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Using lab-based and non-lab-based audio-visual virtual reality experiments for auditorium seat preference studies

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ABSTRACT
Seat preference in a concert hall is affected by both auditory and visual conditions. While traditional concert hall preference studies have mainly focused on auditory preference, visual preference has drawn more recent attention, as the importance of audio-visual interaction has been emphasized. For combined audio-visual studies, using virtual reality simulation with head-tracked audio provides more flexibility and control compared to in-situ studies, while maintaining most spatial information that would be lost in experiments merely using photos and/or binaural recordings. Furthermore, with the popularization of head-mounted virtual reality devices and the ease of online file transfer, the experiments need not be limited to laboratories. This paper provides an overview of techniques used for such experiments and briefly discusses relevant findings.

1 INTRODUCTION
Going to a concert is a multi-sensory experience, and the two most important senses for a live classical concert are hearing and vision. Both visual and auditory perception contribute to the overall preference, or perceived quality, of a music concert, especially when comparing between different seats in a concert hall (Jeon et al., 2008; Kawase, 2013; Sato et al., 2012). On the other hand, visual perception and auditory perception have been found to have mutual influence in various ways (Stein & Meredith, 1993), including in the context of music auditoria (Barron, 1988; Calcagno et al., 2012; Maempel & Jentsch, 2013; Valente & Braasch, 2010; Zahorik, 2001).

Virtual reality, being a relatively new technology, has been gradually integrated into audio-visual auditorium research experiments (Larsson et al., 2001; Maempel & Jentsch, 2013; Postma & Katz, 2017). Compared to using static 2D photographs or renders for visual stimuli display, virtual reality display has the advantage of retaining much more spatial information in the visual stimuli, which is especially useful when the studied attributes include spatial attributes such as distance or room size. Compared to *in situ* experiments, virtual reality allows more freedom and control over the stimuli presented, and makes orthogonal factorial design possible. Another advantage of virtual reality experiments newly discovered and utilized in the current COVID-19 situation is the flexibility of experiment locations. As virtual reality devices become more affordable and popular among the general public, it is possible for experiment participants to take part in experiments without being personally present at the research institutes. This opens up myriad possibilities for future studies in audio-visual perception research.

This paper summarizes three experiments that used virtual reality in studying seat preference. The first one investigated the independent influence of visual distance, lateral angle from centreline, vertical angle from stage plane, and audio gain level; the second one investigated the preference at different seats in two variations of a small concert hall with matching and unmatching visual and auditory stimuli; the third one investigated the visual preference of twelve different variations of the same concert hall. The first one was completely non-lab-based, the third one was completely lab-based, and the second one was a mixture of both.

2 VISUAL AND AUDITORY STIMULI
In all the experiments, head-mounted virtual reality display (VR headset) was used for visual stimuli, and head-tracked digital audio playback (headphones) for auditory stimuli (except for the third experiment).

3D models of music auditoria were built in the software Rhinoceros (Robert McNeel & Associates), then rendered in the software Unity (Unity Technologies) with realistic lighting and material settings. The virtual reality experiences were enabled using SteamVR plugin (Valve Corporation) for Unity, and displayed with VR headsets. All user interactions for the participants, including subjective evaluation for the experiment stimuli, were presented in VR, and operated by the participants using VR controllers.

For the auditory stimuli, in the first experiment, in order to control all other variables apart from the gain, the auditory stimuli were stereophonic concert recordings with the original reverberation mixed down to monophonic.

To add realism, 30% of the sound was localized to match the relative direction of the stage. In the second experiment, Ambisonic impulse responses for each individual source were simulated in the software ODEON (Odeon A/S) and convolved with anechoic recordings. The decoding of the Ambisonic signal to binaural was done in Unity with Resonance Audio plugin (Google). The absolute sound pressure levels for the lab-based experiments were calibrated using a Neumann KU 100 Dummy Head system.

3 USER INTERACTION

Because the researchers could not provide real-time assistance for the non-lab-based participants, all operations were designed to be easily conducted by the participants. After signing up for the experiments, the non-lab-based participants received a standalone executable file along with a PDF instruction through email. They opened the file on their own computer with their own VR devices, input the participant ID they were given, and evaluated each stimulus with their VR hand controllers. They also chose their own order to experience the stimuli (including different seats and auditoria) and could return to the same stimulus multiple times. They also had the option to do the experiment in multiple sessions, between which they could save the progress and exit the program. When they were satisfied with their evaluation, they exported the results into a file and sent it to the researchers through email. The lab-based participants went through the same procedure, except that they needed to prearrange a time to participate in the laboratory using the laboratory VR devices with the researcher’s assistance.

In order to make the operations more natural for the participants, some techniques from game design were used, including tactile feedback on the controllers, visual feedback in the rendering, and a centralized menu in which the participants accessed most of the functions. As a stimulation for participation, there was also an extra “reward level” that the participants could access once the experiment was complete, which was designed as an interactive experience with the concert hall and orchestra models used in the experiments.

4 RESULTS

The results showed no significant difference between lab-based and non-lab-based participants, and no significant difference between participants using different brands of VR headsets. In the first experiment, all investigated factors affected seat preference, and a prediction equation was derived. The equation was verified in the second and third experiment, with new findings that the auditorium dimensions, auditorium design, and detailed acoustic parameters all influence the judgement of seat preference.

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