2aAAa7. Interaction between critical listening environment acoustics and listener reverberation preference

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Reverberation is a central effect in many modern music productions. In the case of classical music, it may even be the only effect used. There is, however, minimal literature concerning the interaction between reverberation preference and the listening environment used during critical mixing tasks. In order to explore this critical interaction, a group of highly trained subjects are tasked with adding reverberation to dry, premixed stereo program material in two different acoustic environments: a recording studio control room and a highly reflective room. The control room is representative of most studios, with an RT of approximately 200 ms. The reflective environment more closely approximates an untreated residential room, with an RT of over 350 ms, with a marked increase in lateral energy. Somewhat predictably, the mean preferred reverberation level is higher in a less reverberant environment, but the distributions of reverberation level preference are shown to be narrower for the more reflective mixing environment. The time it takes for subjects to reach a decision is similar in both environments, but the reflective environment seems to suggest a longer period of adaptation at the beginning of each trial set.

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INTRODUCTION

The acoustics of a listening environment will have a profound effect on any sounds that occur within it. Outside of the niche audiophile community, very little attention is paid to the listening environment in the world of consumer audio. In the professional audio world, however, the critical listening environment is of paramount importance. In fact, the budget for design and implementation of acoustic treatment of a studio or critical listening space can often run into the millions of dollars. Most professional audio engineers feel that the neutrality of the listening environment is of the upmost importance in achieving a desirable outcome when making decisions on microphone placement, mixing or mastering. But in the age of the low-budget production and the ever-increasing share of productions completed in home or semi-professional studios, the viability of such high-quality listening environments is tenuous at best.

On the other hand, some research suggests that acoustic artifacts found in lesser-quality rooms are not nearly the problem that some professionals make them out to be. Researchers such as F.E. Toole state that listeners can easily adapt to and overcome the audible effects of lesser quality rooms. While Toole's research focuses primarily on consumers and casual listeners, little work exists to quantify the effects, if any, of large amounts reflected energy on audio professionals completing critical tasks. A new thread of research is needed to apply the laboratory results found in the cognitive science literature and consumer audio world to the audio professional.

In order to ensure applicability of any such research, it must meet a number of specific criteria. The most important requirement for this research is its relation to the everyday tasks of the recording professional. In order to fully draw upon the expertise of highly trained subjects, testing must mimic the tasks found in the normal workflow of a recording engineer. The task must be interactive, in order engage the subject as they would be while critically listening and making decisions in the studio. The testing should also employ a high-quality monitoring system like those found in high-end recording studios. Likewise, the subjects themselves should be truly expert listeners and audio professionals. Lastly, the test must rely upon truly excellent sound sources. If the samples are fatiguing or at worst, unlistenable, they will fail to illicit the full focus and expertise of the subject.

To meet these requirements, a test has been designed which emulates the mixing process. Throughout the mixing process, engineers are responsible for a number of critically important tasks, including the addition of audio effects. While many effects and signal modification (e.g. dynamic processing, equalization, etc.) are somewhat genre-specific, reverberation provides somewhat of a universal case. Reverberation is common in pop and jazz productions, but is also frequently used in classical and acoustic music. In fact, artificial reverberation may be the only addition to a mix after the recording process in some acoustic productions, making it an ideal aspect of the mixing process to be studied.

HISTORICAL CONTEXT

Much of this research draws from the work of Toole and his research on listener adaptation to reflected energy. In his book Sound Reproduction, he concludes that listeners are able to distinguish and separate the direct sound from a sound source and the effects of reflected energy (namely comb filtering) [1]. In fact, it is commonly accepted that early reflections can indeed add power to a sound source, shaping and reinforcing it [2], [3]. Furthermore, a lack of reflected energy is often considered unnatural and has been described as “not particularly pleasant” by some [4].

These studies are juxtaposed by many prevalent control room design philosophies. Early control room (and even recording space) designers advocated primarily absorptive treatment, creating a dry acoustic environment [5]. This primarily dead control room design philosophy has been adopted by a number of studio designers since [6], [7]. It was not until the early 1990’s that any significant departure from a primarily absorptive designs were adopted [8].
Previous work

The authors have endeavored to link the world of acoustical measurement and design to the practical application of music mixing and critical listening. Previous studies have focused on the recording engineers’ work balancing sources [9]. Past studies tasked subjects with mixing a lead element into a backing track in a variety of different acoustical environments, exploring how lateral energy effects the engineers’ decision-making process and workflow [10]. The work presented in this paper builds on work in [11], with further acoustical and statistical analysis.

TEST DESIGN

Testing was conducted using a similar method as developed in [12]. Rather than balancing individual instruments as in previous testing, however, subjects were presented with a 30-second excerpt of a “dry” (non-reverberant) stereo mix and were asked to add reverberation. Reverberation was generated using a standard algorithmic reverberator and recorded as a separate audio file in advance, as balanced by the balance engineer of the original source audio. Playback of both the dry mix and the reverberation was achieved through the use of Max MSP, which also collected and named data. Data was collected on a number of variables, including the final level set for each trial, the total time elapsed per trial as well as a complete histogram of the level as adjusted by the subject throughout the trial. Each subject completed 24 trials per test session.

The level of reverberation added was adjusted in .5 dB steps controlled from a continuous rotary encoder. The continuous encoder was employed to prevent visual feedback from guiding the subjects. Additionally, the initial level of was randomized by ±1.5 dB each trial, with a nominal starting level of 20 dB below that of the dry mix, ensuring tactile feedback could not be used to repeat level selections.

Subjects were asked to set the level of reverberation based solely on their personal preference. Although there was no defined “correct” level, the level of reverberation set by the original engineer was used as the reference (0 dB). The inclusion of automation during file generation ensures that when the dry mix and reverberation files are mixed at the same nominal level, the original mix is reproduced.

Acoustical Environment

Subjects were asked to complete the task on two consecutive days in two different acoustic environments. The first environment was a medium sized control room equipped with a high-quality, full-range three way monitoring system (Figure 1, left), typically used for ear training, critical listening, mixing and mastering. In this acoustical environment, the playback system displayed a flat frequency response, ±3 dB from 20Hz to 18kHz.

![FIGURE 1: Left: the testing location, in its typical condition. Right: as modified for increased reflectivity.](image-url)
The testing environment was then altered for the second trial set. Reinforced plywood panels and triple-painted drywall modules were used to increase the reflectivity of the room (Figure 1, right). In addition to increasing the overall reflectivity, panels were arranged to re-direct reflected energy back at the subject, as in [10]. The room’s apparent geometry was changed to form a room that was essentially square in the most critical areas of reflection (Figure 2).

The practical effect of the acoustic alterations was a marked increase in reverberation time across all frequencies, as seen in Figure 3. The necessity of covering the front wall negated some of the room’s bass trapping, causing a significant increase in low frequency energy. The change in higher frequencies was somewhat less pronounced, as the unfinished wood panels had a somewhat absorptive effect. In all, the energy return from the room was increased by approximately 1 dB for the first 80 ms, and the high-frequency reverb time was increased by more than 20 ms.

Musical material

The musical excerpts employed in this study were taken from a commercial release featuring soprano and orchestra. The material was deemed ideal for this study since the orchestra was recorded in a dry hall.
which required the addition of artificial reverberation, and the voice, which was recorded separately, could be presented with very little natural ambience or reverberation.

The mix was recalled by the original mixing engineer and stripped of ambient signals from the room microphones and artificial reverb and re-recorded as a single, dry stereo file which included all level and panning information. The reverberation was then printed as a separate stereo file, the level of which was to be determined by the subjects. Three different 30 second excerpts were selected for their consistency both throughout the excerpt and between excerpts.

**Test participants**

Testing was conducted with subjects primarily from McGill University's graduate program in sound recording. All subjects were highly trained listeners, most of whom were currently enrolled or recently completed the program, which focuses on music production and critical listening. Subjects ranged in age from 22 to 34 years of age and included a mixture of males and females. Subjects averaged 13 years of musical experience and more than six years of production experience. Additionally, more than half of the subjects taking part in this study named classical music as the genre upon which they most frequently focus.

**RESULTS & ANALYSIS**

Analysis of the the levels set in the two test sessions showed a significant difference in each acoustic environment (Figure 4). A repeated measure analysis of variance (rANOVA) using a 2x3 full factorial design with level as a dependent variable and two independent variables - musical excerpt (3 levels) and acoustical environment (2 levels) - shows that acoustical environment is a significant factor, while there is no significant interaction between excerpt and environment, as shown in Table 1.

Results show that subjects mixed reverberation lower in the environment with reflective acoustic alterations (REF). The mean mix level for the dry condition (DRY) was -0.28 dB, while the condition's mean was -0.96 dB. The standard deviation for DRY=±4.33 dB and for REF=±3.38 dB indicates a significantly
TABLE 1: rANOVA table showing the influence of musical excerpt, acoustical environment and the interaction between both factors on the dependent variable, level.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum Sq.</th>
<th>d.f.</th>
<th>Mean Sq.</th>
<th>F</th>
<th>Prob &gt;F</th>
</tr>
</thead>
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<td>Excerpt</td>
<td>33.28</td>
<td>2</td>
<td>16.641</td>
<td>1.08</td>
<td>0.3396</td>
</tr>
<tr>
<td>Environment</td>
<td>66.69</td>
<td>1</td>
<td>66.6934</td>
<td>4.34</td>
<td>0.0378</td>
</tr>
<tr>
<td>Excerpt*Environment</td>
<td>38.46</td>
<td>2</td>
<td>19.2325</td>
<td>1.25</td>
<td>0.2872</td>
</tr>
<tr>
<td>Error</td>
<td>8767.32</td>
<td>570</td>
<td>15.3813</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8901.02</td>
<td>575</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 5:** Kernel density estimation showing the elapsed time per trial. The reflective environment (red/solid line) exhibits a possible tendency towards multi-modality.

different variance according to a Two-sample F-test for equal variances with $p=4.1706e-05$. A Kruskal-Wallis test also shows a significant difference in acoustical environment means. Both parametric and non-parametric analysis exhibited the same results, with greater power being found in non-parametric tests.

**Elapsed time results**

While the level set by each subject showed significantly different results in the two environments, elapsed time results were less clear-cut. A one-way analysis of variance (ANOVA) shows that there is no significant difference in the amount of time taken to complete each trial between the two acoustic environments employed ($p=19.8$). An examination of distributions, however, would lend some hope for significance in this area, as well. When the smoothed distributions are plotted (Figure 5), a multi-modal tendency appears in the reflective environment. It is possible that further analysis of this data using non-parametric analysis might reveal further information regarding elapsed time trends.

Trends in elapsed time over individual subjects were also analyzed. These analyses showed a much stronger influence of excerpt on the time needed complete the task. While there was a slight indication of some adaptation time over the first four to six trials, excerpt 3 predictably requires more time for a decision to be made. Excerpt 3 is somewhat more expressive in both the orchestra and soprano, which may have required further listening to determine how each section of the excerpt would respond to a given reverberation level.
CONCLUSIONS

While the previous work of many researchers (including the authors) suggests that acoustical artifacts can be overcome by a listener, the case of reverberation seems to indicate a departure from this trend. The intricacy of this task seems to be more influenced by even the slight alteration of acoustics employed in this test. It is quite possible that, while other more coarse tasks like overall level balance or equalization can be conducted accurately in a non-ideal environment, more subtle tasks may in fact require a more neutral acoustic environment. Even as the number of excellent control rooms and critical listening spaces around the world seem to be dwindling, the results of this study would support the line of reasoning that states that the minimally treated bedroom or on-location studio may not be able to offer a sufficiently neutral acoustical environment for all aspects of the production process.

Future work

The potentially multi-modal nature of the elapsed time data collected certainly bears further investigation. The addition of more subjects or data might also help to detect any underlying significance. In the absence of more subjects, it is also possible that with more powerful non-parametric statistical analysis the data may separate each acoustic condition into more significantly different distributions. Likewise, the effect of excerpt 3 on the elapsed time data also invites further analysis. The exclusion or normalization of excerpt 3 may lay bare trends that reflect the adaptation period in both environments.

This testing leaves one particular topic untouched: what happens when the room is removed completely? Along with the trend towards minimally treated home and “project” studios comes the proliferation of headphones as a main monitoring system. This paper begins the exploration of reverberation as a variable, but a full study of the topic would not be complete without the inclusion of a comparison of headphones to both treated and minimally treated rooms.

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REFERENCES


