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Effects of Music on Emotion, Heart Rate, Respiration, and Electrodermal Activity

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Abstract

The current research project investigates the relationship between music, emotions, and nervous system activity. Participants (N=92) listened to audio recordings of Stravinsky's "The Rite of Spring" and Satie's "Gymnopédie No. 1" as Biopac software recorded heart rate, respiration, and skin conductance; participants then completed a survey to rate music-evoked emotions. Event count and sympathetic nerve response indicated that there was more sympathetic activity during "The Rite of Spring," although there was a lower sustained skin conductance level. Respiratory sinus arrhythmia and vagal nerve response indicated that there was more parasympathetic activity during "Gymnopédie No. 1." Heart rate indicated that there was a higher level of overall activity during "The Rite of Spring." On the survey, emotions of higher arousal were rated more strongly during the first piece, while calming emotions were stronger during the second. Overall, the results indicate that there was a more aroused response in terms of physiological and psychological activity during the more musically complicated piece, "The Rite of Spring." This study suggests that listening to music can elicit a physiological and psychological response in the body, aligning with current research.

Keywords: Music, Emotions, Nervous System Activity

1. Introduction

Music is an abstract stimulus that can be defined as structured sound[15]. There is evidence of music in every known culture[10] and it is the objective of a considerable portion of time and money. Studies have shown that the primary motivation for listening to and producing music is to evoke emotional states[12, 31]. Therefore, it is useful to study this unique route that elicits emotion to better understand the connections between the auditory stimulus, the brain, and the autonomic nervous system (ANS). Implications range from neuroscience to social psychology to therapy[32].

Musical emotions can be described and measured in a variety of ways. One distinction is between the emotions *expressed* by the music and the emotions *felt* by the listener[29]. The current study focuses on felt emotions because the latter have been well documented[7, 30]. Another distinction is between discrete and dimensional emotions. Discrete emotion theory measures a number of basic emotions, including anger, fear, joy, and sadness, while dimensional theories rate emotions based on valence (positive-negative) and activation (aroused-calm)[29]. The current study uses discrete emotion theory and the measured emotions are those usually chosen in emotion research. Emotions such as excited, attentive, nervous, and afraid can be considered motivational emotions because they are utilitarian in a sense; they affect the individual by preparing action tendencies, recovery and reorientation, motivational enhancement, social obligations, etc.[29].

Studies have demonstrated that musical emotions can be identified universally; even people in isolated cultures identified the three basic emotions in music: happy, sad, and fearful/scared[7]. Happy music tends to be characterized by relatively rapid tempos, dancelike rhythms, major harmonies, and relatively constant ranges of pitch and dynamics, while sad music usually has slow tempos and minor harmonies[18].

In studying the link between music and the ANS, it is important to understand what is involved in music processing in the brain. A multitude of imaging studies and studies of patients with brain lesions have contributed to this understanding. When a listener first hears a sound, the auditory cortex works for initial processing of the various components. The frontal regions are then activated to process musical structure and expectations, including any degree of conscious thinking such as understanding lyrics[11, 20]. Finally, blood flow increases in much of the mesolimbic, or reward, pathway[20]. One study found that when participants reported "chills" as a result of the music, there was increased activation in the amygdala[5], the part of the brain that plays a significant role in emotional responses. Even without the "chill" experience, unpleasant music can elicit changes in the amygdala, ventral striatum, and hippocampus[16]. Dopamine release has been recorded during pleasurable pieces[27] and cortisol releases have been recorded during all kinds of music[32]. Throughout the whole process, the cerebellum and basal ganglia were active, processing rhythm and meter[20], as well as the hypothalamus, the region that controls much of the ANS, including heart rate and respiration[20, 24]. Although musical preferences had very little effect on activation of limbic, paralimbic, and reward system areas[15, 24], familiarity with the music was an important factor in activating emotion-related regions of the brain, including the putamen, amygdala, nuclear accumbens, anterior cingulate cortex, and thalamus[24]. For the purposes of this study, it is important to recognize that listening to music can initiate the reward circuitry in the brain as well as affect ANS functions.

Many studies in emotion and music research have tested the hypothesis that increased emotions are correlated with increased nervous system response[26]. The primary physiological functions controlled by the ANS focused on in this study are heart rate (HR), respiration, and electrodermal activity (EDA). While some studies have found little to no change in autonomic response[32], others have found results that this study hopes to contribute to.

HR is considered a controversial measure because there has been conflicting findings[23]. In studies using computerized music, HR was found to be faster during pieces identified as unpleasant by participants than during silence and fastest during pleasant pieces[23], as well as faster during happy pieces rather than sad[2, 33], although there was no noticeable difference with other emotions[6]. In studies on expected versus unexpected chords in music, there was no change in HR as was predicted[17]. However, HR decreased during dissonant (intervals that cause tension) rather than consonant (pleasant, harmonious intervals) pieces; this was attributed to an interaction between unpleasant emotions and increased arousal during the dissonant music[28, 33]. Music has been shown to be correlated to cardiovascular and respiratory signals, particularly skin vasoconstriction and blood pressure[4].

Respiration is the measure most affected by music[3, 4, 8, 9, 22]. This is primarily due to entrainment, a phenomenon in which physiological events—in this case breathing—match their period to environmental oscillation, such as the tempo of a piece[21]. As such, respiration rate was faster when a faster tempo was presented[14]. When melodic and harmonic structures were removed from a piece, there was no change in respiration as long as the tempo remained the same[33]. However, when tempo was presented in a piece that elicits emotion (fast tempo for happy pieces and slow for sad), results were conflicting[6]. The current study utilizes changes in harmonic structures and tempo to determine effects.

EDA can be measured by background tonic (skin conductance level: SCL) and rapid phasic components (skin conductance responses: SCRs), which are due to rapid fluctuations in eccrine sweat gland activity. These are a result of acetylcholine release and indicate the activity of the sympathetic nervous system[1, 13]. Emotionally powerful music has been shown to elicit more SCRs and "chills" than emotionally powerful films[26]. In a study measuring expected and unexpected chords in music, there were significantly more SCRs in listeners of the unexpected pieces[17]. Chords played with expression also stimulated more SCRs than non-expressive chords[17]. Music that expressed more stimulating emotions, fear and happiness, elicited significantly more SCRs and had overall higher EDA than the less stimulating emotions, sadness and peacefulness [13, 14]. However, SCR was dependent more on arousal than the specific emotional category and clarity[13]. Likewise, dissonant music elicits more SCRs than consonant music[33].

The current study seeks to provide physiological validity to changes in bodily arousal elicited by listening to different types of music. Studies have demonstrated that psychophysiological responses can distinguish basic emotions such as fear, happiness, sadness, disgust, surprise, and anger[25]. Therefore, this study aims to measure emotions evoked and autonomic responses elicited by two pieces of music: "Gymnopédie No. 1" and "The Rite of Spring." The pieces chose for the current study are two classical pieces, because it has been shown that classical music evokes strong emotions[19]. The pieces were chosen because of their extreme contrast in mood and style.

"The Rite of Spring" was written by Russian composer Igor Stravinsky in 1913 as a ballet. The piece contains complex rhythms and harmonies, very dissonant harmonies, highly accented, jolting rhythms, dense texture, and a wide range of dynamics from piano (soft) to fortissimo (very loud).

"Gymnopédie No. 1" was written by French composer Erik Satie in 1888, then arranged for orchestra by Claude Debussy. The excerpt used was the version for orchestra. The tempo was Lent et grave, meaning very slow and solemn. The piece can be described as flowing, serene, and gentle, containing a slow triple meter, simple rhythm, soaring melody, and consonant harmonies, and mostly piano (soft) dynamics with gentle crescendos.

In accordance with the literature, it was expected that the Stravinsky piece (fast tempo, dissonant harmonies) would evoke aroused emotions and increase the autonomic response, and the Satie piece (slow tempo, consonant harmonies) would evoke calming emotions and decrease the autonomic response; therefore, it was expected that tempo would have more of an effect than consonance/dissonance on autonomic nervous system activity.

This study is the first in an ongoing project at Auburn University that investigates the psychological and physiological basis for the impact of music on our emotions. Future research will involve brain scans and a more narrow examination of musical emotions.

2. Method

2.1 Participants

The project was conducted within the context of a core Music course at Auburn University over the course of three semesters. Participants were recruited from the Music and Science class taught by Dr. Ann Knipschild in Auburn's Department of Music. The participants gave informed consent prior to the experiment each semester, and the protocol was approved by the Auburn University Institutional Review Board for Research Concerning Human Subjects.

There were 26 students who participated in Spring 2015, 35 in Fall 2015, and 31 in Spring 2016; the total sample size was 92 participants. The sample was 65% male and 35% female. 32% were freshmen, 37% were sophomores, 18% were juniors, and 13% were seniors. The majority of the participants had no formal music education and were unfamiliar with the music pieces used in the study.

2.2 Equipment

Physiological data was recorded using the Biopac BSLBSC-W system with biopotential leads: 2 SS2LB cables for electrocardiogram (ECG) recording and 2 SS57L cables for recording galvanic skin conductance, in addition to a transducer SS5LB belt for recording respiration. Physiological data was analyzed using Acq*Knowledge* Acquisition & Analysis software.

Psychological data was collected using paper-and-pencil psychological surveys in which participants rated on a Likert scale of 1-5 the emotions most and least felt. A score of 1 indicated emotion was felt very slightly, not at all; 2 indicated emotion was felt a little; 3 indicated emotion was felt moderately; 4 indicated emotion was felt quite a bit; and 5 indicated emotion was felt extremely. The emotions listed were as follows: interest, distressed, excited, upset, strong, guilty, scared, hostile, enthusiastic, proud, irritable, alert, ashamed, inspired, nervous, determined, attentive, jittery, active, afraid.

The first audio recording, Piece 1, was a two-minute excerpt from Igor Stravinsky's composition "The Rite of Spring, Part 1: The Adoration of the Earth." The second audio recording, Piece 2, was a two-minute excerpt from the opening of the orchestra version of Satie's "Gymnopédie No. 1."

2.3 Data Collection

In the laboratory setting, a small, quiet room, the principal investigator firmly placed the respiration belt around the abdomen, cleaned the flesh on the palm and wrists, and attached the EDA electrodes to the palm and the ECG electrodes to the wrists. Participants were seated in a comfortable chair and asked to remain quiet, still, and attentive during the duration of the experiment. The Biopac system began recording during a silent, 5-minute rest period before the onset on the first music piece. During the first semester, the rest period was three minutes long, but was lengthened to five minutes for the remaining semesters to ensure that a baseline was reached.

After resting, the participants listened to 2-minute audio recordings of Stravinsky's "The Rite of Spring" and Satie's "Gymnopédie No. 1" as the BIOPAC software recorded their responses. After each of the pieces, they completed a paper-and-pencil psychological survey in which they rated their emotion as elicited by the music clips. Another silent rest period followed the first psychological survey and before the second music piece in order for heart rate, respiration, and electrodermal activity to return to baseline stability.

2.4 Analysis

The data was analyzed using Acq*Knowledge* Acquisition & Analysis software to obtain the six measures detailed in the following section. Data were analyzed using SPSS Version 23. Paired t-tests were carried out comparing each physiological measure from Piece 1 with the same physiological measure from Piece 2. Statistical significance was determined by $p<0.05$.

2.5 Definition Of Measures

2.5.1 event-related skin conductance response (er-scr)

Phasic changes in electrical conductivity of skin that can be attributed to specific eliciting stimuli, measured in number of events.

2.5.2 skin conductance levels (scl)

Tonic level of electrical conductivity of skin, measured in microsiemens (µs).

2.5.3 heart rate (hr)

Measured by beats per minute (bpm).

2.5.4 respiratory sinus arrhythmia (rsa)

Heart rate variability in synchrony with respiration, by which the r-r interval on an ecg is shortened during inspiration and prolonged during expiration. The RSA index for the respiratory cycle is expressed in milliseconds (ms); this is the maximum rate minus the minimum rate.

2.5.5 sympathetic rati

The amount of power in the sympathetic band normalized to an approximation of the total power in the signal. The sympathetic control of the adult human heart causes the R-R intervals to vary over frequencies ranging from 0.04 to 0.15 cycles per second.

2.5.6 vagal ratio

The amount of power in the sympathetic band normalized to an approximation of the total power in the signal. The parasympathetic control via the vagus nerve is believed to primarily modulate the r-r intervals between 0.15 and 0.4 cycles per second.

3. Results

The project was conducted over three semesters, with a new group of participants each time. Because the procedure slightly changed between semesters (lengthened rest period), physiological results are presented by semester (see Table 1). Psychological results were unaffected by procedure changes and are reported together (see Table 2).

3.1 Physiological Results

During Spring 2015, the EDA ER-SCR mean was found to be 2.381 events for Piece 1 and 1.286 events for Piece 2, and was found to be significant. The SCL mean was found to be 6.98 µS during Piece 1 and 7.12 µS during Piece 2, and was found to be significant. The RSA mean was found to be 6.77 ms during Piece 1 and 8.87 ms during Piece 2, and was found to be significant. The sympathetic ratio mean was found to be 0.536 during Piece 1 and 0.512 during Piece 2, and was found to be significant. The HR and vagal ratio were not found to be significant during this semester.

During Fall 2015, the SCL mean was found to be 0.632 μS for Piece 1 and 0.528 μS for Piece 2, and was found to be significant. The sympathetic ratio mean was found to be 0.0868 for Piece 1 and 0.181 for Piece 2; although not significant, the difference was approaching significance at an alpha level of 0.074. The vagal ratio mean was found to be 0.567 for Piece 1 and 0.136 for Piece 2; although not significant, the difference was approaching significance at an alpha level of 0.074. The ER-SCR, HR, and RSA were not found to be significant during this semester.

During Spring 2016, the SCL mean was found to be 3.54 μS during Piece 1 and 4.87 μS during Piece 2, and was found to be significant. The HR mean was found to be 0.510 bpm during Piece 1 and 0.419 bpm during Piece 2, and was found to be significant. The RSA mean was found to be 7.41 ms during Piece 1 and 8.09 ms during Piece 2, and was found to be significant. The sympathetic ratio mean was found to be 0.523 for Piece 1 and 0.472 for Piece 2; although not significant, the difference was approaching significance at an alpha level of 0.103. The vagal ratio mean was found to be 0.477 for Piece 1 and 0.528 for Piece 2; although not significant, the difference was approaching significance at an alpha level of 0.074. The ER-SCR was not found to be significant during this semester.

Table 1. Mean values of physiological measures

	Spring 2015		Fall 2015		Spring 2016	
	Piece 1	Piece 2	Piece 1	Piece 2	Piece 1	Piece 2
Event-related skin conductance responses	2.381	1.286				
Skin conductance response (μS)	6.98	7.12	0.632	0.528	3.54	4.87
Heart rate (bpm)					0.510	0.419
Respiratory sinus arrhythmia (ms)	6.77	8.87			7.41	8.09
Sympathetic ratio	0.536	0.512	0.0868	0.181	0.523	0.472
Vagal ratio			0.567	0.136	0.477	0.528

Note. Values listed were determined statistically significant by $p<0.05$.

In summary, the data measuring sympathetic nervous system activity–ER-SCR and sympathetic ratio–were generally higher during Piece 1, with the exception of SCL, which was higher during Piece 2. This indicated that while the overall electrodermal activity sustained was lower during Piece 1 than in Piece 2, there were more activity and jumps in the electrodermal activity. The data measuring the parasympathetic nervous system activity–RSA and vagal ratio–were generally higher during Piece 2. HR, an end organ measure reflecting the culmination of sympathetic and parasympathetic nervous system activity, indicated that there was more activity during Piece 1. Therefore, it can be concluded that there was more physiological arousal during Piece 1.

3.2 Psychological Results

Participants rated each emotion on a scale of 1 to 5 (1 for least emotion felt and 5 for most). The emotion ratings for each piece, in order of most felt to least felt, can be found in Table 2.

Table 2. Mean ratings of music-evoked emotions

Piece 1	total average	Piece 2	total average
alert	3.92	relaxed	4.405
attentive	3.65	calm	4.355
interested	3.32	interested	2.85
excited	3.24	inspired	2.73
active	2.89	attentive	2.37
jittery	2.78	proud	1.96
strong	2.53	determined	1.94
determined	2.49	alert	1.78
nervous	2.47	strong	1.66
enthusiastic	2.40	enthusiastic	1.61
distressed	2.32	ashamed	1.55
hostile	2.31	active	1.4
afraid	2.04	excited	1.37
inspired	1.99	upset	1.35
scared	1.99	guilty	1.34
irritable	1.84	nervous	1.29
proud	1.76	distressed	1.22
upset	1.45	afraid	1.18
guilty	1.28	irritable	1.14
calm	1.26	jittery	1.12
relaxed	1.20	scared	1.11
ashamed	1.14	hostile	1.02

Note. Emotions are listed in decreasing order of ratings.

In summary, the highest rated emotions for each piece were: alert, attentive, interested, and excited for Piece 1 and relaxed, calm, interested, and inspired for Piece 2. Both pieces were rated highly as interested and lowly as irritable and ashamed. Therefore, it can be concluded that there was more psychological arousal during Piece 1.

4. Discussion

4.1 Conclusions

This study successfully demonstrated the potential for music to elicit changes in emotion and in the autonomic nervous system response. The two pieces chosen, "The Rite of Spring" by Stravinsky, and "Gymnopédie" by Satie, differed primarily in tempo—fast and slow—and in harmonic structure—consonant and dissonant. They also differ synificantly in rhythmic, melodic, and harmonic complexity.

Although there were discrepancies between semesters, the overall trend indicates that there was more arousal during the Stravinsky piece. The data measuring sympathetic nervous system activity was higher during the Stravinsky piece with the exception of SCL, while the data measuring parasympathetic nervous system activity was lower during the Satie piece. The reported emotions—alert, attentive, interested, and excited during the Stravinsky piece and relaxed, calm, interested, and inspired during the Satie piece—indicate that the Stravinsky piece was more psychologically arousing in addition to being more physiologically arousing.

Additionally, this study revealed more about the relationship between musical elements and their effects on the nervous system (see Table 3). Past studies have shown that consonant pieces increase HR, do not affect respiration, and decrease EDA, while dissonant pieces decrease HR, do not affect respiration, and increase EDA[28, 33]. It has also been shown that fast tempos increase HR, respiration, and EDA, while slow tempos decrease HR, respiration, and EDA[2, 13, 14]. Because happy pieces are normally characterized by consonance and fast tempos, happy music has been shown to increase HR and EDA. Likewise, sad music, normally characterized by dissonance and slow tempos, usually decreases HR and EDA. This study examined two pieces that were neither happy nor sad, the first being dissonant and fast, and the second being consonant and slow. The first piece elicited a higher HR, respiration, and SCRs, but a lower overall SCL. The second piece elicited the opposite response: a lower HR, respiration, and SCRs and a lower overall SCL. Therefore, as the dissonant/fast piece was more consistent with the fast tempo alone responses and the consonant/slow piece was more consistent with the slow tempo along responses, it appears as if tempo plays more of a role in autonomic nervous system response than harmonic structure. Because these conclusions are being drawn from different studies, further studies would need to be conducted to confirm this.

Table 3. Elements of music and their effect on the autonomic nervous system

		Heart Rate	Respiration	Electrodermal activity
Harmonic structure	Consonant	↑	No change	↓
	Dissonant	↓	No change	↑
Tempo	Fast	↑	↑	↑
	Slow	↓	↓	↓
Emotion	Happy	↑	?	↑
	Sad	↓	?	↓
Type of music *Findings from this study	Dissonant/fast	↑	↑	↑ ER-SCRs ↓ SCL
	Consonant/slow	↓	↓	↓ ER-SCRs ↑ SCL

Note. ER-SCRs = event-related skin conductance responses; SCL = skin conductance level

Consequently, this study provides further support for nervous systems changes in response to different types of music. It further demonstrates the complexity of music's effect on the body; changes cannot be explained solely by tempo, expression, or harmonic structures. Further research is necessary to determine the particular relationship between music structures and changes. Additionally, this study did not use music pieces previously associated with emotions, i.e. happy or sad pieces, as most musical emotions studies have.

4.2 Limitations

Because this study was conducted as part of a music course, participant demographics were limited by the students in the class. There were more males than females, and several students indicated that they were familiar with the pieces beforehand.

Discrepancies between semesters may be explained by an insufficient rest period, irregularly placed electrodes, or length of music excerpts. In a study where responses were monitored periodically throughout the excerpts, musical emotions were more differentiated after 30 s [14]. Due to experimental constraints, the current study used pieces of just 2 min. Longer and more complex piece would likely produce more differentiated physiological responses and more intense emotions.

4.3 Recommendations

In future studies, several measures should be taken to ensure better control of extraneous variables. Even though there was only one participant in the room, headphones should be used to limit external noise. Data from participants who have heard the music before should be eliminated to control for familiarity. In the current study, there were several instances where SCRs could not be read; therefore, only participants who register SCRs on the Biopac software should be used in the study. The order of the pieces should be randomly alternated to control for any interaction between the two pieces. Monitoring emotions and reactions throughout the entire piece most likely would elicit more intense emotions and more noticeable change in the ANS and build the tension/dynamic aspect of the music more fully.

The current study, in conjunction with the conclusions from previous studies, suggests that tempo plays a more important role in effecting the autonomic nervous system than harmonic structures. To confirm this, subsequent studies should be conducted controlling more carefully for tempo and harmonic structure.

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