Spring 2019

To Conceive of Consonance in Chaos: The Influence of the Harmonic Series on the Perception of a New Musical System

Luke Sandbank
Bard College

To Conceive of Consonance in Chaos:

The Influence of the Harmonic Series on the Perception of a New Musical System

Senior Project Submitted to

The Division of Science, Mathematics, and Computing

of Bard College

by

Luke Sandbank

Annandale-on-Hudson, New York

May 2019

Acknowledgments

This project has been supported by the Department of Psychology at Bard College toward the completion of the author’s senior project. This project is a joint senior project in music and psychology, and could not have been possible without enthusiastic support from people in different departments and with varying specialties. Dr. John Halle, as my Music advisor and general advocate of the inquiry, has since my second of four years at Bard provided me with guidance and input by describing music, language, and their structures, as well as by being a nexus between peers and colleagues to help widen the perspective of the project. Dr. Justin Hulbert and Dr. Thomas Hutcheon as psychology advisors have gone to every length to connect me with resources related to lines of inquiry raised . To the extent that the subject matter of this inquiry is related to subjective experiences of music, my experiences in music composition and improvisation courses on campus have been instrumental in forming these inquiries by providing a place where people can experiment with the materials that lead to musical affect. I extend thanks to John Esposito, Erica Lindsay, and Mike DeMicco of the Jazz Program and Joan Tower and George Tsontakis of the Composition Program for their tutelage in the assembly of meaningful musical materials across various paradigms, as well as for their perspectives on how to engage artistically within these paradigms. Matt Sargent of the Department of Music also provided instrumental insight and instruction to Max/Msp. I extend my love and appreciation to the network of peers at Bard’s Annandale campus and Smolny College at Saint Petersburg State University who have helped develop the ideas behind this project and offered moral support as we pursue our interdependent interests.

Table of Contents

Abstract

While auditory preferences are often correlated with low-integer frequency ratios and the harmonic series, adults are capable of quickly learning music that eschews such patterns. Research on the statistical properties of musical tonality finds correlations between the number of times participants are exposed to a note and the rating that note would receive in a probe tone task, which altogether is taken to indicate the tonality of a piece of music. In western music, consonance (as indicated by low-integer frequency ratios) correlates with the function of notes within the tonal hierarchy, but it may be possible to construct tonal hierarchies based on different parameters while utilizing the same underlying principles. Loui et al. (2010) found that participants in a statistical learning paradigm became sensitive to the underlying rules and regularities of one of two musical "grammars", neither of which contain exact analogues of musical intervals that are usually found to be the most essential in the most widespread musical scales. Participants are given probe tone tasks both before and after 25 minutes of exposure to example melodies in one of two grammars to gauge what the initial biases are of the auditory system and which of these assumptions it is capable of eschewing. The exposure period evidently provides enough melodic information for participants to form mental representations of pitch organization in this artificial system, but it is unclear what the fundamental assumptions of the auditory system are when presented with unfamiliar systems of music, or if this processing is taxed by the foreign nature of the music, and if so at what level the bottlenecking occurs. If the mechanism responsible for musical comprehension is limited by certain principles, then therapeutic and commercial applications of musical materials should conform to the lowest common denominator of musical learnability by using tuning systems and chord progressions

that utilize intervallic patterns that are most conducive to auditory encoding and the forming of a mental representation. This study will mirror the methods and design of Loui et al. (2010), but examine further the responses of participants by predicting pre-exposure profiles with models of intervallic consonance.

Introduction[1]

The questions of what neurological mechanisms relate to musical comprehension and how those neurological mechanisms are attenuated throughout an individual's lifetime by education and exposure remain central topics of music psychology. Using event-related potentials (ERPs) such as the N400 and P3b as indicators of the processing of surface characteristics and non-local dependencies, empirical studies have found even non-musicians to show familiarity with the structural regularities of western music (Bigand and Poulin-Charronnat, 2006), with the principle component of multiple levels of organization seeming to be harmonicity. On top of harmony and consonance, western music is also understood to be organized by factors such as rhythmic regularity that can enforced by timbral cues, but the hierarchical patterns of organization for both timbre (Sethares 1992) and rhythm (Razdan & Patel, 2015; Large et al., 2015) follow the same mathematical formulations that pitch organization has been understood by; compiling evidence suggests that these formulations revolve around the harmonic series, a mathematical sequence which has also been found to be relevant to the harmonic partials found in spectrograms of human speech (Schwartz, 2003), providing a source of exposure to harmonicity in early development. Chang & Merzenich (2003) found that rats deprived of meaningful audio stimuli by means of noise immersion showed less "refinement of response selectivity in the primary auditory cortex" when tested as adults, so the exposure to audio stimuli that embodies patterns of harmonicity (such as the human voice and music) may facilitate the neural encoding of musical information related to the harmonic series.

[1] See Appendix B: Glossary for terminology related to harmony

In research rooted in the Western paradigm of music, the perception of consonance appears to be indispensable when engaging with music. Consonance is sometimes described in Western terminology as a state of rest that contrasts to a state of tension (Bigand et al., 1996; Narmour, 1990); with the relative levels of tension and rest being codified by formal descriptions of the tonal hierarchy that applies to a specific scale. These transitions and the levels of tension that fluctuate throughout a song are the main organizing principles of Western music, but accounts vary as to which musical elements are those most directly related to the perception of tension, with scale membership (Trainor & Trehub, 1992) as well as sensory dissonance being prime candidates. Efforts then become focused on determining an objective metric for quantifying sensory dissonance and comparing this metric to behavioral reports on individual's experiences with dissonant and consonant stimuli. Since any testing materials that would collect data for this metric must be free of cultural associations, the use of drastically unfamiliar musical materials becomes necessary.

Hannon & Trainor (2007) would later note that "*...the degree of universality for each type of structure seems to predict the order of acquisition, with sensitivity to consonance emerging earliest (universal), system-specific knowledge of key membership developing later (scales are found in virtually all cultures but differ in specific composition), and knowledge of harmony observed last (specific to Western music).*" To test a metric of dissonance based on harmonic similarity and not scale membership, a musical system must be utilized that does not permit the recognition of familiar scales and modes that would provide musical context to assign an arbitrary rating to a note based on acculturation. A novel musical context will be presented, and tones within that context evaluated for their degree of fit within that context.Without scale membership moderating the perception of intervals, sensory dissonance should exclusively account for the perception of similarity between pitches.

Consonance

Using conventional looking-time/preferential listening methods (Masataka, 2005) and novel methods whereby participants can physically activate sounds at will (Di Stefano et al., 2016), human infants were observed to spend more time performing actions that result in consonant intervals compared to dissonant intervals. Baby chicks (Chiandetti & Vallortigara, 2011) and 5 month old chimps (Sugimoto et al., 2010) appeared to spend more time listening to consonant sounds compared to dissonant sounds. The ability to perceive consonance may be innate to certain species, but is not always associated with pleasure as it is in Western musical terminology. So while some animals seem to be able to perceive the difference between pitch pairs that we have deemed consonant and dissonant, they may not actually prefer these sounds for their aesthetic value as we do. Additional evidence suggests that preferences for contrasting tones may be accounted for by levels of exposure (Plantinga and Trehub, 2014), poking holes in any account of learning that considers features of stimuli to be solely responsible for the cognitive treatment of that stimuli. Regardless, consonance as an innate perceptive capacity stands at a candidate for a universal building block for musical materials.

One of the first systematic descriptions of consonance comes from Pythagoras, who is fabled to have mistaken the ringing of hammers from a blacksmith for something of musical design. Upon examination of the blacksmith’s hammers, the length of the vibrating bodies was found to exist in certain ratios, providing the means for the ringing of different hammers to sound musically pleasant when juxtaposed. Pythagoras would also discover how the length of a string effects its pitch, and which pitch relationships give rise to pleasant or unpleasant tones. Low integer ratios were found to give rise to the most pleasant tones, with two strings that are in a 1:2 relationship (ex, 300 and 600 Hz) sounding like the same note, but higher in pitch. This idea of similarity came to define consonance, with the etymological root of the word (co-sound) even pointing toward the idea of unison; unison being the term used for two or more pitches (perhaps on two separate instruments) sounding on the same note, either at the same frequency or at frequencies that are octaves apart. Note pairs such as 3:2 and 4:3 are not as pure as a unison or octave, as they sound as two seperate notes, but their cosounding is nonetheless pleasant sounding and still considered consonant, even receiving the qualification of "perfect" from Pythagoras. Note pairs with less simple ratios sounded less pleasant, and these were considered undesirable, foreshadowing the deprioritization of dissonance in Western music.

Models for Interacting Partials in the Middle Ear

More precise formulations of consonance and dissonance were described by Helmholtz, who considered beating to be the driving feature behind the perception of dissonance. The sensation of beating occurs when two pitches of close enough frequency are cosounded. This will present fluctuations in loudness, with the frequency of this fluctuation equaling the difference in Hz between the two pitches sounded (pitches at 200 and 300 Hz would generate . This fluctuation in loudness is referred to as beating, and results in the perception of dissonance if the periodicity of the beating is relatively high, around 30 Hz (Winckel, 1967). However, significant beating is present in certain intervals that are nonetheless rated as consonant and construe simple integer frequency ratios (Terhardt, 1984), indicating that beating is not a reliable predictor of sensory dissonance in all cases.

McDermott et al. (2010) found support for the linking between harmonicity and the perception of consonance. Harmonicity is calculated by measuring the closeness of fit between the combined waveforms of two pitches and the harmonic structure of a single tone. As Pythagoras noted, two tones with enough overlapping partials will be perceived as one note, such as when two pitches a perfect 5th apart are cosounded. These two pitches would then also be considered to have high harmonicity based on the fact that the frequency value of many of their partials are equivalent. In terms of linear analysis, the combined regression of each partial to the value that a single tone would have at that frequency.

Assumptions in Learning Unfamiliar Systems

Despite differences between tonal organization systems of music from around the world, research rooted in the statistical learning paradigm would suggest that unfamiliar systems can be learned quickly during a period of exposure (Rohrmeier & Widdess, 2016). While unfamiliar, the intervallic qualities of scales that participants were able to become familiar with in this study are not fundamentally very different from scales that those participants would encounter in western music, so the learning seen cannot be said to have occurred without significant priming. One major similarity between these tuning systems is their treatment of the octave. The octave is defined universally as any pitch with a frequency value that is twice the frequency value of another pitch. The phenomenon of octave generalization refers to the tendency of notes an octave apart to be heard as the same note. Octave equivalence is one feature of auditory processing that is essential to the formation of mental representations of pitch sequences. Monkeys trained to make *same-different* judgments were able to recognize octave-transpositions of melodies as being the same as their untransposed counterparts, while melodies transposed 0.5 or 1.5 octaves were judged to be different, even though the intervallic sequence of the melodies were identical in each case (Wright et al., 2000). The reliability of the octave as a reference point for pitch comparisons and the importance of this phenomenon across cultures has been discussed (Patel, 2007) but may not be essential to all hypothetical systems of music. Since the cognitive availability of musical information is critical to musical appreciation (Lerdahl, 1992), any hypothetical system that lacks an octave (such as the one utilized in this experiment; see section *Stimuli*) may fail to be conducive to salient pitch information and thereby fail to incite a mental representation of the music.

Since much of the existing work on musical cognition has used musical materials rooted in the western paradigm, it remains unclear which features of the western system are those that are critical to learning in these cases. Because of this, it is difficult to predict the results of similar research done with musical materials of other paradigms that may differ in their structures of organization. Widespread systematic assumptions such as octave-generalization may be based on anatomical features and thereby difficult to exclude from models of optimal learning, but the patterns of learning and preference-forming reported by Loui et al. (2010) indicate that musical materials that eschew octave-generalization can nonetheless be conducive to learning and preference-formation. Whether or not these critical differences are still somehow interfering with optimal rates of learning due to systematic incompatibility between the human listening system and the features of the stimuli remains unclear.

Culturally Bound Systems of Pitch Organization

Music exhibits considerable complexity, yet it can be appreciated equally by both experienced musicians and people with no formal training. Experienced music-listeners can even develop expectations for how music will continue while they are listening, but such expectations are often based on the regularities of a specific musical idiom; and the degree of experience one has with any particular idiom may determine how much information is gleaned from the music that exists in that idiom.

Because of the importance of context for understanding musical passages, gleaning any meaning from music requires the utilization of both 1) perceptive abilities to discriminate pitches and 2) a broader knowledge of how the notes in a song are organized, whether rhythmically, harmonically, or in other modes of organization such as timbre. The organizational systems of music from around the world differ in which mode they emphasize as the most critical, with Indonesian classical music being more reliant on rhythm to indicate an overall framework of a composition than harmony (Becker and Becker, 1981). Regardless of the system being learned, familiarity with the system of organization specific to that idiom is required for higher-level meaning to be perceived by a listener.

While the means to elicit tension via melodic principles may seem to be clearly modeled, the idea of tension itself may be somewhat unique when presented in the Western idiom due to cultural connotations that surround the ideas of consonance, tension and progression. Differences occur between the Western musical tradition and that of Java in terms of the cultural narrative that underlies the organizing principles of their classical music. The system of calendar organization used historically in Java emphasises coincidence between multiple overlapping cycles; an idea which is supplanted by progress driven by patterns of fluctuation, or “a unified causal sequence leading to a climax” (Patel, 2007)

Since scale membership is one of the most defining metrics of fit in Western music theory, presenting a tonal context by using notes in a certain scale and then providing a probe tone that deviates from that established scale should elicit negative affect in any individual who has prior experience with those particular scale structures. That is to say that the perception of sensory dissonance may not be necessary for the identification of a sour note if explicit facts about the scale structure are salient. While both adults and infants are capable of perceiving dissonance, adults are better at identifying when a non-scale note is sounded regardless of the sensory nature of that note (Trainor & Trehub, 1992). These results indicate a dissociation between the intrinsic sensory qualities of a cosounded note pair and the role of that interval within an established, as determined by enculturation.

Consonance is Not Affect or Pleasure

Perception of pleasure as brought about by different states of sensory consonance vs dissonance can be moderated by factors such as the style that a song is presented in (Popescu et al, 2018), which is in turn modulated by the level of experience participants have with that particular style (such as jazz vs classical). In the aforementioned study, individuals with higher levels of musical experience were less likely to rate consonant pairs as being pleasurable, which indicates that consonance itself may become unappealing over time despite it reliably inciting a relaxed state. To paraphrase a metaphor from Patel (2007); there is a difference between rating how spicy food is and rating how much you like that food.

The musical style that a chord progression is presented in (i.e., rock music vs. classical music) can alter the degree to which a certain chord is expected by participants. Vuvan & Hughes (2019) found that “listeners prefer V-I cadences over bVII-I cadences within a classical context, but that this preference is significantly diminished in a rock context”. These results indicate that while formulations of the tonal hierarchy are rooted in a consistent metric, this consistency is diminished when examined in an ecologically valid style of presentation. In other words, the fundamental properties of certain chords may be tied to their innate characteristics, but these properties can be utilized differently across styles of music that may emphasize different aspects of the tonal hierarchy. These different styles will, again, have to be made familiar to an individual before their expectations can become attuned to the regularities of that style. Nonetheless, the innate properties of the chords should still influence the manner with which they can be used, regardless of the stylistic context, due to the innate constraints that consonance may have on preference and/or learning.

Attempting to Generalize (Western) Principles of Organization

The idea of auditory pitch information activating a musical context that then serves to codify the relevance of subsequent pitches originates in behavioral studies using the probe tone methodology, which was first introduced by Krumhansl and Shepard (1979) and further explored by Krumhansl and Kessler (1982). In the probe tone methodology, a sequence of tones is presented to the participant, with an additional tone (the ‘probe tone’) following this sequence.

The task for participants is to rate how well this final tone fits with the context that is established by the preceding tones. The preceding sequence of tones is thought to establish a context by presenting a number of tones that suggest a particular musical key. Once a key is established, a tonal hierarchy is implied, and participants are able to place the probe tone into that hierarchy and form their judgments based on this juxtaposition.

When 'musical context' is discussed in music perception, it is most likely referring to the pitches presented when factors like timbre and rhythm are experimentally controlled. However, while tonality alone is thought to be strongly indicative of a particular context, elements of harmonicity also apply to dimensions of rhythm and timbre, and these dimensions in turn interact to define genres in ways that are not always straightforward. In this sense, 'musical context' as it is understood by Western terminology may be to highly reliant on pitch information, with rhythmic and timbral cues being just as important to spheres of music outside the world of Western music. In probe tone paradigms, variables such as rhythmic and timbral variation are controlled, with only pitch being manipulated, it is thought that the context being activated is reliant on the pitch characteristics of the melodic sequence that precedes the probe tone. Evidence for this comes from the fact that intervals are given different ratings of consonance based on which tonal context has been established by the sequence. Krumhansl and Kessler (1982) found that the same interval would receive different ratings of fit depending on the key implied by the preceding stimuli, even if two keys used the same notes but oriented differently. This means that the same intervals (which would have the same calculated level of sensory dissonance in both cases) might elicit different perceptive results based on the cultural context behind a tonal space.

In the words of Krumhansl and Kessler (1982), “the perception of musical structure depends on the processing of pitch information with reference to a system of knowledge about the conventional uses of pitches”. To our purposes, the insulation of the testing environment from any outside perceptive influence from any conventional system of pitch organization is a priority. The utilization of a music system that does not contain enough familiar pitch information to establish a musical context should limit the degree to which responses to the probe tone task will be related to non-experimental variables, allowing us to measure the degree to which participants are able to perceive consonance in the absence of a familiar musical context.

Methods and Materials

The method described in this section has been approved by the Bard College Institutional Review Board (see Appendix A).

Stimuli

The Bohlen-Pierce (BP) scale is an artificially constructed tuning system that was developed independently by multiple people in the late 20th century. The most striking characteristic of the BP scale when it is compared to most scales is its unconventional definition of the octave, which is “stretched out” to 3:1 (referred to as a tritave) instead of the 2:1 relationship present in most musical systems. This is a drastic alteration given the importance of the octave in the perception of musical passages. By removing the concept of the octave from a musical system but presenting that system as we would a conventional musical system, we can control for the effects of octave equivalence on the perception of consonance, but in doing so may also be removing some of the sonic materials necessary for forming mental representations of pitch.

Despite this fundamental difference in organization, the BP scale embodies similar characteristics to the 12-tone equal temperament system (12-TET), which is nearly ubiquitous in music today. 12-TET divides the 2:1 octave into 12 pitches evenly spaced- in a manner by which any pair of adjacent notes will have the same frequency ratio as any other adjacent pair. By contrast, the tuning system called just intonation is comprised of intervals that are not evenly spaced, and thusly these intervals could not be realised on an instrument that is tuned in 12-TET. By its definition, just intonation. In mathematical terms, in the 12-TET system, intervals other than the octave are irrational numbers that cannot be represented as whole number ratios. These tempered intervals are only slightly different from those found in just intonation and should establish similar musical contexts via their pitch structure despite changes in temperament. The interval between the 1st and 5th scale degree in 12-TET, as a ratio, is 2.996:2, which falls short of the pure ratio of 3:2 present in just intonation. Similarly, the closest approximation of this interval in the BP scale 2:3.052 which falls quite sharp of the perfect 5th present in mainstream musical materials.

The body of tone sequences that is used as stimuli for the experimental procedures in this study are identical to those formulated and employed by Loui et al., (2010). Compositional methods derived from Lerdahl & Jackendoff's (1983) Generative Theory of Tonal Music enable the construction of myriad exemplar melodies given the input of a scale and a tonal hierarchy. Since any scale derived from a tuning system will have points of relative consonance on certain scale degrees, it is possible to apply principles of linear organization to note sequences in a way that enforces the clarity of the pitch structure of the notes presented. The innate features of consonance as determined by intervallic relations and harmonic interactions should then be available as sensations to participants.

Dissonance Model used to Predict Responses

The term "dissonance curve" is used by Sethares to refer to a graph that describes the level of dissonance for each note in a scale when it is compared with the tonic of that scale. Since the harmonic series is also understood mathematically, it lends itself well to interfacing with computer programs. In order to calculate the level of dissonance between each note in the BP scale and the tonic of the scale, the python package "dissonant" (written by Bohumir Zamecnik and first submitted to pypi.org in 2018) was utilized. This package receives as input the frequency values for any number of cosounding pitches and calculates a level of dissonance for the interval or chord. Various models of calculating are available within the program; to maintain theoretical continuity, the model "Sethares" was utilized. This model is based on a summation of the amplitudes of the partials shared by cosounding tones. Generally, tones that can be described by simple frequency ratios will have fewer interacting partials and thusly resemble more closely a single tone.

A modifiable variable in this program is the number of harmonic partials that each frequency will possess when the level of dissonance is calculated. The amplitude of these partials is also able to be modified, if partials are present in the model. The utilized model included 10 partials above each note, with each successive partial above the fundamental value having an amplitude of ½, ⅓, ¼, ⅕, etc… of that of the fundamental. A sine wave by definition does not have any partials when it exists as raw data. However, as sound passes through matter on its way to the ear, it will inevitably interact with the resonating patterns of that matter to obtain harmonic partials that were not present initially. Even when reproduced by high-fidelity noise-cancelling

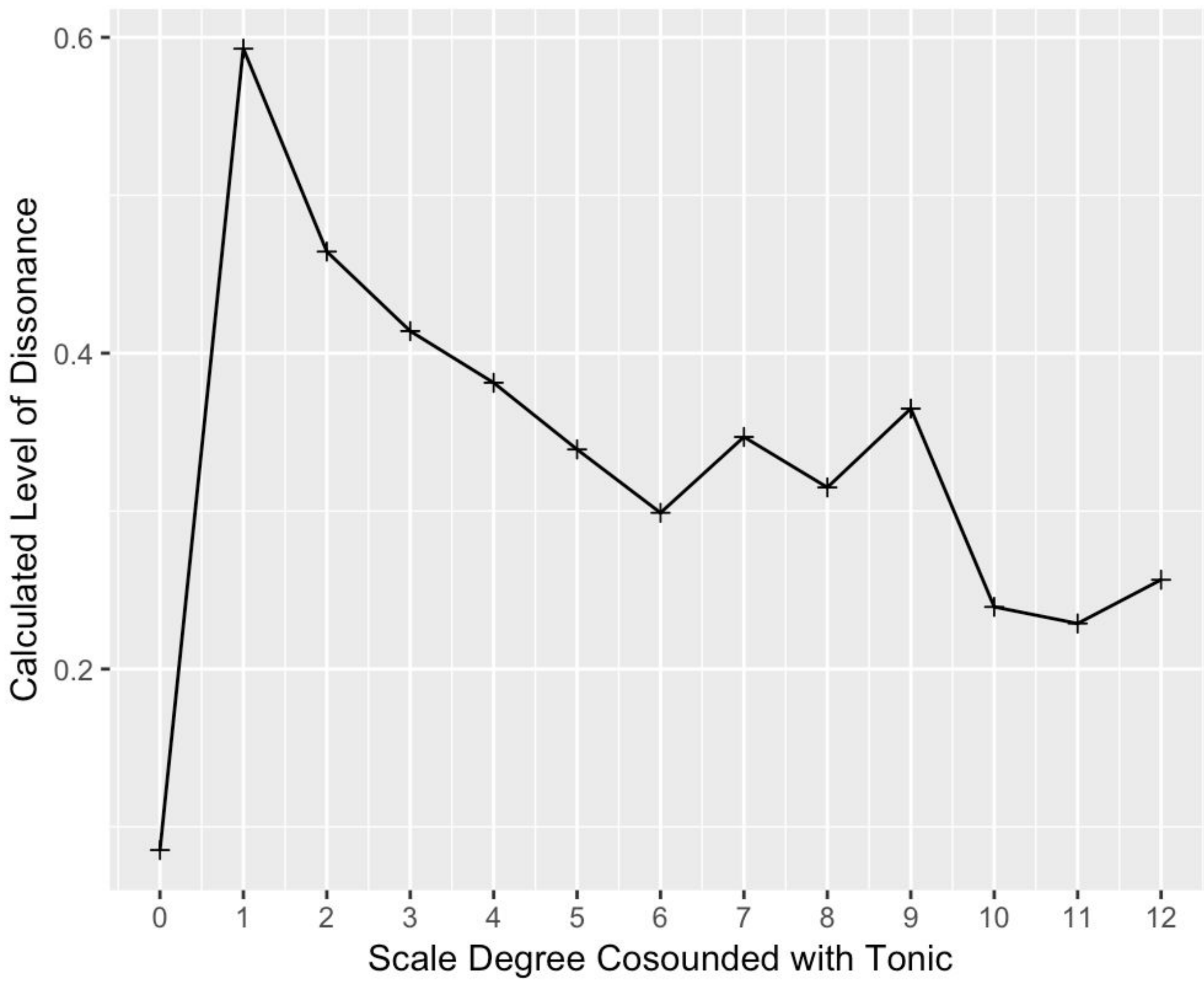

Figure 1: calculated dissonance curve for the BP scale used in this study. On the x-axis is each scale degree in ascending order. Since intervals are used to calculated dissonance ratings, the value at x=0 is derived from harmonically comparing the tonic of the scale with itself; at x=1 the second note in the scale is harmonically compared to the tonic. The y-axis shows the calculated level of dissonance for each interval, with the lowest dissonance (0.085) belonging to the interval

of unison found between the tonic and itself, with the highest dissonance (0.593) between the tonic and the note directly above it.
headphones, some distortion occurs as a result of the inherent physical and electrical patterns of the sound-reproduction mechanisms. To account for any distortions to sound caused by the equipment, 10 partials were included in the model. This assumes a moderate level of distortion, owing to the simple nature of the sound synthesis program utilized in Max, without any filters to reduce noise that would lead to slight levels of harmonic dissonance. See Figure 1 for a plot of the dissonance curve calculated by this model.

Equipment

The data collection portion of the experiment took place on a 2015 Macbook Pro, running a series of programs in the programming language Max 8. A Focusrite Scarlett 2i4 USB Audio Interface was used to carry the audio output of Max to a pair of Sennheiser HD280 Pro headphones, which as advertised should attenuate 32 dB of noise to provide an adequately insulated sound environment. Participants were shown the knob that controls volume and told to adjust to a comfortable level if needed. Since the headphones used are somewhat heavy and completely cover the ears, participants were told they could take short breaks (30 seconds to 1 minute) if they felt uncomfortable during longer phases of the experiment. No participants took this opportunity. The chance to remove headphones while receiving instructions in between experiment phases seemed to maintain sufficient comfort.

The programs used in Max were provided by Psyche Loui available at figshare.com/articles/Bohlen_Pierce_scale_artificial_grammar_learning_experiment/757721 via the researcher's website, www.psycheloui.com. The programs consisted of sound generators and means to present stimuli from the appropriate sources in randomized order, as well as button interfaces to collect behavioral ratings from participants and allocate this data to the appropriate location. Participants were instructed on each task only after the program window was present, and Max's Presentation Mode was used to simplify the program's contents and obscure any meaningful information about the stimuli, as frequency values and scale degrees are displayed in certain parts of the program as its input is indexed.

Participants

Participants were 14 students at Bard College in Annandale-on-Hudson in New York state. No data about the participants was collected, as no personal information was considered necessary to the hypotheses of the study. The anonymity of participation was also described to participants as one of the benefits of participating in the study (see Appendix D). Participants were selected from the Bard College community. Prospective participants were told that the study would take around an hour, and take place in a quiet room in front of a computer wearing headphones while giving ratings to tones. Compensation was also described at this point. An announcement was also made in a non-major biology class that participants are being sought for an empirical senior project. Participants were required to have normal hearing and be at least 18 years of age.

While musical training and experience is known to attenuate certain aspects of an individual's response to musical stimuli, it was thought that sufficient overlap in the relevant skills would exist between musicians and non-musicians participating in this study (see discussion). Because of this no data was collected about the musical expertise of participants.

From the perspective of statistical analysis, including all participants in one group allows for a lower risk of Type-2 error or false negative with fewer participants.

Procedures

The 14 1-hour long experiment sessions took place in a quiet room in Preston on the Annandale campus at Bard College. Participants were compensated with snacks which were available before (while the consent form was read and initial instructions are given) and after the procedures of the experiment. Participants were assured that the focus of the study was on irrepressible process of the auditory system, and that no data would be collected other than their responses to the stimuli.

In order to minimize the effects of priming, no musical language was utilized while describing the tasks. The stimuli in the experiment are only referred to as tones, not notes, and a group of tones is referred to as a sequence, not a melody. After giving the participant the consent form and asking if they understand the nature of the investigation, 5 blocked procedures (experiment phases) were administered .

First, pre-exposure tone ratings were collected. Participants will complete a probe-tone task whose stimuli are formulated by the BP scale and its tonal implications. In this task, participants will listen to a melody that is followed by a probe tone. The listener rates how well the probe tone fits into the previous sequence. 13 probe tones were presented to collect data for all notes in the BP scale. The same melody was used each time, with each condition hearing a melody in their respective grammar, both of which emphasizing the same pitches as tonally hierarchical.

This phase was followed by a period of 25 minutes of exposure to exemplar melodies. Participants are allowed to draw on paper while hearing a collection of melodies that are defined by one of two musical grammars, after which a melody recognition task will be administered in which participants are presented 2 melodies (one from their exposure set, the other from the other group's grammar), and asked which is more familiar. Successfully identifying the less familiar melody should demonstrate recognition of already-heard melodies as facilitated by memory representations of functional musical elements. Participants are also given a melodic rules generalization task- participants presented 2 melodies (one from their assigned grammar, and one from the other group's grammar, both of which they have not yet heard), and asked which is more familiar. Successfully identifying the more familiar melody should indicate the acquisition of a mental representation of the melodies exposed to as well as the pitch regularities of these melodies. Post-exposure tone ratings will then be collected. This task is identical to the first probe tone task and provides a means to see how much participant's sensitivity to sensory dissonance will be attenuated by a familiarity with the pitch structure and tonal context of these BP melodies. Preference ratings for melodies will also collected. We presented 20 melodies and asked for a preference rating from 1-7 for each one, after which participants can ask questions about the experiment. The total expected run time of experiment is approximately 1 hour.

Results

To measure the ability of the dissonance model to predict pre-exposure probe tone ratings of fit, 14 Pearson correlations were calculated between each participant's pre-exposure probe tone profile and the measures of dissonance provided by the model. These r values were converted to Z scores using Fisher r-to-z transformation to account for non-parametric, then combined into a single Z score of -0.3410571 (see Figure 2). To ensure the significance of this statistic, the 14 seperate p-values for these r values were combined using the sum of logs method, also known as Fisher's method, to return sumlog(pval) returns chisq = 56.34174 with df = 28, p = 0.00117, suggesting a significant relationship between the dissonance model and participant's ratings of fit.

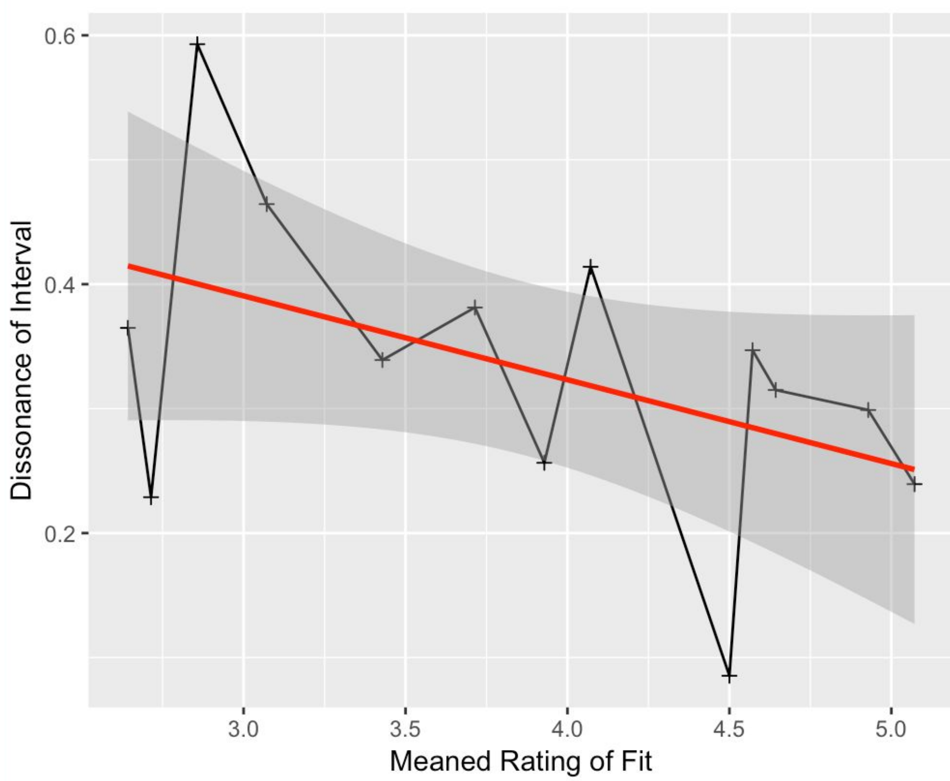

Figure 2: On the x-axis is the range of probe tone ratings of fit for each note- i.e., not ordered by scale degree. The y-axis shows the calculated level of dissonance between that note and the lowest note presented in the sequence of tones. Regression line with a slope of derived from x~y, showing the tendency for notes that sound dissonant with the tonic to receive lower ratings of fit.

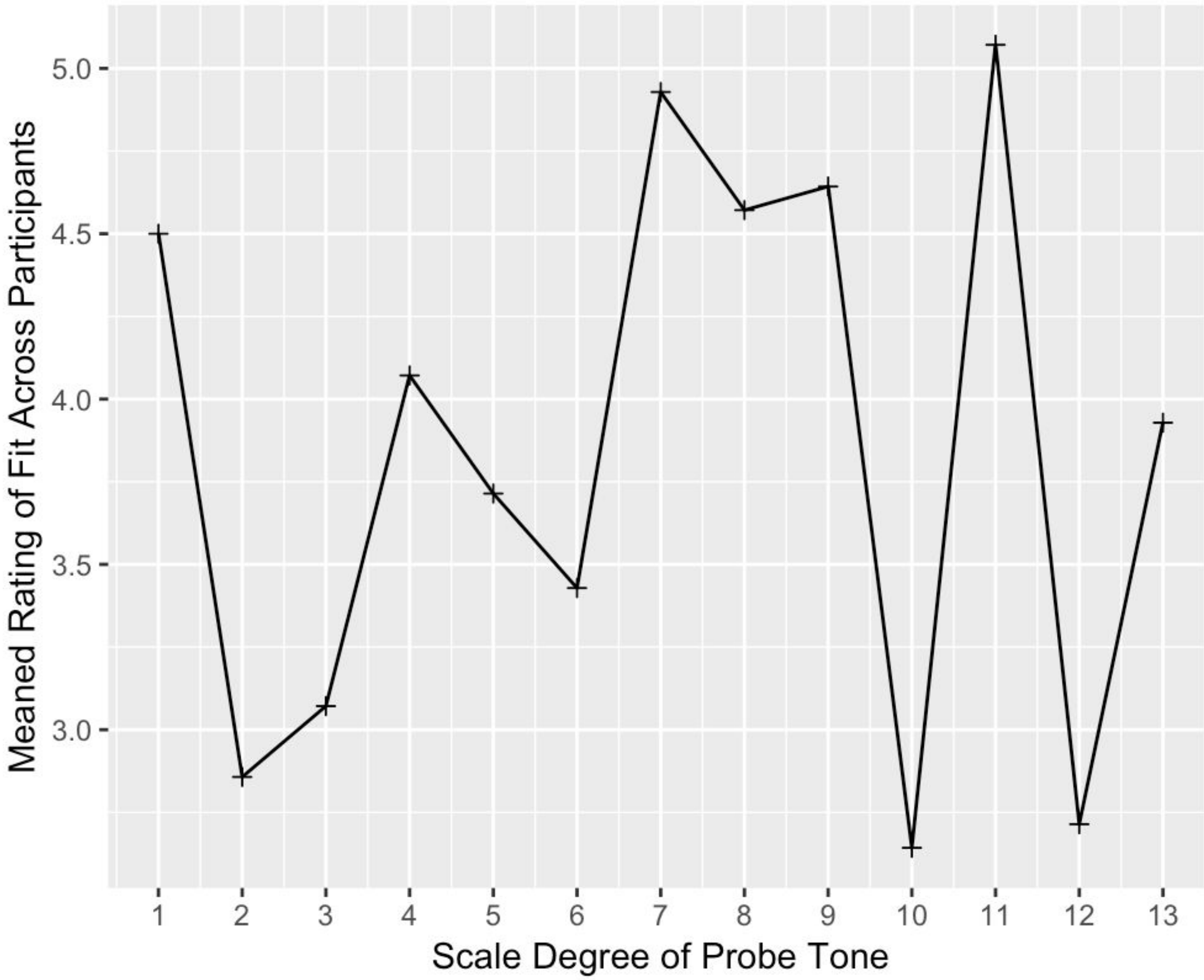

Figure 3: Meaned profile of pre-exposure probe tone ratings across participants. Note that ratings of fit on the y-axis are available from 1-7, but values displayed fall into a more narrow range, with no meaned rating falling below 2.643 or above 5.071, (M = 3.857).

An independent samples T-test between the calculated Z score and an assumed population mean of 0 suggests that there is a difference in the correlations between fit and consonance for this experimental population (M=-0.341, SD=0.2522) and the assumption of a population mean of zero (M=0); t (12)=-4.5, p = 0.000727.

Post-hoc Analyses

Kendall's coefficient of concordance was calculated to examine the inter-rater reliability of the pre-exposure probe-tone task. Inter-rater reliability was shown to be quite low, with $Wt = 0.172$, $p = 0.00407$. This shows that there was considerable variation in the responses from participants, which would not be expected if there is much overlap between the strategies used by participants to respond to the task. A low degree of inter-rater reliability indicates diverging response strategies that may be delineated by musical expertise (Wong et al., 2007) (see Discussion).

To begin to investigate what sources of dissonance (other than that between the probe tone and the tonic) may account for participant's responses, a multiple linear regression was calculated using additional dissonance models calculated from the notes in the BP scale other than the tonic that exist as local minima on a dissonance curve. The two notes in the BP scale used in this study as those hierarchically just below the tonic in terms of significance (this quality deems these notes to be those used in chord progressions that define this specific tonal context) are the 6th and 10th scale degrees, with the 0th scale degree indicating the tonic. Dissonance models for these notes were calculated the same way that for the tonic was, introducing two additional variables that could account for the variation in participant's responses. A significant regression equation was found, with ($F(3, 187) = 7.981$, $p < 0.000$). In this linear model, participant's predicted ratings of fit for each probe tone is equal to 6.3792 - 1.3830 (d0) - 1.3325 (d6) - 5.8776 (d10), where d0, d6, and d10, are the dissonance models for the BP scale with reference points as the 0th, 6th, and 10th scale degrees, respectively. This indicates that probe tones that are considered to be dissonant when cosounded with the 10th scale degree will, on average, receive a rating 5.88 degrees lower on the likert scale. It appears that models of dissonance are capable of predicting a small amount of variation in participant's responses to the tonality of the BP scale as realized through the stimuli of this experiment. This method of analysis would be valid if participants are comparing probe tones to tones in the scale other than the tonic to determine the degree to which the probe tone fits with the preceding tone sequence, especially since unfamiliarity with the BP scale may make it difficult to ascertain which note is to stand as a reference point. It is assumed that the lowest note presented will stand as the tonic, but "inverted" chords nonetheless exist in conventional music theory. In inverted chords, it is understood that a note other than the lowest note presented will act as a reference point, so it is possible that participants neglected the 0th note in the scale due to a lack of aural cues suggesting that this note isn't the most hierarchically significant in the scale. In other words, the harmonicity of the contexts presented may be emphasizing a non-obvious tonal center, and since the 6th and 10th scale degrees are present in the context-establishing melody and these notes are the points of local minima on the dissonance curve calculated for this scale, it is possible that they would be taken as reference points for other notes in the scale.

Discussion

Musicians and Non-Musicians

This study did not collect any data about how much experience any participant has with musical training, education, or about any other recreational engagement with playing, writing or listening to music. While musical training is known to attenuate certain aspects of music cognition, many of the primary functions of the auditory system required for musical appreciation are available to untrained listeners. The processing of pitch begins in the inner ear and relies on processes that are used in everyday life, such as in the processing of F0 speech contour which is critical to the execution and comprehension of certain linguistic phenomena such as pitch accent and tones, as well as emotional delivery and non-linguistic information regarding the state of the speaker (Kameoka et al, 2010). To this end, any individual with working hearing will be able to perceive the details of music as raw sound, but the organization of these sounds into meaningful music requires some sort of scaffolding that is built by experience.

Due to levels of familiarity, this process may not occur equally for all individuals. The process of integrating the details of pitch information into a meaningful mental representation (referred to as "updating the current musical context" in ERP literature) while listening to an ongoing flow of harmonically related stimuli is thought to consist of comparing a presently perceived sound to the already-encoded mental representations of sounds in working memory (Polich 2007). The identity of and means of comparison between these mental representations is usually dependent on idiom-specific terminology that must be learned thoroughly before being able to engage meaningfully with the norms of that idiom. Musumeci (2018) describes the failure of inexperienced listeners to engage meaningfully with the rules of an idiom as "failure to develop spontaneously the links between the inborn and acquired cognitive processes underlying musical understanding and a formal system of description." In the absence of formal descriptors (i.e., idiom-specific terminology such as *the functional tension of the half-diminished seventh chord*), sensory dissonance offers a certain degree of predictability in terms of the perceptions across individuals.

This processes of context-updating utilizes anatomical areas that are responsive to training, such as the brainstem and auditory cortex (Herholz & Zatorre, 2012). Hantz et al. (1992) found that participants in an interval discrimination task with higher levels of musical training tended to show higher neurophysiological responsiveness, as indicated by a P3 with higher amplitude and shorter latency, indicating that the context-updating feature of the musical processing system is affected by latency in perception, which is in turn enhanced by musical training. However, Bigand & Poulin-Charronnat (2006) argued that differences like these are more related to an individual's "ability to analyze surface patterns of pitch, attack, duration, timbre in a refined way is probably less important than the ability to integrate all of these features in a structured whole".

Musical Training, Listening Strategies, Varied Responses

While consonance can be precisely quantified as a measure of interactions between partials in sound and the human auditory system, the skills and abilities that are generally more developed in musicians may only account for part of the entire process of interactions that occur when an individual learns features that are unique to music. Specific physical phenomena active in the cochlea (such as that of Critical Bands, beating, difference tones, and the interactions of sine tones to create complex harmonic patterns that are still reducible by the auditory system to the sine wave components that define the sound's partials) can be described by mathematical formulations that can be used to predict a certain degree of behavioral responses due to the innate qualities of certain musical elements such as the harmonicity of two cosounding pitches. However, due to the subjective way people interact with the sensations of beating and consonance, many affective reactions are possible for an individual to experience, especially when presented with musical stimuli with which they have no prior experience and henceforth a minimal amount of contextual primes that, if experienced congruently between participants, would decrease the amount of variation between their responses.

Lack of clarity in the instruction to “rate how well a note fits with a preceding sequence of notes” could arise from the participant assuming something of the instructions that is not implied. The semantic implications of the word “fit” can lead to different patterns of responses if participants are basing their definition of fit off of musical systems that emphasize dissonance differently than the Western system of music does. A study using ERP analysis while participants listened to and rated preferences for chord progressions found that individuals with training in improvisation (i.e., familiarity with the jazz paradigm) not only preferred unexpected chord progressions, but also had “increased perceptual sensitivity (as indexed by the ERAN), [as well as] higher engagement (as indexed by the P3b), [and] a faster return to baseline after the occurrence of unexpected events” indicating heightened familiarity with and appreciation for dissonant stimuli (Przysinda et al, 2017). However, these results are specific to the desires of a certain idiom and are thereby less influenced by innate factors as they are specific patterns of expectation that are rooted in the regularities of a certain genre. These genre-specific expectations nonetheless rely on principles of dissonance that are innate in their dependence on physical patterns. While subjective experiences with stimuli can be determined by any number of systematic primes, the means by which these primes categorize their contents is by measures of dissonance, so models of dissonance can be used to quantify the differences between the pitch hierarchies of different genres and music systems.

But, musical engagement is a multi-dimensional practice that is facilitated by exposure as well as directed training or education. Because of this, it may be difficult to delineate different types of musical experience or training in terms of their effect on music-related skills. The main benefit of musical training (in the Western paradigm) seems to be a sensitivity to and possible preference for consonance. Bigand et al. (1999) showed that musician's brains respond faster and more accurately to chord progressions that end on chords that are not considered the most stable in the tonal hierarchy. Using ERPs, Besson & Faita (1995) showed that incongruities in melodies (whether familiar or unfamiliar) elicit a larger late positive component (LPC) in musicians than in non-musicians. Bigand & Poulin-Charronnat (2006) also reported that trained musicians generally perform better in explicit tasks that require responses (possibly due to experience with similar tasks in their musical education) and that "Performances of both groups have never been found to be better in musically trained listeners when participants were required to learn new compositional systems", again pointing to a dissociation between the perceptive skills of a musician and the general ability to form meaning out of music when learning unfamiliar patterns. To explain this further, the same authors wrote "the ability to analyze surface patterns of pitch, attack, duration, timbre in a refined way is probably less important than the ability to integrate all of these features in a structured whole." In other words, an individual's level of organizational ability (outside the prescriptions of any one style or genre) may be an additional variable when considering overall engagement with music. This factor may apply more to the tasks of grammar discrimination and post-exposure probe tone ratings, since these tasks will rely more on each participant's methods of reflecting on what they hear throughout the experiment. In contrast, the pre-exposure probe tone ratings occur at the beginning of the experiment and participants have little time to reflect on the stimuli, only being able to hear each probe tone once before giving it a rating of fit. Some participants commented that they wished for additional chances to hear the probe tone before assigning a rating, highlighting the difficulty in making explicit judgments based on (automatic perceptions). Only being able to hear each probe tone once should minimize any reflection that might serve to enforce an arbitrary perception of any tone presented as stimuli. That is, given a structured testing environment, the variation in ratings accounted for by cultural priming should not be as significant as that explained by adherence to the experimental instructions to rate the perception of fit.

The capacity for non-musicians to perceive the most fundamental elements of structure in music is highlighted by results from experiments in the EEG paradigm. (Koelsch et al., 2015) where non-musicians exhibit (ERP). The acquisition of this knowledge via exposure that is attenuated throughout one's lifetime without explicit training is partially accounted for by Bigand and B. Poulin-Charronnat (2006), who pointed out that listening to music organically doesn't normally involve or necessarily require explicit judgments, which puts any experimental paradigm that asks participants to make explicit behavioral responses under scrutiny. It may be unrealistic to ask participants to understand sensations they are not experienced with and then give reports on these sensations. While the probe tone paradigm is cost-effective and non-invasive for participants, the EEG paradigm offers the chance to observe implicit processes occuring, bypassing the need for participants to make behavioral responses. The innate responses of the auditory system can then be observed without relying on the participants to be aware of their responses. Besson and Faita (1995) employed an experimental paradigm similar to that of the probe tone paradigm, where participants heard melodies that strongly implied a particular tonal context, followed by a final tone, while wearing EEG equipment. The researchers found that the amplitude and latency of a late positive component (LPC) cued by the final tone was determined by melody group, with LPCs being more amplitudinous for final tones that followed a culturally familiar melody. It is noteworthy that participants in this study were asked to make explicit judgments of the final tones, since making explicit judgments can interfere with the processes that elicit ERPs related to musical processing (Koelsch & Siebel, 2005) HOWEVER, in a following experiment, the researchers found that “familiarity and type of terminal note on LPC amplitude and latency were still significant when no response was required from the participants” (Besson and Faita, 1995), suggesting that while the perception of tonal fit can be moderated by acculturation, the basic auditory processing that underlies this perception is automatic and not particularly prone to interference from conscious processes. To this end, it becomes clear that a finely-tuned anatomical response to music is available to even non-musicians, likely as a result of their everyday exposure to musical materials.

When given specific instructions to listen for a certain auditory phenomenon, many individuals may not have the task-specific attentional skills necessary to give high-fidelity reports of their own perceptive experiences. To this end, EEG paradigms utilizing passive auditory tasks may be more effective at probing the innate abilities of the general population than paradigms that require active responses from participants, due to the disconnect between an untrained individual’s natural ability and their capacity to faithfully report auditory sensations.

Converging Formal Definitions of Sensory Dissonance

While any number of physical phenomena (roughness via critical band interactions, harmonicity, frequency ratios) can be used to understand what determines our automatic perceptions of pitch, asking participants to report their perception "fit" may encompass multiple dimensions of the semantics of musical perception. The historical description of consonance itself is a complicated web of directionality, with the definition of a consonant note more or less having been "a note that sounds consonant" for the many years it took before precise mathematical formulations of dissonance were available. In a foundational study for music perception, Plomp & Levelt (1965) presented cosounding tones at various frequency intervals and asked participants to rate the *consonance* of the interval on a scale from 1-7. The researchers reported that "Some subjects asked for the meaning of consonant. In that case, the experimenter circumscribed the term by *beautiful* and *euphonious*." Such an explication was deemed appropriate based on the fact that prior research (van de Geer et al., 1962) had found significant correlation between interval pairs being rated as *consonant, euphonious,* and *beautiful,*even when participants were not musically educated. It must be noted that the perception of consonance is different from the perception of beauty or positive affect. Lahdelma & Eerola (2016) found a non-linear relationship between consonance and preference, with slightly dissonance chords being those most favored by participants. These results were unexpected insofar as they diverge from the western prioritization of consonance, but can be explained by the results from Bones et al., (2014) who found that interactions between partials are critical for the harmonic information of even very consonant chords (that would otherwise exhibit very low levels of harmonic interaction) to reach levels of salience that in turn lead to higher preferences. In short, dissonance is sometimes appealing to experienced individuals, and is also a vital component of any interval, defining objectively the patterns present in tone pairs.

Being able to calculate the level of dissonance between any number of tones enables the construction of dissonance models for any given scale that can be used to predict people's automatic responses to artificial scales that are built around novel intervals. Due to the innate ability to perceive dissonant intervals as unfitting within a tonal context that is established almost immediately even when unfamiliar, the identification of local minima in a dissonance curve can point toward the notes which may stand as tones high in the tonal hierarchy to serve toward the construction of novel scales and their unique systems of chord grammar. The probe tone paradigm serves us as a means to obtain relatively reliable measures of a population's organic responses to sensory dissonance, even in a tonal paradigm that does not invoke tonality via any cultural tropes but instead by the innate operations of harmonicity in pitch relations between sine tones, which may help us understand how schemas of musical relatedness are informed by base-level reactions in the auditory system that interact to form systems of organization whose parameters are flexible but nonetheless require certain qualities (such as harmonicity) to be cognitively available. Further research should employ a similar procedure to the present study but collect EEG data throughout to determine if ERPs such as the P3b and ERAN are present as indicators of musical context-updating and mismatch negativity, respectively.

References

Becker, J., & Becker, A. (1981). A musical icon: Power and meaning in Javanese gamelan music. In: W. Steiner (Ed.), *The Sign in Music and Literature* (203-215). Austin: University of Texas Press.

Besson, M., & Faïta, F. (1995). An event-related potential (ERP) study of musical expectancy: comparison of musicians with nonmusicians. *Human Perception and Performance, 21,* 1278-1296.

Bigand, E., R. Parncutt, and F. Lerdahl. (1996). Perception of musical tension in short chord sequences: The influence of harmonic function, sensory dissonance, horizontal motion, and musical training. *Percept. Psychophys.* 58:125–141. [6]

Bigand, E. (2003). More about the musical expertise of musically untrained listeners. *Annals of the New York Academy of Sciences, 999*, 304-312.

Bigand, E., & Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition, 100*, 100-130.

Bones, O., Hopkins, K., Krishnan, A. & Plack, CJ. (2014). Phase locked neural activity in the human brainstem predicts preference for musical consonance. *Neuropsychologia, 58*, 23-32.

Chang, E.F., and Merzenich, M.M. (2003). Environmental noise retards auditory cortical development. Science. Apr 18;300(5618):498-502.

Chiandetti, C. & Vallortigara, G. (2011). Chicks like consonant music. *Psychological Sciences*, *22*, 1270–1273.

Di Stefano, N., Focaroli, V. & Giuliani, A. (2017). A new research method to test auditory preferences in young listeners: Results from a consonance versus dissonance perception study. *Psychology of Music, 45(5), 699-712.*

Geer, J.p. Van De, et al. (1962). The Connotation of Musical Consonance. *Acta Psychologica*, vol. 20, pp. 308–319., doi:10.1016/0001-6918(62)90028-8.

Hantz, Edwin C., et al. (1992).Effects of Musical Training and Absolute Pitch on the Neural Processing of Melodic Intervals: A P3 Event-Related Potential Study." *Music Perception: An Interdisciplinary Journal*, vol. 10, no. 1,, pp. 25–42., doi:10.2307/40285536.

Hannon, EE., & Trainor, LJ. (2007). Music acquisition: effects of enculturation and formal training on development. *Trends in Cognitive Science, 11,* 466-472.

Herholz, S.C., and Zatorre, R.J. (2012). "Musical Training as a Framework for Brain Plasticity: Behavior, Function, and Structure." *Neuron*, vol. 76, no. 3, pp. 486–502., doi:10.1016/j.neuron.2012.10.011.

Kameoka, H., Le Roux, J., & Ohishi Y., (2010) A statistical model of speech F0 contours. Presented at *SAPA@INTERSPEECH 2010.*

Krumhansl, Carol L. "The Psychological Representation of Musical Pitch in a Tonal Context." *Cognitive Psychology*, vol. 11, no. 3, 1979, pp. 346–374., doi:10.1016/0010-0285(79)90016-1.

Krumhansl, C. L., & Kessler, E. J. (1982). Tracing the dynamic changes in perceived tonal organization in a spatial representation of musical keys. *Psychological Review, 89,* 334-368.

Lahdelma, I. & Eerola, T. (2016) Mild Dissonance Preferred Over Consonance in Single Chord Perception. *i-Perception,* 1-21.

Large, Edward W., et al. (2015). Neural Networks for Beat Perception in Musical Rhythm." *Frontiers in Systems Neuroscience*, *9.* doi:10.3389/fnsys.2015.00159.

Lerdahl, F. & Jackendoff, R. (1983). *A Generative Theory of Tonal Music.* Cambridge, MA.

Lerdahl, F.. "Cognitive Constraints on Compositional Systems." *Generative Processes in Music The Psychology of Performance, Improvisation, and Composition*, 2001, pp. 231–259., doi:10.1093/acprof:oso/9780198508465.003.0010.

Loui, P., Wessel, D., & Hudson Kam, C. (2010). Humans rapidly learn grammatical structure in a new musical scale. *Music Perception,* 27(5), 377-388.

Masataka, N. (2005) Preference for consonance over dissonance by hearing newborns of deaf parents and of hearing parents. *Developmental Science, 9(1),* 46-50.

Mcdermott, Josh H., et al. "Individual Differences Reveal the Basis of Consonance." *Current Biology*, vol. 20, no. 11, 2010, pp. 1035–1041., doi:10.1016/j.cub.2010.04.019.

Musumeci, Orlando. "The Cognitive Pedagogy of Aural Training." *Psychology of Perception and Music Education*, 2018, www.escom.org/proceedings/ICMPC2000/poster1/Musumeci.htm.

Narmour, E. (1990). *The Analysis and Cognition of Basic Melodic Structures: The Implication-Realization Model.* Chicago: University of Chicago Press.

Patel, Aniruddh D. (2007). *Music, Language, and the Brain*. Oxford University Press.

Plantinga, J., & Trehub, S. E. (2014). Revisiting the innate preference for consonance. *Journal of Experimental Psychology: Human Perception and Performance, 40,* 40–49.

Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. Journal of the Acoustical Society of America, 38, 518–560.

Polich, John. (2007). Updating P300: An Integrative Theory of P3a and P3b." *Clinical Neurophysiology*, *118* (10), pp. 2128–2148. doi:10.1016/j.clinph.2007.04.019.

Popescu, Tudor, et al. (2019). The Pleasantness of Sensory Dissonance Is Mediated by Musical Style and Expertise. *Scientific Reports*, *9* (1), doi:10.1038/s41598-018-35873-8.

Przysinda, Emily, et al. "Jazz Musicians Reveal Role of Expectancy in Human Creativity." *Brain and Cognition*, vol. 119, 2017, pp. 45–53., doi:10.1016/j.bandc.2017.09.008.

Razdan, AS. & Patel, AD. (2016) Rhythmic consonance and dissonance: perceptual ratings of rhythmic analogs of musical pitch intervals and chords. *Proceedings of the 14th International Conference on Music - ICMPC, July 5-9, 2016.*

Rohrmeier, M. & Widdess, R. (2016) Incidental Learning of Modal Features of North Indian Music. *Proceedings of the 12th International Conference on Music Perception and Cognition and the 8th Triennial Conference of the European Society for the Cognitive Sciences of Music, July 23-28, 2012.*

Schellenberg, E. G., & Trehub, S. E. (1996). Children's discrimination of melodic intervals. *Developmental Psychology, 32*(6), 1039-1050.

Schwartz, D., Howe, C., & Purves, D. (2003). The Statistical Structure of Human Speech Sounds Predicts Musical Universals. *The Journal of Neuroscience, 23(18),* 7160-7168.

Sethares, W. (1993). Local consonance and the relationship between timbre and scale. *Acoustical Society of America, 94*(3)*,* 1218-1228.

Sugimoto, T., Kobayashi, H., Nobuyoshi, N., Kiriyama, Y., Takeshita, H., Nakamura, T., & Hashiya, K. (2010). Preference for consonant music over dissonant music by an infant chimpanzee. *Primates*, *51*, 7–12.

Trainor, Laurel J., and Sandra E. Trehub. (1992). A Comparison of Infants' and Adults' Sensitivity to Western Musical Structure. *Journal of Experimental Psychology: Human Perception and Performance*, *18* (2), 1992, pp. 394–402., doi:10.1037/0096-1523.18.2.394.

Terhardt, E. (1984). The Concept of Musical Consonance: A Link between Music and Psychoacoustics. *Music Perception: An Interdisciplinary Journal*, Vol. 1(3), 276-295.

Koelsch, S., and Siebel, W. A. (2005). Towards a neural basis of music perception. *Trends Cogn. Sci.* 9, 578–584. doi: 10.1016/j.tics.2005.10.001

Koelsch, S., Rohrmeir, M., Torrecuso R. & Jentschke, S. (2015). Processing of hierarchical syntactic structure in music. *Proceedings of the National Academy of Sciences, 110,* 15443–15448.

Vuvan, Dominique T., and Bryn Hughes. (2019). Musical Style Affects the Strength of Harmonic Expectancy." *Music & Science*, *2*, p. 205920431881606., doi:10.1177/2059204318816066.

Winckel, Fritz. (1967). *Music, Sound and Sensation: a Modern Exposition*. Dover Publications.

Wright, AA., Rivera, JJ., Hulse, SH., Shyan, M. & Neiworth, JJ. (2000). Music perception and octave generalization in rhesus monkeys. *Journal of Experimental Psychology: General, 129(3),* 291-307.

Wong, Patrick C M, et al. (2007). Musical Experience Shapes Human Brainstem Encoding of Linguistic Pitch Patterns. *Nature Neuroscience*, *10* (4), pp. 420–422., doi:10.1038/nn1872.

Zamecnik, Bohumir. (2018, April 3). Dissonant 0.1.1. Retrieved from https://pypi.org/project/dissonant.

Appendix A

IRB letter of approval and application.

Bard College

Institutional Review Board

Date: November 20, 2018
To: Luke Sandbank (ls4928@bard.edu)
Cc: Thomas Hutcheon (thutcheon@bard.edu)
From: Sanjay DeSilva, IRB Chair

Re: Conceiving of Consonance in Chaos- the influence of the harmonic series on the perception of a new musical system.

DECISION: APPROVED

Dear Luke,

The Bard Institutional Review Board reviewed your proposal under expedited category 7,

(i) Research activities that present no more than minimal risk to human subjects, and

(ii) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your proposal is approved through November 20, 2019. Your case number is 2018NOV20-SAN.

Please notify the IRB if your methodology changes or unexpected events arise.

We wish you the best of luck with your research.

Sanjay DeSilva
desilva@bard.edu
IRB Chair

PO Box 5000, Annandale-on-Hudson, New York 12504-5000 **Phone** 845-758-6822

IRB Application

Section 1: Contact Information
Luke Sandbank, sandbank.luke@gmail.com, 914-787-0799, Psychology, Undergrad
Thomas Hutcheon, thutcheon@bard.edu

Section 2: External Funding
No, only requesting from the Bard Psychology Department. Qualifies for Expedited Review.

Planned start date for data collection: December 2018
End date: May 2019
Project Title: To Conceive of Consonance in Chaos- the influence of the harmonic series on the perception of a new musical system.

Describe research question- Conventional western music is thought to operate on rules that even non-musicians are aware of (Koelsch et al. 2015). Formal descriptions of these rules (Lerdahl and Jackendoff 1983; Rohrmeier 2011, Sethares 1993) are well-supported by empirical data (Razdan & Patel. 2016; Bigand et al. 1996, Thompson et al. 1997), but since much of this research was done with musical stimuli drawn from mainstream , it remains less clear how well people are able to learn the rules of musical systems that differ critically from what we're used to in everyday life. In this study, participants will learn the rules of a musical system derived from the artificially constructed Bohlen-Pierce scale. The resulting music exhibits sensory dissonance but nonetheless can follow logical rules of harmony and can therefore be understood in terms of the system used to organize musical tones and establish harmonic contexts (tonal hierarchy), albeit an unconventional one. Exposure to a collection of melodies that adhere to one of two musical grammars is expected to alter the perceived dissonance of certain notes in the scale that appear less frequently (Loui et al. 2008). Formal models of dissonance will be tested outside of the tonal context they were conceived in to see if principles of harmonic dissonance can generalize beyond the mainstream musical system and if listener's preference correspond to these models. Pre-exposure ratings should be predicted by the harmonic dissonance of intervals presented, with post-exposure ratings predicted by the exposure profile of the artificial grammar.

Impaired populations? No

How recruit participants- participants will be selected from Bard College's Annandale campus community. They will either be approached by myself or contacted via flyers placed around campus. If necessary, a table will be set up in Kline Commons to encourage people to sign up.

Section 4: Dates of Project

Start Date: September, 2018
End Date: May 2019

Section 5: Description of Project
After listening to a collection of example melodies in an unfamiliar musical system, are people able to learn the musical grammar that underlies these melodies?
What musical qualities are unique to the examples that people have preferences for? Are these the same musical qualities that we prefer in conventional music?

Briefly describe the procedures you will be using to conduct your research. Include descriptions of what tasks your participants will be asked to do, and about how much time will be expected of each individual. NOTE: If you have supporting materials (recruitment posters, printed surveys, etc.) please email these documents separately as attachments to IRB@bard.edu. Name your attachments with your last name and a brief description (e.g., "WatsonConsentForm.doc"). *

- After giving the participant the consent form and asking if they understand the nature of the investigation, the 5 procedures will begin in the following order:
- Pre-exposure tone ratings- participants will complete a probe-tone task. In this task, participants will listen to a melody (or melody fragment) that is followed by a probe tone. The listener rates how well the probe tone fits into the previous fragment. (13 melodies, ~5 minutes)
- Exposure- participants are allowed to draw on paper while hearing a collection of melodies that are defined by one of two musical grammars. (~25 minutes)
- Melody recognition- participants presented 2 melodies (one from their exposure set, the other from the other group's grammar), and asked which is more familiar. (~5 minutes)
- Melody rules generalization- participants presented 2 melodies (both from their assigned grammar, but one they have not yet heard), and asked which is more familiar. (~5 minutes)
- Post-exposure tone ratings- task is identical to the first probe tone task (~5 minutes)
- Preference ratings for melodies- presented 20 melodies and asked for a preference rating 1-7. (~5 minutes) (total expected run time of experiment ~1 hour)

Approximately how many individuals do you expect to participate in your study?

- ~30

Please describe any risks and benefits your research may have for your participants. (For example, one study's risks might include minor emotional discomfort and eye strain. The same study's benefits might include satisfaction from contributing to scientific knowledge and greater self-awareness.) *

- Possible boredom or discomfort from lack of positive engagement with the musical materials heard during the exposure phase. The nature of the music is unconventional and thereby a bit weird, which may make people uncomfortable combined with the controlled environment of an experiment.

Have you prepared a consent form and emailed it as an attachment to IRB@bard.edu?

-

Please include here the verbal description of the consent process (how you will explain the consent form and the consent process to your participants): *

- All the important information is on the form itself; the participant will be asked to read carefully to make sure they are still eligible and wish to participate.

What procedures will you use to ensure that the information your participants provide will remain confidential?

- "The consent form is the only form associated with this research study that contains your name. At the completion of your participation, the data associated with your performance and the questionnaire responses will be separated from this consent form. After doing so, it will be very difficult to link your name to any of the data that you provide. In addition, your records will be kept in restricted access file cabinets and password protected datasets."

Will it be necessary to use deception with your participants at any time during this research? Please note: withholding details about the specifics of one's hypothesis does not constitute deception. However, misleading participants about the nature of the research question or about the nature of the task they will be completing does constitute deception.

- no

Appendix B

Glossary

Pitch- Auditory event that has a clear fundamental frequency (measured in Hz or cycles per second). Perceived as a distinct entity even when other pitches are sounded.

cps/Hz- Unit of measurement for a pitch. Refers to the amount of times a sine wave will cycle between its maximum and minimum amplitude in one second.

Partial- A measurable waveform component of a pitch. A non-pure tone will be accompanied by quieter pitches (partials) that exist at certain frequency ratios above and below the loudest frequency of a pitch. The first partial occurs at twice the frequency of the pitch. Successive partials can be referred to as f0, f1, f2, f3, etc… with the first 10 or so partials having enough amplitude to interact meaningfully in order to define the way a tone sounds.

f0- The waveform component of a pitch that has the highest amplitude.

Note- A specific pitch as described by a particular tuning system.

Interval- The distance between two separate notes. Can be defined using terminology from western music (octave, perfect 5th, unison, 2nd, 3rd, etc.) or with ratios 2:1, 3:2, 15:8 as well as by referring to their frequency values in Hz or amplitude per second.

Dyad- 2 notes sounding simultaneously. 1 interval is present.

Triad- 3 notes sounding simultaneously. 3 intervals are present.

Chord- 3 harmonically related notes sounding simultaneously.

Chord progression- A sequence of chords that may give rise to perceptions of tension and resolution at certain points in the cycle.

Scale- A selection of typically 5 to 7 notes out of those provided by a tuning system that will be used in a piece of music.

Scale degree- the Nth note in a scale, starting from the tonic.

Key- a piece of music can be said to have a key when a particular scale is built off of that song's tonic. If a song's key is 'G major' then a major scale will be built off of the note G.

Tonic- The note that acts as a reference point for a scale or key.

Tuning system- a way of defining which pitches to use when playing music. In other words, it is the choice of number and spacing of frequency values used. (FROM WIKIPEDIA) the same scale can appear in two different tuning systems, with tempered intervals.

Temperament- "Adjustment"; the modification of any particular intervals in a tuning system.

Just Intonation- The most mathematically natural tuning system. The intervals between each note and the tonic can be defined by small whole-number ratios.

Even temperament- An adjustment to the justly intoned scale that places each adjacent note the same distance apart. this distance is 100 cents.

Music system- any (often geographically based) tendency that has been examined and found to have a statistically significant characteristic that is distinct from other regions or styles

Tonal hierarchy- A formal description of which notes in a scale are those most critical to establishing a key. While all 7 notes of a scale may be used in a piece, the three notes most critical to the scale (namely the 1st, 3rd, and 5th notes in the scale. these notes build a triad based on the tonic of the key) are said to be those highest in the tonal hierarchy, and will occur more often in a piece than notes that are lower in the hierarchy. The tonic is always the highest in the hierarchy, with the 5th and 3rd being in 2nd and 3rd place, respectively.

Appendix C

Experiment Script

Hi! Thank you for coming to participate in this experiment. The whole thing should take about an hour in front of a computer, while wearing headphones. The purpose of this experiment is to investigate the workings of the auditory system; these things are processed almost unconsciously so you don't need to think too much about your responses.

Since the only data collected will be your responses on the computer, there will be nothing connecting your name and signature to anything collected today, which means your participation is completely anonymous. To this end, no information about personality or individual characteristics is related to the hypotheses of the experiment.

Secondly, our whole session should last an hour and will all take place on this computer, but you can take a quick break halfway through if you like.

For now, feel free to take an opportunity to take care of anything you'd like to do before I run you through the tasks you will be presented with.

[GIVE CONSENT FORM] Please read this consent form and sign at the bottom if you agree.

[WHEN READY]

Pre-exposure probe tone phase

As you read on the consent form, there are 5 parts to this experiment. In the first, you will hear an 8-tone sequence, followed by a short pause and an additional 9th tone.

Your task will be to rate how well you think that final tone fits, given what is established by that preceding sequence. You'll be answering on the computer here [point to rating scale 1-7 in MAX patch]. If the tone sounds out of place, give it a lower rating. If the tone and the sequence sound like they fit together or are more congruent, give it a higher rating.

You'll repeat this a number of times to give ratings for multiple tones. I'll keep track for you of how many you've done, but you will also see in this window [point to MAX console] a message that pops up when you're done with this task.

When you're ready to start, you'll hit this button here [point to button on MAX patch- *correct condition's button as well as rating scale has been isolated from the rest of the patch's elements by placing all desired elements into presentation mode*]. When you hit the button, you'll hear the 8-tone sequence, and the 9th tone that you'll assign the rating of fit to. Once you give it a rating, you'll hit this button again to hear another sequence and tone.

By the way, you should find the volume of the sounds to be at a comfortable level- feel free to use this knob to adjust to what sounds comfortable to you, while still being able to hear the tones clearly.

Exposure phase

Ok, for this part of the experiment, you'll be listening to 25 minutes of 8-tone sequences. During that time, you'll be allowed to draw on this piece of paper. It is not important that you pay particularly close attention to what you're hearing, as long as you can hear it comfortably on the headphones. I'll keep track of time for you, but you will also be able to see in the console window a message that appears when the time required for this part is done.

[Run 25 minutes of exposure in correct condition]

Okay! [offer time to take a 30-60 second break if strain is occuring]

Forced-choice recognition phase

For this next part, you will press this button and hear two 8-tone sequences, one after the other. Your task is to decide which of the two you think sounds *more familiar* to you, based on what you've heard so far in this experiment. If you think that the first sequence out of the two you hear sounds more familiar, press button number 1 [point to this button in the program]. Likewise, if you think that the second sequence sounds more familiar, press button number 2 [point]. There will do this 20 times, as there are 20 pairs of sequences for you to compare. I will keep track for you, but you can see a message in the console window that will appear when this part of the experiment is over.

Post-exposure probe tone phase

For this next part, you'll be doing the same task you did at the beginning of the study. You will hear an 8-tone sequence, followed by a short pause and an additional 9th tone.

Your task will be to rate how well you think that final tone fits, given what is established by that preceding sequence. You'll be answering on the computer here [point to rating scale 1-7 in MAX patch]. If the tone sounds out of place, give it a lower rating. If the tone and the sequence sound like they fit together, give it a higher rating.

You'll repeat this a number of times to have ratings for multiple tones. I'll keep track of how many you've done, but you will also see in this window [point to MAX console] a message that pops up when you're done with this task.

When you're ready to start, you'll hit this button here [point to button on MAX patch- correct condition's button as well as rating scale has been isolated from the rest of the patch by placing all desired elements into presentation mode]. When you hit the button, you'll hear the 8-tone sequence, and the 9th tone that you'll assign the rating of fit to. Once you give it a rating, you'll hit this button again to hear another round.

Melody preference ratings phase

For this next part, you will hear an 8-tone sequence and give it a rating based on how much you like it. You'll hit this button to hear a sequence. Give the sequence a higher rating, like 7, if you like it a lot. If you don't like it at all, give it a lower rating, like 1. You will do this task 20 times to get ratings for 20 different 8-tone sequences. You'll be able to see here in the console window when the task is done, and I'll be keeping track of how many you've done.

[once tasks are completed, give participant opportunity for questions they might have had about the experiment, including the hypotheses of the experiment and the significance of the research. Remind them that snacks are available. Thank them for coming and make sure consent form is signed by participant.]

If you know of anybody that would like to participate in this experiment, please feel free to give my information to them. All I ask is that you refrain from telling anyone about the nature of the inquires and hypotheses of this experiment.

Appendix D

Informed Consent Agreement

This informed consent document contains a brief description of the purpose of this project, what procedures will be used, and the potential benefits and risks of participating. Please read this document and contact the researchers if you have any questions about the study. You should keep a copy of this form for your records.

Background: This experiment addresses how people absorb important information about music by listening to it.

What you will do in this study: If you agree to participate, you will first be asked to complete a task that involves giving ratings to musical tones that you hear. We will then enter a listening phase where you will hear a collection of musical fragments. After that, you will be given a series of questions about similar musical fragments. This study should take about 60 minutes and will be conducted on a computer that will collect your responses.

Risks and Benefits: This experiment will involve a testing environment and extended periods of sitting, which some people may find uncomfortable. Your participation will allow a Bard College student to produce a senior project.

Compensation: In exchange for your participation in this experiment, you will be compensated with candy/snacks.

Your rights as a participant- Your participation is completely voluntary. You are free to stop the experiment at any time with no questions asked. If you choose not to complete the experiment, you may be denied compensation.

Confidentiality and Anonymity- The consent form is the only form associated with this research study that contains your name. At the completion of your participation, the data associated with your performance and the questionnaire responses will be separated from this consent form. After doing so, it will be very difficult to link your name to any of the data that you provide. In addition, your records will be kept in restricted access file cabinets and password protected datasets.The final published version of this research will be permanently and publicly available as a Senior Project at the Stevenson Library of Bard College.

You must be 18 years or older and have normal hearing abilities to participate in this study. *By continuing this survey, I affirm that I have read and understood the above information and voluntarily agree to participate in the research project described above. I accept the risks of harm described as well as the benefits described above. By continuing this survey, I acknowledge that I am 18 years of age or above.*

____
____ Sign here
Date

The experimenter will give you more information regarding the study after it has ended. If you have questions or would like to know more about this subject or the experiment, please contact the primary researcher, Luke Sandbank at ls4928@bard.edu. If you have questions about the Bard Psychology Program, you may contact Associate Professor Thomas Hutcheon, advisor to this project, at thutcheo@bard.edu. If you have questions or concerns about your rights as a participant, please contact the Bard College Institutional Review Board at irb@bard.edu.