

Emotion elicitation during music listening: Subjective self-reports, facial expression, and autonomic reactivity

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Abstract

The use of music as emotional stimuli in experimental studies has grown in recent years. However, prior studies have mainly focused on self-reports and central measures, with a few works exploring the time course of psychophysiological correlates. Moreover, most of the previous research has been carried out either from the dimensional or categorical model but not combining both approaches to emotions. This study aimed to investigate subjective and physiological correlates of emotion elicitation through music, following the three-dimensional and the discrete emotion model. A sample of 50 healthy volunteers (25 women) took part in this experiment by listening to 42 film music excerpts (14 pleasant, 14 unpleasant, 14 neutral) presented during 8 s, while peripheral measures were continuously recorded. After music offset, affective dimensions (valence, energy arousal, and tension arousal) as well as discrete emotions (happiness, sadness, tenderness, fear, and anger) were collected using a 9-point scale. Results showed an effect of the music category on subjective and psychophysiological measures. In peripheral physiology, greater electrodermal activity, heart rate acceleration, and zygomatic responses, besides lower corrugator amplitude, were observed for pleasant excerpts in comparison to neutral and unpleasant music, from 2 s after stimulus onset until the end of its duration. Overall, our results add evidence for the efficacy of standardized film music excerpts to evoke powerful emotions in laboratory settings; thus, opening a path to explore interventions based on music in pathologies with underlying emotion deregulatory processes.

KEYWORDS

autonomic reactivity, emotion elicitation, facial expression, music, subjective ratings

1 | INTRODUCTION

The scientific study of emotions has been of great interest for decades and it has raised numerous theoretical and experimental questions, such as the suitability of affective stimuli

used for inducing emotions (Moltó et al., 1999, 2013). Most of the previous studies have focused on the use of affective pictures, facial expressions, words, or sounds to induce emotions in laboratory settings, obtaining clear and well-established results. However, the number of studies focused

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on the effects of music listening in methodologically rigorous, controlled laboratory environments has been much lower despite the potential of music to evoke strong emotions (Juslin & Västfjäll, 2008).

Listening to music activates brain regions involved in emotion and reward, including the ventral striatum, amygdala, orbitofrontal cortex, anterior cingulate cortex, and the insula (Blood & Zatorre, 2001), as well as other areas typically associated with cognitive processes such as the anterior hippocampus and auditory cortex (Koelsch, 2020). Interestingly, brain activation reveals a segregation of subcortical areas that responds to differences in affective dimensions. For example, chills evoked by pleasant music tend to correlate with an increased activation in nucleus accumbens and insula (Blood & Zatorre, 2001). In addition, high pleasurable moments during music listening are related to dopamine release in the ventral region of the striatum (Salimpoor et al., 2011). In contrast, amygdala seems to be specifically activated during unpleasant chill responses (Klempzig et al., 2020), as well as during the fear and tension evoked by music (Koelsch, 2006; Koelsch & Skouras, 2014).

Music excerpts can also activate the autonomic nervous system (ANS) and other peripheral correlates (Bhushan & Asai, 2018). In this vein, previous studies have investigated the effects of music listening on classical autonomic correlates such as electrodermal activity (EDA) or heart rate (HR), as well as on emotional expression through facial electromyography (EMG). More specifically, prior research has shown that arousing music was associated with increases in EDA, in comparison to more relaxing excerpts (Gomez & Danuser, 2007; Rickard, 2004). In addition, a number of studies focused on discrete emotions found that happy (Bullack et al., 2018; Khalifa et al., 2002; Lundqvist et al., 2009) and fearful excerpts (Khalifa et al., 2002) prompted greater EDA in comparison to sad music. Interestingly, happy and fear clips have been evaluated as more arousing in comparison to peaceful or sad music (Khalifa et al., 2002). Thus, these results are in accordance with the idea that EDA is more sensitive to variations in emotional arousal rather than valence (Gomez & Danuser, 2007), although other studies have not reached meaningful changes in EDA during music listening (Blood & Zatorre, 2001; DeJong et al., 1973). Regarding cardiovascular measures, prior findings demonstrated that arousing excerpts prompted increases in HR compared to relaxing music (Etzel et al., 2006; Iwanaga et al., 1996; Koelsch & Jäncke, 2015; Krumhansl, 1997; Ogg et al., 2017). In terms of hedonic valence, some studies found decreases in HR during unpleasant music (Sammler et al., 2007; Witvliet & Vrana, 2007) and increases during pleasant music (Krumhansl, 1997; Salimpoor et al., 2009). However, the literature review reflects that some studies reported opposite effects (White & Rickard, 2016), and other works even failed to obtain significant differences in HR (Bullack et al., 2018; Lundqvist

et al., 2009; Merrill et al., 2020), which could pose a problem when interpreting this autonomic measure. With regard to facial EMG, past research generally found greater zygomatic activity during happy in comparison to sad music (Bullack et al., 2018; Lundqvist et al., 2009; Witvliet et al., 1998), and greater corrugator activity during sad compared to happy music (Bullack et al., 2018). However, other investigations failed to find substantial differences in corrugator (Lundqvist et al., 2009) and zygomatic EMG (Roy et al., 2009) when listening to emotional music.

Despite the above reasonable findings, a detailed review of the scientific literature shows important divergences between studies, which might be due to a lack of agreement on relevant methodological issues, as well as variations in their theoretical conceptualizations of emotion (i.e., affective dimensions vs. discrete categories). Regarding the methodological diversity among studies, one important caveat influencing the comparability of results is the duration of music excerpts, which have been ranging between 15 and 30 s (Brushan & Asai, 2018; Gomez & Danuser, 2004) and even more than 60 s (Baumgartner et al., 2006; Bullack et al., 2018; Etzel et al., 2006; Guhn et al., 2007; Lundqvist et al., 2009; Roy et al., 2009; Sammler et al., 2007). Interestingly, only a few studies have used music stimuli with durations shorter than 15 s (Dellacherie et al., 2011; Gringas et al., 2015; Khalifa et al., 2002; Vieillard et al., 2012), despite being the standard procedure in other stimuli modalities such as affective pictures (IAPS: Bradley et al., 2001) or emotional sounds (IADS: Bradley & Lang, 2000). In addition, some previous studies have included music clips with different duration within the same task (Etzel et al., 2006; Sammler et al., 2007), which could pose a problem for the simultaneous recording and analyses of physiological correlates that differ in terms of signal frequency (as happens with fast vs. slow measures such as facial EMG compared to EDA). Another methodological limitation in this field that hinders the comparison of results is the stimuli selection criteria, which in turn depends on the theoretical conceptualization of emotions that guides the investigations. Whereas some studies select happy versus sad music (Bullack et al., 2018; Lundqvist et al., 2009), others include high versus low arousing excerpts (Gomez & Danuser, 2004) or unpleasant versus pleasant music without considering specific emotions (Roy et al., 2009). Finally, most of the past research interested in music listening effects has focused on particular parameters (e.g., maximum or minimum peak and mean of time intervals) when preprocessing the physiological measures. The fact of not considering the time course of affective responses during music listening might lead to certain loss of information and somehow to a lack of replicability of findings, especially when considering the complexity of the autonomic reactivity (Ellis et al., 2012; Lynar et al., 2017) and the dynamic character of the music itself.

With regards to differences in the theoretical framework, both discrete and dimensional models have been commonly used in the study of music and emotions. The discrete model advocates that all emotions can be derived from basic universal and innate emotions (Ekman, 1992). Past research focused on peripheral measures using this model mainly focused on happy and sad music (Baumgartner et al., 2006; Bullack et al., 2018; Etzel et al., 2006; Lundqvist et al., 2009). Both emotions, however, differ not only in terms of hedonic valence but also arousal, which could make the interpretation of the results difficult. Therefore, other additional discrete emotions such as anger, fear, or tenderness should be considered when exploring the peripheral physiology, likewise in previous works measuring subjective correlates (Eerola & Vuoskoski, 2011; Vieillard et al., 2008). In contrast, the bidimensional model (Lang et al., 1990) considers that all emotions can be explained in terms of *hedonic valence* (ranging from pleasant-appetitive motivation to unpleasant/defensive motivation) and *arousal* (ranging from high to low emotional intensity). The studies within this framework select the musical excerpts based on valence and arousal normative ratings with the aim of eliciting a broad range of emotional responses (e.g., Gomez & Danuser, 2004; Ogg et al., 2017). Nevertheless, specific emotions such as anger and fear—evaluated with similar valence and arousal—are generally ignored from this theoretical model (Fuentes-Sánchez et al., 2020). Furthermore, according to the three-dimensional model (Schimmack & Grob, 2000; Schimmack & Reisenzein, 2002), some authors consider that emotional arousal could be divided into two separate dimensions: *energy* (ranging from arousal to calmness) and *tension* (ranging from tension to relaxation). This latter proposal might be particularly more suitable to music research than the classical model considering a unitary arousal dimension (Gringas et al., 2015; Schimmack & Reisenzein, 2002). To this extent, despite prior findings with subjective evaluations have demonstrated that the correlation between both arousal dimensions is highly strong (Eerola & Vuoskoski, 2011; Fuentes-Sánchez et al., 2020), the relationship of each particular dimension with hedonic valence is quite different. Thus, tension arousal had a negative linear relation with valence, whereas energy arousal had a quadratic relationship (i.e., those excerpts rated as pleasant and unpleasant were evaluated as more energetic in comparison to neutral excerpts, which were evaluated as low in energy) (Fuentes-Sánchez et al., 2020). These findings make it necessary to continue exploring how these variables could influence not only on subjective ratings but also on peripheral physiology. In this regard, Gringas et al. (2015) demonstrated that pupillary responses—a reliable index associated with sympathetic activation—were specifically predicted by tension arousal.

In addition, despite dimensional and discrete approaches to emotion are complementary, and combined could overcome

the limitations attributable to each model separately (Eerola & Vuoskoski, 2011; Fernández-Aguilar et al., 2020; Fuentes-Sánchez et al., 2020; Harmon-Jones et al., 2017; Stevenson & James, 2008), prior studies measuring psychophysiological correlates have generally not included both frameworks simultaneously. This theoretical caveat affects the replicability and comparability of previous results but is not exclusive to emotion elicitation through music as it extends to affective pictures and sounds. Indeed, most of the preceding research has explored the covariation between physiological reactions to emotional stimuli and subjective evaluations of their affective properties from a bidimensional approximation (Bradley & Lang, 2000; Lang et al., 1993), despite the divergences in the autonomic and facial EMG reactivity for specific negative emotions. Accordingly, whereas stimuli rated as unpleasant generally prompt increases in corrugator activity, the relaxation of this same facial muscle seems characteristic of fearful expressions (Lang et al., 1993). Similarly, visceral correlates do not only vary as a function of general dimensions—such as hedonic valence and arousal—but could differ among specific discrete emotions (Lang et al., 1993), which makes evident the need to consider simultaneously both theoretical approaches.

The present study seeks to address some of the methodological caveats mentioned above in order to investigate the effects of music listening on experiential, autonomic, and expressive correlates of emotion. To that end, a set of excerpts from the Film Music Stimulus Set (FMSS: Eerola & Vuoskoski, 2011) was selected. The selection of this standardized data set was due to several reasons. Firstly, this type of music is designed to evoke powerful emotions (Eerola & Vuoskoski, 2011) and uses conventions of Western tonal music that reliably and rapidly elicit specific emotional responses in people familiar with this musical style (Johnsen et al., 2009). Secondly, among the currently available standardized databases, the FMSS is a film music data set that was satisfactorily used in prior research (Vieillard et al., 2015; White & Rickard, 2016), and has been recently validated in Spanish population (Fuentes-Sánchez et al., 2020). Accordingly, the selection of the excerpts used in this study was based on the Spanish normative ratings. Furthermore, the FMSS has several advantages over other current music stimuli datasets, such as the control of familiarity and preference, as well as the combination of discrete and dimensional models of emotions. The original FMSS also includes music excerpts with a variable duration (ranging from 11 to 31 s). As previously mentioned, an important methodological limitation of prior research is the great divergence between studies—and within the same study—concerning the minimum length of musical excerpts required to elicit powerful emotional reactions, measurable at different levels. In this regard, those studies focusing on *emotion recognition (perceived emotions)*—mostly using subjective measures—, generally suggest that even very short excerpts—from 1 s—were

able to express and transmit emotions to the listeners (Bigand et al., 2005; Goydke et al., 2004). In contrast, the literature focused on *emotion induction (felt emotions)* using objective measures argues that longer exposure time (e.g., Altenmüller et al., 2002) is necessary to induce an emotional response (Eerola & Vuoskoski, 2013). Nonetheless, some other studies reported physiological changes in response to shorter excerpts (e.g., 6 or 7 s; see Gringas et al., 2015; Khalfa et al., 2002). These findings support the idea that an intermediate duration (between 6 and 8 s) could prompt relatively stable and significant physiological changes, as has been found with other modalities of affective stimuli. As a consequence, the FMMS excerpts selected in the present study were previously edited by shortening them to 8 s in order to ensure a similar trial duration within the task, being therefore comparable to prior music studies (Gringas et al., 2015; Khalfa et al., 2002), as well as other works using emotional pictures or sounds in diverse paradigms such as passive viewing, aversive conditioning, or cognitive reappraisal tasks (Conzelmann et al., 2015; Fuentes-Sánchez et al., 2019; López et al., 2009).

Thus, the first objective was to investigate the correspondence between the subjective ratings obtained in the a priori validation study—with longer and variable excerpts durations (Fuentes-Sánchez et al., 2020)—and those obtained here for the shortened excerpts. A second goal was to investigate the effect of music category (unpleasant, neutral, and pleasant music) on (a) peripheral physiology (EDA, HR changes, zygomatic, and corrugator)—analyzing both specific parameters such as peak response or averaged activity and the time course across half-seconds bin; and (b) subjective ratings—both for affective dimensions (valence, energy, and tension arousal) as well as discrete emotions (happiness, anger, fear, tenderness, and sadness). Finally, a third objective was to investigate the relationship between the self-ratings and peripheral correlates in order to explore the suitability of each emotion approach (three-dimensional vs. discrete model) in the prediction of the objective correlates of emotion. According to previous research (e.g., Bigand et al., 2005), it was expected to find a strong relationship between short and long excerpts in all the subjective ratings evaluated in this study. In addition, an effect of the excerpt category on peripheral measures and self-reports was expected. Specifically, regarding autonomic reactivity, it was predicted to find enhanced EDA for pleasant and unpleasant, in comparison to neutral music. For HR, as previous works showed mixed findings, two different results could be expected: (a) enhanced HR for pleasant in comparison to neutral and unpleasant stimuli (for which a sustained cardiac deceleration was predicted) (Sammler et al., 2007; Witvliet & Vrana, 2007), or (b) enhanced HR both for pleasant and unpleasant in comparison to neutral music, which would replicate prior findings only focused on arousing versus relaxing excerpts (Koelsch & Jäncke, 2015; Ogg et al., 2017). Regarding facial EMG, we predicted enhanced zygomatic responses for pleasant music, compared to neutral and unpleasant,

which should prompt, in turn, larger corrugator activity. Lastly, some level of agreement was expected between the categorical and three-dimensional models, being both approaches good predictors of the emotion-related physiological responses. Based on prior findings (Bradley et al., 2001; Bradley & Lang, 2000, 2007), it was hypothesized that EDA responses—a direct index of sympathetic activity—would be positively associated with both arousal dimensions (energy and tension), as well as with specific emotions of anger, fear, and happiness (characterized as emotionally arousing). With regard to HR, we could again expect different results: whether HR was positively related to valence ratings and happiness, as well as negatively associated with anger, fear, and sadness (common negative emotions), the effect of the hedonic valence on HR would be demonstrated. By contrast, whether HR was associated with both arousal dimensions (energy and tension), then HR could be understood in future experimental designs as an arousal index. Finally, it was hypothesized that valence ratings and happiness would be positively related to zygomatic EMG, but negatively associated with corrugator activity, which should be positively related to anger.

2 | METHOD

2.1 | Participants

Sample size was calculated with G*Power (Faul et al., 2007) considering an effect size (f) of 0.25, an alpha level of .05, a power value of .95, and three measurements, suggesting that at least 43 participants were needed. Fifty participants (25 females) between 18 and 41 years (Mean age = 22.58, $SD = 4.35$) were finally recruited in this study. The sample was composed by volunteer students of Universitat Jaume I (Spain). For the statistical analyses, one participant was excluded due to technical problems during data acquisition, specifically for zygomatic EMG activity. Ethical approval from the Deontological Comision at Universitat Jaume I was obtained, and all participants provided informed consent forms. Participants were compensated with economic incentive for their participation (5€) to ensure they were properly engaged in the experimental task.

2.2 | Stimuli and design

A total of 42 musical excerpts (14 unpleasant, 14 pleasant, and 14 neutral) were selected from the *Film Music Stimulus Set* (FMSS; Eerola & Vuoskoski, 2011) based on the Spanish normative values for two affective dimensions (valence and energy arousal) (Fuentes-Sánchez et al., 2020). Particularly, unpleasant and pleasant excerpts were evaluated below 4 and above 6 in hedonic valence, respectively, whereas all stimuli in both categories were rated above 6 in energy arousal. Music excerpts classified as neutral were rated between 4 and

TABLE 1 Normative Means (*SDs*) values for each music category in affective dimensions and discrete emotions

	Unpleasant	Neutral	Pleasant
<i>Affective dimensions</i>			
Valence	2.86 (0.45)	5.02 (0.56)	7.01 (0.64)
Energy arousal	6.71 (0.61)	3.17 (0.48)	6.87 (0.52)
Tension arousal	7.45 (0.44)	3.46 (0.73)	5.36 (0.57)
<i>Discrete emotions</i>			
Happiness	1.24 (0.12)	2.04 (0.44)	6.79 (1.03)
Anger	5.76 (1.34)	1.99 (0.58)	1.56 (0.42)
Fear	7.19 (0.50)	3.21 (1.26)	1.54 (0.41)
Tenderness	1.19 (0.12)	3.81 (1.06)	3.66 (0.75)
Sadness	3.11 (0.33)	6.36 (0.97)	1.81 (0.63)

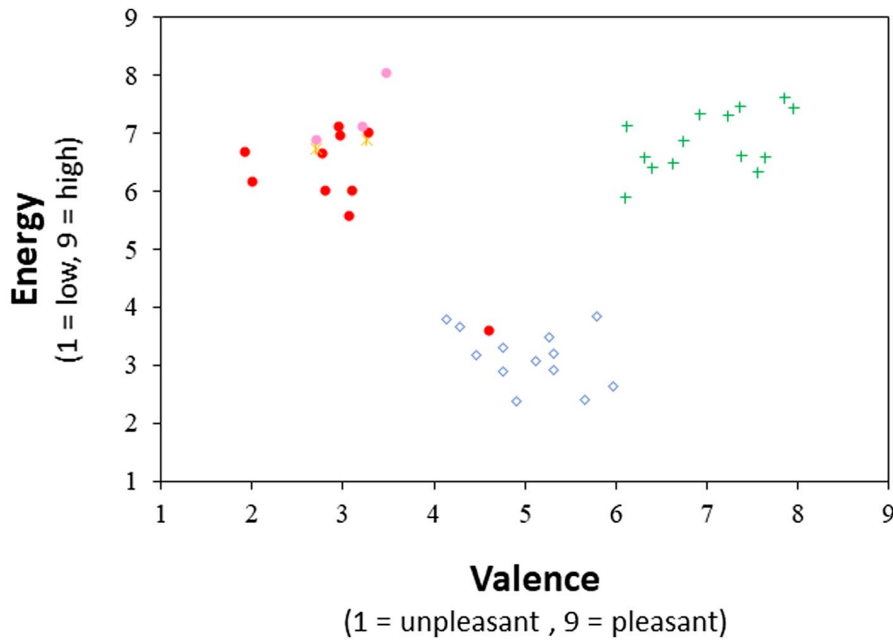


FIGURE 1 Plot of excerpts selected from the *Film Music Stimulus Set* (Eerola & Vuoskoski, 2011; Fuentes-Sánchez et al., 2020) on the basis of their mean valence (x-axis) and energy arousal (y-axis) ratings. Each point in the plot represents the ratings for a musical excerpt. Furthermore, each shape represents the specific emotion that characterizes each musical excerpt. Crosses represent happiness excerpts; rhombus represents sad clips; red points represent fearful excerpts; pink points represent anger excerpts; and stars represent the excerpts that convey both anger and fear in a similar way

6 in hedonic valence, and below 4 in energy arousal.¹ The normative mean values and standard deviations (*SD*) for each music category are summarized in Table 1, and the

¹Excerpts numbers used in this experiment were as follow: Unpleasant (098, 124, 157, 168, 170, 177, 215, 218, 219, 230, 234, 306, 309, 313); Neutral (032, 037, 273, 274, 276, 278, 280, 283, 288, 292, 293, 294, 295, 360); Pleasant (001, 003, 004, 011, 020, 022, 188, 192, 204, 246, 250, 260, 263, 269, 029, 039). Excerpts 029 and 039 were used as practice trials.

Stimuli selection was based on the normative ratings of valence and energy arousal (and not tension arousal) since the relationship between the above dimensions was highly similar to that obtained in prior standardized datasets (affective pictures or sounds), in which only one arousal dimension was considered. For more information about the excerpts properties used in the experiment, see Tables S1–S3 (Appendix).

representation of each musical excerpt in the bidimensional space formed by affective valence and energy arousal is shown in Figure 1. Furthermore, with the aim of reducing other confounding variables, all excerpts used in this experiment were also rated as certainly unfamiliar in the previous Spanish validation study (Fuentes-Sánchez et al., 2020). Particularly, the normative values in familiarity (3-point scale: 0 unfamiliar; 1 somewhat familiar; and 2 very familiar) were as follows: $M = 0.30$, $SD = 0.17$, 95% CI [0.24–0.35].

Musical excerpts were distributed into seven blocks with six excerpts each (2 unpleasant, 2 neutral, and 2 pleasant), with no more than two consecutive trials of the same music category. Furthermore, participants were presented with two practice excerpts before the task started. Each trial began

with a cross presented in the center of a black screen during 1 s of silence baseline, followed by the presentation of unpleasant, neutral, or pleasant musical excerpts during 8 s. Afterward, participants rated different affective dimensions (valence, energy arousal, and tension arousal) and discrete emotions (happiness, sadness, tenderness, fear, and anger) using a 9-point scale as in the validation study (see Fuentes-Sánchez et al., 2020). Thereupon, familiarity was evaluated using a 3-point scale (0 = unfamiliar; 1 = somewhat familiar; and 2 = very familiar).² Each trial ended with an interstimulus interval (ITI) that varied randomly between 8 and 10 s.

2.3 | Psychophysiological data acquisition and reduction

Raw signals were recorded using a Biopac MP36 system. Acqknowledge 4.4 software was used to collect, rectify, integrate, and smooth the physiological data. EDA was recorded through a Biopac SS57LA transducer with disposable snap electrodes, placed on the hypothenar eminence of the palm. Electrodes were attached 10 min before beginning the experiment to ensure the stability of the recording. Previously, the hand was gently cleaned using a tissue with distilled water. The signal was calibrated for each participant before the experiment began and was continuously recorded using a sampling rate of 1,000 Hz and low pass filters (LP: 66.5 Hz, $Q = 0.5$ and LP: 38.5 Hz, $Q = 1$). For each trial, the peak response was scored as the maximum EDA value within a 1 to 6 s time window following picture onset, and amplitude was computed as the maximum electrodermal change score with respect to a baseline of 1 s prior to the music excerpt onset. Logarithms of raw scores ($\log(\text{SCR} + 1)$) were calculated to normalize the data.

Electrocardiogram was recorded at lead II using Ag/AgCl electrodes with electrolyte paste. A bandpass filter of 0.5–35 Hz and a sampling rate of 1,000 Hz were used. HR was obtained online from the ECG, which measured the time interval between consecutive R waves (cardiac period). R-wave detection and artifact correction were performed prior to statistical analyses. For statistical analyses, different parameters were calculated based on the visual inspection of HR waveforms. More specifically, HR waveform scores were computed by determining, for each participant and each trial, the maximum deceleration within the first 3 s of music listening, the maximum acceleration from 3 to 5.5 s of music presentation, and the maximum deceleration from 5.5 s to the end of the trial. Change scores were calculated as the difference from baseline (1 s prior to excerpt onset).

Facial EMG activity was recorded from corrugator supercilii and zygomaticus major muscle, placed directly over the left eye and the left cheek, respectively, with two Ag/AgCl electrodes (4 mm diameter). The EMG was continuously sampled at 1,000 Hz, and filtered online with a high pass (30 Hz) and low pass (500 Hz). The signal was integrated and rectified online using rectify integration with a time constant of 500 ms. For analysis purposes, facial EMG was averaged over the 8-s music presentation interval, and change scores were calculated from a 1-s baseline period before the excerpt onset.

To analyse the time course of the different peripheral measures, HR data, EDA, and facial EMG were reduced as half-second bins periods across music excerpt presentation (8 s). Change scores were calculated as the difference between baseline (1 s prior to excerpt onset) and each half-second bin.

2.4 | Procedure

Each subject participated in one laboratory session, which lasted approximately 1 hr. First, participants read an overview of the task and completed a written consent form. Afterwards, they completed a survey to collect individual variables including age, gender, educational level, history of musical training, and hearing problems. Then, sensors were attached while participants reclined in a comfortable armchair. Before the experiment began, participants were instructed that a series of musical excerpts would be presented, and they had to look at the computer screen and listen carefully during the entire time that it was presented. Participants were trained to rate each musical excerpt using a 9-point scale for each affective dimension (valence, energy arousal, and tension arousal) and for each discrete emotion (happiness, anger, fear, tenderness, and sadness), following the same instructions provided in the Spanish validation study (for more details, see Fuentes-Sánchez et al., 2020). To ensure that they had understood the procedure, two additional practical trials were undertaken before the task began (Vieillard et al., 2008). Thereafter, the experimental task started, which lasted approximately 30 min.

2.5 | Data analyses

First of all, correlational analyses were conducted to assess the relationship between shortened and original length excerpts for all the subjective ratings collected in this study (either affective dimensions—valence, energy, and tension arousal; or discrete emotions—happiness, anger, fear, tenderness, and sadness).

²The distribution of the familiarity scale in the excerpts used in this experiment was as follows: $M = 0.49$, $SD = 0.33$, 95% CI [0.42–0.56].

Secondly, two complementary analyses were performed in order to explore the effect of music category on peripheral and subjective correlates of emotion elicitation. On the one hand, a repeated measures ANOVA with *Music Category* as within-subject factor was calculated separately for each subjective rating and peripheral correlate, considering the overall parameters described above (i.e., EDA amplitude, maximum and minimum HR change scores, and averaged facial EMG activity). Post hoc comparisons (Bonferroni test) were performed to explore plausible differences between conditions. On the second hand, a 3 (*Music Category*: unpleasant, neutral, and pleasant) \times 16 (*Time Course*: each half second) repeated measures ANOVA was conducted on each physiological response in order to explore the time course of the emotion elicitation process (see Haspert et al., 2020). Additionally, post hoc comparisons using pairwise *t*-test were performed between experimental conditions for each half second.³ In the cases where the assumption of sphericity was violated, the Greenhouse–Geisser correction was applied. Partial eta squared (η_p^2) and Cohen's *d* are reported as effect size measures.

Finally, with the aim of exploring the relationship between subjective ratings and peripheral measures, and correlations and linear regression analyses were performed. More specifically, we conducted two linear regressions with the different physiological measures (overall parameters for EDA, HR, zygomatic, and corrugator) as dependent variables, and the theoretical approaches to emotion— affective dimensions (valence, energy, and tension arousal); and discrete emotions (happiness, anger, fear, tenderness, and sadness)—as independent variables.

All statistical analyses were carried out using SPSS IBM Statistics version 26, JMP 15, and G*Power. Assumptions of normality, homoscedasticity, sphericity, and equality of variances were explored using the Mauchly test and the Greenhouse–Geisser correction, where appropriate.

³Both types of analyses—specific parameters and time course—served to explore in more detail the effects of music category on the physiological responses. These analyses were used for two purposes: (a) to investigate the correspondence between specific parameters calculated for statistical analyses and a more detailed exploration of emotional responses over time (expressed as half-seconds bins during 8 s excerpts), and (b) to facilitate further correlational and regression analysis among peripheral and subjective correlates of music-evoked emotions using film excerpts. In addition, the data were explored from a longitudinal perspective using time-series analyses based on autoregressive (AR) models and 80-time measurements per trial and for each participant. To this aim, peripheral data were reduced as 100 ms average periods across 8 s excerpt duration, and expressed as change scores (difference between 1s baseline and each 100 ms means). These exploratory analyses and the corresponding findings for each physiological measure are summarized in the Supporting Information.

3 | RESULTS

3.1 | Correlations between subjective ratings for original and shortened excerpts

Pairwise correlations showed a high correspondence between subjective evaluations for shortened (obtained in this experiment) and longer original excerpts (Spanish normative values), in hedonic valence, energy arousal, and tension arousal ratings, $r(1) = .96, .95,$ and $.94,$ all $ps < .0001,$ respectively. Similarly, strong correlations were found in all the ratings assigned to discrete emotions for shortened and longer excerpts. Specifically, significant associations were found for happiness, anger, fear, tenderness, and sadness, $r(3) = .98, .97, .98, .89,$ and $.93,$ all $ps < .0001,$ respectively.

3.2 | Emotion elicitation during music listening to film music excerpts

3.2.1 | Peripheral physiology: Overall parameters of emotion elicitation through music

The overall ANOVA revealed a significant main effect of the *music category* for EDA amplitude, $F(2, 98) = 11.27, p < .0001, \eta_p^2 = 0.19,$ for HR maximum and minimum change scores both considering the 3–5.5 s and 5.5–8 s time intervals, [$F(2, 98) = 6.44, p < .01, \eta_p^2 = 0.21$ and $F(2, 98) = 3.92, p = .02, \eta_p^2 = 0.07,$ respectively], for zygomatic mean EMG activity, $F(2, 96) = 9.90, p < .0001, \eta_p^2 = 0.17,$ as well as for averaged EMG corrugator, $F(2, 98) = 8.37, p < .001, \eta_p^2 = 0.15.$

Post hoc pairwise comparisons performed separately for each measure showed that pleasant music prompted enhanced EDA, greater HR acceleration for the 3 to 5.5 s interval, less HR deceleration during 5.5 to 8 s time window, and greater zygomatic activity, compared to both unpleasant music excerpts [corrected $p < .02,$ corrected $p < .002,$ corrected $p < .05,$ and corrected $p < .002,$ respectively], and neutral ones [corrected $p < .001$ for EDA; corrected $p < .05$ for zygomatic] (see Table 2). On the other hand, post hoc analyses revealed that unpleasant excerpts prompted enhanced EDA amplitude and averaged corrugator activity in comparison to neutral music stimuli, corrected $p < .05$ and corrected $p < .05,$ respectively. Also, unpleasant prompted greater corrugator activity in comparison to pleasant music, corrected $p < .01$ (see Table 2).

Time course of emotion elicitation through music

As regards EDA amplitude, the repeated measures ANOVA revealed a main effect of *time course*, $F(15, 735) = 4.30, p <$

TABLE 2 Means (*SDs*) and Confidence Intervals (CI) for the self-ratings and peripheral physiology for each music category

	Unpleasant			Neutral			Pleasant		
	<i>M</i> (<i>SD</i>)	95% CI		<i>M</i> (<i>SD</i>)	95% CI		<i>M</i> (<i>SD</i>)	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Subjective ratings									
<i>Affective dimensions</i>									
Valence	2.90 (0.92)	2.64	3.16	5.67 (1.22)	5.02	5.71	7.48 (0.80)	7.25	7.71
Energy arousal	6.49 (1.58)	6.04	6.94	3.75 (1.02)	3.46	4.03	7.45 (0.69)	7.26	7.65
Tension arousal	7.17 (1.24)	6.81	7.52	3.78 (0.90)	3.52	4.03	5.91 (1.32)	5.54	6.29
<i>Discrete emotions</i>									
Happiness	1.64 (0.79)	1.42	1.87	2.88 (1.12)	2.56	3.20	7.29 (0.70)	7.09	7.48
Anger	4.74 (1.58)	4.29	5.18	1.95 (1.02)	1.66	2.24	1.58 (0.70)	1.38	1.78
Fear	6.60 (1.32)	6.22	9.98	3.17 (1.19)	2.83	3.51	1.45 (0.64)	1.27	1.63
Tenderness	1.30 (0.49)	1.16	1.44	3.83 (1.49)	3.40	4.25	3.68 (1.59)	3.23	4.13
Sadness	2.90 (1.36)	2.52	3.29	5.55 (1.38)	5.15	5.94	1.51 (0.51)	1.36	1.65
Peripheral physiology									
EDA	0.03 (0.04)	0.04	0.006	0.01 (0.04)	-0.00	0.02	0.06 (0.07)	0.04	0.08
HR deceleration (0.5–3)	-1.49 (1.78)	-0.199	-0.98	-1.49 (1.78)	-1.99	-0.98	-0.94 (1.56)	-1.38	-0.49
HR acceleration (3–5.5)	-0.04 (1.97)	-0.60	0.52	0.46 (2.25)	-0.18	1.10	1.41 (2.65)	0.66	2.17
HR deceleration (5.5–8)	-2.61 (2.51)	-3.32	-1.89	-2.21 (2.32)	-2.87	-1.55	-1.71 (2.58)	-2.44	-0.98
Zygomatic	-3.89e-5 (0.0003)	-0.00	5.24e-5	-3.23e-6 (0.00)	-8.06e-5	0.00	0.0004 (0.001)	0.0001	0.001
Corrugator	0.0003 (0.001)	0.0001	0.0005	0.0001 (0.0003)	2.47e-5	0.0002	-2.88e-5 (0.0006)	-0.0002	0.0001

.0001, $\eta_p^2 = 0.08$, and *music category*, $F(2, 98) = 3.01$, $p < .005$, $\eta_p^2 = 0.10$, as well as significant interaction between the two factors, $F(30, 1470) = 8.75$, $p < .0001$, $\eta_p^2 = 0.15$. Specifically, pleasant music prompted greater electrodermal reactivity in comparison to neutral music excerpts from 3 s to the end of stimuli presentation (see Figure 2). In addition, significant differences between unpleasant and neutral excerpts were found from the second 4 to the end. Lastly, analysis showed significant differences between pleasant and unpleasant excerpts only from 2.5 to 5.5 s after stimulus onset (see Table S4, Appendix).

Regarding HR change scores, a significant main effect was found both for *time course*, $F(15, 735) = 15.05$, $p < .0001$, $\eta_p^2 = 0.24$, and *music category*, $F(2, 98) = 7.51$, $p < .001$, $\eta_p^2 = 0.13$. The interaction between both factors was also significant, $F(30, 1470) = 4.72$, $p < .0001$, $\eta_p^2 = 0.09$. Post hoc comparisons showed that pleasant music elicited higher HR changes in comparison to unpleasant and neutral music from 3 to 7.5 s, although the difference with the latest was significant only from 3 to 6 s (see Table S4, Appendix). On the other hand, unpleasant music prompted higher HR deceleration in comparison to neutral stimuli, especially from 4.5 to 7 s (see Figure 2).

Similarly, for zygomatic EMG activity, both the main effect of *time course* and *music category* reached the

significant level, $F(15, 720) = 8.74$, $p < .0001$, $\eta_p^2 = 0.15$ and $F(2, 96) = 9.91$, $p < .0001$, $\eta_p^2 = 0.17$, respectively. In addition, the interaction between both factors was statistically significant, $F(30, 1440) = 7.71$, $p < .0001$, $\eta_p^2 = 0.14$. The analyses revealed that zygomatic changes were enhanced for pleasant music in comparison to unpleasant and neutral stimuli from 1.5 s after stimuli onset to the end (see Figure 2 and Table S4, Appendix).

Finally, for corrugator EMG activity, no significant main effect was found for *time course* but for *music category*, $F > 1$ and $F(2, 98) = 8.37$, $p < .0001$, $\eta_p^2 = 0.15$, respectively. In addition, a significant interaction was found between both factors, $F(30, 1470) = 5.06$, $p < .0001$, $\eta_p^2 = 0.09$. As shown in Table S4 Appendix and Figure 2, unpleasant excerpts prompted enhanced corrugator EMG changes from 2.5 to 8 s, in comparison to pleasant and neutral stimuli, although the difference with the first category occurred from 1.5 s to the end of stimuli presentation.

3.2.2 | Subjective ratings

The overall ANOVA revealed a significant main effect of the *music category* for hedonic valence, $F(2, 98) = 381.32$, $p < .0001$, $\eta_p^2 = 0.89$, energy arousal, $F(2, 98) = 219.62$, $p < .0001$,

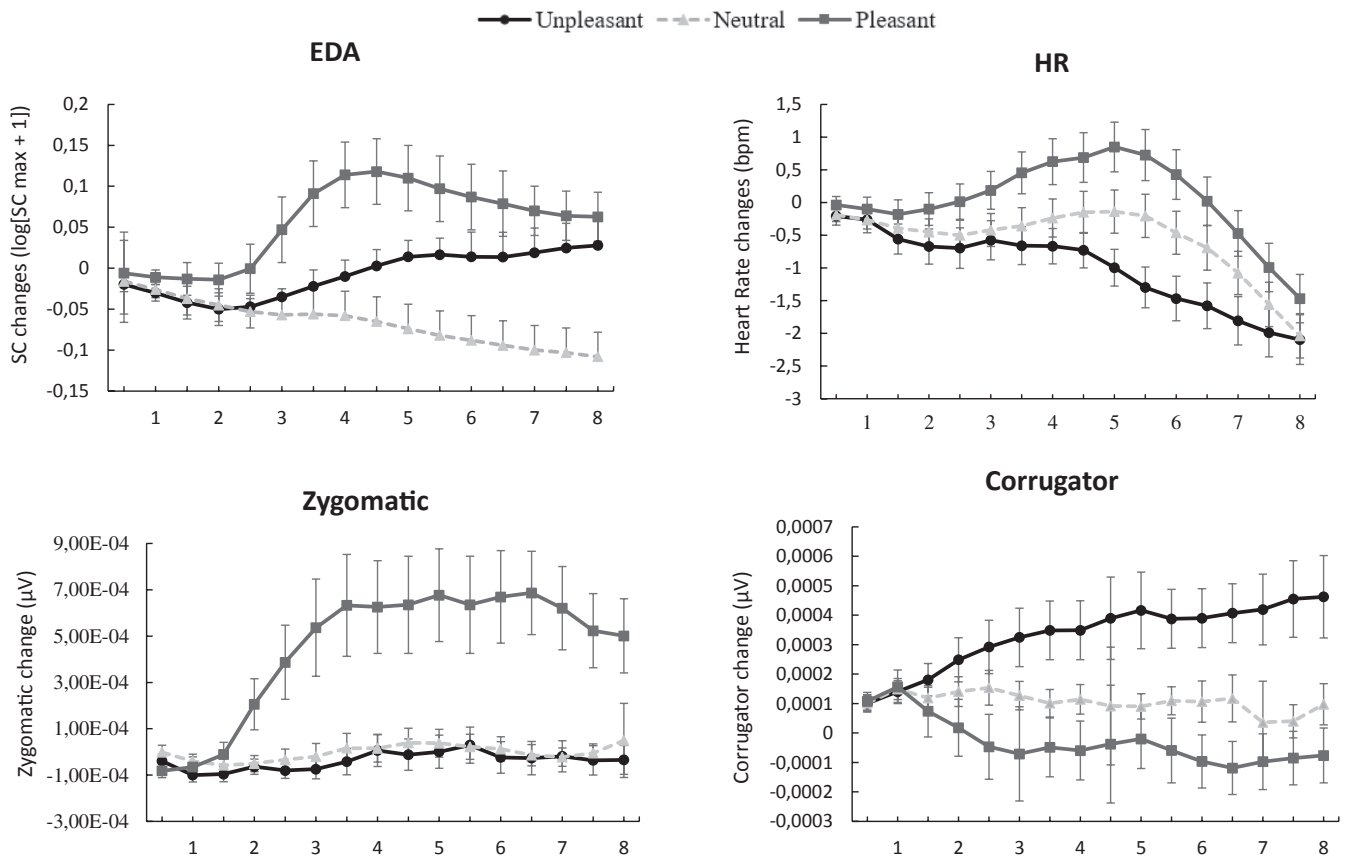


FIGURE 2 Time course of electrodermal activity (EDA), heart rate (HR), zygomatic, and corrugator EMG activity during the music excerpts presentation (8-s). Figure shows EDA, HR, zygomatic, and corrugator changes during 8 s of film music excerpts presentation. From 2 s after stimulus onset to the end of the stimulus duration, EDA, HR, and zygomatic changes were larger for pleasant versus unpleasant and neutral music stimuli, whereas corrugator showed enhanced activity for unpleasant music

$\eta_p^2 = 0.82$, or tension arousal, $F(2, 98) = 102.41$, $p < .0001$, $\eta_p^2 = 0.67$. Specifically, pleasant music was rated as more positive and energetic in comparison to neutral, corrected $ps < .001$, and unpleasant excerpts, corrected $ps < .001$. Moreover, unpleasant music was rated as more tense compared to neutral and pleasant excerpts, corrected $ps < .001$ (see Table 2).

Regarding the discrete emotions, analyses showed a significant main effect of the *music category* for all specific emotions. Particularly for happiness, $F(2, 98) = 689.35$, $p < .0001$, $\eta_p^2 = 0.93$; anger, $F(2, 98) = 221.47$, $p < .0001$, $\eta_p^2 = 0.82$; fear, $F(2, 98) = 483.49$, $p < .0001$, $\eta_p^2 = 0.91$; tender, $F(2, 98) = 83.00$, $p < .0001$, $\eta_p^2 = 0.63$; and sadness, $F(2, 98) = 277.50$, $p < .0001$, $\eta_p^2 = 0.85$. Specifically, pleasant excerpts were rated higher in happiness in comparison to neutral and unpleasant ones, corrected $ps < .001$. In addition, pleasant music was rated as more tenderly in comparison to unpleasant, corrected $p < .001$, but not to neutral, $p > .05$. With regard to unpleasant excerpts, they were rated as more angry and fearful in comparison to both neutral, corrected $ps < .001$, and pleasant music, corrected $ps < .001$ (see Table 2).

Finally, neutral music was evaluated as more sad than pleasant, and unpleasant excerpts, corrected $ps < .001$.

3.3 | Relationship between peripheral physiology and subjective ratings

Correlation analysis revealed a positive relationship between EDA amplitude and valence, energy, and tension arousal ratings, $r(6) = .31$, $.53$ and $.31$, p 's $< .05$, respectively. Regarding the discrete emotions, EDA was significantly associated only with happiness and sadness ratings, $r(6) = .44$ and $-.47$, p 's $< .01$, respectively. Concerning HR, only the 3–5.5 maximum change score was significantly related to valence ratings, $r(6) = .42$, $p < .01$, within the three-dimensional model, and to happiness, anger, fear, and tender evaluations within the discrete model of emotions, $r(6) = .36$, $-.35$, $-.47$, and $.35$, p 's $< .05$, respectively. With respect to zygomatic, a significant positive relationship was found with valence ratings, $r(6) = .59$, $p < .0001$, and energy arousal, $r(6) = .40$, $p < .01$, but not with tension arousal, $p > .05$. In addition, zygomatic

TABLE 3 Summary of fit (R^2 and β) from regression analysis

	EDA	HR			Zygomatic	Corrugator
		Min 0.5–3-s	Max 3–5.5-s	Min 5.5–8-s		
Affective dimensions (R^2)	0.28**	−0.02	0.12	−0.02	0.41***	0.39***
Valence (β)	0.25	0.32	0.44	0.15	0.08	−0.40
Energy (β)	0.44	−0.24	−0.09	0.06	1.02	−0.38
Tension (β)	0.06	0.16	0.01	−0.14	−0.79	0.44
Discrete emotions (R^2)	0.24*	−0.07	0.14	0.02	0.44***	0.32**
Happiness (β)	1.15	−0.18	−0.05	1.36	1.83	−0.20
Anger (β)	0.63	−0.18	0.14	0.08	0.22	0.12
Fear (β)	0.09	−0.35	−0.88	0.26	0.97	0.001
Tenderness (β)	−0.08	−0.17	−0.27	−0.54	0.20	−0.35
Sadness (β)	0.27	−0.05	0.09	0.97	0.52	0.17

* $p < .05$; ** $p < .01$; *** $p < .001$.

averaged changes were significantly related to subjective ratings of happiness, anger, fear, tenderness, and sadness, $r(6) = .68, -.43, -.51, .39$, and $-.43$, p 's $< .01$, respectively. Lastly, within the three-dimensional model, corrugator averaged changes showed a significant relationship only with valence, $r(6) = -.65$, $p < .0001$. Furthermore, a significant correlation was found between corrugator and all specific emotions except sadness ratings, $r(6) = -.59, .55, .59$, and $-.53$, p 's $< .0001$, for happiness, anger, fear, and tenderness, respectively.

Regression analysis showed that both the affective dimensions and discrete emotions predicted significantly the physiological responses for EDA changes (see R^2 in Table 3). More precisely, energy was the most important variable to predict EDA responses within the dimensional model. With regard to the discrete emotions, happiness was the most prominent variable, followed by anger (see Table 3).

For HR changes, the different regression models were not significant for any of the time windows explored here (see Table 3). However, we observed that valence was the most important predictor—negatively—of the cardiac response during the second time window (3–5.5-s), whereas happiness was the most prominent variable for the last time window (5.5–8-s).

Regarding facial EMG changes, results showed that both models predicted corrugator and zygomatic activity (see Table 3). Interestingly, energy was the best variable to predict the facial expression for averaged zygomatic activity, whereas tension was for the corrugator EMG. In relation to the discrete emotions, happiness was the most important variable for zygomatic and both tenderness and happiness (negatively) for the corrugator.

4 | DISCUSSION

This study intended to overcome some methodological and theoretical concerns in the use of music listening to elicit emotions in laboratory settings; adding, therefore, robustness to the prior literature. To that end, several specific objectives were raised. Firstly, we investigated the effect of the excerpts duration on subjective ratings by comparing evaluations for longer film music excerpts from the Spanish validation study (Fuentes-Sánchez et al., 2020) and for the shortened excerpts selected in this experiment. Secondly, we investigated the effect of music listening on peripheral (EDA, HR, and facial EMG) and subjective correlates of emotion elicitation (valence, energy, and tension arousal; happiness, anger, fear, tenderness, and sadness), by contributing to previous research with an additional exploration of the time course of music-evoked emotions. Finally, we intended to investigate the relationship between physiological and subjective measures, considering two theoretical approaches to emotion: three-dimensional and discrete models of emotions.

Regarding the effect of the musical clips duration, according to our a priori hypotheses, current findings revealed a strong positive correlation between subjective evaluations of the shortened and original excerpts, both when analyzing the ratings for the three affective dimensions and specific emotions, suggesting that the selected film music excerpts conveyed similar emotions independently of their duration. Additionally, our findings demonstrate that shortening the film music excerpts did not alter the emotional perception contained therein. This result goes in line with a previous study that certainly reported consistency of the emotional responses between long (30-s) and short (1-s) classical music

excerpts (Bigand et al., 2005). Accordingly, it becomes necessary to open a methodological debate about how much time is needed to elicit steady and consistent emotions in laboratory controlled conditions, especially when using dynamic and complex stimuli such as music excerpts. With this regard, previous research using other affective stimuli such as pictures (Bradley et al., 2001) or sounds (Bradley & Lang, 2000) has repeatedly presented the stimulation during a shorter period of time (i.e., 6 or 8 s). Notwithstanding, the studies focused on music have not been consistent in relation to the excerpts duration, which might lead to problems when interpreting and comparing results across studies. As a consequence, the examination of a minimum length of musical excerpts that preserves their ability to evoke robust emotional responses (and at different levels) in experimental studies is of great importance, particularly to avoid confusion between affective phenomena such as emotions or mood (Beedie et al., 2005; Bradley & Lang, 2007). Thus, those studies presenting musical stimuli during long periods of time (Baumgartner et al., 2006; Bullack et al., 2018; Etzel et al., 2006) could fail to disentangle among both affective phenomena. Furthermore, contrary to prior research that has claimed that longer excerpts are necessary to induce emotions (for a review, Eerola & Vuoskoski, 2013), our findings demonstrated that shortened excerpts were capable to elicit an effect not only on subjective ratings but also on autonomic and expressive measures, which suggests that clips of 8 s might be appropriate to elicit robust, powerful emotions. Consequently, future studies should consider the use of shorter clips, which could also contribute to reducing other confounding variables related to the dynamic nature of music.

With regard to the second goal of this research, our findings showed an effect of music category over the emotional reactions, measured by the self-reported experience, facial expression, and autonomic activity, demonstrating the capacity of unfamiliar film music excerpts to elicit strong emotions. As expected, pleasant excerpts were rated as more pleasant, energetic, happy, and tender in comparison to unpleasant ones, which in turn were evaluated as more tense, angry, and fearful. These data are in concordance with the physiological correlates measured here, as higher EDA, greater HR acceleration, and zygomatic activity—besides lower corrugator activity—were observed for pleasant music compared to neutral and unpleasant music (Ellis & Simons, 2005; Roy et al., 2009; Sammler et al., 2007). These differences between categories were very large and significant both for subjective and, specially, the ANS physiological correlates. Considering the effect sizes obtained in this study, it would demonstrate the strength and potential of this film music stimulus set to evoke emotions that are measurable in the laboratory in a methodologically rigorous way. According to previous findings, our data suggest that EDA was related to the emotional arousal of stimuli (Gomez & Danuser, 2004; Khalfa et al., 2002),

whereas facial EMG and HR vary with their hedonic valence. This latter result is not consistent with a few prior studies that reported that HR failed to distinguish among affective and neutral music (Krabs et al., 2015; Ogg et al., 2017; Ribeiro et al., 2019; Scherer, 2004). In this vein, the inclusion of specific emotions in the present study, together with the affective dimensions, allowed us to compare our results with past research focused on discrete emotions (Etzel et al., 2006; Johnsen et al., 2009; Khalfa et al., 2002). Thus, pleasant music corresponded to happy music, unpleasant excerpts mainly conveyed by fear and anger, and neutral excerpts were fundamentally sad music. Current findings also replicated the physiological pattern previously obtained, in which increases in EDA, HR, and zygomatic were observed for happy as compared to sad music (Bullack et al., 2018; Krumhansl, 1997; Lundqvist et al., 2009). The fact that sad music corresponded to neutral music within the dimensional model does not replicate previous findings, in which sad music was described by participants as unpleasant (Baumgartner et al., 2006; Peretz et al., 1998; Ribeiro et al., 2019). This result would confirm the difficulty of using neutral music in empirical studies (Krumhansl, 1997; Ribeiro et al., 2019), opening the debate about what type of neutral stimulation should be used in laboratory settings. To this extent, one neutral excerpt based on the normative ratings within the dimensional model (i.e., valence and arousal) could be classified as fearful according to the discrete model ratings. Interestingly, physiological responses to that specific excerpt were similar to other stimuli evaluated as low arousing and neutral in valence, which adds support to the notion of combining both approaches to overcome the limitations that each theoretical model has separately, and to understand in more detail the psychophysiology of emotions (Harmon-Jones et al., 2017). Current findings support the hypothesis that music may evoke emotions through the emotional contagion mechanism proposed by Juslin and Västfjäll (2008). This mechanism is a process whereby specific emotions expressed by musical pieces are induced to the listener, being objectively measurable by using physiological measures, for example (Juslin, 2013). In this line, our results demonstrated that pleasurable music (rated as pleasant or happy depending on the theoretical framework) and displeasurable music (rated as unpleasant or anger/fear according to the dimensional or discrete models) somehow prompted a synchronized manifestation in both the expressive and physiological components, consistently with past research (Juslin et al., 2010; Lundqvist et al., 2009).

Furthermore, our study adds to previous literature the analyses of the time course of peripheral correlates of emotions elicited through music. Thus, the differential reactivity pattern prompted by affective and neutral film music excerpts was evident quite early (around 2 s after stimuli onset for facial EMG and around 3 s for EDA and HR) and persisted along the whole excerpt duration. Indeed, a diminished EDA

reactivity was found only during listening to neutral stimuli, which could suggest a trend to physiological relaxation accompanied by sympathetic nervous system deactivation. Our results partially concur with a prior study (Bullack et al., 2018) reporting EDA decreases over time when listening to sad music, which corresponds to neutral music in the present study. In relation to HR waveforms, the triphasic waveform generally found when looking at affective pictures and listening to affective sounds—characterized by an initial deceleration, followed by an accelerative and a second decelerative component—, was partially replicated here (Bradley et al., 2001; Bradley & Lang, 2000, 2007; Sammler et al., 2007). Indeed, slight differences that might be related to the stimulus modality were observed in the cardiac reactivity pattern. Firstly, a shorter initial decelerative component was observed in all affective categories, which may indicate that the orienting, sensory intake, and early attention to the stimuli characteristic in visual perception were not necessary here; leading, therefore, to a lesser early decelerative cardiac response when listening to music excerpts. Since HR has shown to be sensitive to task demands (Vrana et al., 1986), cardiovascular response could be accelerative or decelerative depending on the experimental paradigm. This explanation would be in turn consistent with prior findings in imagery paradigms (Ji et al., 2016; McTeague et al., 2010) or cognitive reappraisal tasks (Bernat et al., 2011; Fuentes-Sánchez et al., 2019), in which the first seconds of stimuli presentation were accompanied by accelerative reactivity. Secondly, our data showed a quite sustained HR acceleration specifically when listening to pleasant compared to neutral music. This accelerative pattern has not been reported with affective sounds from IADS; for example, for which pleasant and neutral stimuli did not differ from each other (Bradley et al., 2001; Bradley & Lang, 2007). In our study, greater EDA was also observed while listening to pleasant music experts compared to neutral and unpleasant ones, which clearly suggests sympathetic activation. These results concur with the self-reports as pleasant music was rated as more energetic than unpleasant excerpts. Taken together, our data suggest an increase in sympathetic activation during the listening of film pleasant music pieces selected here. By contrast, unpleasant music prompted a more sustained HR deceleration, in comparison to neutral excerpts. This decelerative pattern somehow replicated the fear bradycardia (vaguely mediated) elicited when facing threatening stimuli, which has been previously found during picture viewing (Bradley et al., 2001), listening to affective sounds (Bradley & Lang, 2000), and viewing films (Palomba et al., 2000). Furthermore, current findings seem to add robustness to the increased sensory gathering hypothesis proposed for the processing of unpleasant material, which might be shared among diverse stimuli modalities (Bradley et al., 2012; Bradley & Lang, 2007).

In general, our findings replicate prior research of picture viewing (Bradley et al., 2001) and listening to affective sounds (Bradley & Lang, 2000), providing additional empirical support to the underlying activation of appetitive and defensive motivational systems (Bradley & Lang, 2007; Lang et al., 1997). Accordingly, the autonomic responses associated with arousal and metabolic activation (i.e., EDA) increased when participants listened to highly arousing excerpts, regardless of their valence (i.e., pleasant vs. unpleasant music). In contrast, either facial expression correlates (zygomatic and corrugator EMG changes) or HR reactivity tends to vary with the hedonic valence of the stimulation. Therefore, our findings provide additional empirical evidence regarding the contribution of peripheral correlates of hedonic valence and arousal for the psychophysiological study of affect, regardless of the sensory modality. As predicted, electrodermal response increases with ranked energy arousal, replicating prior findings (Bradley & Lang, 2000; Greenwald et al., 1989; Lang et al., 1993; Sato et al., 2020). However, the results demonstrated the lack of association between tension arousal and EDA, contrary to our expectations according to previous research that reported how both arousal dimensions (energy and tension) predicted the pupillary response; for example, which is considered as another index of sympathetic activation (Gringas et al., 2015). Interestingly, despite previous literature showed a strong relationship between energy and tension arousal (Eerola & Vuoskoski, 2011; Fuentes-Sánchez et al., 2020), our findings suggest that both arousal dimensions might differ in the way they reflect activation of the sympathetic nervous system. Thus, only the energy arousal was associated with EDA, suggesting that tension arousal could be a good indicator of other affective states but not emotional intensity. Our result also suggests that subjective ratings of energy arousal were more similar to that measured in previous research (Carretié et al., 2019; Fernández-Abascal et al., 2008; Ruiz-Padial et al., 2021). On the other hand, although the three-dimensional model was not significant, HR changes were positively associated with valence ratings resembling prior works focused on emotional perception using pictures (Hamm et al., 2003; Lang et al., 1993), suggesting the influence of hedonic valence on cardiac reactivity during emotion perception, contrary to other studies that claimed that cardiac responses are sensitive to emotional arousal (e.g., Ogg et al., 2017). To this extent, a number of studies have found an effect of arousal on HR during the emotional recall (e.g., Cuthbert et al., 1990), supporting the idea that HR changes could be used as a valence or arousal index depending on the underlying psychological process, as previously argued. Regarding facial expression, our results showed that muscle EMG activity not only covaried with the subjective ratings of hedonic valence (negatively with corrugator and positively with zygomatic) but also with

the evaluations of energy arousal (positively with zygomatic) and tension arousal (positively with corrugator and negatively with zygomatic). Thus, the strong linear relationship between valence and corrugator resembled prior findings in affective picture perception (Lang et al., 1993; Larsen et al., 2003). Interestingly, our findings also demonstrated that tension arousal predicted corrugator activity, which could indicate that this measure is not a pure indicator of valence, as prior research has claimed (Ogg et al., 2017). Also, zygomatic changes were affected by emotional intensity (both energy and tension arousal), as also previous works have shown (Ogg et al., 2017; Witvliet & Vrana, 2007). Indeed, past research has reported a quadratic trend between pleasure ratings and zygomatic activity, as a function of specific emotion patterns (Lang et al., 1993; Larsen et al., 2003), suggesting possible differences in terms of emotional intensity.

In addition, our study explored how the discrete emotions predicted the physiological reactions elicited by standardized film music excerpts. Particularly, we found that EDA was predicted by the happiness and anger ratings. Interestingly, the happiness and anger excerpts were evaluated, in turn, as more arousing, consistently with the results based on the dimensional model. On the other hand, the discrete model was not significant to predict HR changes, despite the results showing that those excerpts rated as more fearful prompted a sustained cardiac deceleration in comparison to other specific negative emotions. This result might reflect the continued attention to the fearful aversive stimulus, which occurs during a moderate activation of the defensive motivational system (Bradley et al., 2001; Lang & Davis, 2006). In this sense, it would be interesting to explore the cardiac reactions toward fearful music stimulation in subclinical samples with high levels of anxiety and fear. This would allow to investigate whether this orienting response is maintained or, by contrast, cardiac acceleration takes over as occurs when phobic individuals view threatening pictures (Hamm et al., 1997). Lastly, the discrete model predicted both zygomatic and corrugator activity, explaining more variance than the dimensional model for the former, which supports the idea that facial EMG reactivity can vary as a function of specific emotions. As expected, happiness was the most important predictor of zygomatic, in accordance with prior findings (Lang et al., 1993). And contrary to our expectations, tenderness and happiness (negatively) were important variables to predict corrugator.

Taken together, current results might contribute to understanding the relationship between subjective experience and physiological correlates within two different theoretical frameworks of human emotions that have been traditionally considered as opposite. Among the practical implications of our research, it needs to be emphasized that simultaneous exploration of both models of emotions may be promising to further investigate the relationship between self-reports and physiological correlates, as they are complementary

approaches. Additionally, our data suggested that specific peripheral correlates and expressive measures could be used as valence and arousal indices, being especially useful for future studies in which subjective ratings cannot be measured or might be not reliable.

Finally, some limitations and future directions should be mentioned. Firstly, we have not investigated individual differences that could clearly influence music-evoked emotional reactions. In this regard, it has been shown that some factors such as gender, personality traits (Nater et al., 2006; Padmala et al., 2019), or aging (Ebner & Fischer, 2014) certainly impact on affective processing. However, little is known about the effect of those variables when using music as affective stimuli in laboratory settings. Also, it could be interesting that future research investigates culture differences in response to this type of music, not only at the subjective level as previous works have done (e.g., Fuentes-Sánchez et al., 2020) but also at the peripheral or neurobiological levels. In addition, despite the familiarity of the film music excerpts was partially considered in this study—both in their selection from the *FMSS* and in their posterior evaluation during the task—, future studies should investigate in more detail how this variable modulates the emotional reactions. The second limitation concerns the scale used in the experimental task implemented in this study. Although a 9-point Likert scale allowed us to compare the subjective ratings obtained here with those from the Spanish validation study (Fuentes-Sánchez et al., 2020), future research might consider using other rating methods that are free from language effects as the Self-Assessment Manikin (SAM; Bradley & Lang, 1994; Lang, 1980). The SAM has been extensively used in a large number of works in the field of emotion processes and aesthetic perception, with a broader range of stimuli modalities such as affective pictures or standardized brief sounds (Bynion & Feldner, 2017). The third limitation extends to the database selected for this study due to the reduced number of music excerpts currently available in the *FMMS* database, which complicates the stimuli selection according to certain criteria for experimental studies. Although it has been demonstrated that film music stimuli can elicit strong emotions, measurable at different levels, future studies should consider increasing the number of *FMMS* excerpts following the same procedure in the original study (see Eerola & Vuoskoski, 2011), in order to complete their current distribution in the affective space. Furthermore, a larger dataset will facilitate exploring in more detail the relation between the dimensional and discrete models of emotions. Furthermore, future research might consider including additional physiological measures such as the startle reflex, which has been less explored in the field of music and emotions despite being considered a reliable index of defensive activation and affect modulation (Lang et al., 1990, 1992). Finally, another methodological issue that should be

considered in future studies is the duration of the intertrial interval (ITI). In the present study, we used an ITI of 8 or 10 s (randomly). However, this time may not be enough in the case of music, so future research should increase the time between stimuli and, additionally, analyze the peripheral responses during that interval to investigate whether the differences between music categories remain active.

In conclusion, the present work, together with prior literature, provides empirical evidence regarding the efficacy of standardized music stimuli to evoke powerful and measurable emotional reactions in laboratory settings. Interestingly, these emotions might subsequently modulate other cognitive processes such as attention, perception, or memory, which could be studied implementing diverse experimental tasks. Consequently, advances in the acknowledgement of the mechanisms underlying emotion elicitation through standardized music stimuli might contribute to the advancement of psychological interventions in clinical populations such as depression, pain, or dementia, in which emotion disturbances play an essential role.

AUTHOR CONTRIBUTIONS

Nieves Fuentes-Sánchez: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Validation; Visualization; Writing-original draft; Writing-review & editing. **Raúl Pastor:** Conceptualization; Investigation; Methodology; Software; Supervision; Validation; Visualization; Writing-review & editing. **Miguel A. Escrig:** Conceptualization; Data curation; Investigation; Methodology; Resources; Software; Visualization; Writing-review & editing. **Marcel Elipe-Miravet:** Formal analysis; Resources; Visualization; Writing-review & editing. **M. Carmen Pastor:** Conceptualization; Data curation; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing-review & editing.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section.

Supplementary Material

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