Music 251 Final Project Report

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Title: *The effect of even harmonic attenuation on instrument timbre perception across instrument class*

Abstract

Timbre is a fundamental perceptual feature used in distinguishing and assessing the quality of instruments in a musical context. Prior research has attempted to map specific acoustic properties onto perceived timbral quality and dissimilarities across various sounds at a constant pitch and volume. Studies have found certain acoustic parameters particularly important in distinguishing musical instrument timbres from one another, including attack time, spectral centroid, spectral flux, and even harmonic attenuation. However, most studies have not attempted to examine how these parameters may be altered in acoustic recordings of instruments, and in what fashion this will impact perceived timbral dissimilarity. Participants were tasked with rating the dissimilarity between recorded acoustic instrument tones and altered versions created by attenuating even harmonic frequencies at varying levels. It was hypothesized that attention to the attenuation of even harmonics, and thus rated dissimilarity, would vary based on the instrument class, with wind instruments and impulsively excited instruments being assessed in the present study.

Introduction

Caclin et al. (2005) aimed at confirming the importance of a set of timbral properties in pitched tones. Specific timbral components were altered in synthetic tones generated by additive synthesis. The assessed components included: attack time, spectral centroid, spectral flux, and the attenuation of even harmonics. Participants were tasked with rating the dissimilarity between all of the different sets of generated tones. A multidimensional scaling (MDS) analysis was performed on the dissimilarity ratings to generate a perceptual timbre space. The MDS results were then compared to the acoustic alterations used to generate the tones in order to assess the acoustic properties' relative importance in the perceived difference reported by participants. The results of this study confirmed the importance of spectral centroid, the log of attack time, and the attenuation of even harmonics in such synthetic tones. Spectral flux was only found to be important under constrained circumstances. This study builds upon prior work by showing how artificial alteration of audio can validate the importance of certain components of timbre (including the attenuation of even harmonics). However, it is constrained in looking only at very simple tones.

Kendall et al. (1999) compared recorded instrument timbres with synthesized instrument timbres to attempt to identify what acoustical properties might dictate the differences in their perceived timbres. Several different types of synthesizer instrument samples were assessed. In the third of four experiments, participants were tasked with listening to tones across a set of natural and synthesized instrument sounds and rating the perceived timbral dissimilarity. MDS was used to assess these dissimilarity scores by using the scores to create a two dimensional perceptual timbre space. The researchers mapped the dimensions of this space to the change in the spectral centroid, which they classified as indicating the level of instrument nasality, and the spectral variability, which they classified as indicating the level of instrument brilliance. This study is useful in assessing potential acoustic differences that dictate our perception of different instruments from each other. However, while the acoustical properties of spectral centroid and spectral variability mapped relatively well onto the timbre space as analyzed in the study, few acoustical properties were assessed and the timbral space dimension was reduced to a large degree.

Siedenburg et al. (2016) assessed timbre in instrumental and synthesized instrument tones as well, but this time with the aim of investigating whether timbre was dictated more by continuous acoustical properties or categorical associations. In this experiment, acoustic instrument recordings were used as stimuli, as were synthesized instrument samples created by splicing together the spectro-temporal envelope and fine structure of different instruments in various configurations. Once again, participants were asked to rate the dissimilarity amongst acoustic recordings and amongst all stimuli. A hierarchical cluster analysis on ratings among only the acoustic recordings showed some clusters seemed more dictated by categorical instrument classes (such as wind instruments), while others were more dictated by acoustical properties (such as bright instruments). Another finding comparing acoustic instruments and synthesized instruments also found that dissimilarity ratings tended to increase when a synthesized sound was played before the sound of an acoustic instrument. The results of this paper help to show how categorical associations and acoustical cues are both important in dictating our perception of timbre. They also help show how being presented with certain stimuli may prime individuals' perception of timbre. This phenomenon is potentially due to a known sound engaging our focus on different aspects of timbre that may be more relevant to the class of stimuli as we identify them. However, the alteration method used in this study to generate instrument sounds of an altered timbre would rarely arise in other contexts. Altering an instrument sounds timbre in accordance with an acoustic property of timbre deemed to be particularly important may yield more conclusive results as to how categorical associations interact with acoustic property perception.

The present study investigated how the attenuation of even harmonics affects timbre dissimilarity in acoustic instrument recordings. It builds upon the three aforementioned studies (Kendall et al. (1999), Caclin et al. (2005), Siedenburg et al. (2016)) by assessing an acoustic component of timbre shown to be relevant in prior work, yet used to alter instrument recordings, and compare the interaction of the acoustic property with a cognitive category (instrument class). The acoustic property of even harmonic attenuation, deemed relevant to timbre perception in the study by Caclin et al. (2005) will be altered, however in the more complex context of acoustic instrument recordings as opposed to synthetic tones. As in the studies by Kendall et al. (1999) and Siedenburg et al. (2016) the timbres of acoustic instruments were compared to synthetic versions. However, the present study assessed more minute filter operations instead of synthesized tones to better assess the causal relationship between an intentional change in a particular timbral component and the resulting dissimilarity ranking relating to altering just a single parameter. The present study also builds upon the findings of Siedenburg et al. (2016) in assessing how acoustic components of timbre interact with cognitive notions of instrument categories.

The present study investigates how even harmonic attenuation impacts dissimilarity in acoustic instruments by filtering down the even harmonics of acoustic instrument recordings to a variety of degrees. Participants rated the dissimilarity of these altered recordings in relation to the unaltered versions. This procedure ensures that timbre dissimilarity is only being assessed based on this single acoustic property. Participants rated the dissimilarities of samples from two instrument classes: wind instruments and impulsively excited instruments. These classes were shown to be perceptual relevant in the study by Siedenburg et al. (2016) and enable the assessment of how instrument category identification may interact with the perception of timbre dissimilarity imposed by an acoustic timbral property.

It is hypothesized that the attenuation of even harmonics is a more perceptually relevant timbral property of wind instruments than impulsively excited instruments due to their being more steady state, tonal instruments, and thus relying less on how their spectrum changes over time. Prior work (Kendall et al. (1999), Siedenburg et al. (2016)) has shown the importance of even harmonics and spectral distribution on perceived dissimilarity in steady state tones and wind instrument timbres. It is thus believed that even harmonic attenuation will be a more relevant acoustic component in wind instruments, which are more steady-state in nature, as opposed to impulsively-excited instruments, which are more temporally variable. By this justification changes in the even harmonic attenuation applied to wind instrument recordings would result in a higher degree of perceived difference than in impulsively excited instruments adjusted to the same degree.

Methods

Participants

A total of 6 participants were tested in the present study (4 female, 2 male). The average age of participants was 23.5. All participants noted some prior musical experiences. 4 participants noted that they played the piano (relevant to this study as piano material was included in the stimuli).

Stimulus

Acoustic recordings were chosen from the University of Iowa's electronic music studios musical instrument samples dataset. Recordings were used from a total of six different instruments: three for each of the two instrument classes investigated. Sounds of a flute, alto saxophone and oboe were used for the wind instrument class and sounds of a piano, marimba, and vibraphone were used for the impulsively-exited instrument class. Recordings consisted of the instrument playing a single E flat 4 note. Samples were at a sampling rate of 44.1kHz at 24 bits per sample. These acoustic samples were then processed by attenuating even harmonics (from harmonic 2 to harmonic 12) at varying levels of attenuation (from 0dB to 36dB with a step size of 4dB) at a bandwidth of 6.5. Samples were generated in ProTools using the Waves Renaissance Equalizer plugin. Participants were encouraged to take the experiment in a quiet room with over-ear headphones.

Figure 1. Waves Renaissance Equalizer plugin setup in Pro Tools used for even harmonic attenuation applied for the 12dB case.

Procedures
Participants were first presented with a task to familiarize themselves with the dissimilarity rating task. They were presented with a set of two different acoustic instrument recordings (not included in the testing procedure) and asked to rate the dissimilarity of the two sounds. This procedure was replicated for a total of 4 trials. For the experiment task they were presented with an unaltered acoustic instrument recording followed by a processed recording with even harmonics attenuated. Participants were then asked to rank the dissimilarity of the two recordings on a scale from 1 (identical) to 9 (extremely dissimilar). The testing session consisted of 60 trials. The experiment was anticipated to take 30 minutes to complete. A Qualtrics survey was used to administer the experiment.

Figure 2. Experiment task timeline

Data collection and Analysis
Dissimilarity ratings of altered recordings from the baseline were collected. The results of participants were accumulated and assessed within each instrument across the level of even harmonic attenuation. These patterns of dissimilarity rating change vs. amount of attenuation were then compared across different instruments within and across the instrument classes of wind instruments and impulsively excited instruments.

Results

Figure 3 depicts the average dissimilarity ratings evaluated across each instrument for each level of even harmonic attenuation. Figures 4-5 further elucidate these results by focusing on particular instrument clusters determined by patterns in the data.

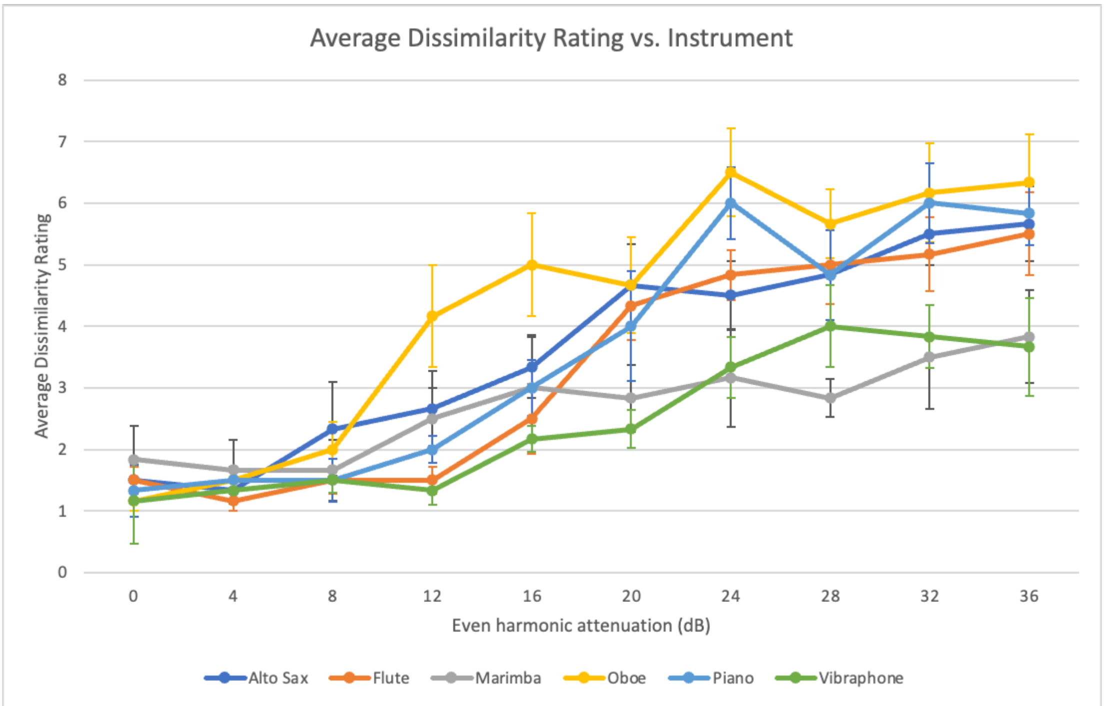

Figure 3. Average dissimilarity rating evaluated across each level of even harmonic attenuation for each instrument investigated.

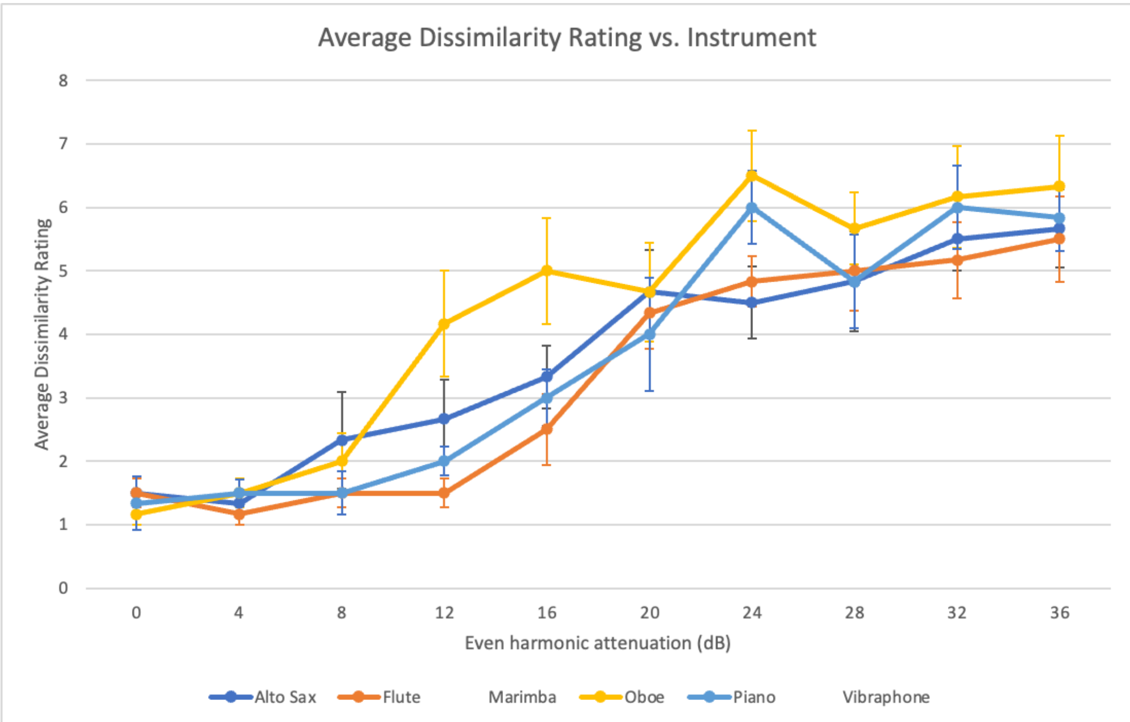

Figure 4. Average dissimilarity rating evaluated across each level of even harmonic attenuation for the alto saxophone, flute, oboe, and piano instruments.

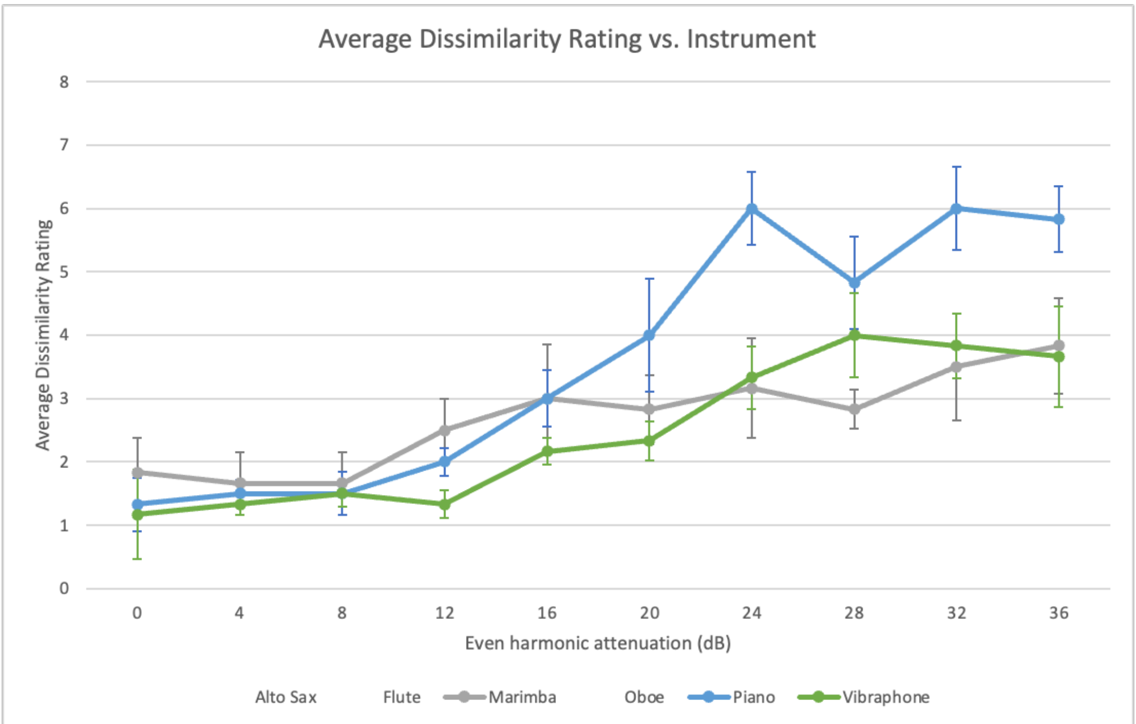

Figure 5. Average dissimilarity rating evaluated across each level of even harmonic attenuation for each of the instruments in the impulsively excited instrument class: marimba, piano, and vibraphone.

Figures 3-5 show a lower slope in the increase of dissimilarity ratings for the marimba and vibraphone instruments as even harmonic attenuation increases, in comparison to the wind instrument class (alto saxophone, flute, and oboe) as well as the piano.

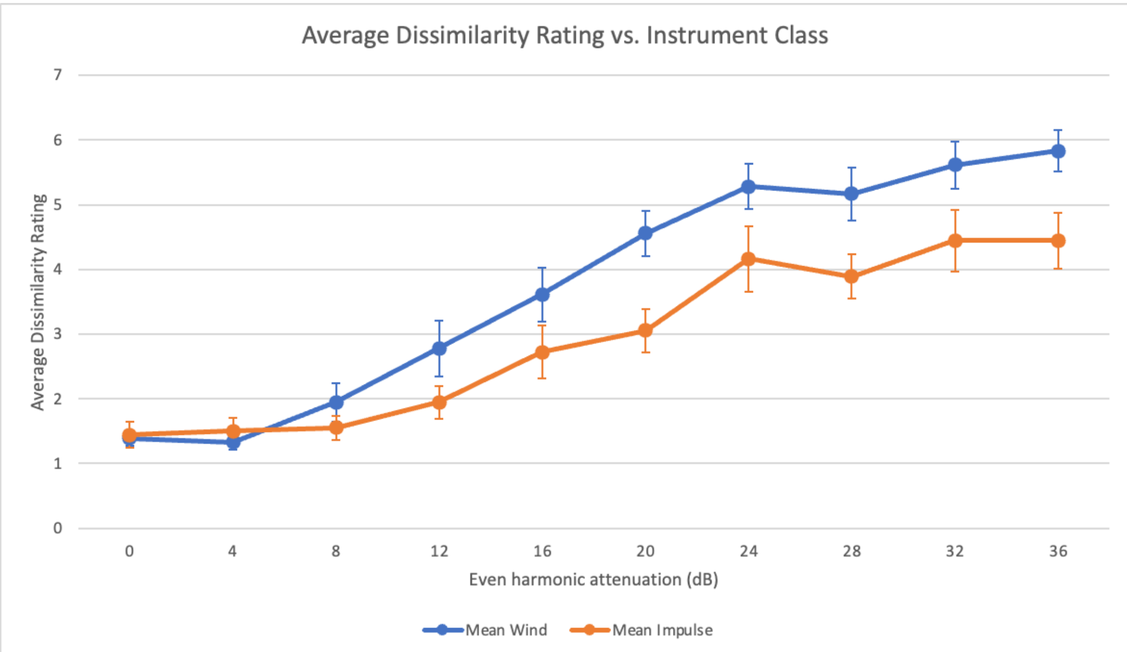

Figure 6. Average dissimilarity rating evaluated across each level of even harmonic attenuation per instrument class.

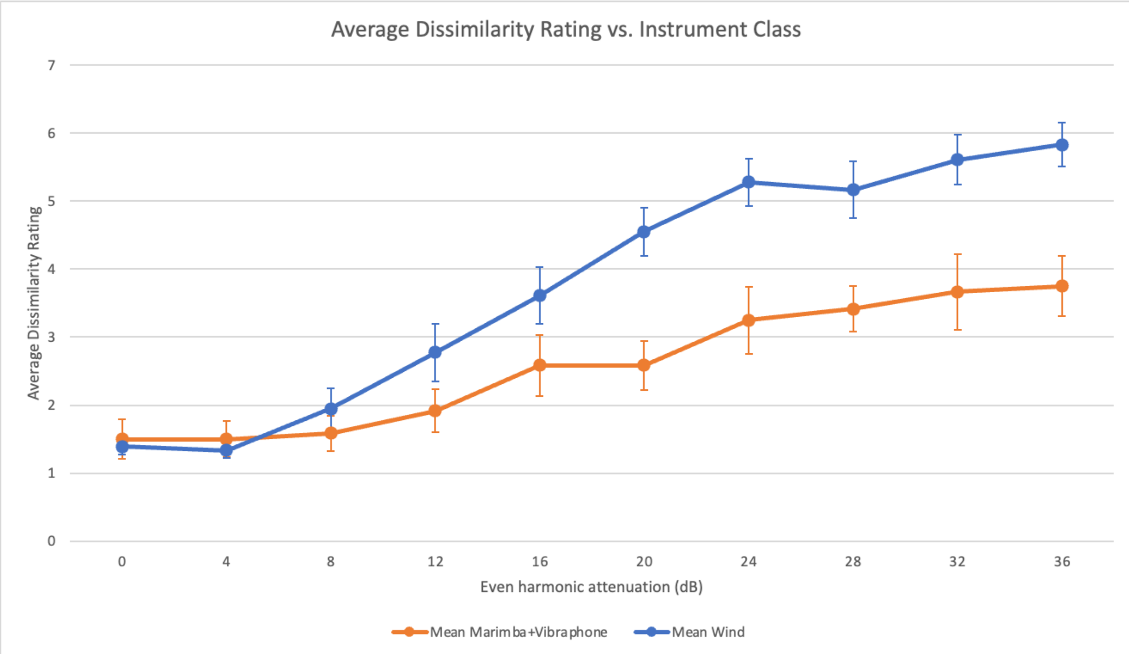

Figure 7. Average dissimilarity rating evaluated across each level of even harmonic attenuation per instrument class (excluding the piano).

Figure 6 further shows how dissimilarity ratings remain lower for the impulsively excited instrument class, in relation to the wind instrument class, as even harmonic attenuation increases. It is also shown how dissimilarity ratings for the impulsively excited instrument class tend to increase from the baseline after 8dB of even harmonic attenuation, while wind instrument dissimilarity ratings tend to increase from the baseline after 4dB of even harmonic attenuation. Figure 7 shows how excluding the piano from the impulsively excited instrument class significantly exacerbates the difference between classes.

Discussion

The results of the present study show that dissimilarity ratings are generally lower in the impulsively-excited instruments, compared to wind instruments at the same level of even harmonic attenuation, as even harmonic attenuation increases. This is true in assessing each class separately, however, separating out individual instruments shows how the instrument classes investigated may not be the most perceptually relevant for this attribute of timbre. These results indicate that sensitivity to this timbral attribute is effected by instrument categorization, though which elements determine relevant categorization may require further investigation.

Figure 6 shows that wind and impulsively-excited instruments do have a distinct difference in how even harmonic attenuation impacts dissimilarity ratings, with impulsively-excited instruments being less sensitive to changes, as hypothesized. However, it can also be shown how one of the instruments in the impulsively-excited instrument class, the piano, follows a similar trajectory to those in the wind instrument class (Fig. 4). When excluded from the impulsively-excited instrument class, the class differences are thus exacerbated (Fig.7). This indicates that the piano potentially should not be classed with the marimba and vibraphone for this particular timbral attribute, and thus that woodwinds vs. idiophones may be a more perceptually important classification in regard to even harmonic attenuation. These findings show the relevance of some instrument categorizations in timbre perception as found by Siedenburg et al. (2016), however, unlike the results found by Siedenburg et al. (2016), impulsively-excited instruments seems like it is not a very perceptually relevant category in dictating dissimilarity ratings.

The present study affirms the results of Caclin et al. (2005), showing even harmonic attenuation's impact on more complex acoustic content through the use of instrument recordings. These studies also both help to establish relationships between manual alteration of musical timbres, and the resulting perceptual impacts on perception. The present study also builds upon the work of Kendall et al. (1999) by focusing on a very narrow timbral attribute and showing how it may be interpreted in the differentiation of instruments, though with timbral variation being artificially introduced to validate whether these findings can be deemed causal in initiating perceptual dissimilarity.

One aspect of this study that may complicate its findings is the fact that 4 out of the 6of participants noted they played the piano, one of the instrument timbres used in the experiment. The increased experience with this instrument may have increased these individual's sensitivity to changes in the piano tone, in particular. Drost et al. (2007) investigated how instrument timbre impacted a different musical task. Drost et al. (2007) enlisted participants with experience playing two different instruments: guitar and piano. Participants were tasked with playing a chord in accordance with a visual stimulus while an irrelevant auditory stimulus was also presented, either the same as the visual stimulus (congruent) or different from it (incongruent). Reaction time and error rate for the task were both assessed and it was found that reaction times increased (from congruent to incongruent) when the instrument timbre used to present the auditory stimulus was similar to the instrument the participant played. Pianists had a greater reaction time when the auditory stimulus used a piano or an organ timbre, while guitarists had a greater reaction time when the auditory stimulus used a guitar timbre. Reaction times were not significantly different (from congruent to incongruent) for instruments the participant did not play. Though Drost et al.'s (2007) experiment relies on the interaction between instrument timbre and pitch, it is indicative that there is a higher sensitivity induced in musicians when presented with timbres close to their own instrument. This may also indicate experience with an instrument could impact the cognitive classification of their own instrument in regards to others. Further research may be explored to further isolate how instrument familiarity impacts timbre sensitivity in a more direct fashion.

The present study was effective in isolating a single component of timbre and utilizing relatively simple methods to show how it relates to categorical cognitive associations. However, the nature of the dissimilarity ratings and the testing procedure using a dissimilarity scale likely implicitly primed the users to rate changes higher than they would if given more dissimilar material (ex. If they were asked to relate different instruments or more fundamentally altered audio). This makes the results difficult to generalize or compare with other research or other components of timbre. Future research might incorporate different types of timbral alterations in a single testing procedure, or include a more comprehensive training procedure in order to make results more generalizable. The present study was further limited by the small number of test participants from a relatively similar background. As was noted earlier, all had some prior musical training and had a variety of experience with various musical instruments. The fact that 4 participants had experience playing the piano also may have skewed the data, if familiarity with a particular instrument increases sensitivity to timbre changes. Further work could also be performed to investigate how these results expand to more instrument classes, like different kinds of percussive instruments, or string instruments.

Conclusion

The present study investigated how the attenuation of even harmonics induced dissimilarity ratings across wind instruments and impulsively-excited instruments. Participants were tasked with rating dissimilarity of altered and un-altered versions of acoustically recorded instrument tones at different levels of harmonic attenuation. It was found that, in general, even harmonic attenuation applied to the impulsively-excited instrument class resulted in lower dissimilarity scores compared to the wind instrument class at the same level of attenuation. However, the trajectory of the piano instrument seemed to more closely mimic that of the wind instruments than the other impulsively-excited instruments in its class. This raises questions on which instrument categories are most perceptually relevant for this particular aspect of timbre, a topic that further research may be able to investigate.

References

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