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Physiological Response to Dissonance in Musicians and Nonmusicians

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PHYSIOLOGICAL RESPONSE TO DISSONANCE IN MUSICIANS AND NONMUSICIANS

by
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Knowing the human response to musical dissonance could have important therapeutic implications in the music therapy setting. The listener's musical experience could significantly impact their response and subsequently its effect in a therapeutic setting. Thus, this study aimed to examine both the psychophysiological and subjective responses to dissonance and the difference in these responses between those with high experience and those with low experience. Participating groups, categorized as high experience (HE) and low experience (LE) in terms of musical knowledge, listened to consonant and dissonant musical excerpts, and rated each excerpt on its pleasantness; their physiologic responses were measured to determine pleasantness and unpleasantness. Facial electromyography (EMG) using the corrugator (eyebrow) and zygomatic (cheek) regions was used to evaluate the emotional valence response to the pleasantness and unpleasantness of the stimuli. The results of our study showed that the HE participants did exhibit stronger reactions to both the dissonant and the consonant excerpts, with the response to dissonance being the strongest. Contrary to our hypothesis however, this response was greatly varied, as HE participants showed more response in the zygomatic muscle during the dissonant excerpts.

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INTRODUCTION

Physiologic responses to consonance and dissonance have been examined in several studies over many years (Baumgartner, R. J., 2015; Dellacherie, D., Roy, M., Hugueville, L., Peretz., I., & Samson, S., 2010; Ellis, R. J., & Simons, R. F., 2005; Gomez. P., & Danuser, B., 2007; Gosselin, N., Samson, S., Adolphs, R., Noulhiane, M., Roy, M., Hasboun, D., Baulac, M., & Peretz., I., 2006; Khalfa, S., Peretz., I., Blondin, J.-P., & Manon, R., 2002; Koelsch, S., Jentschke, S., Sammler, D., & Mietchen, D., 2007; Rickard, N. S., 2004; Rogers, S. E., 2010; Saamler, D., Grigutsch, M., Fritz, T., & Koelsch, S., 2007; Schon, D., Regnault, P., Ystad, S., & Besson, M., 2005;). Listener's musical background may alter this physiologic response. The current study explored the possible alteration of the physiological response to dissonance and the difference in this response between those with high experience and those with low experience. This study is a replication of the 2010 study by Dellacherie, Roy, Hugueville, Peretz, and Samson. The original study sought to examine the effects of musical experience on emotional response to dissonance and the physiological correlates. The researchers collected physiological data in the form of electrodermal activity (EDA), heart rate (HR), and facial electromyography (EMG), as well as self-reported ratings from high experience and low experience.

The present study examined the subjective responses, EDA or skin conductance response (SCR), and facial EMG. This manuscript will focus specifically on the EMG data and others will address the EDA and self-reported ratings. The muscles of the face respond readily to emotionally valenced stimuli. The subjective response can be estimated by the activity in the facial muscles (Cacioppo, J. T., & Petty, R. E., 1996). Certain muscles correspond, most often involuntarily, with certain affective reactions. The corrugator muscle (corrugators supercilii) is otherwise known as the brow muscle. It is most often activated when frowning or furrowing the brow and is associated with negatively valenced stimuli. The zygomatic muscles (zygomatic major) are located on either side of the mouth, in the cheek area. This muscle pulls the mouth into a smile and is most often associated with positively valenced stimuli. It can also be activated while pulling the mouth into a grimace.

The analysis in this manuscript will examine how the muscle responses of the corrugator and zygomatic regions correlate with the consonance and dissonance of musical excerpts. It will also examine how these responses differ in high experience participants as opposed to those with little to no musical experience. The questions to be examined are as follows:

Research questions

1. Will dissonant excerpts increase corrugator muscle activation to a greater degree than consonant excerpts?
2. Will consonant excerpts increase zygomatic muscle activation to a greater degree than dissonant excerpts?
3. Will physiological responses differ between high experience and low experience participants?

The original study (Bumgarner, R. J., 2015) examined these responses in order to determine how music education affects processing of sounds. The aim of the current study is to examine the psychophysiological effects of music, specifically dissonance, and how these responses could be used in the therapeutic setting as well as the educational setting.

REVIEW OF LITERATURE

Consonance and Dissonance

Music consists of several key elements organized in various combinations. The musical element of pitch is the location of a sound on a tonal scale or the highness or lowness of a note, as determined by its frequency. In terms of musical notes, frequency is the rate of vibration per second (Oxford Dictionary of Music, 679). The relationship between musical pitches can either be consonant or dissonant.

Consonance is pleasantness and stability in musical sounds (Bidelman & Krishnan, 2009). When two or more sounds occur simultaneously, they are thought to be consonant if the frequencies form simple integer ratios, are evenly spaced, and do not interact with each other. Consonant sounds are simple and even, making them more pleasant to listen to and easier to process. Consonance occurs more frequently in music than dissonance. This may be because of its qualities of being stable and pleasant. Consonant intervals can include unison (two notes of the same pitch), major third, perfect fourth, perfect fifth, major sixth, and an octave (Foss, Altschuler, & James, 2007).

In contrast, dissonance is an unpleasant sensation produced by the simultaneous presentation of two sounds. (Dellacherie et al., 2010) Dissonant sounds occur as frequencies that are close together and that interact with each other, which produces an auditory beating or roughness in the sound (Bidelman & Krishnan, 2009; Dellacherie et al., 2010; Fishman, Volkov, Noh, Garell, Bakken, Arezzo, Howard, & Steinschneider, 2001; Fritz, Renders, Muller, Schmude, Leman, Turner, & Villringer, 2013; Rogers, 2010; Schon et al., 2005). Dissonant intervals form frequency integer ratios that are complex and uneven. (Bidelman &Krishnan; 2009, Dellacherie, 2010; Fishman et al., 2001; Foss et al., 2007; Schellenberg & Trainor, 1996; Schon et al., 2005) These intervals can include a minor second, a tritone, and a major seventh. In a thesis examining the influence of consonance and dissonance on musical signal processing, Rogers (2010) found that listeners described auditory roughness as unpleasant or annoying. Indeed, this auditory event of roughness is a degree of signal modulation that contributes to sensory dissonance and is linked to the feelings of musical dissonance.

Consonance and dissonance can be placed into two distinct categories: sensory and musical. Sensory dissonance is the perception of the beating produced by the frequencies of the simultaneous sounds. According to Schellenberg and Trainor (1996), sensory consonance and dissonance are a "function of physical properties of the stimulus and [are] therefore independent of exposure to music or to cultural differences in musical styles" (pg. 3321). Similarly, Trainor, Tsang, and Cheung (2002) contend that, even though different cultural systems separate a musical octave into different intervals, and use different sets of notes and scales, the basis of sensory consonance seems to be shared across musical systems. Musical consonance and dissonance on the other hand, are manipulated by composers in order to induce tension and expectation in music (Dellacherie, 2011; Fishman et al., 2001; Schellenberg et al., 1996).

It is interesting to consider the enunciation by Schon et al. (2005) that consonance and dissonance are different depending upon the way they are presented. Harmonic intervals are those that are sounded simultaneously whereas melodic intervals are those that are sounded successively. Dissonant intervals are more often judged or perceived as dissonant when they are presented harmonically as opposed to melodically. (Schon et al., 2005)

Research suggests that the perception of consonance and dissonance occurs in the auditory system within the superior temporal gyrus (Gosselin, et al., 2006; Rogers 2010; Trainor et al., 2002). According to Trainor et al. (2002), consonance and dissonance are encoded in the auditory system. The critical band structure of the basilar membrane in the inner ear can explain the perception of sensory consonance. Distinction between consonance and dissonance is represented in the temporal structure of the firing patterns of the neurons in the auditory nerve. The peripheral auditory system is relatively mature early in life. In fact, even newborn infants can detect differences in auditory events (Masataka, 2006; Trainor et al., 2002).

Valence Judgments of Consonance and Dissonance

People generally rate consonance as pleasant and dissonance as unpleasant. Pythagoras defined consonance as tones that, when played simultaneously, created simple frequency ratios and thus pleasant sounds (Foss et al., 2007). On the other end of the spectrum, Pythagoras stated that tones which, when played simultaneously, produced complex ratios thus produced unpleasant sounds. Foss, et al. (2007) studied the neural correlates of these Pythagorean ratio rules and found that the brain is more activated when listening to dissonant sounds.

Dissonance is perceived as unpleasant and consonance is perceived as pleasant, regardless of a person's musical experience or knowledge. The judgment of consonance as pleasant and dissonance as unpleasant does not appear to depend on musical experience or training. Peretz, Blood, Penhune, and Zatorre (2001) studied a patient who had damage to the auditory cortex. This patient was able to judge the happiness-sadness of musical excerpts based on their modal structure. However, her judgments were not sensitive to consonance and dissonance. The patient rated the consonant versions of excerpts to be as pleasant as the dissonant versions. Normal control subjects rated consonance to be more pleasant and dissonance to be more unpleasant. The researchers studied this further by using PET and CT scans of the subjects' brains while they listened. The parts of the brain that were activated during listening of the most dissonant and consonant versions of the auditory stimuli were consequently the parts of the patient's brain that had been damaged. These results suggest that the processing of dissonance and consonance and their related pleasantness and unpleasantness is a function of the brain that is independent of emotional valence as well as musical knowledge and/or experience.

Even infants, with no prior knowledge or training of any sort, prefer consonance over dissonance. Several studies have examined infants' response to consonant and dissonant sounds and have found that newborns as young as 2 - 4 days show a preference for consonance over dissonance (Perani, Saccuman, Scifo, Spada, Andreolli, Rovelli, et al., 2009; Masataka, 2006; Schellenberg & Trainor, 1996; Trainor et al., 2002). The babies looked longer at a sound source that was producing consonant music than they did from a sound source that produced dissonant music. Perani et al. (2009) found that the brain structures involved in the processing of such things as pitch and sensory consonance-dissonance in mature adults are already present and active in newborns.

Ellis and Simons (2005) studied the impact of music on the subjective ratings and the physiological indices of the emotional response while viewing films. They found that music produced an additive effect in that it modulated the subjects' emotional response to films. The results were less conclusive when it came to physiological response modulation of music paired with film. It was apparent in this study that music had an effect on emotional valence judgments while viewing films. More active and positive music altered the emotional valence judgments of film regardless of the activity and positivity of the film itself. In other words, when the music was faster, more consonant, and in a major key, the subjects tended to rate the film with more positive valence. There was a main effect for skin conductance ratings (SCR) and both music and film valence. Films shown along with positive music elicited greater SCR than did films shown with negative music. Interestingly, music arousal did not evoke change in SCR in negatively valenced films. High-arousal music only elicited greater skin conductance response when it was paired with positive films.

Along with subjective ratings and physiological responses, research has been conducted to examine the correlation of neurophysiological responses to emotionally valenced stimuli. Blood and Zatorre have conducted numerous studies relating to the emotional and physiological response to different aspects of music. Their 2001 study found that music can evoke response in the same brain structures that are involved in reward and emotion having to do with biologically relevant stimuli (food, sex). These brain regions were found to be activated when associated with intensely pleasurable emotional responses to music such as chills, but not when associated with simple consonance. Similarly, in their 2009 study, Koelsch, Jentschke, Sammler, and Mietchen found that the same brain structures in both high experience and low experience were activated when listening to dissonant music. All listeners – regardless of musical experience - rated the dissonant excerpts as unpleasant with the highest degree of dissonance being rated as the most unpleasant. Increasing unpleasantness ratings correlated with increased activity in certain brain structures while decreasing unpleasantness ratings correlated with increased activity in other structures.

Physiological Response to Consonance and Dissonance

Not only do consonance and dissonance have an effect on the behavioral responses of humans, they also have effects on physiological responses. Research has shown that, along with valence judgments (pleasantness-unpleasantness), sensory consonance and dissonance elicit physiological responses including changes in heart rate, skin conductance response, and muscle response (Bradley & Lang, 2000; Fujimura, Katahira, & Okanoya, 2013; Gomez & Danuser, 2007; Sammler, Grigutsch, Fritz, & Koelsch, 2007; Sandstrom & Russo, 2010) as well as neurophysiological responses (Fishman et al., 2001; Foss et al., 2007; Fritz et al., 2013).

In a 2007 study of the physiological correlates of the processing of pleasant and unpleasant music, Sammler et al. used consonant musical excerpts and their permanently dissonant counterparts to determine whether the valence of emotional responses to dissonance would correlate physiological responses. The researchers used Western classical music and altered the excerpts by raising the leading voice and playing the altered version along with the original consonant excerpt. Participants consistently rated the consonant excerpts as pleasant and the dissonant excerpts as unpleasant. Additionally, these valence judgments correlated with the physiological responses measured through electroencephalography (EEG) and heart rate (HR). HR acceleration was stronger for consonant than for dissonant pieces. A secondary deceleration occurred which was significantly greater while listening to the dissonant music than during the consonant music. HR remained lower during dissonant music listening, whereas it was stable during consonant music listening. Further analysis revealed a significant correlation showing that the HR deceleration increased linearly with increasing unpleasantness. (298)

Sandstrom and Russo found in their 2010 study that positively valenced music was most effective in contributing to physiological recovery after an acute stressor. Heart rate and skin conductance response were more quickly recovered and balanced after a stressor when listening to low arousal music with positive valence. Additionally, the researchers found that music with more consonance was more effective than white noise in promoting physiological recovery after a stressor. These results were not affected by liking of the music or any degree of musical training. Gomez and Danuser (2007) found that musical structures such as rhythm, tempo, mode, and consonance affected physiological responses such as heart rate, respiration, and skin conductance.

EMG Response to Dissonance and Consonance

Facial electromyography (EMG) has been widely used in scientific studies to examine physiological reactions to emotionally valenced stimuli. Certain muscles in the face tend to show specific responses to stimuli. The corrugator muscle is the muscle on the forehead, between the eyebrows. This muscle raises and lowers the eyebrows, which often occurs simultaneously with emotional responses. In particular, the corrugator muscle is implicated in a furrowed brow, which one might see in response to a negatively valenced stimulus. The zygomatic muscle, on the other hand, is implicated in the smiling response. This muscle is part of the cheek and is most often known to raises the cheek muscles into a smile. The zygomatic muscle is also part of the muscle group that produces a grimace. Both the corrugator and zygomatic muscles have been used to determine correlation between physiological and emotional responses to various types of stimuli.

Bradley and Lang (2000) examined emotional reactions to pleasant and unpleasant sounds. They used subjective ratings along with physiological measures including startle reflex, heart rate, electrodermal activity, and facial EMG to determine the correlation between psychophysiological response and affective response to emotional stimuli. Three muscles were measured in the facial EMG portion of this study: the corrugator (eyebrow), the zygomatic (cheek), and the orbicularis oculi (beneath the eye). Studies have shown that corrugator EMG, startle response, and heart rate changes are greater in response to unpleasant sounds and pictures, whereas zygomatic and orbicularis oculi EMG and skin conductance response are greater for pleasant sounds and pictures. Results of this study provided evidence in support of these effects. Activity in the corrugator muscle was significantly higher when listening to unpleasant sounds and this activity decreased when listening to pleasant sounds. Conversely, changes in zygomatic activity, although in the predicted direction (increased with pleasant sounds), were small. The orbicularis oculi showed more activity for both pleasant and unpleasant sounds when compared to neutral sounds. The facial EMG activity did indeed correlate with the participants' subjective ratings of the sounds presented in the experiment. Corrugator EMG activity correlated with ratings of unpleasantness and zygomatic EMG activity correlated with ratings of pleasantness.

The body of research examining the EMG response to sensory dissonance is quite lacking. Most studies explore EMG in response to visual stimuli such as pictures, films, and videos. Some studies have examined EMG response to music but the music is most often in combination with some other type of stimuli rather than on its own. The lack of EMG data in response to strictly musical stimuli brings up a major gap in the research base and thus provides a strong basis for the current study.

Differences in Responses Between High Experience and Low Experience

The research findings of several studies (Bidelman et al., 2010; Fishman et al., 2001; Foss et al., 2007; Fritz et al., 2013; Schneider et al., 2002; Fujimura et al., 2013) suggest that, although the initial response and the perception and processing of consonance and dissonance are not affected by musical knowledge and/or training, some eventual impact is still possible. In other words, the neurophysiological response as well as the perception and processing of consonance and dissonance can be modulated and enhanced by musical training and experience. For example, Schneider et al. (2002) found that there are actual neurophysiological differences between the brains of high experience and low experience. In a 2011 study, Bidelman, Krishnan, and Gandour examined brainstem encoding of pitches and found that high experience had faster and stronger encoding of triadic arpeggios than did low experience. Low experience had stronger encoding for typical major and minor chords that were in tune. High experience were better able to discriminate changes in pitch and de-tuned arpeggios. These results suggest that musical training enhances the perceptual abilities when it comes to processing pitch.

Foss et al. (2007) examined the neural correlates of Pythagorean ratio rules and found that, although high experience and low experience did not differ in neural activation when listening to dissonance – all participants showed more activation when listening to dissonance – high experience' brains were more activated overall while low experience only showed activation in one single area. Interestingly, the researchers found that, while low experience showed activation in the right hemisphere when listening to dissonant intervals, high experience showed more activation in the left hemisphere. This contributes to the idea that perception and processing of dissonance can be modulated by musical knowledge and experience.

Rogers (2010) alludes to the interesting point that studies of ERP and ECG which elicit response under passive testing conditions show that auditory perception processing before attention does not differ between high experience and low experience. In other words, rapid response to consonance and dissonance without the possibility of knowledge or experience biases appears to be similar across respondents. When evaluative discrimination is allowed and familiarity with the auditory stimuli is taken into consideration, the response is significantly different between high experience and low experience.

It has been a common finding of research studies examining the response to emotionally valenced stimuli that judgments of a perceived stimuli are often influenced by pre-existing feelings (Baumgartner, Esslen, & Jancke, 2006; Fujimura et al., 2013; Gosselin et al., 2006; Juslin & Vastfjall, 2008; Pallesen, Brattico, Bailey, Korvenoja, Koivisto, Gjedde, & Carlson, 2005; Rickard, 2004). Fujimura et al. (2013), present the possibility of the “feelings-as-information hypothesis” (pg. 1) as one explanation. This hypothesis suggests that feelings related to experiences serve as information when forming judgments about an experience. In other words, feelings connected to an experience can inform our response to present situations. Results from the Fujimura et al. (2013) study suggest that valence judgments from a previous experience with a stimulus may be carried over into the emotional response to present stimuli. These responses have been measured in terms of subjective feelings as well as facial activities (facial EMG responses) elicited by the target stimuli.

In the current study, we examined the connection between valence judgments and emotional response to stimuli through the physiological response of facial EMG. We also examined the results based on the participants' level of experience in music in order to determine whether there was a connection between physiological response and experience.

METHODS

Participants

Participants in this study were recruited from the campus of Western Michigan University. Recruitment emails were sent inviting participation. When respondents showed interest in participating, an enrollment email with details about the study was then sent. Participants were offered a $10 gift card for their participation in the study. Thirty participants were enrolled, ranging in age from 19 to 51, with a mean age of 24.4 years. Once recruited, participants filled out a researcher-created questionnaire (see appendix A) in order to determine their level of musical experience. This procedure was based on the criteria used in the original Dellacherie et al. study (2010) upon which we based our research. Participants were asked to describe their music listening habits, their level of experience in music, the depth of that experience, current musical practice habits, and their musical preferences. Based on the results of the questionnaire, respondents were placed into one of two groups: high experience (HE) or low experience (LE).

Of the thirty participants for the study, 16 (6 male, 10 female) were classified as high experience (HE) and 14 (3 male, 11 female) as low experience (LE). The high experience group included 15 college music majors and one occupational therapy major with extensive musical training. Altogether, the participants in the high experience group had 2 -14 years of institutional training in music. In addition, the majority (15 out of 16) of the high experience participants reported attending live music events at least once a month. The low experience group had two participants that reported any musical training which they indicated as being in the past. One of the 14 low experience participants reported attending live music events at least once a month.

Stimuli

This study used 10 of the 16 excerpts from the original Dellacherie et al. (2010) study, which were taken from a set of classical music excerpts used in previous studies (see appendix B) that had also examined response to dissonance (Dellacherie et al., 2010; Gosselin et al., 2006; Khalfa, S., Guye, M., Peretz, I., Chapon, F., Girard, N., Chauvel, P., et al., 2008; Koelsch et al., 2009; Peretz, I., Gagnon, L., & Bouchard, B., 1998; Peretz et al., 2001). The 10 excerpts used in the present study were chosen based on their distinct melody line in order to make the modification more concrete. The excerpts were all instrumental, meaning there were no words, and were played through a MIDI piano so as to eliminate any expression. The process of playing each excerpt through a MIDI piano was meant to mechanically remove all expressivity by standardizing all note velocities, lengths, and attack volumes. The leading voice, or melody line, of each of the 10 excerpts was shifted in pitch by both one semitone up and one semitone down in order to create a total of 20 dissonant excerpts. In the experiment, each consonant excerpt was played twice in order to match the number of dissonant excerpts, giving us 40 listening excerpts in total. Table 1 lists the details of the original excerpts used in the current study.

Table 1. Listening excerpts

Composer	Work	Measures	Tempo (bpm)
Beethoven	Symphony no. 3 (3rd mvmt.)	38-56	180
Handel	Utrecht's Te Deum	5-14	112
Mozart	Eine Kleine Nachtmusik (1st mvmt.)	5-10	154
Mozart	Piano Concerto no. 23 (3rd mvmt.)	1-8	240
Saint-Saëns	Carnaval des Animaux (Finale)	10-26	220
Saint-Saëns	Carnaval des Animaux (La Voliere)	1-9	88
Schumann	Kinderszenen (Op 15 no. 9)	1-9	240
Verdi	La Traviatta (Brindisi)	1-15	100
Verdi	Rigoletto (Act 1 no. 4)	69-73	150
Vivaldi	L'Autunno (1st mvmt.)	1-4	126

Measures

Physiological data collected for electrodermal activity (EDA) and electromyographic (EMG) activity was measured using the MP150 Biopac software in the BRAIN lab on the campus of Western Michigan University. The electrodes used for collecting EDA data were BioNomadix EL507. EMG data was collected using BioNomadix EL504-10 electrodes on the corrugator and zygomatic muscle regions of the face. All measures were processed using the AcqKnowledge software in the BRAIN lab. The subjective ratings of pleasantness and unpleasantness used a scale between -5 and +5 with -5 being the most unpleasant and +5 being the most pleasant.

Procedure

Participants first read and signed an informed consent document and then completed the musical experience questionnaire before entering the experiment room.

Once in the experiment room, the electrodes were placed on each subject to collect the physiological data. Although not reported as part of this manuscript, EDA data was collected through the BioNomadix EL507disposable electrodes placed on the subjects' index and middle fingers on the non-dominant hand. EMG data was collected using the BioNomadix EL504-10 disposable cloth electrodes attached over both the corrugator (brow) and zygomatic (cheek) muscle regions of the face. The EMG signals were continuously monitored and filtered between 100 and 500 Hz. The physiological data measurements were processed with the AcqKnowledge software and were sampled at a rate of 2000 Hz. The last step before the procedure began was to give the participants the pleasantness rating sheets and instruct them on how to rate the excerpts using the rating sheets.

The experiment progressed through four listening blocks. The order of presentation of the excerpts within each listening block was counterbalanced within subjects. The listening blocks were also counterbalanced between subjects as half of the participants began the block with a consonant excerpt and the other half with a dissonant excerpt. As an index of individual EDA and startle response, each block began with a loud burst (90 db) of white noise that lasted 50 milliseconds followed by a 10-second recovery period. The participants were given a 2-second verbal reminder not to move (so as not to create artifacts via the electrodes) and then there was a rest period of 7 seconds before each excerpt was played. Each excerpt was 7 seconds in duration. Another short 1-2 second rest period immediately followed the excerpt and then a 2-second verbal confirmation that the participant could move. The participants then gave a report of their perceived pleasantness/unpleasantness rating of the excerpt. This entire procedure continued through the four blocks with a 22-second rest period between each block to allow the participant to move around and to control for habituation.

Design and Analysis

A mixed design was used where each participant was assigned to one of two groups (HE or LE; the between groups factor) whilst also being subjected to both listening conditions. Tonality (consonant vs. dissonant) and time window (first vs. second) were the within subjects factors. For the purposes of this manuscript, we have only analyzed and reported the EMG data. The independent variables were experience (high vs. low) and tonality of the excerpts (consonant vs. dissonant). The dependent variables were estimates of the EMG response in the corrugator and zygomatic muscles. Before analyses were performed, we collapsed the data across the 40 excerpts into one of two measures – consonant or dissonant. We also examined two measures of the dependant variable of physiological response: the first time window comprising the initial 2 seconds of the excerpt, and the second time window comprising the last 5 seconds of the excerpt. The EMG data was rectified and smoothed over 100 ms slices which were then averaged over the 7 second period following the onset of each musical excerpt. The average of an 800 ms baseline just prior to the onset of each excerpt was then subtracted from the 7 second excerpt to determine the changed scores.

RESULTS

The aim of this study was to explore the difference in response to consonance and dissonance in music and to determine whether musical training has an effect on that response. We examined these effects through both subjective ratings by the participants and physiological responses measured through skin conductance and facial EMG. The subjective ratings and the skin conductance measures have been analyzed and reported in separate manuscripts. The purpose of the current manuscript was to analyze and report on the data pertaining to the EMG responses. Our research questions pertaining to the physiological response were:

1. Will dissonant excerpts increase corrugator muscle activation to a greater degree than consonant excerpts?
2. Will consonant excerpts increase zygomatic muscle activation to a greater degree than dissonant excerpts?
3. Will physiological responses differ between high experience and low experience?

As previously discussed, the corrugator muscle most often correlates with a frown or a negative response. Therefore, we hypothesized that corrugator responses would be higher for dissonant excerpts than for consonant excerpts. Conversely, we also hypothesized that zygomatic responses would be higher for consonant excerpts than for dissonant excerpts as the zygomatic muscle most often corresponds with a smile or positive response. In order to test these hypotheses, separate analyses were performed for each muscle response. Regarding level of experience, we hypothesized that high experience would exhibit a greater overall physiological response in both consonance and dissonance and that the response to dissonance would be the greatest. Although we did not have an official research question or hypothesis addressing time window, it became of interest after observing a difference in the raw EMG responses, differentially based on time window upon the initial inspection of the EMG data.

In accordance with the procedure in the Dellacherie (2010) study upon which the current study was based, we calculated the EMG responses by taking the difference between the raw signal while listening to the musical excerpt and the 80 ms baseline just prior to the onset of the excerpt. We then averaged the resulting response curves by 100 ms slices in both the corrugator and the zygomatic muscles. Then we determined the mean responses for the area under the curve in both the consonant and dissonant excerpts and the high and low levels of experience. We further examined the data in both time windows: the first 2 seconds of the excerpt and the last five seconds of the excerpt.

The data were analyzed using a three-factor, mixed model ANOVA. The independent variables had two factors: within subjects, and between subjects. The within-subjects factors were tonality (consonant, dissonant), time window (first 2 seconds, last 5 seconds), and muscle (corrugator, zygomatic). The between-subjects factor was experience (high, low). The Greenhouse and Geisser adjustment was applied to the data when needed and the corresponding corrected p values are reported. Mauchly's Test of Sphericity was performed but was deemed unnecessary as each of our repeated measures variables only had two levels.

Table 2 shows the estimated marginal means and standard deviations for each muscle response according to the level of experience, the tonality of the excerpt, and the time window. It must be noted that all of our values were very small which reflects the fact that there was very little muscle activity across all subjects throughout the procedure. The highlighted values reflect the highest level of activity within that time window and tonality. It is interesting to note that, in these preliminary descriptive statistics, we can already see some surprising results. For instance, there is more activity in the corrugator muscle for consonant excerpts in the first window. The second window shows a reaction that is closer to our hypothesis with the most activity showing in the zygomatic muscle for consonant excerpts. The activity for dissonant excerpts is the most surprising, with the highest activity being in the zygomatic muscle rather than the hypothesized corrugator muscle.

Table 2. Estimated marginal means (± standard deviation) of the facial EMG recordings for consonant and dissonant excerpts in the first and second time windows.

		First Window		***Second Window***	
		Consonant	***Dissonant***	***Consonant***	***Dissonant***
Corrugator	High Experience	.00368 (±.04566)	.00165 (±.07190)	-.03678 (±.17275)	.29991 (±.62508)
Corrugator	Low Experience	**.01268 (±.03278)**	.02792 (±.08863)	.10176 (±.24806)	.22072 (±.46244)
Zygomatic	High Experience	.00517 (±.01789)	-.00848 (±.04640)	.07875 (±.16732)	**.38648 (±.89152)**
Zygomatic	Low Experience	.00028 (± .02876)	**.03705 (± .14833)**	**.10551 (± .34571)**	.04820 (± .06375)

Note: All values reflect difference from baseline.

There was a statistically significant main effect of time window on facial EMG response. This means that, regardless of tonality, muscle, or level of experience, there was a significant difference in the EMG response between the first and second time windows (F(1,28) = 6.188, p = .019) with the second time window showing more activity. Although not statistically significant, the tonality of the excerpt (consonant or dissonant) showed a positive trend in the EMG response (F(1,28) = 4.165, p = .056). These results suggest that there was a difference in the EMG response depending on whether the excerpt was dissonant or consonant. There was no significant effect for level of experience, meaning that the response between those with high experience and those with low experience was generally the same across all measures (F(1,28) = .130, p = .721). The muscle response did not show any significant effects either (F(1,28) = .007, p = .936), meaning that there was not a significant difference between the response in the corrugator muscle and the response in the zygomatic muscle. Nor was there any significant interaction between muscle response and tonality (F(1,28) = .618, p = .438) meaning that the tonality (consonant or dissonant) of the excerpt did not have a significant effect on the response of either the corrugator or zygomatic muscle.

There was a trend in the interaction between the tonality of the excerpt and the time window, (F(1,28) = 3.986, p = .056). This indicates that responses to consonance and dissonance differed between the two time windows with the response being greater in the second time window. Figure 1 shows the response to consonance between the muscle groups in the two time windows and figure 2 shows the response to dissonance between the muscle groups in the two time windows.

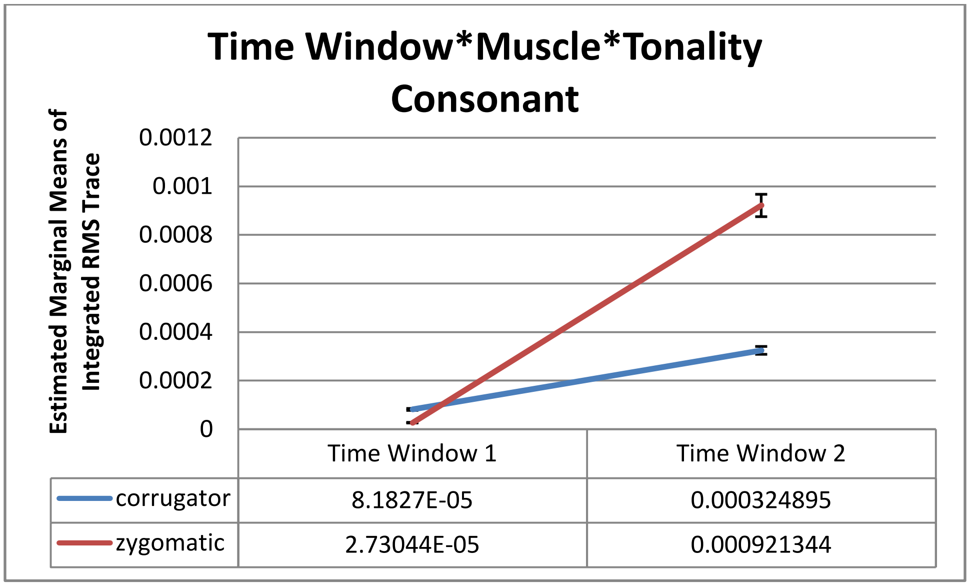


Figure 1. Estimated marginal means of the muscle responses to consonance by time window.

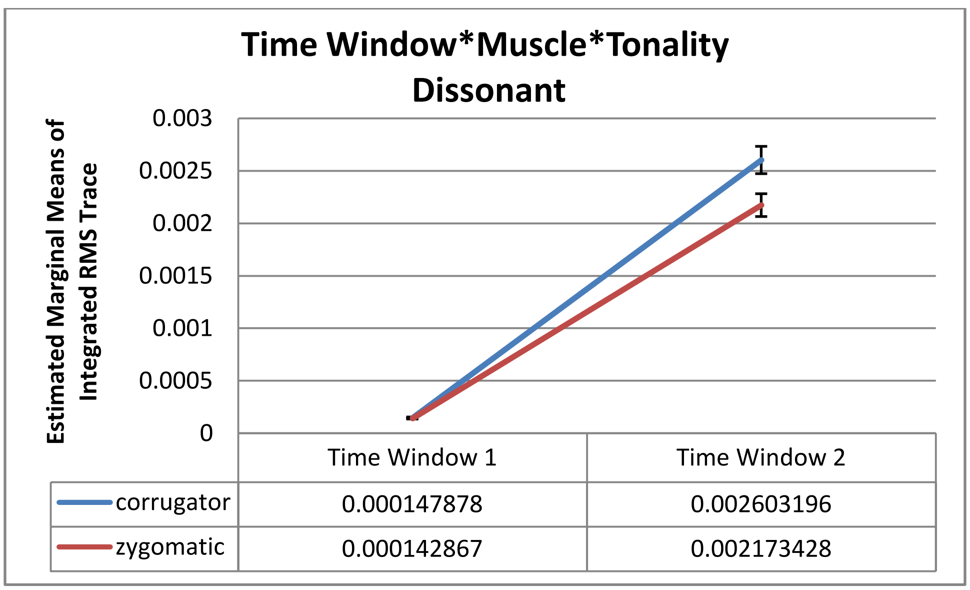
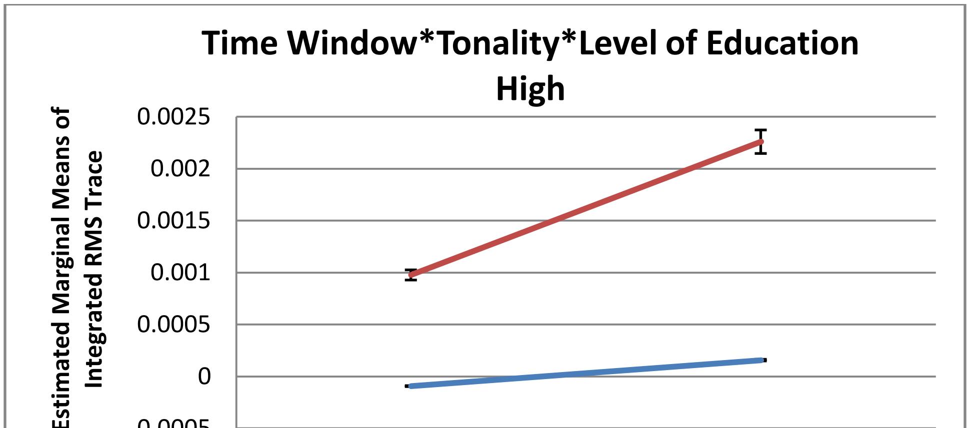


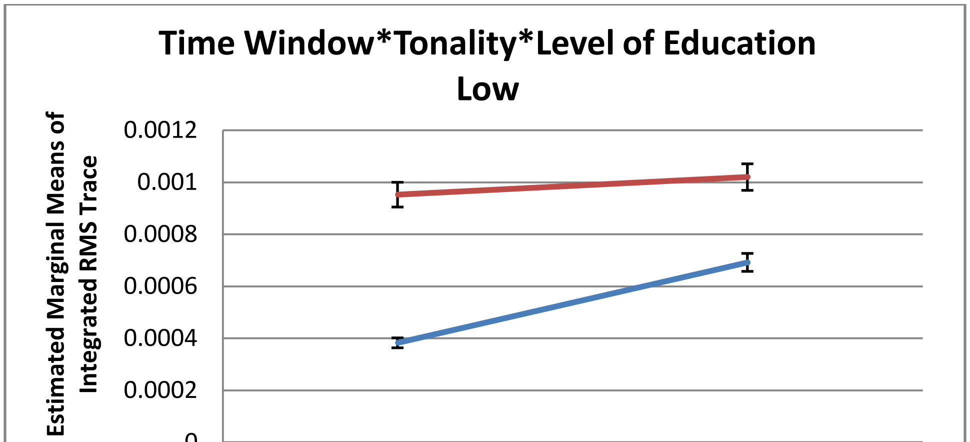
Figure 2. Estimated marginal means of the muscle responses to dissonance by time window.

Although not statistically significant, there was a trend in the interaction between tonality, time window, and experience ($F(2,56) = 3.760$, $p = .063$). This means that the tonality by time window interaction was different in high experience and low experience participants. Figures 3 and 4 show the plots of these interactions. As is evidenced in figures 3 and 4, those with more experience in music not only had greater responses to tonality in the two time windows, their response to dissonance was stronger than those with less experience in music.



	Time Window 1	Time Window 2
consonant	-9.30868E-05	0.000157147
dissonant	0.000976956	0.002259718

Figure 3. Estimated marginal means of high experience responses to consonance by time window.



	Time Window 1	Time Window 2
consonant	0.000382438	0.000691882
dissonant	0.000952338	0.001019943

Figure 4. Estimated marginal means of low experience responses to dissonance by time window.

An interaction between time window, muscle, and experience showed a small trend ($F(2, 56) = 2.300$, $p = .141$). This indicates that, although not statistically significant, the time window by muscle interaction differed between high experience and low experience participants. (See figures 5 and 6) This result suggests that experience in music had an effect on the muscle response in the two time windows. As can be seen in figures 5 and 6, those with high experience had a more varied muscle response in the second time window. Furthermore, the zygomatic muscle showed greater response in those with high experience.

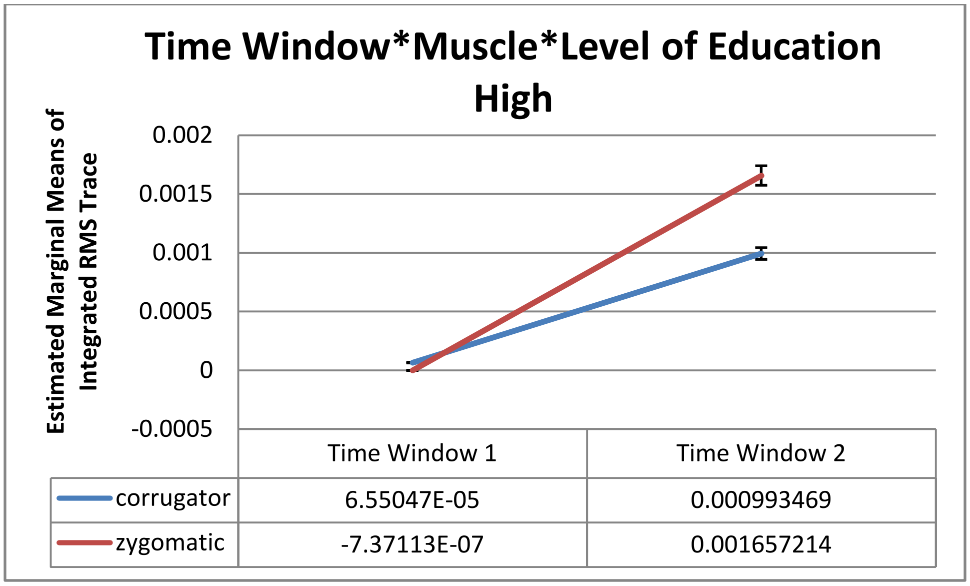


Figure 5. Estimated marginal means of high experience muscle responses by time window.

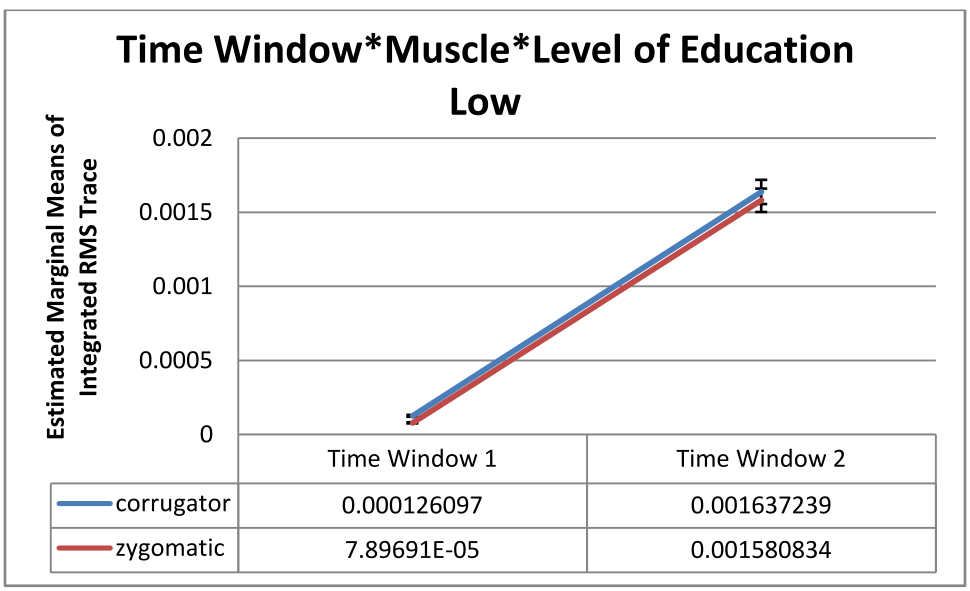


Figure 6. Estimated marginal means of low experience muscle responses by time window.

DISCUSSION

The purpose of this study was to examine both the psychophysiological and the subjective responses to musical dissonance and the difference in these responses between high experience and low experience. This manuscript is part of a larger study that will examine behavioral responses in the form of personal valence judgments, and physiological responses in the form of EMG and EDA. The purpose of this manuscript was to examine and report the findings on the EMG responses.

Overall, there was a greater response to dissonance than there was to consonance, regardless of the level of experience, the muscle, or the time window. As we hypothesized, the results showed that corrugator response was greater in dissonant excerpts than in consonant excerpts. Also as we hypothesized, zygomatic activity was greater than corrugator activity in consonant excerpts.

There was no statistically significant difference in the EMG response between those subjects with a high level of experience and those with a low level of experience. High experience subjects did appear to have a greater response to dissonance; however that response was not as may be expected. Those with high levels of experience showed a greater response to dissonance in the zygomatic muscle than in the corrugator muscle, which is opposite of what was expected. This result is difficult to interpret without actually observing the facial reactions of each subject and aligning them with the physiological data. However, based on the subjective ratings of the subjects in the first part of the current study (Bumgarner, 2015) and the previously examined research regarding experience in music, we can speculate that this response may have to do with the presence of the ironic smile, grimace, or look of confusion on the subjects' faces as they heard the altered versions of the excerpts.

The EMG responses in the current manuscript reflect the subjective ratings given by the participants in the Bumgarner (2015) portion of the larger study. High experience participants rated dissonant excerpts as more unpleasant and consonant excerpts as more pleasant than low experience participants. These ratings align with our findings of greater EMG response to both dissonance and consonance in the high experience participants. High experience participants also varied greatly in their ratings of dissonant excerpts. The physiological data in our study reflects these ratings as we saw a higher zygomatic response to dissonance in the high experience participants.

An interesting aspect of our findings was the difference in the EMG response between the two time windows; the response in each muscle (corrugator and zygomatic) was more pronounced in the second time window. There was more response to the tonality of the excerpt (consonant or dissonant) in the second time window. The interaction between tonality and time window, although not significant, showed a trend toward more pronounced response in high experience than in low experience. These results suggest that those with higher levels of experience had a greater response to the tonality of the excerpt in the second time window. In particular, the response to dissonance in the second time window was much greater than to consonance in those with high levels of experience. Those with low levels of experience did have a greater response in the second time window, but it was nearly identical in both consonance and dissonance.

The Dellacherie et al. (2010) study upon which our research is based states that "the late EMG reactivity reflects a more controlled psychological process related to conscious emotional evaluation which is characteristic of the defense response" (pg. 10). According to the defense cascade model, emotional autonomic responses to stimuli have two steps – the initial orienting response and the defense response. Dellacherie et al. (2010) hypothesized that negatively valenced emotions created by or associated with dissonance would elicit that two-step response. Corrugator muscles are known to be influenced by negative valence and show more activation in response. Juslin et al. (2008) examined the underlying mechanisms of emotional response to music and presented a novel approach that considered many other factors which are not unique to music processing. For instance, they posit that some acoustical characteristics of music, including dissonance, can be interpreted by the brain stem reflex as an impending change or important event.

In light of the defense cascade model (Dellacherie et al., 2010) and the brain stem reflex (Juslin et al., 2008), it is not surprising that we found differences in responses between the two time windows. The difference between the first and second windows was much greater in the high experience group than in the low experience group. As previously mentioned, the zygomatic muscle showed much more activation in the dissonant category than the consonant category, contrary to our predictions. Being that this response was so much more exaggerated in the second window of the dissonant excerpts, we can suggest that the zygomatic response is a controlled response to dissonance that is more pronounced in high experience participants.

Dellacherie et al. (2010) also point out that musical emotion unfolds in time whereas visual stimuli present all the emotional information at once. Conversely, EMG activity unfolds over time (Fridlund & Cacioppo, 1986). This may be the reason for the initial orienting response followed by the more controlled defense response that we observed in our participants. Additionally, just as was discovered in the Dellacherie et al. (2010) study, the response between consonance and dissonance was more exaggerated in the high experience group than in the low experience group with the response to dissonance being much greater.

The fact that we see this orienting and defense response in both the high experience and the low experience groups, and that it is more pronounced for dissonance in both groups, suggests that there is an overall stronger response to dissonance. The stronger response in the high experience group could suggest a more highly developed processing of dissonance or unpleasant music. All this taken together may suggest that musical experience enhances the response to dissonance.

However, we cannot overlook the fact of exposure. Trained musicians are more exposed to dissonance and may therefore have a heightened response based simply on the fact that they are more familiar with dissonance than low experience. This brings us to the question of ecological validity in the current study. According to Field (2009) in Discovering Statistics Using SPSS, ecological validity means that the results of the research can be applied to real world conditions (pg. 785). Real world conditions would not alter the music in the way that it was altered in the current study. The current study, the Dellacherie et al. (2010) study and the previous studies that have used this process of altering the musical excerpts by changing the leading tone are interesting because, this seems to be a form of musical dissonance rather than sensory dissonance. It seems inevitable that those with more experience would have more of a response to musical excerpts that have been altered. Those with high experience may hear the alteration as the musical piece being wrong or ruined – knowing it has been changed purposefully for this experiment.

These studies also chose all classical excerpts. It is interesting to consider what the response would be if we conducted the study with other types of music and presented it to high experience and low experience. It is safe to speculate that if we altered popular music and presented it to both groups, we would likely get a very different reaction in low experience because, although they do not have musical training, they could most likely tell if a song that they knew had been altered to sound different. Low experience would likely rate it more dissonant and it would likely show in their physiological response as well.

Limitations and Future Research

As evidenced by previous studies and results of the current study, the zygomatic response may not be a positive response (smile) but rather an additive response along with the corrugator: the respondents may not only be furrowing their brow but also raising their cheeks in a sort of confused and disgusted manor. They may also be raising their eyebrows in curiosity or interest and this response may affect the activity in both the corrugator and zygomatic muscles. Video recordings of the participants' response coupled with the physiological measures may prove useful for future research in determining whether these responses appear to be positive or negative.

Konrad (2006) explains that EMG signals are very sensitive and can be influenced by external noises like ground noise from a power source. It is not clear whether the room where our study was conducted had been controlled to reduce interfering power hum. As the current writer signed on to this project after the data was collected, it is also unclear whether the averaged baseline noise was controlled so as not to interpret noise or instrument interference as increased activity.

Our study was a replication of the 2010 Dellacherie study. In the article, they stated that the excerpts were selected based on the presence of a distinct melody line and the criteria of being pleasant or evoking happiness, and they were all played in major mode. (pg. 4) These excerpts were chosen based on previous research that has also explored the psychophysiological response to consonance and dissonance. It is interesting to note that they did not simply choose excerpts proven to be "consonant" and "dissonant". Perhaps the researchers did not want to conjecture what was happy and what was not, or they did not want to inadvertently tie happiness to consonance and sadness to dissonance. It is interesting to note that other studies that Dellacherie (2010) based their excerpts on chose both happy and sad musical excerpts. Future research may explore similar subjective and physiological response to music excerpts which involve other qualities besides being pleasant or happy.

It was articulated in the Dellacherie et al. (2010) study that they controlled for tempo differences in their excerpts whereas previous studies had not. They also stated that the tempo ranged from 80 to 225. (pg. 4) That appears to be a rather large tempo range. Dellacherie et al. (2010) state that these excerpts were selected because they were played with a fast tempo. It seems speculative that quarter note = 80 could always be considered fast, especially in some of the excerpts that they use. The tempo could be affecting the response and it is something to be considered if not more carefully controlled in future research.

Furthermore, some of the excerpts begin and end with abrupt attacks and decays and some do not. Research in this area could benefit from the examination of whether the quality of the attack and decay of the musical stimuli has any effect on the physiological response and/or the subjective ratings of the excerpts. In one of the studies from which Dellacherie (2010) based their choice of excerpts they state, when speaking of how they created their musical stimuli, “To provide as much context as possible, the deviation never occurred on the initial and last measure of the excerpt.” (Gosselin et al., 2006) pg. 2588. In the current study, the deviation would be whether the excerpt begins and ends in a natural context, as in the beginning or end of a phrase, or whether it cuts into and/or out of the middle of a phrase or melody line. Especially if the excerpt is particularly dissonant, an abrupt attack or decay could have a significant effect on the response.

Implications

The results of this study imply that people respond differently to consonance and dissonance. Positive response most often corresponds with consonance and negative response most often corresponds with dissonance. People also tend to respond more intensely to dissonance than to consonance. In addition, those with more experience in music tend to have a higher response to dissonance than those with less experience. Facial muscles have been shown to be a reliable physiological indicator of response to dissonance as well. The corrugator muscle of the brow corresponds with a negative response of frowning and the zygomatic muscle corresponds with a positive response of smiling. The zygomatic muscle can also be associated with the response of a grimace or look of confusion. The results of our study have shown that muscle responses differ between those with high experience and low experience in music. Those with high experience tend to respond atypically to dissonance; we found more activity in the zygomatic muscle in response to dissonance.

The implications of these results appear to suggest that experience in music can have a greater impact on a person's response to consonance and dissonance. As for music education, these implications could be used to advocate for the use of dissonance in music education in order to expand and refine the students' experience and subsequently their level of musicianship. There are similar implications for the use of dissonance in music therapy. This study has shown that there is indeed a greater and more varied response to dissonance than to consonance and that this response is even more pronounced in those with higher levels of experience in music. This knowledge could greatly affect a person's response to the music and sounds used in the therapeutic setting. The controlled use of dissonance could help draw out a response from a person with musical experience who may be less responsive. It could also be used to prompt discussion regarding the music. On the other hand, the knowledge that a person could have a negative reaction to dissonance could aid in the selection of music and sounds used in the therapeutic setting so as to avoid a negative experience.

The results of this study, though not novel information, help add to the body of knowledge regarding the human response to consonance and dissonance. Our findings are similar to the findings in the study upon which we based our research (Dellacherie et al., 2010). The final step in the process of the larger study will be to analyze the EDA data, a project which will be taken on by another graduate student in the near future. Once the EDA data has been analyzed, the results of all of the steps of the larger study will be compared in order to determine the overall response to dissonance based on both subjective and physiological measures. The end result will be another appropriate tool by which to assess the response to consonance and dissonance and the differences in these responses between those with differing levels of experience in music.

APPENDIX A

MUSICAL EXPERIENCE QUESTIONNAIRE

Participant #:
Gender:
Age:
Year in college:
Major/Minor:

1. Have you received institutional training in music? Yes No
    a. How many years?__________
2. Have you received music lessons in the past three years? Yes No
    a. Vocal (part?)____
    b. Instrumental (instrument/s?)______________________________
3. Approximately how many hours per week do you practice music?____
4. Are you self-educated in music? Yes No

a. Please explain____

5. Approximately how many hours per week do you listen to music?____
6. Approximately how many hours per week do you listen to music with attention (*i.e.,* not just as background to driving/doing chores/etc)?_____
7. On average, do you attend at least one live music event per month? Yes No
    a. What type of concerts (*e.g.,* symphony, rock, jazz*)?*___________
8. Please mark any music genres you regularly listen to and enjoy:

    Popular
    New Age
    Country/Folk
    Rock
    Gospel/Contemporary Christian
    Musicals/Showtunes
    Rap/Hip-Hop
    Classical
    Atonal/Avant-garde
    Jazz/Swing
    Free Jazz
    Other____________________

APPENDIX B

EXCERPT LIST FROM PREVIOUS RESEARCH

Composer	Work	Measure[a]	M.M.♩	Key	Instrumentation	Emotion
Beethoven	Piano Concerto no. 4 (3rd mvt)	191–200(2)	150	G Maj	Piano and orchestra	Happy
Beethoven	Piano Concerto no. 4 (3rd mvt)	439–452(2)	150	G Maj	Piano and orchestra	Happy
Beethoven	Symphony no. 3 (3rd mvt)	38–56	180[b]	F Maj	Orchestra	Happy
Beethoven	Symphony no. 6 (3rd mvt)	9(3)–16(1)	240	D Maj	Orchestra	Happy
Haendel	Utrecht's Te Deum	5–14(1)	112	D Maj	Orchestra	Happy
Mozart	Die Zauberflöte (Act 1 no. 2 Papageno's Aria)	18(2)–24(2)	80	G Maj	Orchestra	Happy
Mozart	Eine kleine nachtmusik (1st mvt)	5(3)–10(3)	154	G Maj	String orchestra	Happy
Mozart	Piano Concerto no. 23 (3rd mvt)	1–8	255	A Maj	Piano	Happy
Mozart	Piano Concerto no. 27 (3rd mvt)	1–8	167	B flat Maj	Piano and orchestra	Happy
Ravel	Tombeau de Couperin (Rigaudon)	Bar1–9(2)	100	C Maj	Piano	Happy
Saint-Saëns	Carnaval des Animaux (Finale)	10–26(4)	220	C Maj	Piano and orchestra	Happy
Saint-Saëns	Carnaval des Animaux (La volière)	1–9(2)	88	F Maj	Piano and orchestra	Happy
Schumann	Kinderszenen (Op 15 no. 9)	1–9	240	C Maj	Piano	Happy
Verdi	La Traviatta (Brindisi)	1–15(1)	100	B flat Maj	Orchestra	Happy
Verdi	Rigoletto (Act 1 no. 4)	69–73	150	C Maj	Orchestra	Happy
Vivaldi	L'Autunno (1st mvt)	1(2)–4(3)	126	F Maj	Orchestra	Happy

(Peretz, Gagnon, & Bouchard, 1998, p. 140)

APPENDIX C

HSIRB APPROVAL LETTERS

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: April 22, 2013

To: Edward Roth, Principal Investigator
Rebecca Bumgarner, Student Investigator for thesis

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number 13-03-32

This letter will serve as confirmation that your research project titled "Psychophysiological and Emotional Responses to Musical Dissonance in Musicians and Non-musicians" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may **only** be conducted exactly in the form it was approved. You must seek specific board approval for any changes in this project (e.g., ***you must request a post approval change to enroll subjects beyond the number stated in your application under "Number of subjects you want to complete the study***)." Failure to obtain approval for changes will result in a protocol deviation. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

Reapproval of the project is required if it extends beyond the termination date stated below.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: April 22, 2014

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: June 22, 2015

To: Edward Roth, Principal Investigator
Rebecca Bumgarner, Student Investigator for thesis
Angela Biehl, Student Investigator

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number 13-03-32

This letter will serve as confirmation that the change to your research project titled "Psychophysiological and Emotional Responses to Musical Dissonance in Musicians and Non-musicians" requested in your memo received June 22, 2015 (to add student investigator Angela Biehl) has been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: April 22, 2016

1903 W. Michigan Ave., Kalamazoo, MI 49008-5456
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