The Effects of Convolution Reverberation on the Emotional Characteristics

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ABSTRACT

Previous work has shown that the emotional characteristics of musical instrument sounds are significantly changed with parametric reverberation .This paper considers the effects of reverberation time on the emotional characteristics of instrument sounds with convolution reverberation. We compared eight musical instruments and ten emotional characteristics over five hall impulse responses ranging from the 1-second Royal National Theatre to the 5-second King's College Chapel. The results showed that convolution reverberation had more pronounced effects on the emotional characteristics compared to parametric reverberation. While the results were more pronounced for convolution reverberation compared to parametric reverberation, there was also a strikingly strong agreement in their results, and correlation coefficient between them was 0.74 over all emotional characteristics. This strong correlation indicates that reverberation time has a remarkably consistent effect on the emotional characteristics regardless of whether using convolution or parametric reverberation.

1. INTRODUCTION

When someone thinks of a piece of music, they usually think of its melody. They might also consider other striking features related to tempo, dynamics, pitch range, mode, or harmony. The instrument playing the melody, and the spaciousness of the place where it is played also shape the emotional characteristics of the music, and are the topic of this paper.

Parametric reverberation was a natural starting place for our initial investigations, since the parameters - reverberation length and amount - were easy to control and manipulate [1, 2, 3]. But, do the results from parametric reverberation apply to real concert hall reverberation as well? This is a critical next step, since convolution reverberation is very popular and probably even more frequently used than parametric reverberation, and it is probably a better indicator of how instruments sound in real concert hall environments. With convolution reverberation you are working with impulse responses at a few discrete points in the hall, while with parametric reverberation you have a continuum of parameter values for the reverberation amount and reverberation time. In any case, it would be useful to have the results for both convolution and parametric reverberation, since they are both widely used for acoustic musical instruments, and yet they are fundamentally different - you cannot just assume that the results of one apply to the other.

In this study, we seek to understand how the emotional characteristics of musical instruments vary with reverberation time in convolution reverberation. In our previous study on parametric reverberation, reverberation time had strongly significant effects on the emotional characteristics Romantic and Mysterious, and medium effects on Sad, Scary, and Heroic. Anechoic tones were judged most Comic. We are particularly interested to compare and contrast these results to those for convolution reverberation. The work will give audio engineers and musicians an interesting perspective on reverberation since many recordings are done in studios where the type and quantity of artificial reverberation added is decided by recording engineers and performers. The work also has applications in music designed for virtual environments, computer games, film soundtracks, and karaoke systems by adjusting reverberation to emphasize desired emotional characteristics.

2. METHODOLOGY AND LISTENING TEST

In this study, we seek to understand how the emotional characteristics of musical instruments vary with reverberation time in convolution reverberation. We conducted a listening test for convolution reverberation in the same way that we did for parametric reverberation [1, 2]. Listeners compared the convolution reverberations pairwise for each instrument and emotional characteristic. Below are some the main points, especially the differences from the parametric reverberation tests.

We tested sustained anechoic musical instruments representing the wind and bowed string families obtained from the University of Iowa Musical Instrument Samples [4]. The sustained instruments are nearly harmonic and have fundamental frequencies close to Eb4 (311.1 Hz). In addition to the anechoic sounds, we compared convolution reverberated sounds with reverberation lengths of approximately 1s and 2s, generated by several representative hall convolution reverberations based on the impulse responses in Altiverb [5] (i.e., Royal National Theatre, Empire Hall, Disney Hall, and Concertgebouw Hall). We also included the cathedral impulse response of King's College Chapel with a 5.44 second reverberation time to determine the effects for a more extreme case.

For this study we tested the ten emotional categories: Angry, Calm, Comic, Happy, Heroic, Mysterious, Romantic, Sad, Scary, and Shy. Some choices of emotional characteristics are fairly universal and occur in many previous studies roughly corresponding to the four quadrants of the Valence-Arousal plane [6]. For this study, we used the same categories that we used in our previous research on musical instruments and parametric reverberation [1, 2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19]. Before the listening test, subjects read online definitions of the emotional categories used in our experiment, which were taken from the Cambridge Academic Content Dictionary [20].

We hired 72 subjects to take the listening test, and each subject heard half the emotional categories. Therefore, 36 subjects compared each emotional category. All subjects were fluent in English, and were undergraduate students at the Hong Kong University of Science and Technology. Subjects were average attentive listeners. In the listening tests, subjects heard paired comparisons between the hall impulse responses for the each instrument and emotional category. During each trial, subjects heard a pair of sounds and was prompted to choose which more strongly aroused a given emotional category. Subjects did not need to remember all of the tones, just the two in each comparison.

Each combination of two different hall impulse responses were presented for each of the eight instruments and ten emotional categories, and the complete listening test totalled $C_2^6 \times 8 \times 10 = 1200$ trials (600 trials per listener since we divided the task into two groups). For each listener, the overall trial presentation order was randomized to average out effects due to learning or fatigue. For the two sounds A and B, they heard AB where the order of A and B was random for each comparison (but if they heard AB, they did not hear BA later). The listening test took about 75 minutes, with forced short breaks every 25 minutes.

3. RESULTS

There were originally 36 subjects for each group of five emotional categories. We screened their responses, and found 7 subjects from group A and 6 subjects from group B were obviously spamming the same key responses toward the end of the test, so we excluded all of their data. Based on the filtered listening test data (29 subjects for group A, and 30 for group B), we ranked the hall impulse responses by the number of positive votes they received for each instrument and emotional category and derived scale values using the Bradley-Terry-Luce (BTL) statistical model [21, 22]. For each graph, the BTL scale values for the six tones sum to 1. In other words, if all six hall impulse responses were judged equally Happy, the BTL scale values would be 1/6 ≈ 0.167.

Figures 1 to 4 show BTL scale values and the corresponding 95% confidence intervals for emotional categories Angry, Happy, Romantic, and Shy. Though there are certainly individual differences, for each emotional category the trend from anechoic to cathedral usually follows the same direction for the different instruments. For example, Angry trends down, Calm trends up, and Shy trends up to the Disney Hall and then down. The trumpet for Mysterious was the most strongly effected among all the instruments and emotional categories with a BTL value of more than 0.5 for King's College Chapel.

We wanted to determine the number of times each hall impulse response was significantly greater than the other five hall impulse responses over the eight instruments for each emotional characteristic. Since most of them were not normally distributed, both parametric and nonparametric statistical tests (parametric: Paired t-tests, Pearson correlation ; nonparametric: Wilcoxon signed-rank tests, Spearman correlation) were used to analyze the voting data. The results from the two tests showed some minor differences, but basically they were in agreement. Table 1 shows the paired t-test results.

Based on Table 1, we see that, halls with shorter reverberation times were the strongest for the emotional categories Angry and Comic. Halls with medium reverberation times were the strongest for Happy, Heroic, and Shy. Halls with long reverberation times were the strongest for Calm, Mysterious, Romantic, Sad, and Scary. We compared this characterization with our results from parametric reverberation [1, 2] and found agreement in 7 of the 8 emotional categories that we tested in that study (Heroic was the only one that was different).

As a further comparison, we correlated the BTL data from the hall impulse responses with the BTL data from our previous study of parametric reverberation, and found a correlation of 0.74 over all emotional categories, indicating a rather remarkable level of agreement. Table 2 also shows the correlations between the individual emotional categories. Seven of the emotional categories were significant, but Shy was not. The seven significant correlations were fairly strong ranging from about 0.47 to 0.87 for the individual categories. The emotional categories with the strongest correlations were Mysterious, Romantic, and Sad which also had the largest number of significant differences in Table 1.

4. DISCUSSION

The main goal of our investigation was to see how the emotional characteristics of musical instruments changed with reverberation time in convolution reverberation. Based on Table 1, our main findings are the following:

1. Halls with shorter reverberation times tended to emphasize the emotional characteristics Angry and Comic.
2. Halls with medium reverberation times tended to emphasize the emotional characteristics Happy, Heroic, and Shy.
3. Halls with longer reverberation times tended to emphasize the emotional characteristics Calm, Mysterious, Romantic, Sad, and Scary.

We were curious to see how the results for convolution reverberation would compare to the results from our previous study on parametric reverberation. The biggest difference between them was that the convolution reverberation emotional characteristics were more pronounced. There were 62% more significant differences for the eight categories and five reverberation times that we tested in both experiments (see Table 3). This difference shows up most clearly in the emotional category Shy where there was only one significant difference for parametric reverberation and 27 for convolution reverberation.

While the effects on the emotional characteristics were more pronounced in convolution reverberation compared

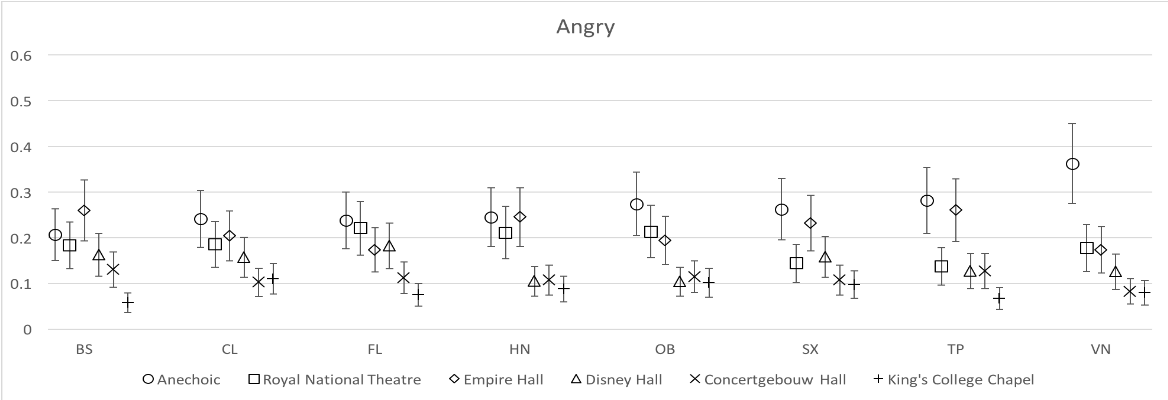

Figure 1. BTL scale values and the corresponding 95% confidence intervals for Angry.

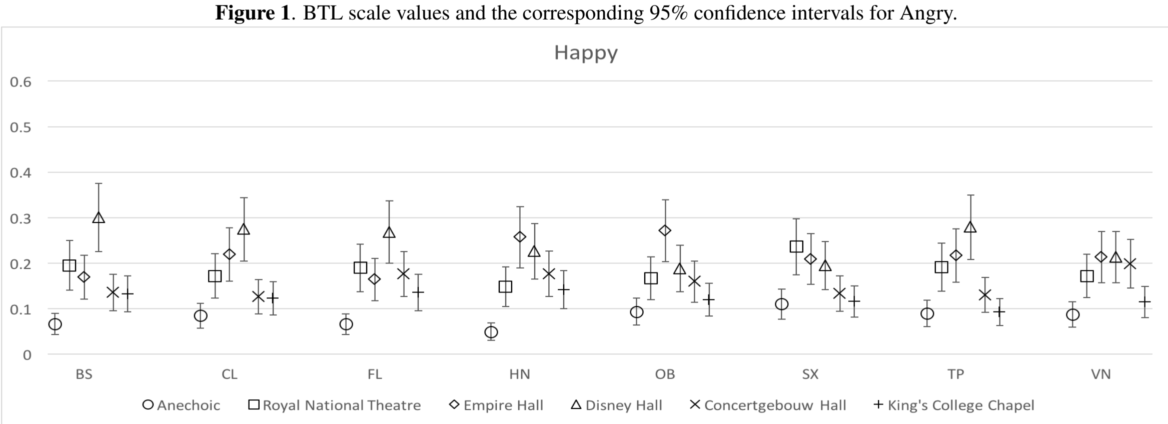

Figure 2. BTL scale values and the corresponding 95% confidence intervals for the emotional category Happy.

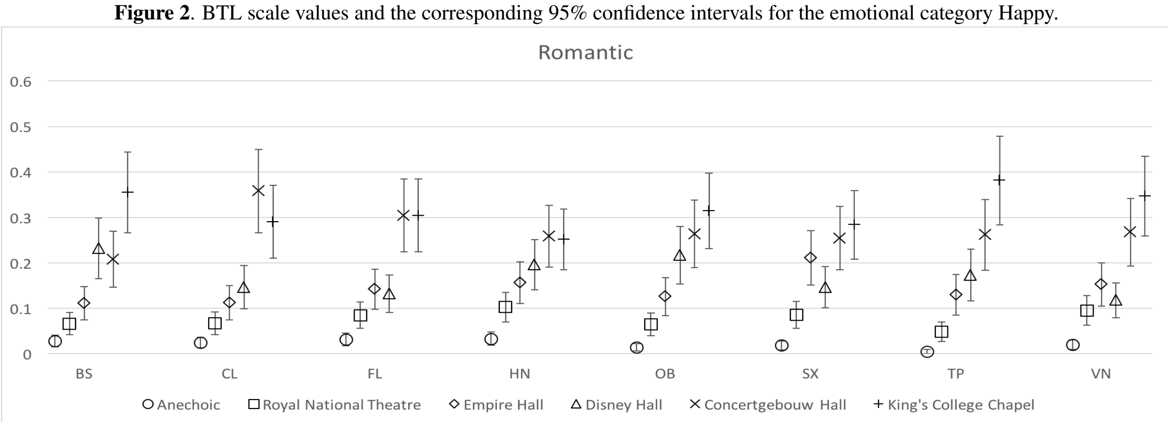

Figure 3. BTL scale values and the corresponding 95% confidence intervals for Romantic.

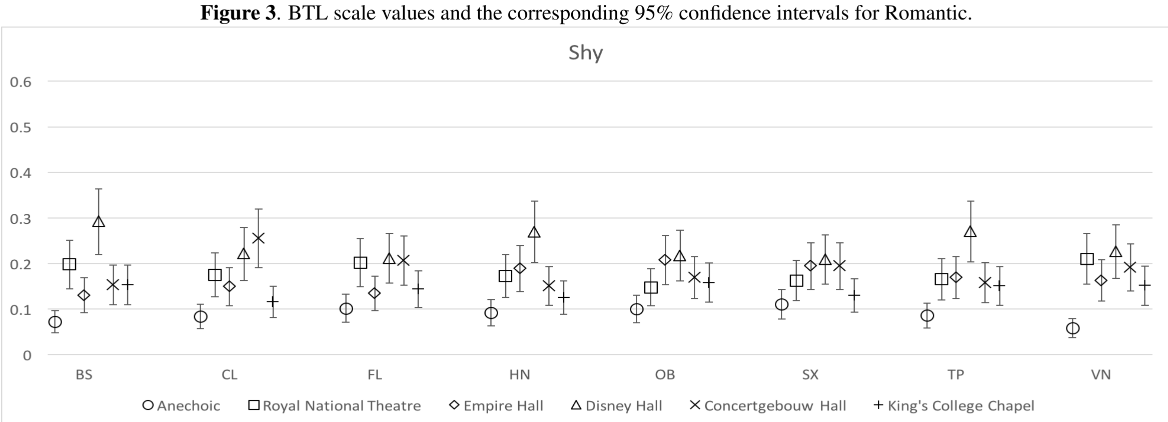

Figure 4. BTL scale values and the corresponding 95% confidence intervals for Shy.

	Anechoic Chamber RT_{60}=0	Royal National Theatre RT_{60}=0.94	Empire Hall RT_{60}=1.31	Disney Hall RT_{60}=1.80	Concertgebouw Hall RT_{60}=2.32	King's College Chapel RT_{60}=5.44
Angry	**21**	13	20	4	2	0
Calm	0	8	8	13	**19**	15
Comic	0	**17**	5	9	2	0
Happy	0	10	17	**18**	5	2
Heroic	0	3	**15**	3	6	0
Mysterious	0	4	17	16	29	**34**
Romantic	0	8	15	17	26	**28**
Sad	0	8	12	13	**28**	26
Scary	0	0	4	1	**8**	7
Shy	0	6	5	**18**	4	1

Table 1. Based on paired t-tests, How often each hall impulse response was statistically significantly greater than the others for each instrument and emotional characteristic.

	Pearson Correlation		Spearman Correlation	
Emotion	Correlation	P-value	Correlation	P-value
Comic	0.50	0.00	0.48	0.00
Happy	0.50	0.00	0.50	0.00
Heroic	0.61	0.00	0.52	0.00
Mysterious	0.86	0.00	0.88	0.00
Romantic	0.79	0.00	0.83	0.00
Sad	0.79	0.00	0.77	0.00
Scary	0.71	0.00	0.66	0.00
Shy	0.28	0.084	0.28	0.09
Overall	0.74	0.00	0.68	0.00

Table 2. Pearson and Spearman correlation between the BTL values for the convolution reverberation and parametric reverberation.

Emotion	Parametric	Convolution
Comic	15	8
Happy	9	36
Heroic	12	16
Mysterious	49	65
Romantic	42	64
Sad	29	59
Scary	21	14
Shy	1	27
Total	178	289

Table 3. Number of significant differences for eight emotional categories and five reverberation times used in both experiments.

to parametric reverberation, there was also a striking basic agreement in the results. The BTL rankings for convolution and parametric reverberations were significantly and strongly correlated with a correlation coefficient of 0.74 over all emotional categories. Seven out of eight individual emotional were also significantly correlated with correlation coefficients ranging from 0.5 to 0.87. Shy was the only category not significantly correlated since its BTL rankings were very flat for parametric reverberation. These strong correlations indicate that reverberation time has a remarkably consistent effect on the emotional characteristics regardless of whether using convolution or parametric reverberation.

It was really surprising that the emotional characteristics Angry and Scary, which have near-identical Valence and Arousal values, were so completely opposite in their results (see Table 1). Angry was the strongest for halls with short reverberation times, and Scary was the strongest for halls with long reverberation times. The Scary results agree with our previous parametric reverb results [1, 2], as well as the results by Västfjäll et al. [23] and Tajadura-Jiménez et al. [24], who found that larger reverberation times and larger rooms were more unpleasant. Similarly, the emotional characteristics Comic, Happy, Heroic, and Romantic all have similar Valence and arousal values, yet they showed distinctly different results in Table 1. The results of Västfjäll [23] and Tajadura-Jiménez [24] suggested all four of these characteristics would be stronger in smaller rooms, but Table 1 shows the differences between these emotional characteristics.

In a sense the columns of Table 1 represent the "footprints" of emotional characteristics of the individual halls relative to one another. The Anechoic Chamber was singularly Angry in its response. The crisp sound of the Royal National Theatre was strong for Angry and Comic. The hard bright surfaces of the Empire Hall brought out emotional characteristics such as Angry, Happy, and Heroic. The warm sound of the Disney Hall was especially unique in bringing out Shy and Happy. The sophisticated elegance of the Concertgebouw Hall was apparent in the categories Calm, Mysterious, Romantic, and Sad with a touch of Scary. Finally, the spacious King's College Chapel also brought out the characteristics Mysterious, Romantic, and Sad, the first two even a bit more than the Concertgebouw Hall with its 5-second reverberation time.

So, to what extent do the data in the columns of Table 1 represents the particular colorings of these halls as compared to the general characteristics of a generic concert hall with these reverberation times? We cannot tell at this stage, but this is a great area for further work. Nevertheless, the strong agreement of the convolution and parametric reverberation results already suggests that the trends emerging in the two studies are basically indicative of how the underlying emotional characteristics change with reverberation time. Within these trends, the colorations of the particular halls may bring out individual emotional characteristics such as Comic, Happy, Heroic, or Shy.

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