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Physiological and Psychological Reactions to a Musician, Robot, or Boombox Music Player: Comparison between EDA, HRV, and EEG

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ABSTRACT

The purpose of this study is to monitor changes in healthy individuals' physiological and psychological responses to listening to nursery rhymes. Heart rate variability and skin conductance are physiological data that measure an Individual's arousal response. Individuals were exposed to the nursery rhymes, and an electrodermal activity (EDA) wristband was used to track changes in their physiological factors: heart rate variability and skin conductance. Two self-report questionnaires were designed to investigate individuals' psychological responses after listening to the rhymes. We also compared the EDA and electroencephalogram (EEG) data of participants to understand the relationship between EDA and brain data. After analyzing Individuals' sensor data and their responses to the questionnaires, no statistically significant results were found that correlated all participants' physiological and psychological changes. However, inconsistent trends such as increases in heart rates, decreases in skin conductance, and reporting feelings such as lively, alert, happy, cheerful, and calm and relaxed were observed for some participants.

Keywords
EDA, EEG, Music therapy, Physiological signals, Psychological signals.

Introduction (Background Physiological and Psychological Reactions)

Evidence shows that listening to music can alter human psychological and physiological signals. Listening to music can reduce a person's stress and improve moods [1-3], pain [4], blood pressure level and heart rate [5], and boosts the sleep cycle [6]. It can improve the memory function of patients with memory disorders [7], and aid patients with recovery from seizures, brain injuries, or strokes [8,9,10]. Music can have a relaxing or disturbing effect on humans; thus, researchers explore changes in physiological and psychological signals to understand how music stimulates and consequently changes human emotion. Consequently, one of the areas explored by many researchers is emotion recognition in people while listening to music.

The emotions that individuals experience in reaction to the same music differ from person to person [11]. An effective tool for studying music emotion recognition and understanding stress levels is exploring physiological signals. This data can be recorded from photoplethysmography, respiration, skin temperature, electrocardiography and electroencephalogram (EEG), electrodermal activity (EDA) [10-12]. EDA data includes two components: skin conductance level (SCL) and skin conductance response (SCR) [11-12]. SCL and SCR are the tonic and phasic changes in electrical conductivity of skin, respectively. SCL is an indicator of the general changes in arousal during the entire experiment, and SCR indicates quick changes in EDA after sudden arousal. Another tool to measure music emotion recognition is using heart rate variability (HRV) that shows the tiny changes in beat to beat interval between consecutive heartbeats (RR intervals) [12,13].

Researchers have examined the impact of silence and noise on individuals by monitoring skin conductance along with data on heart and respiration rate [11]. Among all of the selected parameters, skin conductance has been known as a good indicator of arousal level. Study results on 30 individuals showed significant changes in the mean value of skin conductance for all participants while experiencing silence. Also, it was observed that intensifying silence, which has an intensifying effect, has an incrementally increased physiological signal. While relieving silence, which has a relaxing effect, had an incrementally decrease in physiological signals [11]. In another study, the emotional response of individuals to visual, auditory, and a combination of audio and visual input were explored using EDA [15]. EDA data of 12 participants was monitored before and after watching, listening, or both watching and listening to the stimuluses. Researchers observed that the visual-auditory scenario had a higher average value of electrodermal amplitude and the highest correlation between EDA and tension, while the audio stimulation had the lowest values. Additionally, no correlation between mode of stimuli was recorded. Another study investigated the effect of emotional music on healthy individuals and patients with impairments in their ventromedial prefrontal cortex (VMPFC) or right somatosensory cortex (RSS) [16]. Skin conductance data and self-reporting was used to understand how listening to emotional music can alter participant's feelings. Music simulations containing happy, sad, and fearful emotions were chosen from movie tracks because they convey high emotional responses. The VMPFC patient showed responses based on both skin conductance and self-reporting. The RSS patients' skin conductance showed no responses but their self-reported feelings indicated that music conveys emotion [16]. In one study, researchers observed differences between heart rate variability (HRV) features while individuals were watching video stimuli containing sad and happy scenes [12]. Researchers also used HRV data to classify positive and negative emotional responses of healthy individuals and patients with traumatic brain injury while passively listening to music [17]. A study investigated how live music therapy affects HRV, stress and anxiety of women with high-risk pregnancies [18]. After the therapy session, participants used a questionnaire to indicate their stress and anxiety levels. Although the questionnaires did not show considerable changes in stress and anxiety, changes in HRV features were detected. Another study considered the impact of music therapy on HRV in patients with vascular dementia. The outcomes showed that music therapy decreased sympathetic and increased parasympathetic nervous activity, which in turn caused a decrease in anxiety and an increase in relaxation and comfort [19].

Most of the studies have investigated the impacts of music on physiological signals. However, none of them has considered changes in both individuals' physiological and psychological while they are listening to nursery rhymes. We know that lower levels of heart rate, HRV, and tonic activity of the EDA, are associated with a calmer state and higher levels of heart rate, HRV, and, phasic activity of the EDA with higher stress [20]. Thus, the aim of this study is to explore the effects of listening to nursery rhymes on individuals' physiological signals gathered by using EDA wristbands and their psychological data using questionnaires and EEG. The following hypothesis was tested: Exposure to the nursery rhymes can make individuals calmer and more relaxed.

Methodology

Participants

Forty-two healthy individuals who were university students and faculty over the age of 18 were recruited for this study. Unfortunately, eight participants' data was lost due to the wireless connectivity issues or malfunction of the device or software. In total, data from 14 females and 20 males who mostly were included for further study.

Stimuli

The stimuli for this study were selected by a group of musicians at the department of music of UMD. They chose seven nursery rhymes: "Baba Black Sheep," "Itsy Bitsy Spider," "Mulberry Bush," "Old MacDonald Had a Farm," "Ring Around the Rosie," "Twinkle Twinkle Little Star," and "You Are My Sunshine." These songs were played for individuals in three scenarios: by a musician, robot, or boombox. The musician was recruited from the Music Department at the University of Minnesota Duluth; she played the piano while singing the rhymes. The robot chosen for this study was Pepper, a semi-humanoid robot manufactured by SoftBank Robotics that has the ability to sing the rhymes and move its body parts [21]. The boombox was a transistorized portable music player.

Experimental Procedure

The experiment was arranged in three sessions: baseline, experiment (music listening), and post-experiment. The participants sat on comfortable chairs, read the consent forms, and then an instructor described the experiment procedure. Participants were randomly assigned to one of the three conditions: musician, robot or boombox. Fifteen participants listened to the musician (6F, 9M), thirteen to the robot (6F, 7M), and six to the boombox (2F, 4M). Participants wore EDA wristbands that measured EDA and heart rate variability (HRV). Their baseline EDA and HRV values were taken prior (baseline data), during, and after the experiment (post-experiment). These data are indicators for the level of arousal, stress, and anxiety. Individuals' baseline, experimental, and post-experimental data were repeatedly captured for one, ten, and fourteen minutes, respectively.

Equipment and Data Acquisition

To collect EDA and HRV data, an Empatica E4 wristband was utilized [22]. E4 wristband provides continuous measurements of changes in physiological data like EDA and HRV via skin conductance. The E4 wristband captures the data at 4Hz sampling rate and can be managed with the Empatica E4 Manager Software. We also asked individuals to rate their perceived emotions after the experiment by responding to two questionnaires. One was a combination of a modified PANAS [23] and POMS [24] questionnaires, and the other was a music preference survey [25]. The questionnaires contained rating scales from low to high with reference to the music playing mechanism.

Data Analysis

The processing of the physiological signals for EDA and HRV consist of four steps: noise reduction, signal segmentation, signal decomposition, and feature extraction [11]. In this study, the collected baselines for each participant were compared to the data for other scenarios to determine whether there were major changes in physiological data. We used Ledalab 3.4.9 and Kubios 3.3 which are visual open source Matlab toolboxes. Ledalab separated EDA data into its phasic and tonic components. Since we were interested in analyzing skin conductance data, continuous decomposition analysis was applied on the EDA data [14]. Kubios provided us with time-domain data such as: Mean RR that is the time between two successive heart beats, RMSSD that reflects the root mean square of successive differences between normal heartbeats. It also gave the frequency-domain (mean HR), and non-linear data: stress index (SI) and Poincaré plots indexes: SD1 that In Poincaré plot, is the standard deviation perpendicular to the line-of-identity and SD2 that In Poincaré plot, is the standard deviation along the line-of-identity. Mean RR, RMSSD, SD1 mainly reflects parasympathetic nervous system (PNS) activity, whereas Mean HR, SI, SD2 mainly reflects sympathetic nervous system (SNS) activity. Furthermore, SPSS software was used for all statistical analyses.

Feature Extraction

We extracted the mean as descriptive statistical features from both the tonic and the phasic components of EDA. From HRV, time-domain features such as Mean RR and HR, SDNN, and SI as a nonlinear feature were considered.

Results and Discussion

Table 1 shows the mean values for EDA and HRV features for all participants at each of the three stages in the three scenarios. The Mean RR and RMSSD components were expressed as power and were measured as ms, SD1 and SD2 were measured as %, Mean HR was measured as bpm.

Statistical analysis of EDA features

In the musician scenario, the mean value of both tonic and phasic was high, meaning that participants experienced higher levels of stress. In the robot scenario, during the baseline, the tonic level had the lowest mean values and participants were calmer than in the other two scenarios. We expected the tonic portion of the EDA to continue to decline during and after listening to the nursery rhymes, however a slight incline was noticed. In the boombox scenario similar to the robot scenario, during the baseline, participants had the lowest mean value of the tonic component while it started to increase during and after the experiment. This means that participants had more stress during and after the experiment. Also in this scenario, the highest mean value of the tonic portion was observed during the baseline in comparison to the other two scenarios.

Table 1: Average and standard deviation values of EDA and HRV features for all participants of each scenario for different levels of obtained data.

		Mean ± Std (Robot Scenario)	Mean ± Std (Boombox Scenario)	Mean ± Std (Musician Scenario)
EDA	Phasic_Baseline	.04±.05	**.14±.19**	.09±.10
	Phasic_Experiment	.01±.01	.03±.02	**.14±.14**
	Phasic_After	.04±.05	.04±.03	**.10±.11**
	Tonic_Baseline	**.36±.51**	.90±.80	**6.08±14.36**
	Tonic_Experiment	**.76±.82**	1.41±1.08	**5.87±9.20**
	Tonic_After	**.84±.99**	1.97±2.29	**2.67±3.71**
PNS	Mean RR_Baseline	**907.8±163.7**	849.1±139.6	772.5±110.3
	Mean RR_Experiment	**905.8±160.1**	850.0±167.8	766.5±79.73
	Mean RR_After	**882.8±126.4**	843.6±178.8	743.1±100.7
	RMSSD_Baseline	63.22±30.94	80.75±31.75	**140.9±293.4**
	RMSSD_Experiment	**64.08±32.29**	44.15±9.15	52.80±22.26
	RMSSD_After	**48.81±23.52**	30.03±10.76	51.75±18.99
	SD1_Baseline	**49.78±9.82**	48.56±8.29	45.40±8.10
	SD1_Experiment	**49.49±9.05**	46.20±7.02	41.80±7.47
	SD1_After	**46.70±8.8**7	42.48±10.90	42.14±7.52
	PNS Index_Baseline	.71±1.33	**.89±1.47**	-.16±.98
	PNS Index_Experiment	**.71±1.28**	-.11±.75	-.30±.89
	PNS Index_After	**.16±1.05**	-.35±.84	-.44±.83
SNS	Mean HR_Baseline	**67.87±11.42**	72.00±10.7	78.92±10.21
	Mean HR_Experiment	**68.00±10.46**	72.67±13.1	79.25±8.39
	Mean HR_After	**69.27±9.33**	73.50±14.3	80.08±11.42
	SI_Baseline	12.17±3.85	**8.63±1.67**	12.20±4.02
	SI_Experiment	11.20±3.65	**11.41±1.4**5	11.10±3.79
	SI_After	12.42±4.20	12.55±2.36	**10.45±2.81**
	SD2_Baseline	**50.22±9.82**	51.43±8.29	54.60±8.10
	SD2_Experiment	**50.51±9.05**	53.80±7.02	58.19±7.47
	SD2_After	**53.30±8.87**	57.51±10.90	57.85±7.52
	SNS Index_Baseline	.36±1.18	**.10±.85**	1.14±1.08
	SNS Index_Experiment	**.22±1.06**	.60±.71	1.01±.98
	SNS Index_After	**.52±1.14**	.88±1.02	1.11±1.01

Statistical analysis of HRV features

In the musician scenario, for the mean values of PNS activity during the baseline, the mean value of RMSSD was higher than the other two scenarios. While the mean values of Mean RR and SD1 were lower than those in the boombox scenario, the mean values of the RMSSD were higher than the boombox scenario. In this scenario, for the mean values of SNS activity after the experiment, the mean value of SI was lower than the other two scenarios. Also, the mean values of SD2 after the experiment was higher than the boombox scenario. In the boombox scenario, for the SNS activity, except the mean value of RMSSD during the baseline all values were lower than the musician. Also, for the PNS activity, the mean values of the SI during baseline and experiment were much lower than the other two scenarios. In the robot scenario, during and after the experiment, the mean values of the PNS activity were high while the mean values of the SNS activity were low. These outcomes did not show which scenario could relieve the participants.

Bivariate Pearson correlation

To measure the strength and direction of linear relationship between pairs of obtained data (baseline, during and after the experiment), a Pearson correlation coefficient was applied on all the scenarios

Table 2: Pearson correlation between the mean values of HRV and EDA features.

		PNS features of HRV						SNS features of HRV						HED features			
	Scenarios	**Mean RR Music**	**Mean RR After**	**RMSSD Music**	**RMSSD After**	**SD1 Music**	**SD1 After**	**Mean HR Music**	**Mean HR After**	**SI Music**	**SI After**	**SD2 Music**	**SD2 After**	**Phasic Music**	**Phasic After**	**Tonic Music**	**Tonic After**
Mean RR Base	**Robot Boombox Musiciani**	.97** .98** .81**	.87** .98** .71**														
Mean RR Music	**Robot Boombox Musician**		.88** .99** .90**														
RMSSD Base	**Robot Boombox Musiciani**			.70* .11 .37	.57* -.13 .19												
RMSSD Music	**Robot Boombox Musician**				.61* .65 .83**												
SD1 Base	**Robot Boombox Musiciani**					.79** .82* .50	.71** .82* .14										
SD1 Music	**Robot Boombox Musician**						.63* .87* .86**										
Mean HR Base	**Robot Boombox Musician**							.96** .97** .87**	.90* .98** .73**								
Mean HR Music	**Robot Boombox Musician**								.93** .99** .84**								
SI Base	**Robot Boombox Musician**									.50 .02 .81**	.26 -.04 .66*						
SI Music	**Robot Boombox Musician**										.68** .50 .77**						
SD2 Base	**Robot Boombox Musician**											.79* .82* .50	.71** .82* .14				
SD2 Music	**Robot Boombox Musician**												.63* .87* .86**				
Phasic Base	**Robot Boombox Musician**													.45 .25 .83**	.53* .51 .76**		
Phasic Music	**Robot Boombox Musician**														.45 .93** .94**		
Tonic Base	**Robot Boombox Musician**															.66** .52 .95**	.42 .51 .83**
Tonic Music	**Robot Boombox Musician**																.79** .93** .96**

for different levels of obtained data. Pearson correlation coefficient values change from -1.0 to 1.0, in which -1.0 presents a perfect negative correlation and 1.0 is an indicator of perfect positive correlation. Table 2 presents a complete list of correlation between EDA and HRV features.

Pearson Correlation between EDA features

By looking at EDA features, it was observed that for the musician scenario, there were considerable correlations between mean value of both phasic and phasic components for baseline and during (r=0.83, r=0.95) and after the experiment (r=0.76, r=0.83), and during and after the experiment (r=0.94, r=0.97), respectively. It was noticed that for the robot scenario, there were moderate correlations between mean values of both phasic and tonic for baseline and during the experiment (r=0.53, r=0.66), respectively. Also for the tonic portion a notable correlation for during and after the experiment (r=0.79) was observed. It was seen that for the boombox scenario, there were significant correlations between mean values of both phasic and tonic components for during and after the experiment (r=0.94, r=0.96), respectively.

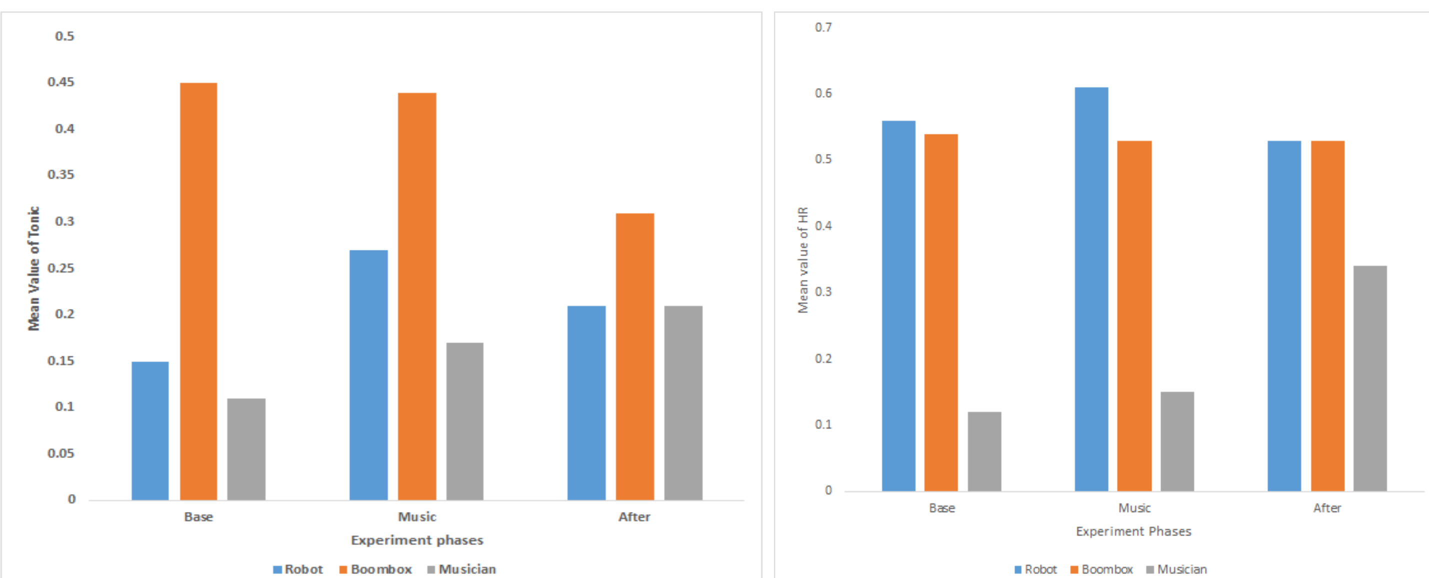
Pearson Correlation between HRV features

For the musician scenario, strong correlations between the mean values of Mean RR, Mean HR, and SI for baseline and during (r=0.81, r=0.87, r=0.81) and after the experiment (r=0.87, r=0.73, r=0.66) and during and after the experiment (r=0.90, r=0.84, r=0.77), for RMSSD, SD1, and SD2 for during and after the experiment (r=0.83, r=0.77, r=0.86), respectively were seen. For the other features, minor or moderate correlations between each feature for each different state of data gathering was observed. For the robot scenario, significant correlations between the mean values of Mean RR, RMSSD, SD1, Mean HR, and SD2 for baseline and during (r= 0.97, r=0.70, r=0.79, r=0.96, r=0.79) and after the experiment (r=0.87, r=0.57, r=0.71, r=0.90, r=0.71) and during and after the experiment (r=0.88, r=-0.61, r=0.63, r=0.93, r=0.63), respectively were noticed. Additionally, a moderate correlation between mean value of SI for during and after the experiment (r=0.77) was seen. Like the musician scenario, minor or moderate correlations between each feature for each different state of data gathering was seen. For the boombox scenario, similar to the robot scenario, significant correlations between the mean values of Mean RR, SD1 and Mean HR for baseline and during (r=0.98, r=0.82, r= 0.97) and after the experiment (r=0.98, r=0.82, 0.98) and during and after the experiment (r=0.99, r=0.87, r=0.99), respectively were noted. Additionally, minor negative correlations between the mean value of RMSSD for baseline and after the experiment (r=-0.13) were seen. Like the other two scenarios, for other features, slight or moderate correlations between each feature for different states of data gathering was noticed.

Figure 1 demonstrated the mean values of the tonic component and the HR of all of the experiment scenarios. The findings indicate that listening to the nursery rhymes live considerably changed the EDA tonic level, while the recorded songs (robot and boombox) had no significant impact on the EDA data. By looking at HRV data, it was noted that no matter which scenario was chosen, nursery rhymes slightly changed the mean value of the HRV, while the correlation was strong between the data of each pair of baselines, during, and after the experiment.

Comparison between data of EDA, HRV, and EEG

The authors of this paper conducted a previous yet published study that captured participants' EEG data while individuals were listening to nursery rhymes. The results indicated that while for some participants nursery rhymes was relaxing for others it was disturbing. Also, the results suggest that both human to human and human to robot contact are more complicated than human to boombox contact. For this study, our aim was to understand whether there is any relation between the EEG, the EDA, and the HRV data.



(a) (b)

Figure 1: Mean value of Tonic and HR for all scenarios.

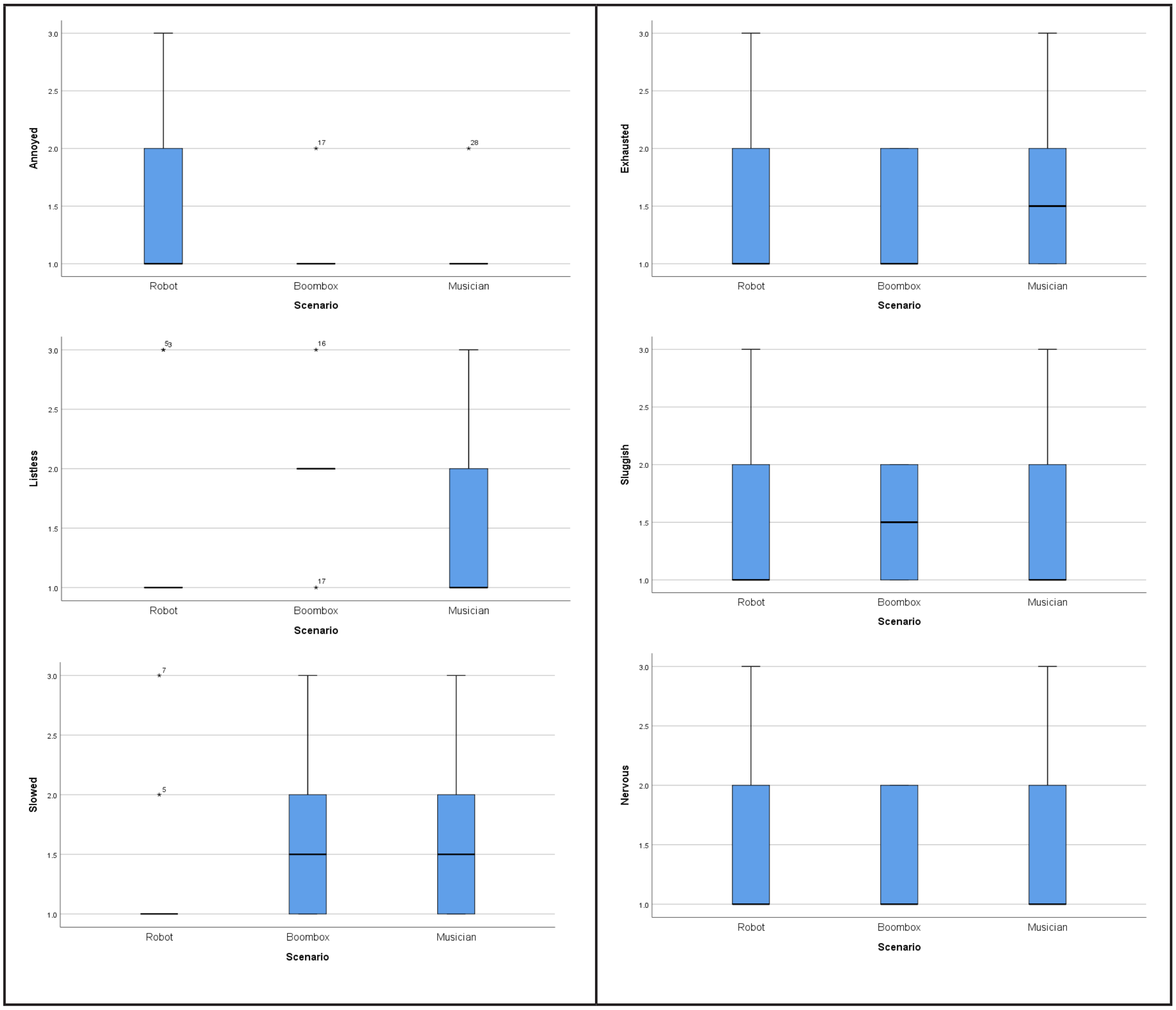


Figure 2: Box plots of experienced emotion after experiment.

Table 3: Normalized mean values of the major features of each sensor for all of the scenarios.

Sensor	EDA			HRV						EEG					
	Mean Tonic			Mean PNS Index			Mean SNS Index			Mean Alpha			Mean Beta		
Scenario	**Base**	**Music**	**After**	**Base**	**Music**	**After**	**Base**	**Music**	**After**	**Base**	**Music**	**After**	**Base**	**Music**	**After**
Robot	0.16	0.28	**0.21**	0.03	0.03	0.02	**0.49**	0.52	**0.37**	**0.87**	**0.74**	**0.88**	0.84	0.76	0.76
Boombox	0.46	0.45	0.32	0.30	0.28	0.33	0.62	0.61	0.59	0.58	0.44	0.36	**0.16**	**0.17**	**0.80**
Musician	**0.11**	**0.17**	**0.21**	**0.31**	**0.56**	**0.48**	0.56	**0.41**	0.40	0.44	0.28	0.52	0.58	0.47	0.17

Table 4: Mean values of the most and least preferred music genres.

	Most favorite		Least favorite		
Scenario	**Classical**	**Rock**	**Religious**	**Gospel**	**Heavy Metal**
Robot	5.00	5.33	3.22	3.33	3.33
Boombox	5.67	5.67	2.00	2.83	3.67
Musician	5.19	6.06	3.44	3.88	3.75

Table 5: ANOVA results for experienced emotions and age groups.

Emotion	ANOVA Results	Ages
Cheerful	F(2,28)=3.41, (p=0.023)	{26-30} and {over 35}
Angry	F(2,28)=6.1,(p=0.001)	{18-20} and {26-30}, {21-25} and {26-30}
Exhausted	F(2,28)=3.30, (p=0.026)	{21-25} and {over 35}
Demoralized and sad	F(2,28)=2.89, (p=0.042)	{21-25} and {26-30}, {26-30} and {over 35}

We know that a combination of HRV, EDA, and EEG features such as higher levels of PNS and alpha waves, lower levels of SNS and beta waves, tonic data is an indicator that a person is relaxed or calm. For this purpose, we normalized the mean of these features for each level of obtained data (baseline, during and after the experiment) for each scenario, and the results are summarized in Table 3.

Based on Table 3 and box plots in Figure 2, participants in the musician scenario had lower average values for SNS and tonic data, but their average values of the PNS activity and alpha waves were not higher than those of the participants in the other two scenarios. Also, their mean values of beta waves were not lower than those of the participants in the other two scenarios. Thus, these results suggest that none of these three scenarios clearly made the participants relaxed.

Results of self-report questionnaires

The response of 31 participants was analyzed because some of the 42 participants declined to complete the questionnaires. Table 4 shows the participants' two most and three least favorite music genres of the 15 choices provided. The values show that classical music is the most popular genre among all of the participants, while religious music was the least preferred genre.

The participants' most common feelings were lively, alert, happy, cheerful, and calm and relaxed after the experiment. However, Figure 2 shows that listening to nursery rhyme made some participants in all of the three scenarios nervous, slowed, sluggish or exhausted. Also, it was interesting some participants in the musician scenario reported feeling listless, and some participants in the robot scenario felt annoyed after the experiment.

We applied one-way ANOVA to test (Table 5) whether a statistically significant difference exists between participants' emotional experience in the different scenarios. The outcomes of ANOVA and Tukey post hoc tests showed that cheerful emotions in the musician scenario were higher than in the robot scenario. They resulted in a value of $p=0.003$, which is below 0.05, which means that the only statistically significant difference $F(2,28)= 7.14$ was for cheerful emotions. There was no statistically significant difference between the musician and boombox ($p=0.071$) or boombox and robot scenarios ($p=0.716$).

The ANOVA and Tukey post hoc tests on emotion and gender, and scenarios and music preference did not show any significant results. However, emotions and age groups showed significant differences for cheerful between age 26-30 and over, angry between age 18-20 and 26-30 and 21-25 and 26-30, exhausted between age 21-25 and over 35, and demoralized and sad between age 21-25 and 26-30, and 26-30 and over 35. The results are summarized in Table.

Discussion

In this study, we considered the effects of nursery rhymes on healthy individuals' physiological and psychological signals while listening to a musician, robot, or boombox. The outcomes indicated that none of these three scenarios clearly increased the individuals' comfort and relaxation levels. Although Pearson correlations coefficients showed positive correlations for the EDA data, some negative correlations for mostly the boombox were noticed for the HRV data. This may have happened because the number of participants in this scenario was much lower than that in the other two scenarios. Individuals' sensor data and their responses to the questionnaires indicated that many but not all of the results aligned with our hypothesis that "Exposure to the nursery rhymes can make individuals calmer and more relaxed."

The results of both sensors and the questionnaires may be misleading because the number of participants in each scenario was not equal. To determine statistically significant results, further testing needs to be performed with a larger population. It also is important to make sure participants in all of the scenarios have similar characteristics such as age and gender. Additionally, if they played music is not the individual favorite it may not impact their emotion. Also, it may be necessary to include a control group to the experiment. It may be useful to utilize the boombox for the control group, as it may yield relevant and useful correlations between the musician and the robot.

In general, the outcomes of the signals and questionnaires expressed that while listening to nursery rhymes can mitigate some individuals in each scenario, it made others anxious, exhausted or listless.

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