Psychoacoustic Dissonance Measurement in Reverberant Spaces
Music 251 Final Report

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Abstract

Assessments of acoustics in spaces which music is performed typically consider a sense of *richness*, involving reverberant and resonant qualities, and *clarity*, which describes the degree to which individual and sequential musical events retain their intelligibility as effected by these factors. Implicit, but not entirely understood, is how the delicate balance between *richness* and *clarity* that defines the quality of musical acoustics, effecting the perception of musical consonance and dissonance. Musical consonance and dissonance integrates a sensorial factor (that is, the sensation of tonal clarity or roughness) with a cognitive awareness, whether implicit or explicit, of how musical elements (such as intervals and chords) relate to one another both as simultaneities and sequentially in terms of stability or instability.

Introduction

Traditionally, a concurrent dissonant interval creates a tendency for resolution to a consonance - which constitutes one of the fundamental bases for centuries of western musical style. Less well studied, is the effect of reverberant space on the perception of musical dissonance. It is not at all uncommon, for example, for choral works from the 17th century and beyond, to be performed and recorded in highly reverberant spaces such as churches, in which long decay times tend to blur the boundary between a dissonance and its resolution. The presence of this overlap affects perception, and often affects performance decisions regarding tempo and articulation. Even consonant chord changes might introduce perceptual dissonance because the reverberation tail of the first chord still persists while the second chord is being played, making the transition sound muddy. We observed examples of such dissonance in tonal music recordings from Church of the Gesu and Sant'Aniceto nel Palazzo Altemps in Rome. In this paper, we study the effect of reverberation on dissonance perception during chord changes.

Psychoacoustic dissonance curves using pairs of sine tones have been generated experimentally by Plomp and Levelt in [1] and extended by Sethares in [2]. Psychoacoustic dissonance is related to roughness, which is defined as *the element that destroys musical consonance -the undistributed simultaneous sounding of pure tones* [3]. A quantitative measurement of roughness can be found in [4,5]. Moreover, the relationship between musical consonance and psychoacoustic roughness has been explored in [6] - *listeners typically describe roughness as unpleasant and it has been thought to be prevalent in dissonant, but not consonant, musical chords.* In this study, we only focus on musical dissonance but a proposed future work is to reconcile sensory roughness with perceived dissonance and come up with a quantitative metric for measuring the same. Relative musical dissonance among chords has been studied in [7]. As expected, the results in decreasing order of consonance are - major > minor > diminished > augmented. In [7], perceived dissonance was also observed to be higher when the chords were played in a random sequence, rather than following a cycle of fifth.

We conduct an experiment where we ask subjects to rate chord snippets with varying dissonance and reverberation decay times. Our results show that there is a correlation between reverberation decay times and the perceived dissonance of chords, but it's not directly proportional, i.e, bigger room sizes don't necessarily result in higher dissonance. Each chord shows maximum dissonance rating under a different room size. We also observe that the relative dissonance rating among chords is affected with reverb. However, to draw more conclusive results, a better experiment design involving more subjects with preferably 10+ years of training in western music is desired.

Experiment Design

In our experiment, we ask the subjects to rate chord snippets with varying dissonance and reverberation decay times. The experiment consists of two sections and lasts approximately 10 minutes. In the first part, we asked them to fill out a questionnaire with questions relating to their musical background. The composer and music theorist Norman Cazden emphasized the cultural difference in dissonance perception[7]. One of the aspects which affects dissonance perception is one's familiarity with non-western music. McDermott ran an experiment on infants and non-Western adults to examine the effects of musical experience and musical background[6]. We collected the information from our subjects on their musical experience in years and their familiarity with either Western or non Western music.

Participants

We ran the experiment on 22 participants whose age ranges from 21 to 63. Our participants mainly identify their musical familiarity in Western music except than one participant whose musical background in non-Western music and three participants who prefer not to declare their musical background. 60% of the participants have 10-20 years of musical experience. 22% of the participant are experienced in Western music more than 20 years and 18% of them have less than 10 years of experience including one non-musician subject.

Stimulus

Cazden suggests that the dissonance perception is strongly linked to the chord sequence rather than resulting from *properties of chords* [7]. This idea is parallel to our experiment motivation which is the dissonance in chord changes introduced by reverberation. That's why we limit our stimuli to short snippets of tonal chord changes. After reverberation is applied, the second chord is windowed keeping the first chords tail present in the stimuli.

Artificial reverberation is added using impulse responses of two churches, one with shorter decay time around 4 seconds, the other with approximately 10 seconds long decay time. The plug-in Altiverb is used to implement convolution reverb with these impulse responses. The intermediate stimuli with varying decay times are obtained by changing the room size of these churches. Ranging from 75% of the small church's size to the 125% of the cathedral's size, chord snippets with decay times from 3 seconds to 12 seconds are selected. The number chords and decay times are limited to keep the experiment non-repetitive and less distracting for subjects.

The individual tracks are grouped into groups of 5 chords including one reference chord and 4 randomly selected chords with varying decay times. There are 8 chords with 6 different decay times including the dry ones forming 12 groups in total. The experiment was run in the same room for all subjects with little background noise. Figs. 1-2 show examples of chord changes in the stimuli. The spectrogram of the dry signals for #16 and #18 are shown in following chords.

Data Analysis and Results

Data from all subjects were saved as MATLAB *structs*. Data was scaled and normalized for each subject individually. As mentioned, each of the 12 groups had the same reference chord. To scale all the ratings relative to the reference chord, we found the maximum of the reference ratings in all groups, and divided all ratings in each group by that maximum, to ensure that all the reference chords in all groups had the same rating. Then, we normalized the ratings to a percentage between 0 and 100, such that the most dissonant chord among all groups was given a rating of 100.

Fig. 3 shows how the perception of relative dissonance among chords is affected by reverberation. In this case, the box plot shows the lower and upper quartile, median, maximum and the outliers among the 22 subject ratings. We can see that Chord #3 is rated more consonant than Chord #1 for the dry stimulus. However, for the 3s decay time, it is rated more dissonant than Chord #1. With a 12s reverb tail, subjects

Fig. 1: Chord change #16

Fig. 2: Chord change #18

gave vastly different ratings to Chord #18, which was rated as being fairly consonant with all other decay times. The 4s and 6s decay times also affected the dissonance perception of Chord #16.

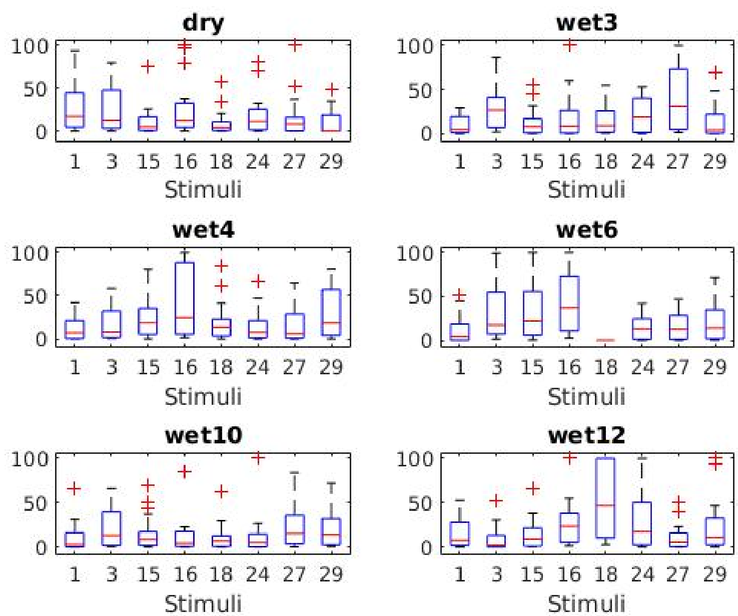

Fig. 3: Relative dissonance among chords with different reverberation rates

The responses to each chord's dry and wet versions for all decay times are compared in Fig. 4. More variance in ratings is observed in Chord #16 and Chord #18. In Chord #18, the stimulus with 12s decay time is rated more dissonant than both the dry version and the other decay times. This corroborates the expected hypothesis, i.e, perceived dissonance increases with increasing room size. However, in Chord #16, we observe that the stimulus with 4s decay time is rated more dissonant than the 10s one. This shows that the decay time affects the dissonance perception in chord changes, but not necessarily in a proportional way. Spectrograms of the corresponding chord changes, 4s and 10s decay time for Chord #16, and dry and 12 s decay time for Chord #18, are plotted in Figs. 5-6 and 7-8.

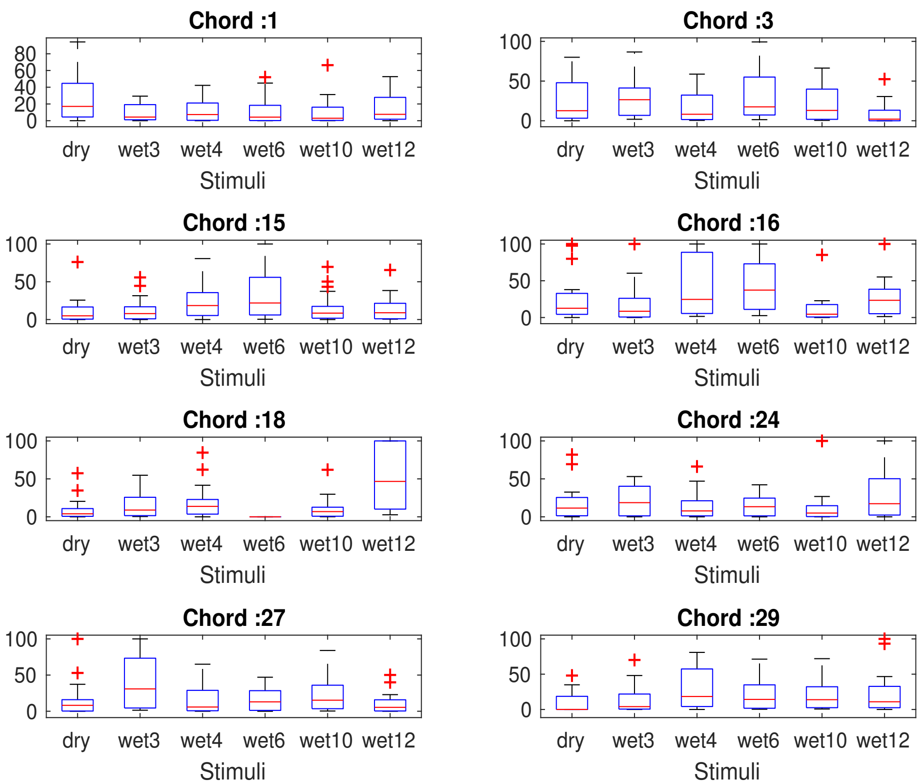

Fig. 4: Box plot of each chord's relative ratings among all decay rates

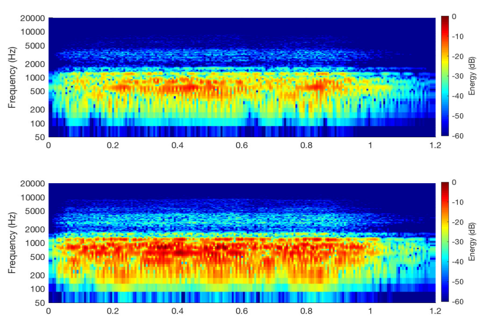

Fig. 5: Spectrogram of the dry sound sample of Chord #18

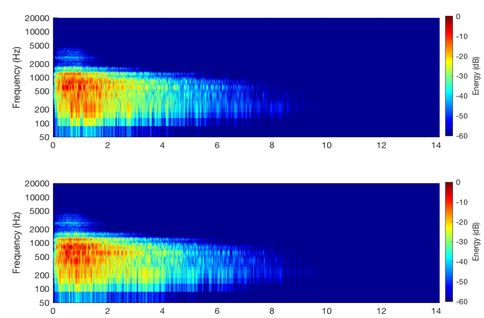

Fig. 6: Spectrogram of the sound sample with 12s decay time of Chord#18

In the spectrograms, the energy is significantly higher in the chord changes under reverberation. Especially, for chord #16 compared in Fig. 7 vs Fig. 8, the region between time 0.5 s and 2 s shows higher amplitude due to the first chord's reverb tail which is rated as dissonant by the majority of chords.

We plotted the histograms of the mean ratings of all chords for all the dry and wet stimuli, Fig. 9. The trend is that the dry, 6s and 10s stimuli were rated to be more consonant, whereas 3s and 12s decay times

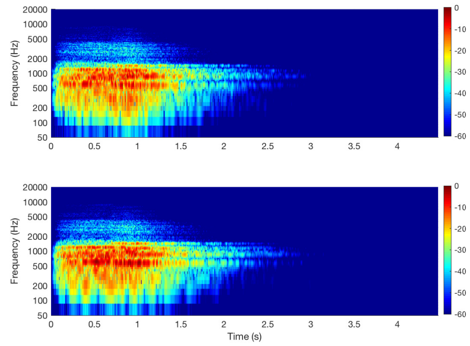

Fig. 7: Spectrogram of the sound sample with 4s decay time of Chord #16

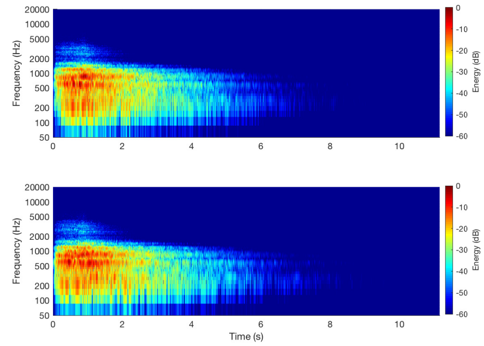

Fig. 8: Spectrogram of the sound sample with 10s decay time of Chord #16

were rated to be more dissonant overall. This shows that reverberation decay times alter the perception of dissonance, but dissonance does not necessarily increase with increasing room size.

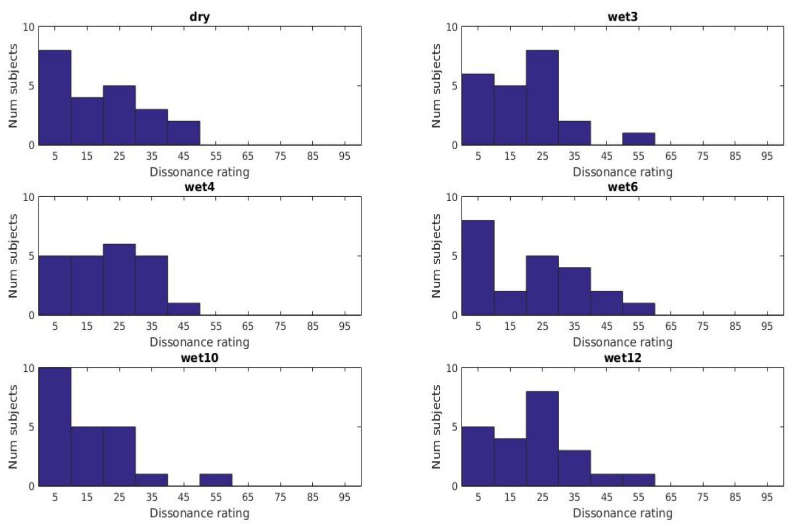

Fig. 9: Histograms of mean ratings of all chords

To see if the ratings are correlated among different reverb rates, we plotted the correlation matrix, Fig. 10. The correlation coefficients between dry signals and the 4s, 10s, and 12s decay times are quite small. This indicates that a chord rated as consonant for the dry stimulus, maybe rated as dissonant with these decay times and vice versa.

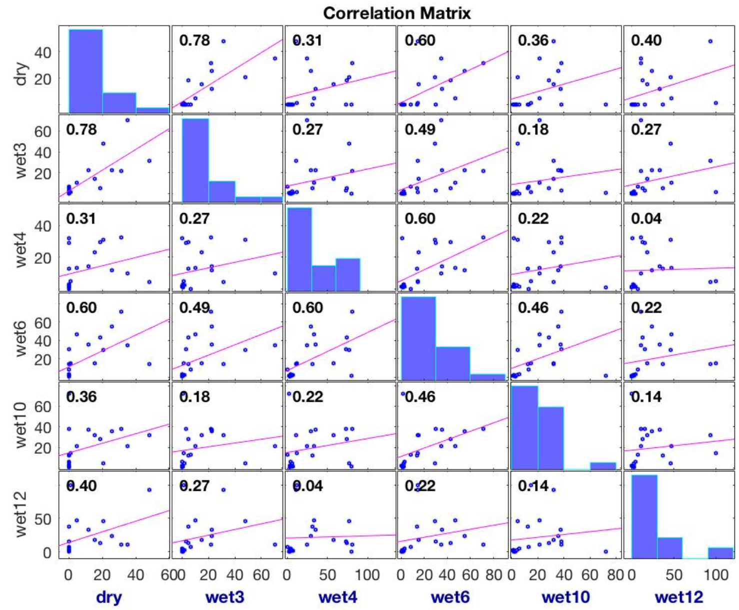

Fig. 10: Correlation matrix

Discussion

Our main observations after analyzing the data are :

- Decay times affect dissonance perception, not always proportionally.
- Relative musical dissonance among chords is also influenced by reverberation.

Some shortcomings with our experiment and things that could be improved are:

- Subjects were confused about the 0-100 dissonance rating. We did not define what 100% dissonance meant. Maybe giving a relative choice between two stimuli and asking which one is more consonant would it easier for subjects to rate.
- We did not fix the loudness while making subjects take the test. Loudness most likely affects perceived dissonance, so it's a variable that should have been fixed.
- We need more subjects with 10+ years of training in western music to get more reliable data.

Conclusion

In this study, we investigate the effects of reverberation, predominantly the decay time of spaces, on the perception of dissonance, and explore the relation between the sensory roughness and musical dissonance, as defined in tonal Western music.

The experiment and the data analysis process provide insights about confounds of the experiment design, significantly relating to the parts where subjects had confusions on rating scales and absolute dissonance level. These observations direct us to design a new experiment where the ratings of each separate dissonance metrics, i.e. sensory dissonance, musical dissonance, and unpleasantness of a chord change, are asked explicitly to the subjects. Additionally, a clearer approach to distinguish relative and absolute dissonance is needed to be adapted in the future study.

The experiment results show that the acoustic properties of spaces affect the perceived dissonance, either increases or decreases depending on the chords' *richness* and *clarity*. This outcome lead to another question which inquire the intersection of sensory and musical dissonance. One future study direction is to examine the reasons resulting in perceptual change of the chord quality in different spaces. Another, with more practical focus to benefit performers and composers, is to derive a quantitative measurement metric for dissonance perception for a given space and a chord sequence.

References

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