Electrodermal Activity Study of Aesthetic Emotions Through Pleasant and Unpleasant Stimuli

Ajeng Rintan Septiani[1], **Sri Kusrohmaniah**[1*], **Supra Wimbarti**[1], **Noor Akhmah Setiawan**[2]
[1]Faculty of Psychology, Universitas Gadjah Mada, Yogyakarta, Indonesia
[2]Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

Abstract. Aesthetic emotions are inherently affective because exposure to the concept evokes emotional responses. In this context, autonomic arousal can be indexed through electrodermal activity (EDA), which reflects sympathetic nervous system activation. Therefore, this study aimed to examine aesthetic emotional arousal through EDA restricted to the musical domain using auditory stimuli. A total of 20 non-musician students aged 20–28 years were adopted using a within-group experimental design. Participants were exposed to music stimuli from the Film Music Stimulus Set (FMSS), categorized as pleasant and unpleasant to represent positive and negative emotional valence, respectively. EDA responses were also quantified using the mean amplitude of the phasic component as an indicator of emotional arousal during stimulus exposure. The results showed that arousal during exposure to pleasant and unpleasant stimuli differed significantly. Furthermore, music with pleasant valence elicited more intense emotional arousal.

Keywords: aesthetic emotions, electrodermal activity, music, pleasant, unpleasant

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Introduction

Aesthetics carries a philosophical meaning associated with beauty as grounded in judgments of pleasure (Ishizu & Zeki, 2013; Schindler et al., 2017). In the context of psychology, especially neuropsychology, the concept of aesthetics belongs to the sub-discipline of neuroaesthetics discovered by Ishizu and Zeki. Neuroaesthetics shows the relationship between brain regions and pleasant or unpleasant stimuli, as well as the perceptions of beauty and ugliness, as reflected in increased neural activity during experiences such as listening to music, viewing images, or touching objects perceived as beautiful (Ishizu & Zeki, 2013).

Music is an important domain with the fourth-highest engagement with aesthetics, especially in empirical aesthetic clusters (Anglada-Tort & Skov, 2020). This domain has the same characteristics as visual and olfactory stimuli, which do not require active participation from the recipient (Juslin, 2013). The trend of using music as an auditory stimulus in psychological contexts related to therapy and creativity is also increasingly in demand. Over the past two decades, therapy using music as a stimulus has experienced significant improvement. Music is used as a complementary method in the psychological treatment of stress, anxiety, depression, autism, traumatic brain injury, and neurological symptoms caused by stroke (Li et al., 2021; Rodriguez Novo et al., 2021). Besides clinical areas and psychological disorders, this therapeutic stimulus has favorable prospects for healthy individuals, especially in improving well-being (Li et al., 2021). The assumption is grounded in the idea that music and sound possess non-denotative characteristics or are not bound by language, allowing interpretation by the recipient without requiring fundamental knowledge (Juslin, 2013). Due to aesthetics and diversity, music is known to be more accessible to anyone and can adapt to personal tastes and preferences (Siles et al., 2019). The determination of tastes and preferences also includes aesthetic judgment (Fuentes-Sánchez et al., 2022; Lundy et al., 2013; Nater et al., 2005; Xenakis et al., 2012).

The brain area activated during the aesthetic judgment process is the prefrontal cortex (PFC) (Xenakis et al., 2012). This activation does not occur independently since the process requires distributed neural activation, including other brain regions and tissues associated with processing the specific type of sensory stimulus received. Each human sensory system has an area of the primary cortex activated by incoming stimuli, namely the visual, auditory, olfactory,

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[*]Corresponding author: Faculty of Psychology, Universitas Gadjah Mada, Yogyakarta, Indonesia
E-mail: koes_psi@ugm.ac.id

gustatory, and somatosensory cortices. Subsequently, the processing is passed to the secondary sensory cortex, which continues to the multimodal association and insular cortex, which play a role in integrating and associating stimuli from different senses (Sydnor et al., 2021). This distinguishes stimulus processing as single-sensory or multisensory before progressing to more complex processing such as memory (Weigand & Jacobsen, 2021), limbic structures (Belfi et al., 2019; Sabatinelli et al., 2007), and emotions (Brattico et al., 2013). Even though aesthetic stimulation may enter through a single sensory channel, the process of judgment is not limited to only the modality.

Music engages widespread neural networks, including the auditory cortex, limbic system (amygdala, hippocampus, nucleus accumbens), reward-related regions such as the ventral striatum, and prefrontal areas in evaluation and meaning-making (Klepzig et al., 2020). This distributed activation explains the particular effectiveness of music in eliciting aesthetic engagement. At the physiological level, music modulates autonomic nervous system activity, influencing heart rate, skin conductance, and arousal states (Kim & Andre, 2008). Music can enhance sympathetic activation and emotional arousal while also influencing affective valence (Juslin, 2013; Menninghaus et al., 2019). This domain is capable of eliciting positive and negative aesthetic emotions, rather than pleasant feelings.

The evaluation and meaning-making aesthetics are closely connected to the significant role of emotions, which influence judgments of all forms of information or stimuli containing aesthetic elements (Schindler et al., 2017). This is due to an emotional function, which detects the presence of a stimulus and elicits an impulse when perceived as a threat (Chatterjee & Vartanian, 2014). Emotions also contribute to comparing and evaluating information derived from stimuli, guiding the selection based on reference levels in cognitive processes (Xenakis et al., 2012). Throughout the aesthetic evaluation process, emotional states can shape responses and lead to judgments that elicit positive or negative emotions. These experiences evoked by aesthetic stimulation are accompanied by changes in autonomic nervous system activity, particularly in the sympathetic branch, reflected in electrodermal activity (EDA). Previous studies showed that increases in emotional arousal were associated with psychophysiological changes, as evidenced by high EDA (Mancini & Jasra, 2019; Rahma et al., 2022).

The neural processes in aesthetic judgment and emotion influence activity in the autonomic nervous system, including EDA (Gatti et al., 2018; Lang, 2014). Even though aesthetic emotions include the brain's reward system and stimulate dopamine release associated with pleasurable experiences, the underlying mechanism differs from the pleasure activation produced by drug use and psychotropic substances. This distinction arises because dopamine release induced by drugs and psychotropic substances can alter receptor functioning, leading to changes in neuroplasticity and disruptions to the balance of the reward system (Volkow & Morales, 2015).

EDA reflects changes in skin conductance resulting from sweat gland activity, which is influenced by the autonomic nervous system. The increased activity in sweat glands is recognized as an indicator of emotional arousal (Caruelle et al., 2019; Horvers et al., 2021; Rahma et al., 2022). The emotional response that arises when individuals are exposed to aesthetic stimuli is referred to as emotion, including subjective experiences elicited by stimulation (Juslin, 2013; Schindler et al., 2017). Aesthetic emotions are distinct from positive and basic emotions such as fear, anger, and sadness. Emotional experiences elicited by aesthetic stimuli may be positive (e.g., pleasure, awe) or negative (e.g., sadness, tension), depending on the stimulus's valence and arousal (Juslin, 2013; Schindler et al., 2017). Basic emotions are adaptive affective responses triggered by biologically salient events and often prepare individuals for immediate goal-directed action. Meanwhile, aesthetic emotions arise through the perception and evaluation of a stimulus based on the aesthetic qualities (Schindler et al., 2017). The elicitation is grounded in the intrinsic qualities of the stimulus, such as beauty, harmony, novelty, or expressive meaning, rather than the instrumental relevance for achieving personal goals. Aesthetic emotions are characterized more strongly by reflective appreciation and subjective savoring than by action-oriented response tendencies. The domain is closely connected to aesthetic judgement since the concept informs evaluative processing of a stimulus's perceived aesthetic qualities.

Aesthetic emotions are an important topic related to empathy and the meaning of experiences, such as listening to music or sounds from the surrounding environment, watching movie scenes or advertisements, listening to poems, rhymes, or other forms of literature (Merrill et al., 2021). In this domain, aesthetic auditory stimuli have been widely used for the treatment and improvement of psychological conditions (Li et al., 2021; Ozenc-Ira, 2023; Slattery et al., 2020) and creativity (Ozenc-Ira, 2023). Music as an auditory aesthetic stimulus is widely used in neuropsychological studies within the tourism and marketing sector (Moreno-Lobato et al., 2023). Furthermore, a previous study has provided evidence of psychophysiological mechanisms underlying emotional reactions to aesthetic stimuli. Increased arousal of the autonomic nervous system, measured by skin conductance sensors, when responding to pleasant and unpleasant audio stimuli (Greco et al., 2017; Klepzig et al., 2020) triggered by aesthetic stimuli (Fuentes-Sánchez et al., 2022), show the variability and diversity of individual responses through psychophysiological measurements of skin conductance from EDA, heart rate, and changes in facial muscle expression and movement in electromyography.

The concept of aesthetic emotion has not been discussed despite examining emotions stimulated by stimuli. Meanwhile, analyses into aesthetic emotions are beginning to develop, with the introduction of measurement scales, including self-reports developed by Schindler et al. (2017). As a limitation, Schindler et al. (2017) proposed the need for further study supported by psychophysiological data as evidence of the biological dynamics of emotional arousal. The measures are important because self-report assessments remain vulnerable to subjective bias and retrospective interpretation. Meanwhile, psychophysiological indices such as EDA provide objective indicators of autonomic arousal that complement subjective evaluations of aesthetic experience.

Studies focused on the field of art and the connection between aesthetics and emotions in psychology remain very limited. This is in contrast to international analysis, where art and aesthetic stimuli have increasingly been examined as therapeutic instruments (Lafo et al., 2017; Li et al., 2021; Peñaloza et al., 2022; Rodriguez Novo et al., 2021; Slattery et al., 2020; Veronese et al., 2017; Zeppegno et al., 2021). The application of psychology in entertainment, marketing, and tourism is frequently discussed in everyday life (Hayashi et al., 2022; Juslin, 2013; Moreno-Lobato et al., 2023; Ozenc-Ira, 2023; Weigand & Jacobsen, 2021; Yeh et al., 2015). This gap motivated the present study to provide empirical data on aesthetic processes related to emotional responses, specifically focusing on the domain of music and auditory sensors. Therefore, physiological responses were measured to provide psychophysiological evidence of autonomic emotional arousal elicited by pleasant and unpleasant music, indexed through EDA.

Methods

The experimental design used was a within-subjects design with a counterbalanced order. Therefore, this study included only one group of subjects, divided into two. Each of the groups received the same treatment of pleasant-unpleasant audio stimuli in a different time order (Sarkies et al., 2019). The participants consisted of 20 non-musician students aged 20–28 years, including 16 females and five males, with a mean age of 24.5 ± 2.6 years. The inclusion of 20 participants was based on prior EDA studies where approximately 16–18 participants were adequate for controlled psychophysiological experiments using GSR/EDA measurements (Klepzig et al., 2020; Rahma et al., 2022). Given the within-subject design, this sample size was considered sufficient for detecting within-condition physiological differences. Participants were physically healthy, reported no history of hearing impairment, had normal or corrected-to-normal vision, and scored within the normal-to-moderate range on emotional screening (DASS-21). Female participants were not in the pre-menstrual syndrome (PMS) or menstruation phases since the phases were known to biologically affect emotional states (Álvarez et al., 2022). Participants were not subjected to any treatments requiring drug consumption and caffeine before the study since these conditions could affect physiological responses (Lomax & Schonbaum, 1998; Zahn & Rapoport, 1987).

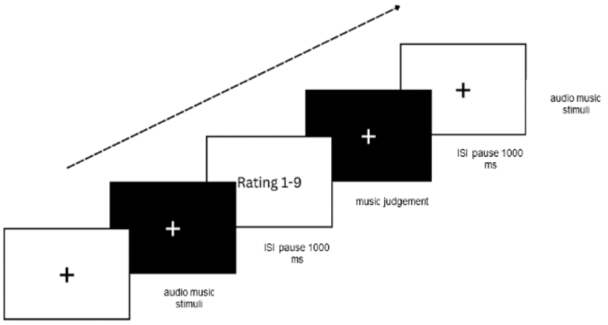

Figure 1. Experimental Trial Design Structure

Screening

Depression, Anxiety & Stress Scale (DASS-21)

Emotional stability was screened using the Indonesian-adapted version of the DASS-21 (Hakim & Aristawati, 2023). Participants with scores in the normal, mild, or moderate categories were included.

Goldsmiths Musical Sophistications Index v1.0 musicality questionnaire

The questionnaire was part of the Goldsmiths Musical Sophistications Index v1.0 subtest (Sauvé et al., 2021) and was used to select non-musician participants. The scale was translated into Indonesian and subjected to expert judgment by three experts. Participants were classified as non-musicians when responses indicated low-to-moderate levels of musical sophistication. This was reflected in limited years of formal music theory or instrumental training, low frequency of daily musical practice, and the absence of self-identification as musicians.

Instruments

The GSR sensor and software used were Shimmer3 GSR+ and Consensys, respectively. The sampling frequency adopted in the EDA measurement was 32 Hz. This frequency was quite commonly used in applicable EDA measurements, especially to calculate emotional sensitivity to music, because the frequency was assumed to be sufficient in detecting significant physiological changes (Bannister & Eerola, 2021; Kim & Andre, 2008; Stuldreher et al., 2020; Thammasan et al., 2019; van Der Zwaag et al., 2009; Visnovcova et al., 2016; White & Rickard, 2016).

The aesthetic music audio stimulus used was Film Music Stimulus Set (FMSS), which was categorized as pleasant or unpleasant and known to elicit emotional responses (Eerola & Vuoskoski, 2011). Music in FMSS was a non-denotative stimulus aesthetic, without lyrics, dialogue, or other sound effects. The FMSS was also accompanied by a 9-point rating scale that represented the affective dimensions of valence, energy arousal, and tension arousal. The scale was translated into Indonesian through expert judgment. To ensure cultural suitability, the stimuli were subjected to preliminary validation with Indonesian raters before the main experiment. This procedure was intended to confirm that the affective categorization remained consistent within the local context, with eight and four raters from a musical background and the general public, respectively (seven female and five male; average age 23.83 ± 4.73).

The FMSS music in the pleasant category had an average valence of ≥ 4 and an energy arousal of≥ 6, totaling 14 pieces. Meanwhile, the unpleasant category possessed an average valence of ≤ 4 and an energy arousal of ≥ 6, totaling 13 pieces (Fuentes-Sánchez et al., 2022). These categories were selected with high energy arousal (≥ 6) to ensure comparable levels of physiological activation across conditions. The primary distinction between categories was in valence (≥ 4 vs. ≤ 4), not arousal intensity. Therefore, the categories represented high-arousal stimuli but differed in emotional quality (pleasant vs. unpleasant), allowing the study to examine affective valence while controlling for magnitude.

Procedures

This study was conducted at the Psychodiagnostic Laboratory (PSD) of the Faculty of Psychology, University of Gajah Mada (UGM), in line with the required standard. The procedure included checking body temperature in the range of 37.50–36.0 °C (Geneva et al., 2019) and monitoring room temperature through an air conditioner (AC) set to 25 °C, in line with ASHRAE 55 standards (Ozsagiroglu et al., 2022). This procedure minimized any interference caused by elevated body temperature and activity in sweat glands not directly stimulated by the stimulus.

GSR sensors were placed on the palms of the index and middle fingers of the non-dominant hand. The experiment was presented in OpenSesame in two separate blocks, namely pleasant (258 seconds) and unpleasant stimuli within 258 and 216 seconds, respectively. Block order was counterbalanced across participants to control for order effects. The total experimental duration ranged between approximately 25 and 41 minutes, depending on the stimulus block order (Figure 1). After completing the series of experiments, participants were instructed to complete the Aesthetic Responsiveness Assessment (AreA) scale through an online form.

EDA signals were decomposed using cvxEDA to obtain a noise-reduced phasic component for subsequent analysis. This method was selected because the concept enabled separation of tonic and phasic components and reported robustness to noise at different levels. The cvxEDA algorithm was robust to noise at different levels (Greco et al., 2016), and the analysis was performed using Python through Google Colab. Statistical analysis of experimental data compared EDA data on the amplitude of phasic components during pleasant and unpleasant stimuli to assess autonomic emotional arousal elicited by stimuli. The data analysis process adopted Jamovi, and the differences between stimulus conditions were analyzed using the Wilcoxon signed-rank test, given the non-normal distribution. Additionally, a correlational analysis was conducted to examine the relationship between EDA amplitude of phasic components and scores on the AreA scale.

Results and Discussion

Results

Convex Optimization Approach EDA (cvxEDA)

The EDA data set for all participants was analyzed using the cvxEDA method to decompose the components. EDA consists of two components, namely phasic and tonic (Horvers et al., 2021; Rahma et al., 2022). The tonic component or electrodermal level (EDL) indicates activity that develops slowly and is characterized by changes in skin conductance eliciting basic physiological responses. Meanwhile, the phasic component or electrodermal response (EDR) is a skin conductance response (SCR) characterized by a rapid change in EDA signaling and represents a reactive response to stimuli (Boucsein, 2012).

The decomposition results showed normalized EDA data, phasic components, sparse sudomotor nerve activity (SMNA), tonic components, and residual models. The signal data in cvxEDA were normalized to control for individual variability, such as skin traits, hydration levels, skin surface hygiene, emotional conditions, and basal physiology. The normalization of EDA signal data during preprocessing could help the analysis focus more on the dynamic changes caused by the stimulus.

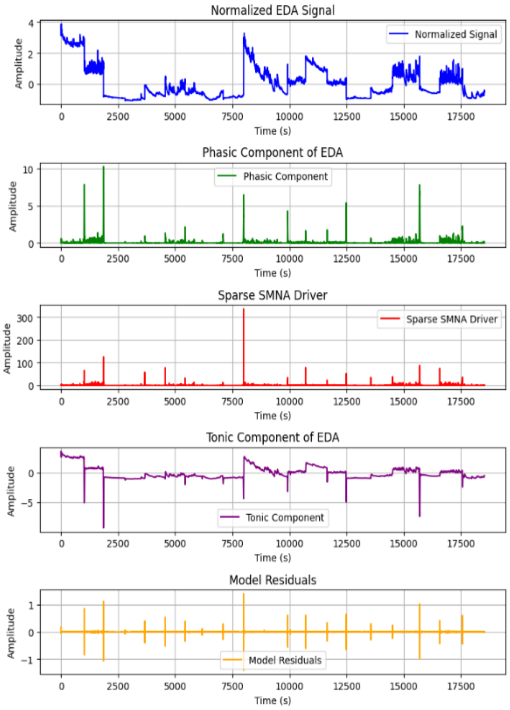

Figure 2. Decomposition of EDA Pleasant

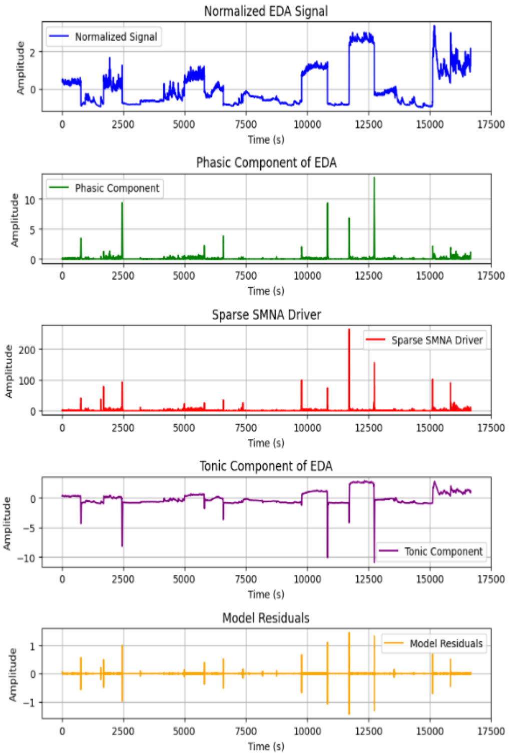

Figure 3. Decomposition of EDA Unpleasant

The decomposition of the phasic (EDR) and tonic (EDL) components provided an overview. The EDL was reduced when the EDR was increased, as reported in Figure 2. This pattern occurred in both periods, during the pleasant and the unpleasant stimulus exposure. Increased EDR and relatively decreased EDL movement served as an adaptive response of the autonomic nervous system and reflected the process of restoring homeostasis. However, when an increase in EDR was not followed by a decrease in EDL, an imbalance would be reported in the mechanisms of the autonomic nervous system (Amin & Faghih, 2022; Debnath et al., 2021; Kim et al., 2018).

Pleasant stimuli that elicit positive emotions were associated with increased EDR, a rapid, transient reaction. This was followed by a decrease in EDL, indicating a slow, gradual adaptation as a stable response to restore physiological conditions to a normal baseline (Boucsein, 1999). At ±8000 milliseconds, the tonic curve appeared to be moving slowly after the increase, suggesting a gradual change in the basal level as an adaptive response (Figure 2). This condition could be attributed to physiological reactions that had not fully adapted to the stimulus exposure. In the next phase, the pleasant period curve showed a relatively continuous pattern between the phasic and tonic components, which reflected a physiological response. The curve in the unpleasant period reported a relatively continuous pattern between the phasic and tonic components. At ±15000 milliseconds, the tonic component appeared to experience a spike, as reported in Figure 3. In this context, there was a basal change that showed a slow response, gradually adapting until the end of the unpleasant period.

Model Assumptions of cvxEDA

The EDA processing model using cvxEDA has four assumptions (Greco et al., 2016) as follows:

1. Skin conductance response (SCR) is preceded by an increase in the sudomotor nerve, which controls sweat glands. This model can be verified using SCR, which shows nerve spikes with sparse, non-negative activity. SMNA reports a sparse pattern and non-negative values.
2. The relationship between the number of sweat glands recruited and the increase in linear amplitude response must be considered. This model can be verified by ensuring that the stimulus's SCR is not affected by the previous response. A consistent inter-stimulus interval (ISI) pause of 10 seconds on each exposure to the music stimulus ensures that SCR is not affected by the previous result. The 10-second ISI is known to return EDA to normal levels (Breska et al., 2011), minimizing SCR and reducing the increase in the next.
3. The process of sweat diffusion in the subject must show a relatively stable impulse response function (IRF). This model is verified by examining the

pattern on the decomposition curve. The peak shape of the phasic and SMNA components appears relatively consistent in shape and duration. A relatively small, unstructured residual model captures EDA signal variations well.

4. Superimposed phasic activity on tonic activity is subjected to a slow change, with a spectrum below .05 Hz represented every 10 seconds. The phasic component of EDA shows that the rapid response to a stimulus has a sharp, high peak shape, corresponding to phasic activity. Tonic components are relatively slow, indicating that the activity does not change rapidly and suggesting a reduced frequency.

Baseline and Tonic Component

The measurements included baseline data collected at the beginning, before the core experiment. This baseline was measured after the electrodes were installed, and the data recording in ConsensysPro is free of noise and artifacts. During the measurements, participants were asked to relax and refrain from performing any tasks for one minute (60 seconds). This was conducted to determine the basic biological conditions of the participants. Baseline periods were presented during each 10-second ISI to return the physiological responses elicited by the stimuli to the baseline. EDA data were analyzed using the cvxEDA method, which decomposed signals. Specifically, cvxEDA separated the IRF that modeled stimulus-evoked phasic EDA responses after removal of the tonic component and adaptive noise. The analysis replaced the conventional filtering process, which was typically performed with a low-pass filter. The cvxEDA analytical approach was assumed to be capable of distinguishing overlapping SCRs, which occurred when the ISI between stimuli was shorter than the response period. Furthermore, the algorithm was robust and reliable across varying levels of noise. EDA signal decomposition using cvxEDA effectively separated tonic and phasic components as well as isolated other sources of variability, including noise (Greco et al., 2016).

The Amplitude of Phasic Component

The present study focused on quantifying stimulus-evoked physiological responses in an interpretable manner. The amplitude of the phasic component was operationalized as the peak–valley difference of the decomposed phasic signal. This method captured the strength of individual SCRs while preserving temporal consistency with stimulus presentation. The cvxEDA was used exclusively for signal decomposition to obtain a noise-reduced phasic component. Meanwhile, amplitude extraction was performed using an automated peak–valley detection procedure implemented in Python, following commonly used SCR definitions in the EDA literature (Niu et al., 2020; Subramanian et al., 2021).

The amplitude was calculated as the difference between the peak and valley of the phasic curve within each response cycle during the stimulus period, as shown in Equation (1). A response cycle refers to a stimulus-evoked increase in physiological activity followed by a return toward baseline during the ISI. Amplitudes were derived by pairing each peak with the nearest neighboring valley when the number of detected peaks and valleys was unequal, provided the discrepancy was minimal. Variations in the number of detected peaks and valleys were expected in EDA recordings and reflected individual biological differences (Niu et al., 2020; Subramanian et al., 2021). This alternative approach identified the presence of only minor differences in the number of peaks and valleys based on individual biological conditions.

$$\text{Amplitude} = eda\ (edr.Peak) - eda\ (edr.Valley) \tag{1}$$

The pattern in the amplitude of the phasic components during periods of pleasant and unpleasant stimuli appeared different (Figures 4 and 5). The amplitude pattern of the phasic component in the pleasant stimulus period was more intense. However, unpleasant stimuli reached a higher peak amplitude than pleasant counterparts. Based on the visualization, the highest arousal average occurred at ±2000 and ±12500 milliseconds after the exposure to pleasant and unpleasant stimuli, respectively.

The results of manual calculations of the amplitude of the unpleasant stimulus period show higher values than the pleasant period (Table 1). This indicates that greater fluctuations in physiological activation or arousal occur during periods of unpleasant stimuli. The mean amplitude, which shows the mean strength of the physiological responses in both stimulus periods, reports a small difference of .46 and .43 for pleasant and unpleasant stimuli (Table 1). For each participant and stimulus condition, phasic SCR amplitudes (defined as peak–valley differences) were aggregated across trials within each participant. The mean phasic amplitude per participant was used as the unit of analysis for inferential statistics. Reported sum amplitudes reflected within-participant accumulation of SCR events and were presented for descriptive purposes only. In both periods, the stimulus was assumed to be equally able to elicit physiological responses or provide aesthetic emotional arousal, with a higher level of intensity in the pleasant stimulus period.

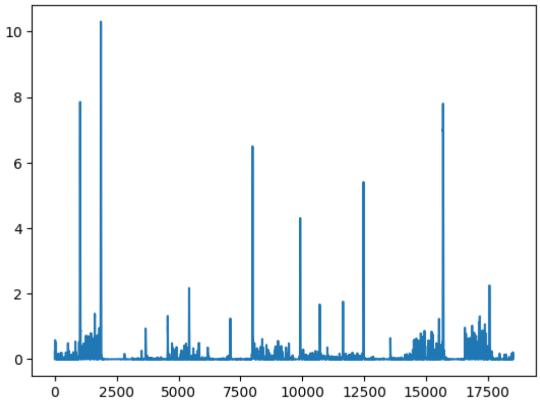

Figure 4. Phasic component of the pleasant stimulus period

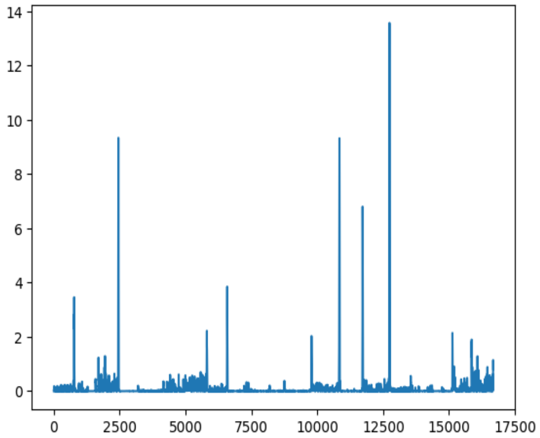

Figure 5. Phasic component of the unpleasant stimulus period

Manipulation Check (FMSS)

The FMSS aesthetic music stimulus served as a manipulation check. The response results from the 9-Point Rating Scale showed that the unpleasant music stimulus fit the defined categorization, with a mean valence of ≤ 4 (3.75) and arousal energy ≥ 6 (6.67). For pleasant music stimuli during the main experiment, the mean arousal value was slightly lower than the established categorization, which had a valence value of ≥ 4 (7.60) and arousal energy ≥ 6 (5.67) (Table 2).

These results show that music with lower valence and higher arousal is perceived as more unpleasant and strongly representative of negative emotions. Higher valence and arousal in music were associated with greater pleasantness and a stronger representation of positive emotions.

Statistical Results

Non-parametric statistical analysis. Given the small sample size, data normality was assessed prior to inferential analysis using the Shapiro–Wilk test. The results indicated that the phasic amplitude data were not normally distributed ($p < .001$). Therefore, non-parametric statistical tests were applied (Tabachnick & Fidell, 2014).

Table 1.

Mean and summed phasic SCR amplitudes (aggregated within participants)

Stimulus	Mean Amplitude	Sum Amplitude
Pleasant	0.46	329
Unpleasant	0.43	334

Table 2.

Mean value of valence and arousal

Stimulus	Mean Valence	Mean Arousal
Pleasant	7.60	5,67
Unpleasant	3.75	6,67

Differences in EDA phasic amplitude between pleasant and unpleasant stimulus conditions were analyzed using the Wilcoxon signed-rank test, a non-parametric alternative to the paired-samples t-test. The results showed a statistically significant difference between conditions ($p = .040$, mean difference = .0273), with a small effect size ($r = .13$) (Cohen, 2013; Tabachnick & Fidell, 2014).

An exploratory comparison of EDA phasic amplitude between female and male participants was conducted for descriptive purposes. Given the highly unbalanced and small group sizes, this analysis was not powered for reliable inferential testing and was interpreted with caution (Figure 7). Even though no statistically significant difference was observed (Mann–Whitney U, $p = .057$), the effect size was reported descriptively. These preliminary results informed future hypothesis-driven studies with adequate and balanced samples.

Correlational Analysis. Spearman and Kendall's tau were considered suitable for nonparametric undisturbed data. The correlation between aesthetic responsiveness, as measured by the AreA scores, and EDA during exposure to pleasant and unpleasant aesthetic stimuli showed negative coefficient values ($\rho = -.228$, $p = .333$; $\tau = -.133$, $p = .416$). In this context, there was an opposite relationship between the variables, with the value of Spearman's coefficient $\rho = -.228$ and Kendall's tau $\tau = -.133$ in a negative direction. The relationship was assumed to be weak or significantly low because Spearman’s ($\rho = -.228$, $p = .333$) and Kendall's tau ($\tau = -.133$, $p = .416$) had coefficients close to null (0) and p-values greater than general significance (>.05) (Tabachnick & Fidell, 2014).

The statistical correlation between aesthetic responsiveness (AreA) and EDA is shown in a plot with lines similar to Figure 8. Plots with gently sloping lines suggest that the inverse relationship between aesthetic responsiveness (AreA) and EDA is significant at a low p-value. The direction of the line suggests that higher area values are associated with lower EDA.

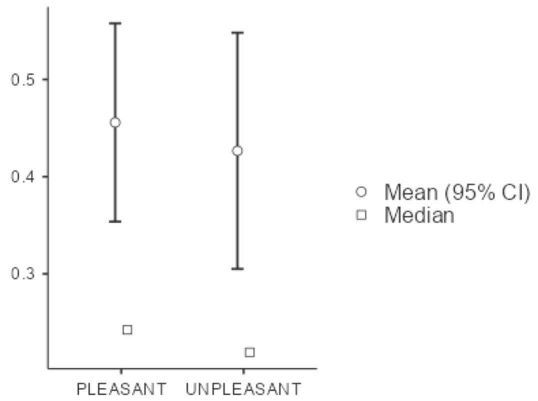

Figure 6. Comparison of phasic amplitude between pleasant and unpleasant stimulus conditions using the Wilcoxon signed-rank test. Error bars represent standard error.

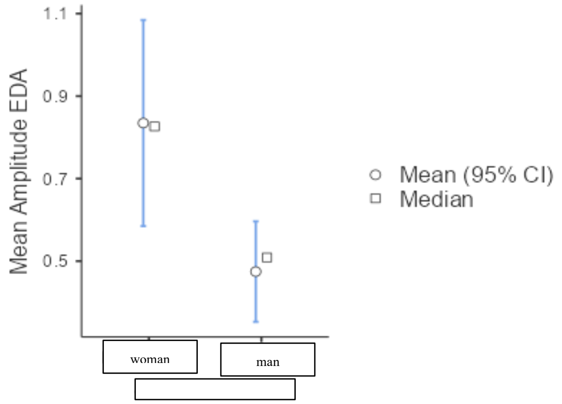

Figure 7. Exploratory comparison of phasic amplitude by gender using the Mann–Whitney U test. Error bars represent standard error.

Correlational analysis was performed on EDA sub-variables to determine the relationship between aesthetic responsiveness (AreA) and EDA in each stimulus. The correlational analysis showed a negative relationship between aesthetic responsiveness (AreA) and EDA stimulus pleasantness (ρ = -.003, p = .990; τ = -.016, p = .922). The results of aesthetic responsiveness with EDA unpleasant stimulus indicate a positive relationship (ρ = .170, p = .473; τ = .123, p = .454). However, the correlation has low significance (p-value > .05) and is assumed to be weak for pleasant stimuli. This is because the coefficients of Spearman and Kendall's tau are close to null (0), and the p-value is not significant.

The relationship between aesthetic responsiveness (AreA) and the EDA sub-variables, pleasant and unpleasant, obtains opposite results. The AreA and EDA of a pleasant stimulus visually represent a straight horizontal line with a slight slope toward the lower right (Figure 9). Even though the two variables show an inverse relationship, the association is negligible and statistically insignificant.

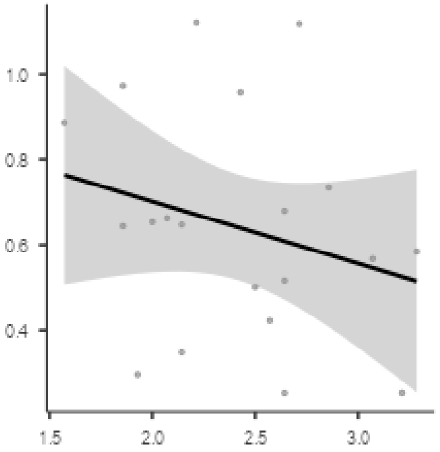

Figure 8. Scatterplot illustrating the relationship between aesthetic responsiveness (AreA scores) and EDA phasic amplitude (x = AreA; y = EDA).

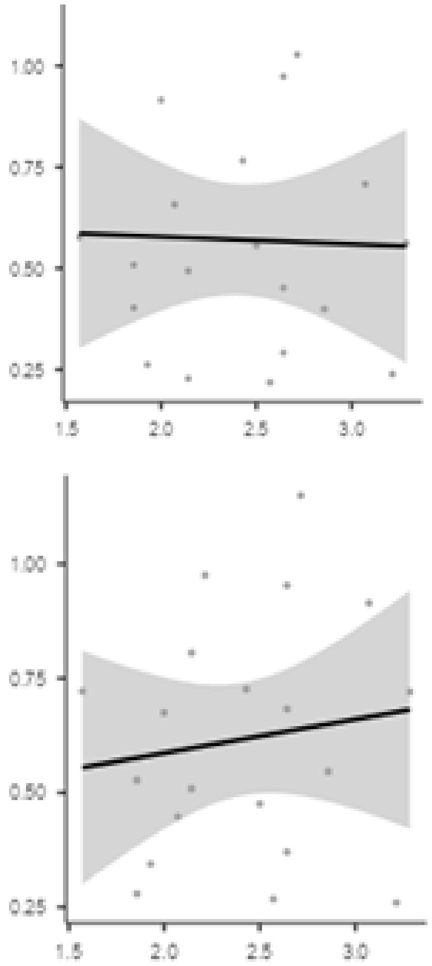

Figure 9-10. Correlation between aesthetic responsiveness and phasic amplitude across stimulus conditions (x = AreA; y = EDA). The left panel represents pleasant stimuli, and the right panel represents unpleasant stimuli.

AreA with an unpleasant stimulus has a slope line towards the upper right (Figure 9). This indicates that higher AreA is associated with increased EDA responses to unpleasant stimuli. A less steep slope suggests a weak relationship and low statistical significance between the two variables.

Discussion

The problem identified concerns the measurement of aesthetic emotions, which remain limited to self-reports. In this study, aesthetic emotion was examined indirectly by measuring physiological arousal, indexed by EDA, during exposure. EDA measurements show enhanced activity in sweat glands in response to various stimuli. Psychological stimuli, such as stress and emotional arousal, can trigger psychological sweating, which becomes a parameter in EDA measurement (Khakim, 2023). Sweat has a high electrolyte content and serves as a good conductor for detecting EDA (Rahma et al., 2022). Changes in skin electrical conductivity in response to aesthetic music stimuli serve as indicators of physiological arousal associated with aesthetic stimulation.

This study uses stimuli with aesthetic elements to elicit aesthetic emotions, focusing on auditory stimulation. Auditory sensory input is known to have a strong capacity to induce and stimulate emotional reactions (Greco et al., 2017). The FMSS was selected as the musical stimulus with aesthetic value because the context provides a categorization of pleasant and unpleasant music (Eerola & Vuoskoski, 2011).

Experiments show that FMSS music stimuli elicit arousal, as detected by EDA. The arousal of aesthetic emotions during the presentation of an aesthetic stimulus is inferred from the amplitude of the phasic component derived from EDA decomposition. Amplitude is an arousal parameter indicated by the magnitude of physiological changes over a period that includes phases of rise (peak) and descent (valley) (Greco et al., 2016; Niu et al., 2020). The sum and mean amplitude in the phasic component indicate physiological or arousal activation in response to the stimulus (Boucsein, 2012). The higher the sum of amplitudes, the greater the variation in physiological response. The greater the mean amplitude, the stronger the physiological or arousal response. The arousal of aesthetic emotions was reported by analyzing the quantity and mean amplitude of phasic components following exposure to aesthetic stimuli.

EDA Pleasant and Unpleasant Stimuli

EDA measurements indicate emotional arousal, but cannot classify the emotion type. Therefore, stimuli with positive (pleasant) and negative (unpleasant) emotional valence were used. A statistically significant difference ($p < .05$) was reported using the same mechanism and indicators. Unpleasant musical stimuli elicited greater fluctuations in physiological response, which reflected increased autonomic sensitivity to negatively valenced auditory information. This condition is attributed to the stimulation of negative feelings such as discomfort, surprise, and fear that arise during exposure to unpleasant stimuli. From an evolutionary perspective, organisms are more responsive to potentially threatening or aversive cues due to negativity bias and defensive survival mechanisms. The following evaluation of the FMSS also shows a low mean unpleasant valence ($4 < 3.75$). Therefore, music's valence is progressively negative, with high average arousal ($6<6.67$). Low-valence and high-arousal auditory stimuli may activate neural systems associated with vigilance and threat detection, including the amygdala and related limbic circuitry. This may explain why unpleasant music produced higher phasic peaks, reflecting transient defensive arousal responses.

The results are in line with (Flores-Gutiérrez et al., 2007; Greco et al., 2017), where unpleasant music stimulated by negative emotions can activate areas in the brain associated with anxiety, such as the hippocampus, amygdala, and medial temporal lobe area. In contrast, pleasant stimuli produced lower peak fluctuations but higher mean phasic amplitude, suggesting a more sustained and stable arousal pattern. This pattern may reflect reward-related engagement through mesolimbic dopaminergic activation, particularly including the nucleus accumbens associated with pleasurable music listening (Flores-Gutiérrez et al., 2007; Sabatinelli et al., 2007). Even though fluctuations in arousal levels were not higher, pleasant stimuli produced more stable physiological activation in triggering aesthetic emotions. Therefore, exposure to pleasant and unpleasant music stimuli produces different patterns of aesthetic emotional arousal, with pleasant stimuli showing stronger sustained activation.

EDA Differences in Female and Male

An exploratory analysis was conducted to descriptively examine potential gender-related patterns in EDA phasic amplitude. Even though female participants exhibited a numerically higher mean phasic amplitude than male participants, this observation should be interpreted with caution due to the highly unequal and small group sizes. The gender analysis was not powered for confirmatory inference and was intended to identify preliminary trends. Previous studies suggested gender-related differences in aesthetic experience and emotional processing (Bae, 2023). Meanwhile, the present results did not constitute confirmatory evidence of the effects on autonomic reactivity. Given the limited sample size and imbalance between groups, no strong conclusions were drawn regarding gender differences in EDA responses. Future studies using larger, balanced samples and a priori hypotheses were required to adequately investigate potential sex-related differences in aesthetic emotional arousal.

EDA and Aesthetic Responsiveness

The arousal of aesthetic emotions is associated with individual responsiveness to aesthetic stimuli (Schlotz et al., 2021). Aesthetic responsiveness is an individual's capacity to respond to an aesthetic stimulus. The assumption that individuals with high aesthetic responsiveness will have higher arousal aesthetic emotions is not true. This is affected by various factors, including the type of aesthetic stimulus presented (Pearce et al., 2016).

The results showed negative correlations between aesthetic responsiveness and the arousal of aesthetic emotions. This indicates that higher aesthetic responsiveness is associated with lower physiological arousal. The correlation results indicate a weak negative association and reflect a possible relaxation state, perceived as an aesthetic experience of the pleasant stimulus. The type of aesthetic stimulus used represents positive and negative emotions with pleasant and unpleasant music, respectively. Stimulation from emotionally positive music can produce a relaxing effect (Flores-Gutiérrez et al., 2007). In relaxed conditions, EDA tends to decrease (Greco et al., 2016; Ishizu & Zeki, 2011; Schindler et al., 2017). This reduction in EDA affects the arousal of aesthetic emotions.

Different conditions can occur when the stimulus presented is arousing and high in tension, which falls into the category of unpleasant stimuli. The results suggest that arousal elicited by unpleasant stimuli may show a positive tendency of association with aesthetic responsiveness. These provide a more complex description of an individual's physiological response and aesthetic responsiveness. Individuals may have an aesthetic preference for a pleasant stimulus, indicated by higher arousal intensity. This suggests that the mean individual is more responsive to unpleasant stimuli, experiences tension, and tends to experience discomfort, as reflected in enhanced EDA. The arousal of aesthetic emotions elicited by unpleasant stimuli may be related to individuals' aesthetic responsiveness.

The non-significant correlation between EDA responses and aesthetic responsiveness may reflect the distinction between implicit physiological reactivity and explicit cognitive-evaluative processing in aesthetic experience. EDA captures rapid autonomic arousal responses that operate largely outside conscious awareness (Khakim, 2023). Meanwhile, aesthetic responsiveness as measured by self-report reflects reflective appraisal, personal meaning-making, and trait-level sensitivity toward experiences. This distinction is consistent with dual-process perspectives in aesthetic processing, where experience includes an automatic sensory-affective pathway and a higher-order reflective evaluative pathway (Belfi et al., 2019; Chatterjee & Vartanian, 2014; Pearce et al., 2016; Weigand & Jacobsen, 2021; Xenakis et al., 2012). Therefore, increased physiological arousal does not necessarily correspond to higher self-reported aesthetic responsiveness since individuals may consciously interpret, regulate, or cognitively elaborate aesthetic experiences differently.

This study has several limitations. First, the relatively small sample size limits the generalizability of the results and reduces statistical power for detecting smaller effect sizes in correlational analyses. However, this sample size remained consistent with controlled psychophysiological EDA studies and was considered adequate given the within-subject experimental design. Second, limitations in synchronization between the EDA recording software (Consensys) and the stimulus presentation platform (OpenSesame) prevented detailed trial-by-trial marker integration, limiting more precise analysis of physiological responses. This contributed to variability in the observed relationship between EDA and aesthetic responsiveness. Third, the decomposition analysis depended on the cvxEDA method. Even though this method was selected for the precision in phasic decomposition and noise handling, future studies benefited from comparative decomposition approaches, such as continuous decomposition analysis (CDA), to strengthen analytical robustness. Despite the limitations, precise psychophysiological evidence supporting the use of electrodermal responses was provided as indicators of aesthetic emotional arousal in the musical domain.

Conclusion

In conclusion, physiological arousal can provide evidence that strengthens concepts of aesthetic emotions from previous studies (Schindler et al., 2017). The results provide additional variability in pleasant and unpleasant ratings as representations of the valence of positive and negative emotion types and suggest the possibility of practical differences between females and males. Music that produces a pleasant effect is known to elicit aesthetic emotions more intensely (Flores-Gutiérrez et al., 2007; Sabatinelli et al., 2007). The arousal of aesthetic emotions has implications for responsiveness. Individuals with higher aesthetic responsiveness tend to engage more with experiences, which may manifest as differences in physiological arousal. However, the type of stimulus presented can affect increases and decreases in EDA.

Music with a pleasant effect may indicate an individual's aesthetic preference in arousal aesthetic emotions (Flores-Gutiérrez et al., 2007; Greco et al., 2016; Ishizu & Zeki, 2011; Schindler et al., 2017). These preferences are not reflected in the individual's responsiveness in response to aesthetic stimuli.

Individuals with higher aesthetic responsiveness may exhibit greater sensitivity to unpleasant musical stimuli, but the tendency requires confirmation in larger samples. The results provide insight into the application of aesthetic stimuli across contexts, suggesting that music with pleasant effects tends to elicit intense emotional arousal. This study reports several opportunities for future analyses. The absence of a more detailed and precise analysis of each musical stimulus trial constituted a limitation. This resulted from constraints related to synchronization and connectivity within the EDA recording software (Consensys) and the stimulus presentation applications (OpenSesame). The decomposition method used in this study depends on cvxEDA. The CDA method is incorporated as a comparative method in the EDA decomposition process, even though the selection of the cvxEDA method is in line with the objectives of the study, particularly for more precise decomposition of phasic components, improved noise handling, and reinforcement of the analytical results.

Declaration

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The author, Ajeng Rintan Septiani, is a student in the Master's Program in Psychology at the Faculty of Psychology, Universitas Gadjah Mada. This study was conducted under the supervision of Sri Kusrohmaniah, with Supra Wimbarti and Noor Akhmad Setiawan serving as examiners.

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Author Contributions

Conceptualization: ARS, SK; Methodology: ARS, SK, NAS, SW; Data collection and investigation: ARS, SK; Data analysis: ARS, NAS; Writing—Original Draft Preparation: ARS; Writing—Review & Editing: ARS, SK, SW, NAS; Supervision: SK, SW, NAS.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Use of Artificial Intelligence

One of the authors used AI-based tools to assist with discussion of Python code, including identifying coding errors, explaining error messages, and suggesting possible code modifications. AI tools were not used to perform data analysis, generate results, or make analytical decisions. Grammarly was also used for grammar and language correction. All data processing, statistical analyses, interpretation of results, and final manuscript content were conducted, reviewed, verified, and approved by the authors.

Ethical Clearance

Ethical clearance was acquired from the Komite Etik of the Faculty of Psychology, Universitas Gadjah Mada, Number: 1188/UN1/FPsi. 1.3/SD/PT.01.04/2024.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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