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Investigations of Multi-channel Auralization Technique for Various Orchestra Arrangements, with Phase-Shifted String Sections

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INVESTIGATIONS OF MULTI-CHANNEL AURALIZATION TECHNIQUE FOR VARIOUS ORCHESTRA CONFIGURATIONS, WITH PHASE-SHIFTED STRING SECTIONS

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ABSTRACT
An orchestra can be simulated in room acoustics computer modelling using a variety of methods, ranging from a single omni-directional source to individual sources of all instruments. This study utilizes the method of individual sources for each instrument, but with reduced source representation for the string sections. The anechoic recordings used in this investigation are five-channel recordings, which capture the source directivity of the individual instruments. For each string section, the individual anechoic recordings were phase shifted several times, up to 23 ms, and combined to create a single recording for use in the simulations. An orchestra was simulated in three different configurations – American (first and second violins adjacent), European (first and second separated) and a completely random arrangement. For each configuration, auralizations were created using a single channel and five-channel representation for each instrument or section and for both a Brahms and Mozart symphony. Listening tests were conducted to determine if subjects could detect differences in auralizations created using the three different orchestra configurations. Preliminary results from this pilot study show subjects can detect differences between some of the configurations, particularly the American versus Random, and European versus Random, with more of an effect with Brahms than with Mozart.

INTRODUCTION
The experience of listening to a live orchestra is a function of many variables, including the musicians, room acoustics and the ambience. Another key component is the conductor and his/her choice of orchestra configuration, whether it be a traditional American configuration, with the first and second violins adjacent to each other, or a traditional European configuration, with the first and second violins split, or any other number of arrangements. The tonal characteristics of the orchestra vary considerably for the different configurations. The tonal balance in the orchestra changes dramatically by repositioning the second violins to the right of the conductor and moving the lower strings towards the centre [1,2]. The goal of this current work is to determine if multi-channel auralizations of an orchestra in various configurations sound different subjectively, as the sound of an actual orchestra in different configurations would.

BACKGROUND INFORMATION
The sound of an orchestra is a function of the instrument sections' placement on stage, the interaction within the sections, and the instruments' directivities. Meyer has done extensive studies of individual instruments' directivities and also the effects of different orchestra configurations [1,2]. In general, instruments are fairly omni-directional at frequencies below 500 Hz and tend to become more directional as the frequency increases. The typical American orchestra configuration, starting from the conductor's left, is the first and second violins, violas, celli and double basses, whereas the typical European configuration has the first violins, double basses, celli, violas and second violins surrounding the conductor. The principal advantage to the former configuration is that there is good blending between the violin sections, as it is easier for the musicians to hear each other. The primary disadvantage is there is a tonal imbalance, with all of the high strings on one side of the stage and the lows on the other. With the European configuration, there is a much better tonal balance, since the high strings are split and the first violins sound even brighter being separated from the second violins. The obvious disadvantage is the added difficulty for the musicians to hear each other and play in synchronization.

The effects of incorporating accurate source directivities into room acoustics computer modelling has been studied in some detail [3,4]. These studies have shown that the distribution of some room acoustics parameters in a hall, such as sound pressure level and clarity, will vary significantly when different source directivities are implemented into the model. Previous work has focused on using the measured directivities from Meyer and incorporating them into room acoustics computer models. More recently, the method of multi-channel auralizations has been explored [5]. To create an auralization with the previous method, a binaural room impulse response (BRIR) is calculated using the source directivity and then convolved with a single channel anechoic recording of a short melody from a solo instrumentalist. The multi-channel method involves splitting an omni-directional source into the number of anechoic channels recorded. The BRIR is calculated for each "channel" source and then convolved with the appropriate anechoic recording. The auralizations are then mixed together to create one final multi-channel auralization. This method has been shown to produce improved auralizations from the previous method. Otondo and Rindel found an improvement in the naturalness of timbre [5], while Wang and Vigeant found an increased sense of realism as the number of channels was increased [6].

EXPERIMENTAL METHOD

Five channel anechoic recordings of every instrumental part in Brahms' Symphony No. 4, 3rd movement and Mozart's Symphony No. 40, G minor, 1st movement were obtained by researchers at the Danish Technical University (DTU). The recordings were made with omni-directional microphones positioned approximately two meters from the instrumentalist, as shown in Figs. 1 and 2. These recordings were then edited into short segments for each instrumental section for all five channels. The instrumentalists listened to the entire piece over headphones and watched a recorded view of the conductor on a video screen to ensure synchronization between the recordings.

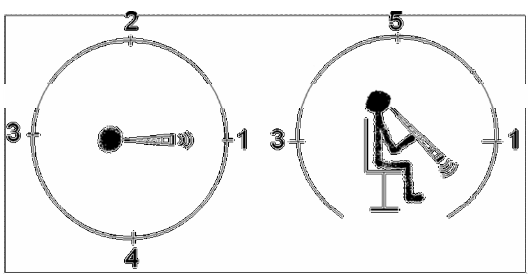

Figure 1: Multi-channel anechoic recording configuration (adapted from [5]), where position 1 is the "front".

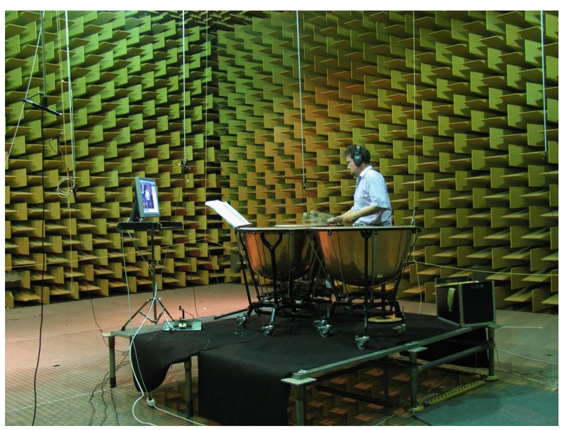

Figure 2: Multi-channel anechoic recording of timpanist. (Photo courtesy of Prof. J.H. Rindel.)

Single and multi-channel orchestra auralizations were created using these recordings in a special multichannel version of Odeon v8.5, within a calibrated model of the Musikvereinssaal (Fig. 3). For the single channel case, a BRIR was calculated for each individual point source as shown in the figures and then the front channel recording of each corresponding instrument was convolved with the BRIR. All of the auralizations were then combined to create a final orchestra auralization. This procedure was repeated for the multi-channel case, where each instrument was represented by five BRIRs and five anechoic recordings. Each of the five BRIRs was computed for each instrument/section, the corresponding channel recordings were convolved and then all of the auralizations were combined together to again create a final orchestra auralization.

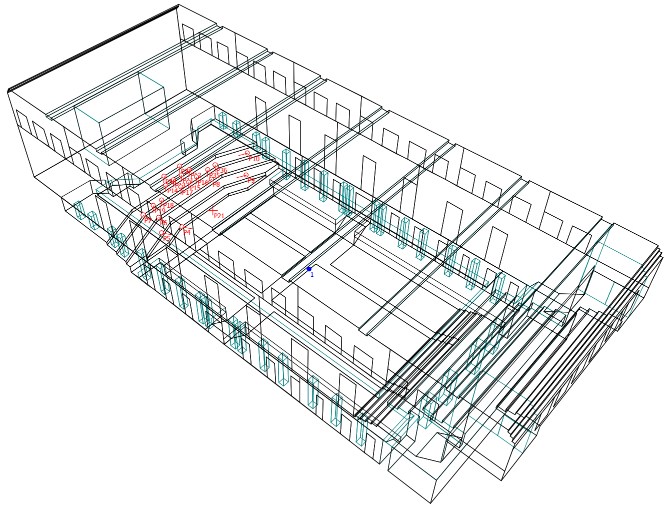

Figure 3: Odeon model of Musikvereinssaal, with multiple sources on the stage and the receiver about one-third of the way back in the audience.

The string sections were represented by one or two single sources as shown in Figs. 4-6, as individual recordings of every string player were not obtained. In a previous study [7], the sound power levels of the individual instrument representations were increased to represent the appropriate number of instruments. For instance, for the Brahms symphony simulation, there were 16 first violins represented by two individual sources. Each sources' sound power level was adjusted to represent eight sources. In the current study, the individual string melodies were phase shifted to represent multiple instruments in an effort to create a chorus effect. The phase shifts for the string sections for the Mozart orchestra are shown in Table I. Similar phase shifts were used for the Brahms orchestra.

Table I: Phase shifts used for Mozart symphony

Part	No. of Instruments	No. of Delays	Delay1 (ms)	Delay2 (ms)	Delay3 (ms)	Delay4 (ms)	Delay5 (ms)	Delay6 (ms)	Delay7 (ms)	
1st Violin 1	**5**	**4**	7	11	13	19				+ original
1st Violin 2	**5**	**4**	7	11	13	19				+ original
2nd Violin	**8**	**7**	3	7	11	13	17	19	23	+ original
Viola	**6**	**5**	3	11	13	19	23			+ original
Cello	**4**	**3**	7	13	17					+ original
Double Bass	**3**	**2**	7	11						+ original
Solo Instrument	**1**	**0**	11.63							

The final variable was to create auralizations for three different orchestra configurations: 1) American, 2) European and 3) Random, as shown in Figs. 4-6, respectively. The American configuration has the two violin sections grouped together, while in the European arrangement the violin sections are separated. The random configuration was not based on any specific unusual arrangement. The goal was to mix instrument types as much as possible and disperse them around the stage. Sections of the same instrument were kept in proximity to each other, as shown for example with the clarinets in the front row.

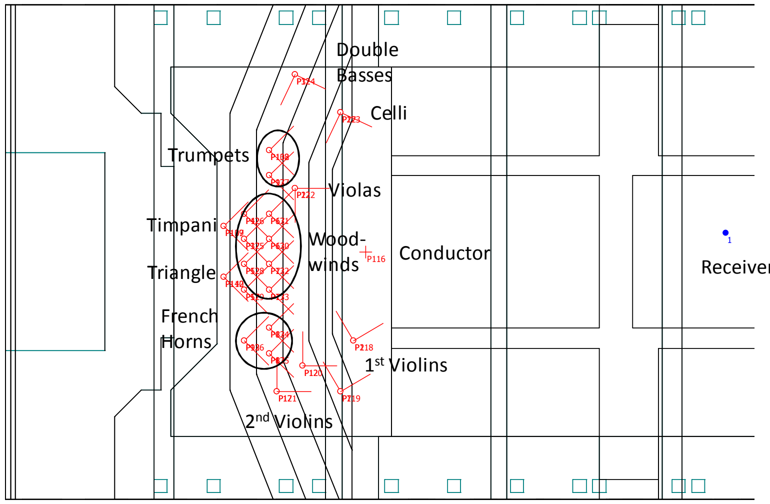

Figure 4: American Brahms orchestra configuration.

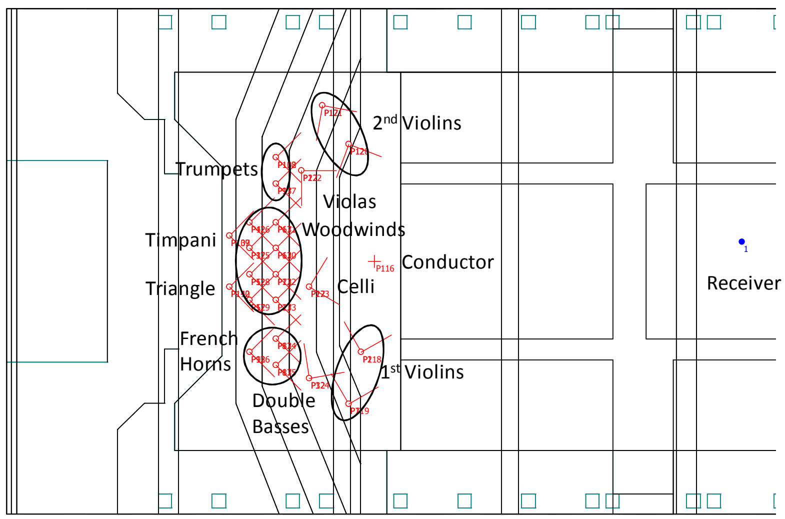

Figure 5: European Brahms orchestra configuration.

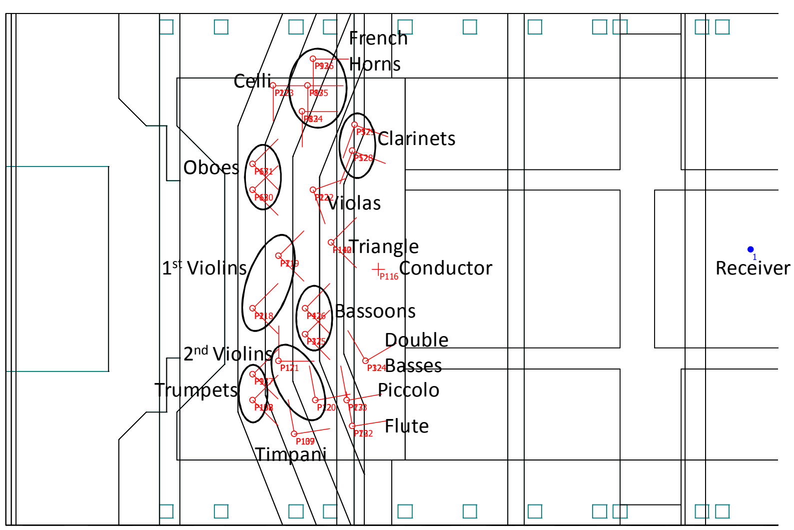

Figure 6: Random Brahms orchestra configuration.

The subjective testing procedure used is the AB/X method, as described in Leventhal [8]. Subjects were presented a series of three auralizations, where A and B would be different orchestra configurations and X would be either A or B. The task was to determine which of the first two tracks sounded identical to the reference track. All subjects heard all comparisons twice, with each track as the reference track in one of the trials. In total, subjects had 24 ABX comparisons.

For this pilot study, 14 musically trained subjects participated, with 12 of those subjects having participated in previous listening tests. The subjects were required to have a minimum of three years of musical training and had on average about eight years of training and experience. All subjects were screened to have normal hearing thresholds of 25 dB or lower at six octave bands from 125 Hz to 8 kHz.

ORCHESTRA AURALIZATION LISTENING TEST RESULTS

The results from the listening tests were analyzed using the binomial theorem [8]. The probability of obtaining a correct answer is 50%, which is taken into account to determine the probabilities of the group of subjects obtaining a correct answer for any given comparison. The null hypothesis is that no differences are audible between the different orchestra configurations or that the probability of choosing the correct track is equal to 50%. With a significance level of $p < 0.05$, if 10 or more subjects obtain the correct result ($p < 0.05$), then the null hypothesis is rejected and it is concluded that the differences between auralizations of different orchestra configurations are audible. The results for the two symphonies are shown in Tables II and III.

Table II: Listening Test Results for Various Orchestra Configurations Auralizations - Brahms

Brahms - 1 channel

A	B	X	Incorrect	Correct	p	Signficant?
American	European	American	8	6	0.209	No
American	European	European	4	10	0.125	
American	Random	American	4	10	0.022	Yes
American	Random	Random	3	11	0.006	
European	Random	European	3	11	0.006	Yes
European	Random	Random	4	10	0.022	

Brahms - 5 channel

A	B	X	Incorrect	Correct	p	Signficant?
American	European	American	4	10	0.022	No
American	European	European	9	5	0.183	
American	Random	American	3	11	0.006	Yes
American	Random	Random	3	11	0.006	
European	Random	European	3	11	0.006	Yes
European	Random	Random	0	14	< 0.001	

Table III: Listening Test Results for Various Orchestra Configurations Auralizations - Mozart

Mozart - 1 channel

A	B	X	Incorrect	Correct	p	Signficant?
American	European	American	6	8	0.122	No
American	European	European	5	9	0.062	
American	Random	American	4	10	0.022	Possibly
American	Random	Random	6	8	0.122	
European	Random	European	5	9	0.061	No
European	Random	Random	5	9	0.061	

Mozart - 5 channels

A	B	X	Incorrect	Correct	p	Signficant?
American	European	American	6	8	0.122	Possibly
American	European	European	2	12	< 0.001	
American	Random	American	5	9	0.061	No
American	Random	Random	6	8	0.122	
European	Random	European	2	12	< 0.001	Possibly
European	Random	Random	5	9	0.061	

The results for the Brahms symphony are more obvious than for the Mozart symphony. In terms of the significance of the number of channels, one versus five channels, the same conclusions can be drawn from either number of channels. Subjects were able to distinguish the American versus Random configurations, and the European versus Random configurations when the auralizations were either single or five channels. No significant audible differences were found between the most similar configurations of American and European.

For the Mozart symphony comparisons, the results are much less conclusive. For the single channel case, the only possibly significant difference is between the American and Random configurations. There are mixed results depending upon the reference track, X. In the five channel case, there is possibly stronger evidence that the differences between the American and European, and the European and Random configurations are audible, especially when the European configuration is the reference track. The results will hopefully become clearer once the final study is completed with 30 participants.

CONCLUSIONS

The purpose of this study was to determine if differences in orchestra auralizations, created with one or five channels, for three different orchestra configurations are audible. Subjects compared auralizations of the different orchestra configurations, while holding the variables of channel, one versus five, and composer, Brahms versus Mozart, constant. The results for the Mozart auralizations are less conclusive than the Brahms, but there is possibly an effect of number of channels in that differences between auralizations with five channels are more audible than those made from single channel instrument representations. For the Brahms auralizations, subjects were consistently able to detect differences between the American and Random, and European and Random configurations with both single and five channel auralizations. Therefore, the method of single and multi-channel orchestra auralizations is an effective representation of differences between some orchestra configurations.

Acknowledgements

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