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The effects of performance space acoustics on musical performance can be evaluated most effectively by eliminating the influence of powerful non-auditory factors, such as the visual appearance of the performance space. To allow for such relatively unbiased evaluations, a virtual acoustic stage support system was set up for a live musical performance, and a single performer was asked to make blind comparisons between a variety of architectural acoustic simulations. The approach taken during this preliminary stage of the investigation was that of an interview with this performer who had substantial experience with the virtual acoustic stage support system. While results support the broad generalization that the preferred reverberation time for acoustical stage support depends upon the piece of music to be performed, it was also clear that preferences strongly depended upon performers' aural familiarity with architectural acoustic spaces in which they had considerable experience in previous performances.

# 1 Introduction

Acoustical conditions surrounding musicians affect their performance and have a direct bearing on musical expression, articulation, and tone production. A performer's image of self versus the ensemble, and also a sense of musical comfort, depend on room reflections and reverberation, which amplify instrumental sounds presenting them to the ears of musicians and listeners from all directions. The sound permeating the room gives musicians an awareness of how their sound contributes to the overall blend and the pulse of the music. The room helps them to monitor how their actions influence the sound and the flow of the music they can control with skills in sound production and musical interpretation. The room, therefore, provides a mirror for a performer's expressive efforts and helps to create a performer's artistic image of self.

It is well known that when musicians perform in a large acoustically absorptive space they play with extra force in order to hear some of their energy returning from the room. Musicians prefer smaller, narrower spaces where much of their emitted sound returns to them relatively early, but they also like rooms of larger cubic capacity where ambient sound does not become excessively loud or reverberant. An in-depth analysis of the role played by the acoustics of a performance space needs to be informed by these subjective factors, which are not addressed by psychoacoustic studies designed to relate measurable physical parameters and their associated perceptual attributes. Therefore, the current study focussed upon a detailed examination of the responses of a single performer engaged in a series of recordings for which virtual acoustic stage support was implemented over an extended period of time.

Since this virtual acoustic stage support was fully under the control of the experimenters, a number of physical parameters could be adjusted for the performer, and his overall subjective evaluation of the environmental simulation could be recorded via an interview that followed the recording sessions. This case-study approach to the complex problems faced in such an attempt is the first stage of a more comprehensive investigation into the subjective factors underlying the relative success of the implemented virtual acoustic stage support system. The methods by which the virtual acoustic simulation was manipulated were informed by the results of previous studies of musicians' responses to variation in reflections and reverberation. Particularly pertinent results on the influences of stage acoustics on musical performance are briefly reviewed in the following "Background" section of this paper.

# 2 Background

The scientific assessment of the effect of acoustical conditions on musical performance has been generally divided into studies of acoustic support for a solo musician, and studies of ability to hear other musicians in the ensemble. In the first case, the evaluation of hearing one's own sound production was normally conducted via a questionnaire asking musicians to describe subjective parameters of room acoustics and rank their relative importance, with respect to the changes in acoustical condition presented during performance. Nakayama [1] studied preferred time delay and direction of a single reflection providing feedback to the musician in anechoic chamber. While Nakayama did not find any dependence on the angle of incidence of the reflection, he found that preferred delay time of a single reflection was related to the auto-correlation-function (ACF) of the music. For faster tempo, the preferred delay was shorter (35ms), and for slower tempo it was longer (50ms). The alto-recorder soloist reported that a shorter delay time was lacking in 'support' from the reflection, and a longer delay time created an echo. Interestingly, Nakayama pointed out the phenomenon that the performer, unlike the listener, was suppressing his sensitivity to direct sound and was more eager to listen to the reflection.

Gade [2] and Meyer [3] studied the importance of early reflections and reverberation on the ability of musicians to hear themselves in rooms that were simplistically simulated in anechoic chamber. Gade [4], who studied the importance of early reflections and reverberation stated, that "hearing oneself via early reflections and reverberation seems to be highly correlated with the preference of acoustic support", and that "subjective responses of musicians correlate principally with the parameters that measure reflected energy relative to emitted energy of the direct sound". The 'Soloist Experiments' he conducted showed that total reflected energy, up to 100ms and beyond 100ms, contributed strongly to the sensation of acoustic 'Support'. In his setup, the early reflection was emitted through one loudspeaker 3 m directly above the player, and the diffuse reverberation came from 5 loudspeakers distributed on the upper hemisphere, in anechoic chamber.

Ueno, et al. [5], Gade [4], and Meyer [3] conducted separate ensemble experiments to measure musicians' ability to hear each other during real-time simulations of acoustics arranged in two anechoic chambers in which direct sound, a ceiling reflection plus reverberation were generated with loudspeakers for each duo of players. Gade's studies on orchestra platform acoustics [6] showed

that the important factor for musicians' ability to hear each other was the magnitude of early energy transmitted between the players (direct sound plus early reflections). The second effect, although statistically not significant, was that low reverberation levels were preferred. Thus the influence of reverberation was positive in the case of a soloist, but negative for the ensemble, possibly due to the increased masking of direct sound and reflections by reverberation.

Ueno, et al. [5] showed that reverberation is also largely responsible for the 'ease of ensemble' performance. Previously, early reflections were considered to be the principal factor for assuring musicians' easiness of hearing each other. During a face-to-face inquiry in anechoic chamber, musicians commented that the acoustical conditions provided by early reflections and reverberation helped them to make music ("made music performance easier"). The mid reverberation time (2.0s) was preferred, and longer reverberation (2.4s) was considered excessive and reducing their ability to hear each other. The early reflections also made it easier for them to hear their own sound, but too much early sound made it more difficult to interact in the ensemble.

# 3 Performance Case Study

The case study reported in this paper made a direct interview-style inquiry into the specific qualities of acoustic support desired by Tom Beghin, a solo keyboard performer. The supporting conditions have been created in a virtual acoustic environment that reconstructs as faithfully as possible the acoustics of an existing space, which is experienced and known to the performer. The details describing the means used to capture the acoustic response of historical spaces for interactive music performance and recording are beyond the score of this paper, and were described in Woszczyk & Martens [7]. The principles of virtual acoustic reproduction necessary to support the performer's presence in the virtual acoustic environment were described in Martens & Woszczyk [8]. These details are briefly summarized here.

The performer, seated at the instrument, was surrounded by a multitude of loudspeakers that re-transmit almost instantly the sound emitted from the keyboard and convolved with the measured room (as shown in the picture on the following page). The digital processing system employs real time convolution-based virtual acoustics rendering and uses quasi-wave field synthesis. Multichannel high-resolution impulse responses of historical rooms relevant for Haydn and his repertoire were measured in order to reconstruct detailed sound characteristics of these rooms in a laboratory for the performer/musicologist Tom Beghin to hear. Twenty-four panels of loudspeakers, each having four full-range drivers, are arranged around and above the performer in a hemispherical dome installed in a laboratory having RT60 of 0.3s. The performer interacts "live" with the recreated acoustics of a certain room and keeps full control over the interpretation, *as if* in the actual location, immersed in the ambience restored in the richest possible way. Over period of three months, Haydn's keyboard music is performed in a variety of "virtual rooms," such as the magnificent Ceremonial Room in Esterháza Castle (Hungary), Haydn's own study in his Eisenstadt home (Austria), a salon-type room in the Albertina of Vienna, or the Oxford Holywell Music Room (Europe's oldest concert hall in the UK), all of which are known to the artist. The performer rehearses in virtual space created by loudspeaker sound, and then records in the same space using the headphones. Surround sound recordings of Haydn's complete solo keyboard music made in several virtual rooms and matched to specific historical keyboard instruments will be released in a collection of 13 commercial SA-CD's in 2009. Beghin plays Haydn's music on seven different keyboards, from a 1760s clavichord to a 1798 English grand piano, and the premise of the recording is to match the type of instrument to an appropriate acoustical space, justified for each of Haydn's sonatas.

# 4 The Interview with Tom Beghin

The following interview conducted on April 4, 2008 with Tom Beghin provides his evaluation of the virtual acoustic stage support. The numbered and indented items are the questions that he was asked, and the paragraphs that follow are excerpts of his oral responses.

1) In which way was the virtual acoustic support most effective?
    a. Providing the sense of place, location?
    b. Reverberation decay as timing marker for tempo?
    c. Sustain of sound as a reference or stabilizer of pitch?
    d. Loudness enhancement in audibility of layers and voices?
    e. Increased awareness of tonal color?
    f. Increased awareness of own dynamics and overall intensity and energy?

I remember paying most attention to the scope of the music gestures I was about to produce…whether you have to make grand gestures, or whether they can remain miniature. More than dynamics or color, if I were to isolate one parameter, it was the length of notes, i.e., articulation. Just to make yourself understood to someone listening…

There's a triangle of listening: listening locally to the instrument, listening to the sound in the room, and listening to what the observer will hear. But in the virtual acoustic situation, the observer is like the privileged eavesdropper, and thus plays a less important role here than in the live hall. I am not communicating to the audience; I am allowing someone to listen up on my conversation with the room. With virtual acoustics I was much less aware of a potential listener in a hall, since I wasn't really thinking about what the sound would be like out there at a different location. It's just not a part of the virtual reality that has been created. Room acoustics becomes a crucial part of the public performance situation, and whether you want to or not, you have to deal with it. You're fighting the acoustics because the articulations that you're focused upon at close range may not be making it over to the listener's location.

You have to realize that you're working in an idealized context with virtual acoustic stage support. This acoustic support makes the distinction between local sound and environmental sound more clearly than in the live hall. Perhaps because the virtual room feels very different than the laboratory room you can see. Although visual and auditory modalities may disagree, for a musician the auditory one takes precedence.

Having the virtual acoustic stage support of a particular size and shape becomes part of my instrument, it becomes attached to it and therefore becomes inseparable from it; it defines reality. You can practice with it to optimize the articulation. You make the room as one of your tools. It makes it possible to explore new possibilities of how your performance will form the room response, and how the room response will form around your performance. Whenever the system was turned off, it was like finding yourself suddenly naked, like something private has been taken away from you. It's only when you turn it off that you realize how dependent you have become upon it. The sound has defined you and what you were presenting. The instrument, performer, and room become triune entity. There are things about timing and tone that you just wouldn't focus on otherwise.

Something I was afraid of at the beginning of the recording was that I might be distracted by the element of enjoyment that comes from listening to the reverberant tail, instead of focusing upon the performance itself. Of course, when confronted with a hall for the first time, a good player learns to adjust immediately to the acoustics, almost unconsciously. I certainly used the reverberation decay as timing marker for tempo, since the notes played on the pianoforte would decay rather rapidly without the reverb. With it, the sound blooms, the reverb bringing out the sound of the instrument. Reverberation also served as a background reference for harmony, pitch, and voices. Singers use reverb to allow them to stay in tune with what they have just sung… The attached reverberation becomes a stabilizer of pitch. In 18$^{th}$ century language, you would say that the reverberation aids in judging attacks and releases, of dissonance and consonance that provides tension and release (Note: Here a follow-up questions was asked: Were you aware of the symbiosis between virtual rooms and certain instruments?).

The large-scale picture is that Haydn was such a rhetorical perfectionist… There's a level of clarity there since the instrument was a delivery agent of his musical statement. It's a social-cultural thing: You play a clavichord under certain circumstances, in certain rooms. He made it possible for those who could not afford a larger instrument still to play… but in a smaller room. In fact, for the clavichord a low ceiling was required for getting a proper sound. Too high a ceiling would make it impossible to hear the detail. In contrast, for the harpsichord or the piano it's very nice to have a taller room. Bach also enjoyed being alone with his clavichord in a small room. In virtual rooms I felt very much the appropriateness of the musical choices we have made concerning matching rooms and instruments.

2) Was the virtual acoustic support similar to the actual acoustic support you remember?

In terms of recognizing acoustics, to me, it was convincing. You have the immediate feedback of the instrument. You have a sound that's immediately received from the

instrument that is separated from the response of the room. In the real space, you are more focused upon what happens in the room, and less upon what is immediately received from the instrument.

3) What was the same and what was different between real and virtual acoustics? What do you listen to in virtual acoustics? Is it different from what you focus on in real acoustics?

I have a very vivid memory of having played in the real space, and so I come into the space with a clear expectation of what it should sound like. And that's the memory that I want to replicate. Some may say that the reverb is too artificial. How do I respond to this criticism? Even if it's artificial, it's essential. Regardless of whether an expert would say that the reverb sounds artificial, the reverb has become real by becoming part of my performance. Taking it away would take away part of the artistry. I'm not a judge; I'm an accomplice.

If I'm performing in a reduced version of the room, then you will get a reduced version of my performance. I have to know that in the eventual result I will get what I was thinking I would get. Because I am "Playing the Room" just as much as I am playing the instrument; the room is attached to my instrument, they are one and respond together.

4) Was there a noticeable latency difference between the two types? Was the virtual room as responsive as you would expect it to be in a real room?

It didn't cause any delay on my part. If anything, if I compare my performance in the Holywell Music Hall, I took more time to listen for the room response in virtual space, and so I took more time in the pauses and the tempo was slightly slower.

5) What was the difference between headphone and loudspeaker monitoring?

With the loudspeakers there's a big difference in level… The difference in level is too large between the immediate response of the instrument and the response of the room. You were afraid you were waiting too long. You didn't want the gaps to kill the flow. It takes longer before the sounds go out into the room with the loudspeaker system, and you must wait for the reverberant sound to return to you.

This is also a big difference between rendering rooms with headphones and loudspeaker arrays. You cannot share your impression of music when monitoring with headphones. The best experience for me was with the small audience in the shared virtual environment created by the dome of loudspeakers. The loudspeaker dome really provides the best virtual acoustics for performance, since you share the environment with the listener. It energizes you.

Normally, when you record in a studio you hear something drastically different in the control room, but with the headphone system there was much less need to spend time learning to compensate for the difference between control room acoustics and the virtual acoustic reproduction that was to be created for the result. It's good that we chose to do the recording using headphones, since with loudspeakers we would have been committed to the balance of instrument and room, and with headphones we were able to revise the balance without a compromise in the re-recording process.

6) Is the lack of visual presence of the room a detriment or benefit? (Would you like to see the room in which you perform?)

For my purpose, I didn't need to see the rooms. This was of course in part because I had seen the rooms and I knew them. For me, seeing the large-screen projection of visual images of room was more of a distraction than any help. In my work, I always say that the eyes are very important to articulate what I do musically. This is why I like to face the audience to articulate my experience of the music using the eyes. They are an expressive asset of the performer. With the headphones, the visual images are a greater distraction, than with the loudspeakers.

7) What type of adjustability would you consider beneficial or necessary to arrive at the optimum presence and balance of the virtual sound field around you?

If I had the option to adjust the virtual environment itself, I would try for better balance of sound field around me. I had to be placed off-center in the dome of loudspeakers, and therefore I was in a pocket that was not as spatially diffuse as it could have been. It would sound better to me if I could be in the center, instead of having the instrument in the center (which was required for optimal placement of the microphones for recording). I would also try to adjust the tone color, the balance between treble and bass.

8) Is variety in acoustic simulations desirable, and how best to harness the variety to arrive at the optimal stage support solution?

Given the choice between two types of control over the reverb - a switch between different reverb scenarios or categories of reverberation, or more continuous control, the latter would be an advantage. The priority would be to compare between different rooms, and perhaps different listening positions within those rooms. I would very much like to be able to walk through the room, listening to how the reverb changes. It would help a great deal to be able to look at a visual display that would let me know where in the room I was walking.

9) How would virtual stage support need to be structured if two or three instrumentalists or vocalists were to share it? What would be different from the case having only one performer?

If you're talking about a trio situation – e.g., a keyboard with a cello and a violin – there's no problem with balance when the performers are all standing close together. Since the performers would all be sharing the same ambience, they likely would have an easier time playing together as they would communicate their instrument sounds directly.

10) Would the presence of the orchestra or accompaniment enhance the sense of stage support in virtual acoustics?

As a pedagogical thing, I'm sure many musicians would like to try this. But something would be missing, since something new always comes out of the interaction between performers. This is particularly important in creating a shared sense of time that is lost when you attempt to play along with a pre-recorded performance (in which you must regard the timing in the recording as the correct timing). It's more like trying to play with a metronome. If you know you've got only one or two rehearsals, then it might be of real value; however, if you have a chance to spend more rehearsal time together, the interaction between performers will no doubt prove to be more beneficial and satisfying.

11) How important is having the sensation of sound being above you?

It is very important, isn't it? I am constantly aware of what is happening up there. It is particularly important to me, because I play mostly with the lid open (which is historically what was done). I want to be able to get a complete picture of the space developing up above me. Then, in the ensemble situation, looking up helps me to listen into the diffuse blend above the sounds of other instruments, to gain perspective.

It's nice to have the height dimension in the speaker dome, because you're immersed in it. But I like to be able to face the audience so that I can see their faces, rather than setting up sideways. Here, if you remove the lid, you can set up a communication with the audience. By having the performer facing them, the audience can see the emotions on the face of the performer.

Also, facing the performers allows them to hear the pitches as arrayed spatially from left to right in front of the audience. Modern instruments have crossed strings that are arranged to create the impression that all pitches arrive from the same location. But the clavichord presents the low pitches on the right and the high pitches on the left.

# 5 Conclusion

This keyboard musician's experience of rehearsing and performing in virtual acoustics shows a remarkable level of acceptance of this technology. Impulse responses containing a blend of early reflections and reverberation representing the likely positions of source and receiver within room boundaries generate a good approximation of the environment expected by a musician. Low-latency convolution producing 24 channels of decorrelated room response seems to satisfy the requirement for real-time responsiveness, as long as the processing delay is within 10 ms, and the rendered rooms are not exceedingly small. The important value of reverberation providing acoustic support for a solo keyboard performer was acknowledged both for the player and for the audience attending the performance in a virtual acoustic stage. The performer also stressed the importance of a uniform sound distribution around and above. In conclusion, this study of virtual acoustic stage support used for rehearsal and recording conducted over a long period of time, further validates the results reported in the earlier studies with musicians performing in anechoic chambers where spatial reconstruction of real spaces was limited, and likely incomplete.

Future work will include an investigation of virtual acoustic stage support for opera singers in rehearsal spaces (typically much smaller than performance venues). Already three young professional opera singers have been interviewed to gauge the potential value of virtual acoustic stage support to their training. As young professionals with relatively little stage experience, the singers were all much more accustomed to singing in rehearsal spaces than performance venues, and those interviewed unanimously reported having had difficulties adjusting to the acoustical conditions of performance venues. Rehearsing in virtual stage acoustics can aid them in acclimatizing to stage acoustic conditions, better preparing them for performance.

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