Analysis of the musicians' preferences for the parameters of first sound reflections in rooms

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Abstract. To play music, musicians need to hear themselves well. In some cases, direct sound generated by the instrument is radiated equally in the direction of the performer as well as towards the listeners. However, for many instruments reflections from walls, ceiling or floor are essential for a musician to hear himself easily. Especially important are the proper delay and the amplitude of the sound first reflection. These parameters are essential to let the musicians create the best sound they can, and allow them sense properly the space where they are playing. The goal of the project was to define the ranges of the delay and the amplitude of the first reflection of sounds generated by musicians connected with specified player's impressions. Obtained values were compared with the preferences of the listeners defined earlier by different researchers.

Keywords. Amplitude, delay, first reflection of sound, musician, stage

1 Introduction

Playing a musical instrument or singing is possible only with a feedback loop. Players need to control the sound very precisely - the better they can hear themselves, the better the sound produced for the listeners is.

Usually, while playing an acoustic instrument, the musicians can hear themselves better or worse. It depends mainly on the musical instrument's directional characteristics (how the produced sound is distributed in each direction). Suppose playing in an open space (without walls and ceiling) or in an anechoic chamber, where no sound is reflected from the walls. In that cases, a musician could only hear a direct sound from the instrument without any reflections from the room. Even for singers, who have relatively small distance from the sound source to ears, such conditions are not preferable and lead to excessive vocal strain and problems with intonation precision [1], [2]. For directional instruments such conditions are much worse. It should be noted that directional characteristics depend on the frequency.

To improve the perception of the sound generated by the musicians themselves, it is essential to give them some feedback. According to the time of arrival, the feedback in room acoustics can be divided into two parts: first reflections and so-called reverberation tail. First reflections come right after the direct sound. There are only a few of them, so the listener can distinguish direction, delay and amplitude of one or more of them. In the second part of the room's response, there are a lot of sound reflections coming to the listener from almost everywhere. They are mixed in diminishing reverberant sound called a reverberant tail, which is responsible for the impression of the room size and sound immersion.

The first part of the room response lets listeners feel the distance from the sound source and it is responsible for the clearness of the sound. For many years, initial time delay gap (ITDG, time between direct sound and first reflection) and connected with it subjective "intimacy" were considered the most important parameters in the room acoustics [3]. Beranek proposed 25 ms as a maximum value of ITDG. Also, Ando considered this parameter as one of the four most important in room acoustics [4], connecting its preferred value with the speed of the music being played. Later, many authors suggested that early reflections, depending on their amplitude and delay, could be a source of different subjective impressions. Barron [5] proposed laboratory subjective evaluation of boundary values for delay and amplitude of lateral single reflection that give desirable (like spatial impression) and undesirable (like image shift, disturbance) effects (Fig. 1). On Barron's graph, Beranek's 25 ms limit gives spatial impression, which is positive, but leads to tone coloration and image shift for very small delay (below 5 ms).

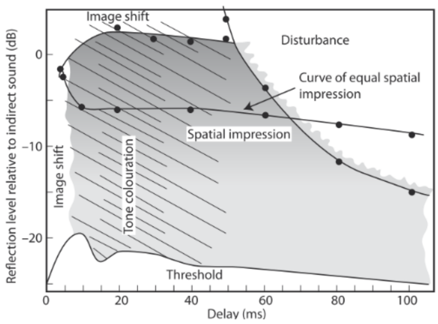

Fig. 1. Subjective effects with music of a single reflection perceived by a listener on the audience [5].

For musicians, selective reflections in the first part of the room response are crucial to create good music. Only a small time gap between direct and reflected sound lets them play even fast passages on time. A proper amplitude and the time of arrival of reflections improve especially ensemble playing.

For non-amplified music instruments, additional feedback for the musicians is provided only by the reflections of sound waves from walls, ceiling and other surfaces. A delay between a direct sound and first reflections depends on a distance, which the sound has to travel from the sound source to a reflecting plate and back to the receiver. The amplitude depends on the size and the geometry of a reflecting plate, its material and a distance from the sound source. While the main body of the hall should provide adequate reflections for the audience, the stage area should be designed primarily for the musicians. Designing a stage of a concert hall or an auditorium, the acoustician should provide a sufficient number of surfaces reflecting sound to the audience, as well as to the musicians. The most effective surface for providing early reflections on the stage is the ceiling [6]. In high halls, it is necessary to use single reflector of array of smaller reflectors to shorten the delay of the reflections. An array of reflectors can be designed to distribute sound in a proper direction, delay and amplitude depending on their position, shape and size [7]. If the sound generated by a musicians is reinforced electronically, the feedback is provided by loudspeakers or in-ear headphones [8]. Sound engineers takes care about delay, amplitude and reverb added to the sound obtained from the instrument, to let the musicians work in comfortable conditions.

The aim of the study was to specify in details the requirements of the musicians, connected with the amplitude and the delay of the first reflections. Obtained values could be used by the acousticians in designing reflecting walls around the stage as well as by the sound engineers in developing proper sound for in-ear or monitor loudspeaker feedback for the musicians.

2 Methodology

Barron's results presented in Fig. 3 were a basis for the analysis of the areas of different musician's impressions on the amplitude and the delay of the first reflection. In order to apply a listener analyzed by Barron to a musician, the sound played by Barron was changed to the sound generated in a real time by the musicians themselves during the test. While the direct sound was heard by a musician directly from their instrument, "first reflection" was played though the open headphones, which do not disturb the direct sound perceived by the musician's ears. All tests were conducted in an anechoic chamber. The musicians rated total sound – natural direct sound coming from the instrument they played, as well as a delayed and amplified feedback sound from the headphones, as an imitation of the first reflection from surfaces of the room. During the test, the musicians had to rate the sound according to five criteria:

- audibility of the first reflection – if the signal played through the headphones is audible by the musician,
- image shift – if the virtual sound source as a combination of direct and feedback sound is shifted to another place,
- disturbance, echo – if the feedback disturbs the musician, can be heard as a separate sound, not consistent to the direct sound,
- tone coloration – if the tone of the instrument's sound is unnatural or incomplete as a result of amplification and suppression of some harmonics of complex sounds
- space impression – if the virtual sound source is in the right place, being simultaneously wide and/or immersive.

The musicians were asked to rate only one criterion at a time. Apart from playing and listening the instrument and the feedback, the musician could adjust one of the parameters of the feedback (amplitude or delay). Playing whatever they wanted, the musicians were asked to find the limit of the analyzed parameter audibility. For example, for a hard-coded first reflection delay, the musician adjusted the amplitude of the sound heard in the headphones to the value for which the sound was almost inaudible. The value obtained in this way was then treated as the limit for the first reflection audibility for a given delay. The tests were repeated for different delays and different musicians. An adjustment was made at the same time as playing the music, a foot pedal connected to a proper parameter of the VST plug-in was provided to the musician (Fig. 2). The ranges of the parameters and hard-coded values basing on Fig. 1. can be found in the TABLE 1.

TABLE 1. THE PARAMETERS REGULATED IN THE FIRST REFLECTION ANALYSIS

Subjective parameter	**Hard-coded parameter**	**Hard-coded parameter values**	**Adjusted parameter**
First reflection audibility	delay	100ms, 60ms, 40ms, 20ms	level
Echo, Disturbance	delay	100ms, 80ms, 60ms, 40ms	level
Sound source localization 1	delay	60ms, 40ms, 20ms, 10ms	level
Sound source localization 2	level	0dB, -5dB, -10dB	delay
Tone coloration	level	-2,5dB	delay
Space impression	delay	60ms, 40ms, 20ms	level

All the musicians taking part in the measurement had normal hearing which was confirmed by the audiological tests.

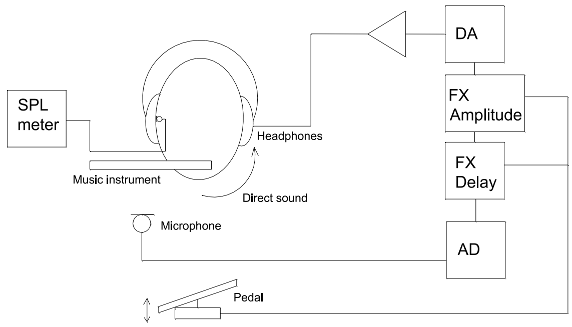

Fig. 2. Measurement stand. Sound is acquired by a microphone and processed in VST plugins. One of the parameters (amplitude or delay) is controlled while playing music with a foot pedal.

The main phase described above was preceded by two initial phases. At the beginning, the calibration of the feedback sound was made. Using in-ear microphones, sound pressure level (SPL) of the music phrase in each ear was measured. Amplification of the headphones was set to 0.0 dB when a direct and a headphones-played sound gave the same SPL. In the second phase, musicians were trained to differentiate different subjective parameters of the sound. While playing the music, the musician was instructed what kind of sound should be perceived at the moment (e.g. with echo) and the headphones were fed with the sound delayed and amplified in the way that the impression called before was very clear. The tests were performed for six musicians.

3 Results

Obtained results, averaged for all the musicians, are presented in Fig. 3. Areas connected with the subjective impressions were highlighted. The most important change of a musicians' impression (Fig. 3) comparing to the listeners' results (Fig. 1) is the Image Shift area increase.

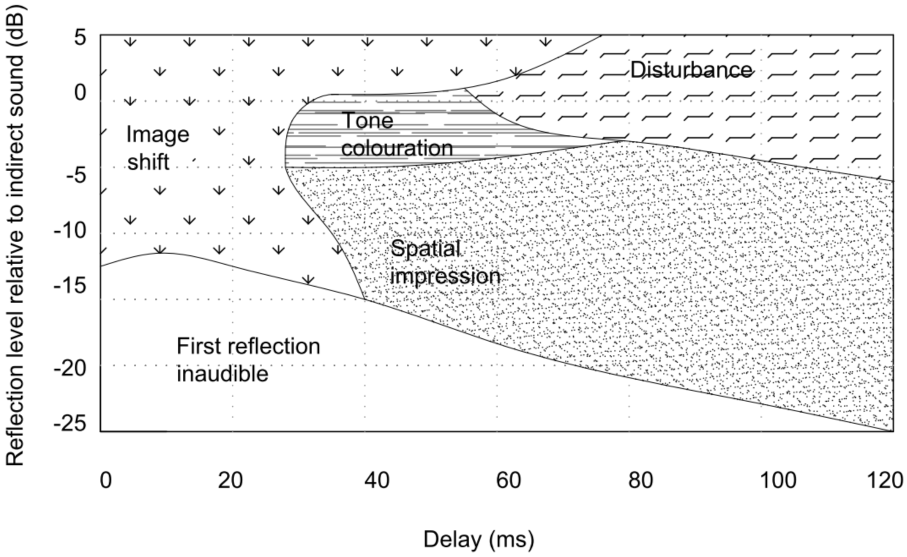

Fig. 3. Subjective impression of musicians for different delay and amplitude of sound's first reflection

According to Barron's listeners, the virtual sound source moves from the real sound source position only if the first reflection is 2 dB louder than the direct sound or if it is delayed by less than ca. 8 ms. For the musicians, however, the Image Shift was perceived even for the reflection 12 dB quieter and delayed as much as 30 ms. Normally, the first reflection of such values is treated as giving space impression, while the musicians taking part in the experiment found the sound spatial when the delay was set to values above 35 ms. While Barron's listeners could perceive first reflection even if it was ca. 20 dB quieter than the direct sound, musicians set the limit value at 12 dB with the maximum for 20 ms delay. The tone coloration area was reduced by the spatial impression. According to the musicians, the feedback with the amplitude from 0 to – 5 dB according to the direct sound could lead to the tone coloration (delay between 40 and 70 ms), while quieter sounds gave spatial impression.

4 Conclusions

The analysis presented in the paper describes subjective impressions of the musicians on the different parameters of the feedback for the sound they produce. Apart from the direct sound, the musicians could hear the reflections of sound from the room where they played, which leads to different impressions, depending mainly on the delay and the amplitude of the first reflections. Subjective analysis was made using interactive measurement stand, where musicians were able to play music and adjust one of electronically controlled feedback parameter at the same time. Obtained limit values of areas connected with specified impressions (image shift, tone coloration etc.) are slightly different from the ones which can be found in the literature. Musicians perceive the change of the virtual sound source position in much wider range of first reflection delay. On the other hand, tone coloration is perceived less frequently – only for loud, delayed sound. If delayed sound is reduced by 5 dB, the musicians perceive the sound positively, as spatial.

The differences between the musicians analyzed in the paper and the listeners' impressions known from the literature results from different listening conditions for the both groups. A very close distance from the instrument to the musician's ears masks the room reflections. What is more, apart from a precise definition and a training phase, the listeners could name some impressions differently, which could be a reason of the changes between image shift and spatial impression.

As a further step, the measurement should be repeated with other musicians and with more starting points for specific impressions resulting in more precise areas.

Acknowledgments

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