DURMS
Durham Undergraduate
Research in Music & Science

The Effect of Inharmonic Timbre on Western Consonance Perception and Familiarity: A Replication Project

Victoria Ridgway
Durham University

ABSTRACT

Consonance is typically connoted with pleasantness, and scientists have debated the origins of this feeling, as well as what factors contribute to it for centuries. Replicating Lahdelma & Eerola's 2020 paper: *Cultural familiarity and musical expertise impact the pleasantness of consonance/dissonance but not its perceived tension*, this study aims to integrate the commonly overlooked characteristic of inharmonicity by comparing 28 self-reported consonance ratings of 6 triads on piano and gamelan. Familiarity to each stimulus was also reported, as current literature indicates cultural familiarity has a large effect on timbral preference and consonance perception. Stimulus familiarity was shown to have a dominating influence on consonance perception in both musicians and non-musicians, musicianship was not found to have any overall effects. Inharmonicity was found to have a significant negative effect on consonance perception when played using consonant Western chords. However, as chord dissonance increased, the difference in consonance perception between gamelan and piano diminished. Acoustic roughness, commonly used as a measure of timbre, was expected to correlate with a decrease in consonance rating, but piano was calculated to have a higher acoustic roughness than gamelan. This indicates that future studies should consider using dissonant chords from non-Western cultures, based on the specific inharmonic spectra of the instrument used.

1. INTRODUCTION

Academics have debated theories of consonance for centuries. The most used theories of consonance perception focus on either: biological processes (Bones et al., 2014; Helmholtz, 1875; Plomp & Levelt, 1965; Tramo et al., 2001) or psychological, using Gestalt-based perceptual rules (Dewit & Crowder, 1987; Huron, 2001; Johnson-Laird et al., 2012; Wright & Bregman, 1987). Two of the most accredited were proposed by Helmholtz (1875) and Stumpf (Dewit & Crowder, 1987). The former refers to the interaction of closely related tones causing the experience of acoustic roughness as dissonance, while the latter suggests that consonance perception arises via fusion of complex tones, when tuned to simple frequency ratios. Further studies are in accordance with Helmholtz in that dissonances are caused by acoustic roughness (Johnson-Laird et al., 2012; Plomp & Levelt, 1965). The original study (Lahdelma & Eerola, 2020) aimed to investigate Western participant's perception of consonance and dissonance in both single intervals and chords. Two empirical experiments were conducted. Experiment 1 explored the overlap of seven most used concepts denoting consonance and dissonance (C/D), (Consonance, Smoothness, Purity, Harmoniousness, Tension, Pleasantness, Preference). Experiment 2 involved the stimuli's cultural familiarity, excluding purity and smoothness. Both experiments aimed to have a participant pool size comparable to Bowling et al., (2018), the first containing 407 participants, and the second with 392. The study was conducted using the website *Qualtrics Survey Software,* where basic demographic questions were asked (including OMSI). In both experiments participants were randomly allocated one concept to rate on a Likert scale, where the intervals/chords presented were based Bowling et al., (2018). Results drawn from these indicate that all concepts display high correlations, and that with decreasing cultural familiarity came a decrease in the ratings of three concepts, including consonance.

Current literature is largely focused on the influence of timbre on listener emotions or affect, where the majority suggest that timbre is correlated to emotional perception (Eerola et al., 2012; Hailstone et al., 2009). Dissonance tends to induce stronger defence responses and unpleasant feelings for participants with a higher musical education (Dellacherie et al., 2011; Terhardt, 1974). Dellacherie et al. found evidence that an increase of musical expertise, results in 'a long sustained associative learning between dissonance and unpleasant emotions' (2011, p. 347), in line with the previously mentioned studies. However, another found that an increase in musical training and familiarity to a chord resulted in a reduction of perceived dissonance (McLachlan et al., 2013). Similarly, a recent study concluded that participants prefer timbres that are found in the musical styles prominent in their cultures, due to familiarity of the sonorities (Marjieh et al., 2024). The original study for this project found that, while most concepts denoting C/D are not affected by musical expertise, tension was consistently rated higher in musicians than non-musicians, which was concluded to be the most preferable synonym for C/D (Lahdelma & Eerola, 2020). A commonality between most of these studies is the use of acoustic roughness as a measure of timbre; an increase in acoustic roughness is correlated with an increased sense of dissonance, as theorised by Terhardt (1984). Thus, it was clear that the most common variables in C/D studies were acoustic roughness,

musical expertise, and familiarity. One obvious gap in previous research regards the investigation into inharmonic timbres, as the most common procedure is to use tones tuned in equal temperament, as is done in the original study (Eerola et al., 2012; Lahdelma & Eerola, 2020).

This study uses acoustic roughness, musical expertise, and familiarity, which were all included in Lahdelma & Eerola's (2020) study, as well as integrating an inharmonic timbre to investigate a range of aspects which were previously neglected. It aims to empirically explore if inharmonic timbres will impact Western musician and non-musician's consonance perception, essentially combining experiment 1 and 2 of Lahdelma & Eerola (2020). The hypotheses state that: gamelan (inharmonic) will consistently be perceived as more dissonant than piano (harmonic, in equal temperament). There will be a correlation between acoustic roughness, as a measure of timbre, and C/D perception. An inharmonic spectra will always be rated more as dissonant. A subhypothesis states that due to their involvement in orchestras (which can include inharmonic instruments, particularly percussion) and greater opportunity to study non-Western music, musicians are expected to be more familiar with inharmonic stimulus, thus are predicted to perceive gamelan as less dissonant than non-musicians.

2. METHODS

Participants. Consistent with Lahdelma & Eerola (2020), the experiment was conducted via *Qualtrics Survey Software,* which is an online survey tool. 28 Western participants were recruited through convenience sampling method, via text message and social media interaction. They were asked basic demographic questions, such as age, gender, and musical expertise, taken from the Ollen Musical Sophistication Index (Ollen, 2006). The mean age was 23.38, standard deviation (SD) of 8.38 and all participants were over 18. 68% were female and 32% were male, the average time taken was 309 seconds (s), SD was 6.14. Due to participant pool size, the only results excluded were those that did not complete 100% of the study. OMSI results indicated that *amateur musician* was the most common at 36%, followed by *non-musician* at 25%, *serious amateur musician* 21%, and *music loving non-musician* 18% (no participants reported semi-professional or professional musician), these results are similar to Lahdelma & Eerola and Bowling et al., (2018) where an even split of musicians and non-musicians was achieved. As the participant pool size was distinctly smaller, and to aid in statistical analyses, non-musician and music loving non-musician were grouped into *non-musician* (12 people at 43%), amateur musician and serious amateur musician were grouped into *musician* (16 people at 57%). Every participant was given the definition of consonance and dissonance used in Bowling et al. in the information sheet, however if the OMSI result chosen was below serious *amateur musician* the definitions were given again before the study began. All participants above non-musician were asked to report total years of formal music theory training.

Materials. Stimuli were chosen based on the ratings in Bowing et al. (2018), and chords were grouped into three levels of consonance (consonant, middle, dissonant). A random number generator was used to select two chords from each group- ensuring there was a representative spread of very consonant to very dissonant. While Lahdelma & Eerola (2020) used dyads, trichords, and tetrachords, only trichords were used in this study following the theory that harmony is a three-tone phenomenon (Cook & Fujisawa, 2006), and to keep the study at an acceptable length of time. This is also why most of the seven concepts denoting consonance used in the original study were excluded.

Procedure. The six chosen triads were: root major triad, 1st inversion major triad, 1st inversion minor triad, Italian 6th, Viennese triad, and root diminished triad- all in C. These were abbreviated to C1, C2, M1, M2, D1, and D2 respectively. Logic X was used to create the .wav files, using Bosendorfer Grand Piano and Indonesian Gamelan, the six triads were produced in both instruments for a total of 12. The average pitch was set to C4, velocity at 65, and duration at 2s. No reverb or fade out was used. In accordance with Lahdelma & Eerola, participants were played the stimuli in a randomised order to remove bias, for each triad participants were asked to rate consonance level on a typical 5 point Likert scale (1 = dissonant, 5 = consonant), and familiarity to the stimuli (1 = not familiar at all, 5 = very familiar).

3. RESULTS

Analyses have been done regarding consonance and timbre, musicianship, and familiarity. Figures are included for key results. Figure 1 displays results mostly in line with Lahdelma & Eerola (2020).

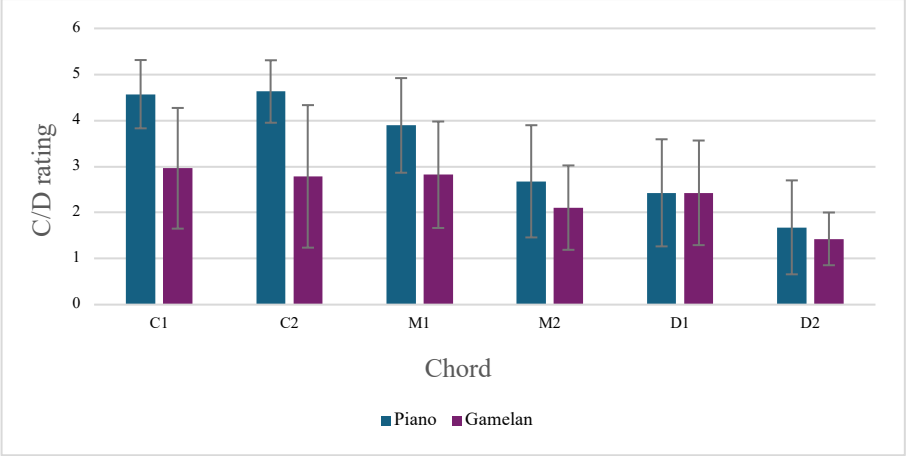

Figure 1. C/D ratings, musician and non-musician results combined

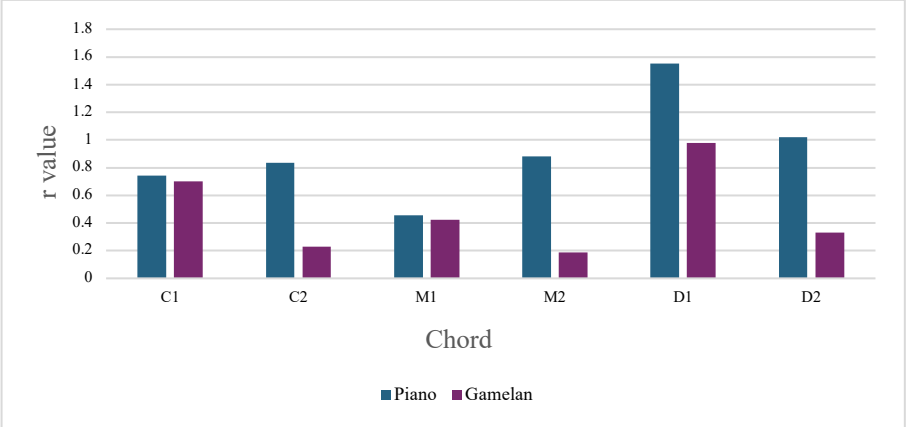

Figure 2. A comparison of the r values for acoustic roughness, calculated using a model based on human auditory perception (Wang et al., 2013)

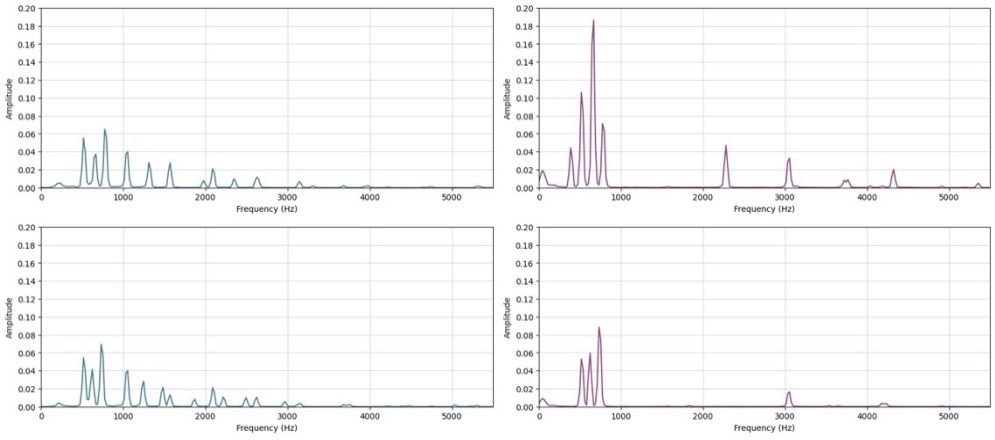

Figure 3a. Frequency spectrums C1 and D2 respectively (piano in blue; gamelan in purple)

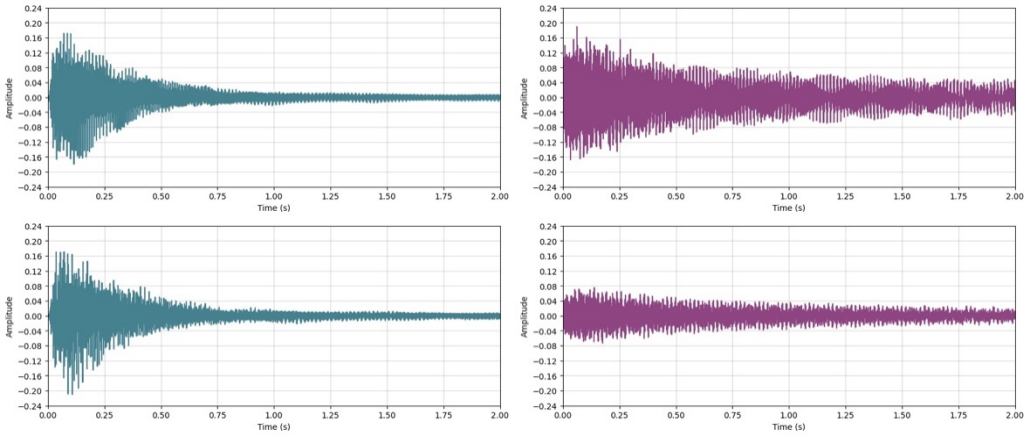

Figure 3b. Waveforms for C1 and D2 respectively (piano in blue; gamelan in purple)

Consonance and timbre. An ANOVA analysis revealed that acoustic roughness had a statistically significant effect of C/D ratings, $F(310, 11) = 24.600$, $p = < .001$. However, after a t-test was conducted for the C/D ratings of the two most dissonant triads between gamelan and piano: D1: $t(27) = .00$, $p = 1.00$ and D2: $t(27) = 1.27$, $p = .215$, in both cases $p > .05$ indicating no statistically significant difference. While timbre did have an overall effect on C/D ratings, the two most dissonant chords are outliers in this pattern. Thus, Pearsons's r correlation was used to investigate the relationship between acoustic roughness and C/D ratings. The result, $r = .018$, $p = .741$, indicates no significant correlation.

Familiarity. An ANOVA analysis revealed that acoustic roughness had a significant effect on familiarity rating, $F(320, 11) = 6.792$, $p = < .001$, and familiarity to the stimuli had a significant effect on C/D ratings, $F(322, 4) = 26.012$, $p = < .001$, as in both $p < .05$. A linear regression was performed to explore the mediating effects familiarity had on the relationship between acoustic roughness and C/D rating, $t = -2.474$, $p = .014$. As $p < .05$ there was a significant mediating effect. Furthermore, the two most dissonant chords saw a slight decrease in piano familiarity when a t-test was run between the 2 timbres, D1: $t(2.962) = 26$, $p = .006$ and D2: $t(2.875) = 27$, $p = .008$, but in both tests $p < .05$ so there was still a significant difference.

Musicianship. Two linear regressions were conducted to explore: any mediating effect musicianship had on the relationship between acoustic roughness and C/D ratings, $t = -.026$, $p = .979$, as $p > .05$ musicianship had no significant mediating effect on C/D ratings. And the mediating effect musicianship had on the relationship between familiarity and C/D ratings, $t = .801$, $p = .423$, $p > .05$ therefore no significant mediating effect was found.

4. DISCUSSION

As current C/D experiments focus on Western timbre, this study aimed to replicate Lahdelma & Eerola's (2020) study with the incorporation of inahrmonic timbre (gamelan). Replication research has seen a sudden increase in popularity due to the realisation of the need to test replicability of past experiments (Woodell, 2020).

Overall, the study replicated Lahdelma & Eerola's (2020) main findings. Timbre (or acoustic roughness) were found to have significant influences on C/D ratings, as well as familiarity. Furthermore, in both studies musicianship did not have a significant effect on C/D ratings, the only exceptions in the original were *Purity* in experiment 1, and *Tension* in experiment 2. Lahdelma & Eerola's observation- that musicians constantly perceive stimuli as more tense, especially when it is unfamiliar- provides evidence in favour for Marijeh et al. (2024) and against McLachlan et al. (2013). Our findings, however, did not indicate any relationship between musicianship and any other variable, although there was evidence in favour of the influence of familiarity on C/D ratings which is in accordance with Lahdelma & Eerola's sine wave conclusion.

Interestingly, both Terhardt (1984) and Lahdelma & Eerola (2020) found that sensory consonance resulted in higher consonance perception. The conclusions from this study provide evidence against these claims, most likely due to the use of inharmonic timbre. As seen in Figure 2 piano acoustic roughness was found to be consistently

higher than gamelan, however gamelan was reported as being less consonant. The Pearson's r correlation indicated that as acoustic roughness increased in the piano, the difference between C/D ratings in both instruments was insignificant, which was not found in Lahdelma & Eerola (2020). The final two most dissonant chords (D1 and D2) are of particular interest due to their lack of statistical difference. A compelling explanation for this is given by Sethares (2004, p. 199), this study used triads based on Western 12 note divisions of the octave, however 5 or 7 note scales, slendro and pelog, align better with the inharmonic specra of the instrument. Therefore, it could be argued that the dissonant characteristics of inharmonic instruments are artificially inflated when used in studies that use exclusively Western based chords. This is supported in Marjieh et al., (2024) where non-harmonic intervals were preferred when dyads were tuned to bonang tuning. Furthermore, the results for D1 and D2 support the idea that with familiarity, comes a decreased sense of dissonance (Friedman et al., 2021; Marjieh et al., 2024; Cazden, 1962), however, no evidence was provided in favour of musicianship having the same, or any, effect (Dellacherie et al., 2011; McDermott et al., 2010; McLachlan et al., 2013). As the current study found no significant interaction between musicianship and any of the other tested variables, no further analyses were able to be performed- as was done in the original study. Sensory consonance was higher in gamelan for more dissonant triads (Bowling et al., 2018). As there was a lower acoustic roughness r value, fewer frequency peaks and less attack than in more consonant triads (Hailstone et al., 2009, p. 2152), as can be seen in Figure 3. Regardless, piano stimuli were consistently rated higher in familiarity and consonance although it had higher acoustic roughness. The t-test results regarding the C/D rating between piano and gamelan for D1 and D2 provide strong evidence for cultural familiarity playing a more important role in consonance perception than acoustic roughness. The original study found evidence in favour of Terhardt's views on the dominance of cultural familiarity over acoustic roughness in C/D perception (1984) which was successfully replicated in this study.

Improvements and future research. A larger pool size may have enabled a greater precision of statistical analysis, which would have allowed a more direct comparison to Lahdelma & Eerola (2020), as well as between other connotations of consonance, such as pleasantness and harmoniousness. Furthermore, an alternative software could have been used to generate a defined gamelan sound, as Logic X contained only one generalised gamelan. This would have allowed accurate audio analysis, focusing on the inharmonic spectra of a specific gamelan instrument, in comparison to piano. Changing consonance and dissonance to *tension*, as indicated in Lahdelma & Eerola, would have improved consistency between musician and non-musician data, as musicians may have been more familiar and had a concrete understanding with the subject specific terms.

This study aids wider consonance theory debate, as many well-respected experiments focus on using harmonic instruments tuned in equal temperament. As was also suggested in the original study (Lahdelma & Eerola, 2020), this study indicates that more research should be performed regarding cultural familiarity and consonance perception. Marjieh et al., (2024) recommend that new research should also focus on the use of inharmonic timbre to bring consonance debates out of the Western-centric view, which is an argument supported by this study. Research should incorporate both Western chords and those derived from slendro and pelog scales. Stimuli should be played on both piano and gamelan to explore whether a Western instrument, tuned in equal temperament, is perceived to be equally dissonant to the gamelan when Western chords are employed.

REFERENCES

Bones, O., Hopkins, K., Krishnan, A., & Plack, C. J. (2014). Phase locked neural activity in the human brainstem predicts preference for musical consonance. *Neuropsychologia*, *58*, 23–32. https://doi.org/10.1016/j.neuropsychologia.2014.03.011

Bowling, D. L., Purves, D., & Gill, K. Z. (2018). Vocal similarity predicts the relative attraction of musical chords. *Proceedings of the National Academy of Sciences*, *115*(1), 216–221. https://doi.org/10.1073/pnas.1713206115

Cook, N. D., & Fujisawa, T. X. (2006). The Psychophysics of Harmony Perception: Harmony is a Three-Tone Phenomenon. *Empirical Musicology Review*, *1*(2), 106–126. https://doi.org/10.18061/1811/24080

Dellacherie, D., Roy, M., Hugueville, L., Peretz, I., & Samson, S. (2011). The effect of musical experience on emotional self-reports and psychophysiological responses to dissonance. *Psychophysiology*, *48*(3), 337–349. https://doi.org/10.1111/j.1469-8986.2010.01075.x

Dewit, L. A., & Crowder, R. G. (1987). Tonal Fusion of Consonant Musical Intervals: The Oomph in Stumpf. *Perception & Psychophysics*, *41*(1), 73–84. https://doi.org/10.3758/BF03208216

Eerola, T., Ferrer, R., & Alluri, V. (2012). Timbre and Affect Dimensions: Evidence from Affect and Similarity Ratings and Acoustic Correlates of Isolated Instrument Sounds. *Music Perception*, *30*(1), 49–70. https://doi.org/10.1525/mp.2012.30.1.49

Friedman, R. S., Kowalewski, D. A., Vuvan, D. T., & Neill, W. T. (2021). Consonance Preferences Within an Unconventional Tuning System. *Music Perception*, *38*(3), 313–330. https://doi.org/10.1525/mp.2021.38.3.313

Hailstone, J. C., Omar, R., Henley, S. M. D., Frost, C., Kenward, M. G., & Warren, J. D. (2009). It's not what you play, it's how you play it: Timbre affects perception of emotion in music. *Quarterly Journal of Experimental Psychology*, *62*(11), 2141–2155. https://doi.org/10.1080/17470210902765957

Helmholtz, H. L. F. (1875). *The Sensations of Tone: As a Physiological Basis for the Theory of Music* (A. J. Ellis, Trans.). Green and Co.

Huron, D. (2001). Is Music an Evolutionary Adaptation? *Annals of the New York Academy of Sciences*, *930*(1), 43–61. https://doi.org/10.1111/j.1749-6632.2001.tb05724.x

Johnson-Laird, P. N., Kang, O. E., & Leong, Y. C. (2012). On Musical Dissonance. *Music Perception*, *30*(1), 19–35. https://doi.org/10.1525/mp.2012.30.1.19

Lahdelma, I., & Eerola, T. (2020). Cultural familiarity and musical expertise impact the pleasantness of consonance/dissonance but not its perceived tension. *Scientific Reports*, *10*(1), 8693. https://doi.org/10.1038/s41598-020-65615-8

Marjieh, R., Harrison, P. M. C., Lee, H., Deligiannaki, F., & Jacoby, N. (2024). Timbral effects on consonance disentangle psychoacoustic mechanisms and suggest perceptual origins for musical scales. *Nature Communications*, *15*(1), 1482. https://doi.org/10.1038/s41467-024-45812-z

McDermott, J. H., Lehr, A. J., & Oxenham, A. J. (2010). Individual Differences Reveal the Basis of Consonance. *Current Biology*, *20*(11), 1035–1041. https://doi.org/10.1016/j.cub.2010.04.019

McLachlan, N., Marco, D., Light, M., & Wilson, S. (2013). Consonance and pitch. *Journal of Experimental Psychology: General*, *142*(4), 1142–1158. https://doi.org/10.1037/a0030830

Norman Cazden. (1962). Sensory Theories of Musical Consonance. *The Journal of Aesthetics and Art Criticism*, *20*(3), 301–319.

Ollen, J. E. (2006). *A criterion-related validity test of selected indicators of musical sophistication using expert ratings* [Ph.D thesis]. The Ohio State University.

Plomp, R., & Levelt, W. J. M. (1965). Tonal Consonance and Critical Bandwith. *The Journal of the Acoustical Society of America*, *38*, 548–560. http://dx.doi.org/10.1121/1.1909741

Sethares, W. (2004). *Tuning, timbre, spectrum, scale*. Springer.

Terhardt, E. (1974). Pitch, Consonance, and Harmony. *The Journal of the Acoustical Society of America*, *55*(5), 1061–1069. https://doi.org/doi:10.1121/1.1914648

Terhardt, E. (1984). The Concept of Musical Consonance: A Link between Music and Psychoacoustics. *Music Perception*, *1*(3), 276–295. https://doi.org/10.2307/40285261

Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2001). Neurobiological Foundations for the Theory of Harmony in Western Tonal Music. *Annals of the New York Academy of Sciences*, *930*(1), 92–116. https://doi.org/10.1111/j.1749-6632.2001.tb05727.x

Wang, Y. S., Shen, G. Q., Guo, H., Tang, X. L., & Hamade, T. (2013). Roughness modelling based on human auditory perception for sound quality evaluation of vehicle interior noise. *Journal of Sound and Vibration*, *332*(16), 3893–3904. https://doi.org/10.1016/j.jsv.2013.02.030

Woodell, A. (2020). Leaning into the replication crisis: Why you should consider conducting replication research. *Psychology Student Network*. https://www.apa.org/ed/precollege/psn/2020/03/replication-crisis

Wright, J. K., & Bregman, A. S. (1987). Auditory stream segregation and the control of dissonance in polyphonic music. *Contemporary Music Review*, *2*(1), 63–92. https://doi.org/10.1080/07494468708567054

APPENDICES

Appendix A

Definitions of Consonance and Dissonance, Given to Participants

Consonance was described as “the musical pleasantness or attractiveness of a sound,” and “if a sound is relatively unpleasant or unattractive, it is referred to as dissonant” (Bowling, 2018, p. 217).

Appendix B

Survey Questions, Given in Order of Appearance

OMSI 1-question

Which title best describes you?

- Nonmusician
- Music-loving nonmusician
- Amateur musician
- Serious amateur musician
- Semi-professional musician
- Professional musician

Listen to this triad and rate the level of consonance or dissonance you hear. Afterwards, indicate your overall level of familiarity to the sound.

0:00 -0:02

Press the play button to listen to the music.

	1 = Very dissonant	2 = A little dissonant	3 = Neither consonant or dissonant	4 = A little consonant	5 = Very consonant
C/D level	○	○	○	○	○

Indicate how familiar you are with the sound you just heard.

- Not familiar at all
- Slightly familiar
- Moderately familiar
- Very familiar
- Extremely familiar