Investigating Emotional Granularity with Music

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LIST OF CONTRIBUTIONS

This current research project was conceived by Dr. P. Loui and N. Kathios but jointly designed by F. Ahmed, Dr. P. Loui, N. Kathios, and Dr. L. Gabard-Durnam. Behavioral data collection and MRI data collection was conducted by F. Ahmed, N. Kathios, K. Lopez, Q. Dillard, A. Toivonen, J. Timmins, A. Russo, and R. Kudaravalli. MRI scans were completed and monitored by Northeastern University Biomedical Imaging Center's MRI technicians, F. Bidmead and V. Olafsson. MRI preprocessing was completed by N. Kathios and K. Lopez. All statistical analyses and analyses of MRI data were done by F. Ahmed with the assistance and guidance of N. Kathios. Data and results were interpreted by F. Ahmed with under the guidance of N. Kathios and Dr. P. Loui, with help in the revision process from Dr. L. Gabard-Durnam, Dr. L. Wong, N. Kathios, and Dr. P. Loui.

ABSTRACT

Emotional granularity, the ability to differentiate between emotional experiences, has traditionally been studied using static visual stimuli. Here, we explore music as an informative medium for assessing emotional granularity due its dynamic nature. Unlike static images, musical experiences unfold dynamically over time, offering listeners opportunities to experience and differentiate a wide range of emotions. In the present study, participants rated their emotions on 10 emotion words after listening to musical excerpts or viewing affective images. Emotional granularity was calculated using intraclass correlation coefficients of positive and negative emotion word responses for pictures and music separately. Across two studies (n = 122), emotional granularity in response to music was significantly positively correlated with that in response to pictures, suggesting that these methods tap into similar constructs. Further, emotional granularity was consistently significantly higher for music than for pictures, suggesting that music elicits more differentiated emotional responses. Granularity was not significantly associated with mental health measures, nor was it consistently associated with musical emotion discrimination ability. In the second study (n = 50), we analyzed structural MRI data and identified a positive correlation between negative emotional granularity in response to music and cortical thickness in the right pars triangularis of the inferior frontal cortex. These findings suggest that music may serve as an effective tool for studying emotion differentiation.

TABLE OF CONTENTS

STUDY 1

INTRODUCTION

Music is known for its ability to evoke strong emotional experiences and regulate mood (Juslin & Västfjäll, 2008; Gabrielsson, 2001). Music elicits a wide array of emotional responses (Brattico & Jacobsen, 2009), and these different emotions are reflected in physiological changes, such as changes in heart rate, skin conductance responses, blood pressure, temperature, and respiration (Hoemann et al., 2021b; Altenmüller et al., 2002; Panksepp & Bernatzky, 2002; Baumgartner et al., 2006; Krumhansl, 1997). These emotional experiences are one reason people enjoy listening to music (Sloboda, 2010; Dubé & Le Bel, 2003; Mas-Herrero et al., 2013). Feelings reported to be evoked by music include joy, love, longing, tenderness, sadness, anger, and fear, among others (Gabrielsson, 2010; Juslin & Laukka, 2003).

Given music's ability to evoke emotions, music is often used to *regulate* existing emotions, such as helping to energize, relieve tension and stress, and/or reduce feelings of loneliness (Wells & Hakanen, 1991; North et al., 2000; Pelletier, 2004; Granot et al., 2021). Music usage for emotion regulation has been observed across several countries, with a strong emphasis on maintaining well-being (Granot et al., 2021). Others may use music to regulate their emotions differently, choosing instead to intensify or align with their existing emotional states, such as listening to sad music while feeling sad, rather than using music to alter their emotional state (Chamorro-Premuzic & Furnham, 2007; Sachs et al., 2015). DeNora (1999) describes how music functions as a "technology of the self," helping individuals construct and manage their emotional lives. Indeed, some have argued that music's capacity for emotion regulation highlight its evolutionary significance (Panksepp and Bernatzky, 2002). Similarly, Juslin and Laukka (2003) and Pelletier (2004) discuss the strategic use of music for coping, stress relief, and emotional resilience. The significant involvement of music in activating reward and emotional brain circuits could explain why people value music. Zald and Zatorre (2011) emphasize the pleasure derived from music, while Chamorro-Premuzic and Furnham (2007) and Sloboda (2010) underscore its role in relaxation and stress relief. These findings highlight music's utility in promoting emotional well-being and its centrality to human life.

Emotion Differentiation

One model for understanding emotions is the Theory of Constructed Emotion (TCE; Barrett, 2017). This theory is based on the tenet that our understandings of emotions are constructed from sensory experiences, where experiences that are similar to each other are used to "construct a categorization" of an emotion that captures all of those experiences (Barrett, 2006; Barrett, 2017). When we have experiences that do not seem to fit into an existing category, they can either form a new category, or they can direct us to modify our existing categories to accommodate these new experiences. These categories are known as emotion concepts, and when a sensory experience is categorized into an emotion concept, we experience that emotion in response to the sensory experience. This theory is a departure from the theory that emotions are innate, as it argues that individuals can experience different emotions based on their experiences and the emotion concepts that they have constructed from those experiences rather than everyone experiencing a fixed set of basic emotions (Barrett, 2006). Different cultures experience and express emotions differently, given that our constructions of emotion concepts are dependent on our cultural knowledge, social contexts, and the language available to us to label those emotions (Lindquist et al., 2015).

These differences in emotional experience can be explained, in part, by a concept of emotional granularity. Emotional granularity refers to the ability to differentiate and label discrete emotional experiences with precision and specificity (Barrett et al., 2001; Tugade et al., 2004; Kashdan et al., 2015). It involves recognizing and distinguishing between variations within similarly valenced emotion categories, such as differentiating between feeling anger, sadness, or fear (Kashdan et al., 2015). The term "emotional granularity" is at times used interchangeably with "emotion differentiation." Here we will use emotion differentiation when talking about differentiation conceptually and emotional granularity when talking about the specific way of measuring emotion differentiation ability.

Typically, this ability to differentiate emotions is separated into negative emotions (i.e., negative emotional granularity) and positive emotions (positive emotional granularity), with negative emotional granularity having been studied more extensively than positive (Hoemann et al., 2021a). Individuals with greater emotional granularity tend to be more capable of accurately identifying and articulating their emotions. The emotion words provided to participants are separated into negatively and positively valenced emotions, finding the correlation between responses for negative valence emotions, and the correlation between responses for positive valence emotions (Erbas et al., 2018). A high correlation between different emotions across stimuli suggests lower emotional granularity, as it indicates that the individual more frequently experiences different emotions together rather than being able to pinpoint and differentiate their emotions based on the type of stimulus.

One popular method to measure emotional granularity involves participants reporting the extent to which they feel different emotions on a numerical scale after being exposed to various affective images (Nook et al., 2018; Kashdan et al., 2010; Pond et al., 2012; Tugade et al., 2004; Erbas et al., 2018) such as the International Affective Picture System (IAPS) and Open Affective Standardized Image Set (OASIS) (Coan & Allen, 2007; Kurdi et al., 2017). Emotional granularity is then measured using the intraclass correlation (ICC; Shrout & Fleiss, 1979) of participants' responses across trials (Kashdan et al., 2010; Pond et al., 2012; Tugade et al., 2004; Kalokerinos et al., 2019; Nook et al., 2018). Emotion words commonly used for measuring positive emotional granularity in response to standardized stimuli include relaxed, happy, joyful, proud, excited, and satisfied (Erbas et al., 2016, 2018, 2022; Tugade et al, 2004; Nook et al., 2021a; Baumgartner et al., 2006; Barrett et al., 2001; Vedernikova et al., 2021). Emotion words commonly used for measuring negative emotional granularity include angry, ashamed, disgusted, scared, fearful, sad, upset, anxious, depressed, nervous, and lonely (Nook et al., 2018, 2021a; Erbas et al., 2014, 2016, 2019, 2022; Pond et al., 2012; Kashdan et al., 2010; Vedernikova et al., 2021). The Photo Emotion Differentiation (PED) task in particular is commonly administered, involving participants rating the extent to which they feel 20 different emotions when viewing 20 standardized affective images, one at a time (Erbas et al., 2014; Thompson et al., 2021).

Although tasks including responses to standardized stimuli are convenient in that they require low time and effort, are low cost, and can be administered online, they have low ecological validity (Thompson et al., 2021). Alternatively, longitudinal studies referred to as either experience sampling or ecological momentary assessments (EMA) may also be used to measure emotional granularity (e.g., Jacobson et al., 2023). In these studies, participants record the extent to which they feel a set of emotions repeatedly throughout the day for a certain time period. This allows researchers to measure emotional granularity in the context of the emotions people experience in their everyday lives, making for a highly ecologically valid measurement of granularity. In Erbas et al. (2019), emotional granularity scores from the PED task and EMA were only moderately associated ($r \sim 0.22$).

Understanding individuals' abilities to differentiate between specific emotions is essential for understanding methods of emotion regulation and the long-term behavioral and mental outcomes thereof. High positive emotional granularity is linked to better mental health outcomes after negative events, as individuals with high emotional granularity specific for positive emotions are more capable of identifying positive elements within different experiences, helping them to cope and recover after stressful events (Tugade et al., 2004; Kang & Shaver, 2004; Kashdan et al., 2010). This capacity to recover from stressful events is known as resilience, measured in the past with the Ego-Resiliency Scale, (ER89; Block & Kremen, 1996) and more recently by the Connor-Davidson Resilience Scale (CD-RISC; Connor & Davidson, 2003). Individuals with high positive emotional granularity may be able to find positivity even within negative experiences, separating parts of a negative emotional experience into more specific components and focusing on the potential positives, improving overall well-being (Tan et al., 2022).

High negative emotional granularity is associated with better mental health outcomes specifically for depression (Willroth et al., 2020) and anxiety (Seah et al., 2020; Erbas et al., 2014; Starr et al, 2017). Higher negative emotional granularity indicates a better ability to differentiate between specific negative emotions, which can allow individuals to use targeted coping mechanisms rather than feeling a general negativity and being unable to isolate the cause of that negativity. Specifically, after stressful live events, low negative emotional granularity has been associated with greater depressive symptoms (Starr et al., 2020). Many studies measure these mental health outcomes using daily diary entries and repeated emotion ratings as part of a longitudinal study rather than using pre-existing validated scales like the Beck Depression

Inventory-II (BDI-II; Beck et al., 1996) or State-Trait Anxiety Inventory for Adults (STAI; Spielberger, 1983) (Willroth et al., 2020; Erbas et al., 2014; Pond et al., 2012; Seah et al., 2020).

Music and Emotion Differentiation

Music's ability to evoke complex and varied emotions may provide a unique avenue for studying emotion differentiation. Unlike static visual stimuli, musical experiences unfold dynamically over time, offering listeners opportunities to experience and differentiate a wide range of emotions (Bachorik et al., 2009; Koelsch, 2014). Part of this dynamic experience is "musical expectancy" and "tension," where chord progressions around a specific tonal center can be altered, moving away from that tonal center and going against our expectation of what chords are to follow, creating musical tension (Koelsch, 2014). Changes in tempo, syncopation, and dissonance can also create tension, while consonance can decrease tension, particularly if this consonance is used to resolve dissonance. Another unique quality of music is its ability to mirror acoustic characteristics of speech that differ by emotion. For example, human speech expressing excitement may include the characteristics of 1) fast tempo, 2) loud volume, and 3) higher pitch, which can be reflected in music in a way that is not possible with visual stimuli (Koelsch, 2014; Juslin & Laukka, 2003).

An important framework for understanding music-evoked emotions is BRECVEMA, which includes eight mechanisms: "Brain Stem Reflex, Rhythmic Entrainment, Evaluative Conditioning, Contagion, Visual Imagery, Episodic Memory, Musical Expectancy, and Aesthetic Judgment" (Juslin, 2013). Under this framework, emotional responses are triggered by the brain stem reacting to acoustic properties of music, such as loudness or sudden changes in sound. Emotions also arise from the synchronization of the listener's physiological rhythms (like their heartbeat), with the rhythm or tempo of the music. Music evokes emotions through learned associations, where a specific piece of music can become linked to a specific emotion over time. Emotional expressions in music can also cause listeners to mirror or “catch” those emotions like a “contagion” (Juslin, 2013). Music can induce emotions by evoking mental images or memories that have emotional significance to the listener, especially personal episodic memories. These dynamic qualities make music particularly well-suited for measuring emotional granularity.

Understanding individuals’ abilities to differentiate between specific emotions is essential for understanding methods of emotion regulation. Given that music is frequently used as a tool for emotion regulation, it may have a relationship to emotional granularity. Music’s emotionally dynamic nature may offer richer, more nuanced emotional experiences compared to static stimuli like visual images. Since musical stimuli do unfold over time, evoking varying emotional responses that more closely mirror real-life emotional experiences, they could provide more ecologically valid measures of emotional granularity, particularly in research focusing on stress and coping mechanisms. Given that music listening is commonly used for coping with stress, music might also play an important role in affecting individuals’ ability to regulate their emotions (Thoma et al., 2012). Therefore, investigating this role of music may improve methods of measuring and understanding emotional granularity.

Music’s dual role as an emotion-evoking and mood-regulating medium makes it an essential area of study for affective science. By bridging physiological, psychological, and neuroimaging research, we gain a deeper understanding of how music influences human emotion across cultures and contexts. The current body of literature provides robust evidence of music’s ability to activate reward-related brain networks, evoke complex emotional states, and serve as a tool for emotional regulation. Investigating the role of music in emotional granularity offers promising opportunities to enhance our understanding of emotion differentiation and its implications for well-being.

Current Study

Across two studies, we compared emotional granularity experienced in response to both affective musical excerpts and OASIS images. Participants were exposed to either eight seconds of a musical excerpt or OASIS image and then rated their emotional experience on ten emotion words (five positive, five negative). For both studies, we hypothesized that:

1. Emotional granularity in response to music would be correlated with granularity in response to picture stimuli.
2. Musical stimuli would yield greater emotional granularity than picture stimuli (i.e., greater emotion differentiation will be experienced in response to music than in response to picture stimuli).
3. Both positive and negative emotional granularity in response to music would be positively correlated with the ability to discriminate emotions in music.
4. We would replicate the positive relationship between positive emotional granularity and resilience (Tugade et al., 2004) and the negative correlation between negative emotional granularity and levels of depression (Willroth et al., 2020) and anxiety (Seah et al., 2020; Erbas et al., 2014).

MATERIALS AND METHODS

Data Collection

Participants

A pilot experiment (n = 61) indicated that the correlation between positive emotional granularity elicited by music and pictures had an effect size of $r = 0.34$. Power analysis (using the *pwr* package in R) indicated that a sample size of 65 would achieve 80% power to detect this effect ($\alpha = 0.05$). Given this, 73 participants completed the study using the emotion rating task. 67 participants were undergraduate students at Northeastern University recruited through PsyLink who completed the task online for course credit, and 6 participants were individuals that completed the task in-person. One participant was excluded from analyses due to missing data for one stimulus in the emotion rating task, leading to a final sample size of 72. Demographic data for the sample are shown in Table 1.

Table 1 Study 1 Sample Demographics

Demographic	Study 1 sample (n = 72)
Age	
Mean (SD)	18.6 (0.77)
Range	18–21 years
Sex	
Male	18 (25%)
Female	51 (70.83%)
Prefer not to answer	1 (1.39%)
No response	2 (2.78%)
Gender	
Man	18 (25%)

Woman	48 (66.67%)
Gender non-conforming	2 (2.78%)
Genderfluid	1 (1.39%)
Other gender identity	1 (1.39%)
No response	2 (2.78%)
Race/Ethnicity	
American Indian or Alaska Native	0 (0%)
Asian	20 (27.78%)
Black or African American	6 (8.33%)
Hispanic or Latino	8 (11.11%)
Native Hawaiian or Other Pacific Islander	0 (0%)
White	29 (40.28%)
Two or more races	6 (8.33%)
Prefer not to answer	1 (1.39%)
No response	2 (2.78%)

Demographic information for the Study 1 sample.
Note: 2 participants did not complete the Qualtrics survey and are indicated as "No response." Their ages therefore have not been factored into the "age" demographic.

Materials

Picture stimuli used for the emotion rating task were drawn from the Open Affective Standardized Image Set (OASIS; Kurdi et al., 2017). OASIS includes 900 color images that depict people, animals, objects, and scenes, all of which have normative affective valence and arousal ratings, as determined from a study (n = 822) where each participant rated a set of 225 images individually on both valence and arousal scales (Kurdi et al., 2017). We excluded the 346 images belonging to the "people" category to avoid potential social biases in emotion appraisal

(Watson & de Gelder, 2017), and then separated the images into four groups based on their valence and arousal ratings (i.e., negative valence and low arousal, negative valence and high arousal, positive valence and low arousal, positive valence and high arousal). We selected ten images from each valence category that had the greatest magnitude of valence within their respective groups, resulting in 20 picture stimuli. After testing the emotion rating task on five pilot participants, we calculated the average emotional response to each image (averaged across all ten selected emotion words) to decide which four images to remove from the stimulus set for a final picture stimulus count to 16. We found that removing the pictures with the highest and lowest emotional responses within their valence category brought the average emotional response to pictures overall closer to the average emotional responses to music stimuli. We therefore removed the highest- and lowest-scoring negative and positive valence stimuli, reducing the picture stimulus count from 20 to 16.

Musical stimuli were drawn from excerpts of original instrumental compositions used in Sachs et al. (2023). These pieces were experimentally composed to portray specific emotions in music: sad, anxious, joyous, calm, or dreamy (Sachs et al., 2023). Specifically, we used time-series valence/arousal data of these compositions to select 8-second excerpts. These stimuli were normed with (n = 176) ratings of perceived valence and arousal of the music while listening (Sachs et al., 2023). Because these stimuli contain transitions across emotional states, we avoided transition periods between sections of the music. Any sections of the music that did not remain within positively- or negatively-valenced for at least 8 seconds were excluded. After meeting these qualifications, excerpts were further evaluated to ensure they accurately represented specific affective states.

For negatively-valenced excerpts, we prioritized music in minor modes, as minor keys are generally associated with negative emotions in Western music, and for positively-valenced excerpts, we prioritized music in major modes (Hevner, 1935; Gerardi & Gerken, 1995; Kawakami et al., 2013, 2014). For low arousal excerpts, we avoided sections with pronounced instrument onsets and high spectral flux within the 8-second window (Gingras et al., 2014), as well as slower tempos (Hofbauer & Rodriguez, 2023; Gomez & Danuser, 2007; Schubert, 2004). Spectral flux is a measure of how quickly the frequency content of a signal changes over time, helping to identify instrument onsets based on fluctuations in rhythm (Weineck et al., 2022; Müller, 2015). The amplitudes of all excerpts were normalized to control for the effects of differences in sound intensity on arousal, as sound intensity has been found to be positively associated with arousal (Gingras et al., 2014; Ilie & Thompson, 2006; Scherer, 1989; Dean et al., 2011; Schubert, 2004; Gomez & Danuser, 2007).

We identified eight negatively-valenced excerpts (four low-arousal and four high-arousal) that met our selection criteria. Three of our low-arousal excerpts were labeled as high arousal in the time-series data; however, all three exhibited very little spectral flux, suggesting they should be considered low-arousal stimuli (one example is shown in Figure 1A, while a high-arousal stimulus with high spectral flux shown in Figure 1B). One of our high arousal excerpts was labeled as low arousal in the time-series data but was relabeled as high arousal due to consistent high spectral flux. Another excerpt began as low arousal but switched to high in the time-series data, and it was relabeled as high arousal due to sustained high spectral flux throughout the excerpt.

Similarly, for the positively-valenced excerpts, we selected four high-arousal and four low-arousal stimuli. Two of our low-arousal stimuli were labeled as high arousal in the normed data but were relabeled as low arousal due to low spectral flux. Two of our high-arousal stimuli were labeled as low arousal in the normed data but showed high spectral flux and were therefore relabeled as high arousal. An example of a true positively-valenced low-arousal stimulus showing low spectral flux is shown in Figure 1C. One high-arousal stimulus was identified as half high arousal and half low arousal in the normed data, but it did not show any distinct changes in spectral flux between the first and second half of the excerpt (Figure 1D). Since it remained high in spectral flux, it was labeled as high arousal. Once relabeled accordingly, the final ratio of low- to high-arousal excerpts matched that of the picture stimuli for both positively- and negatively-valenced stimuli.

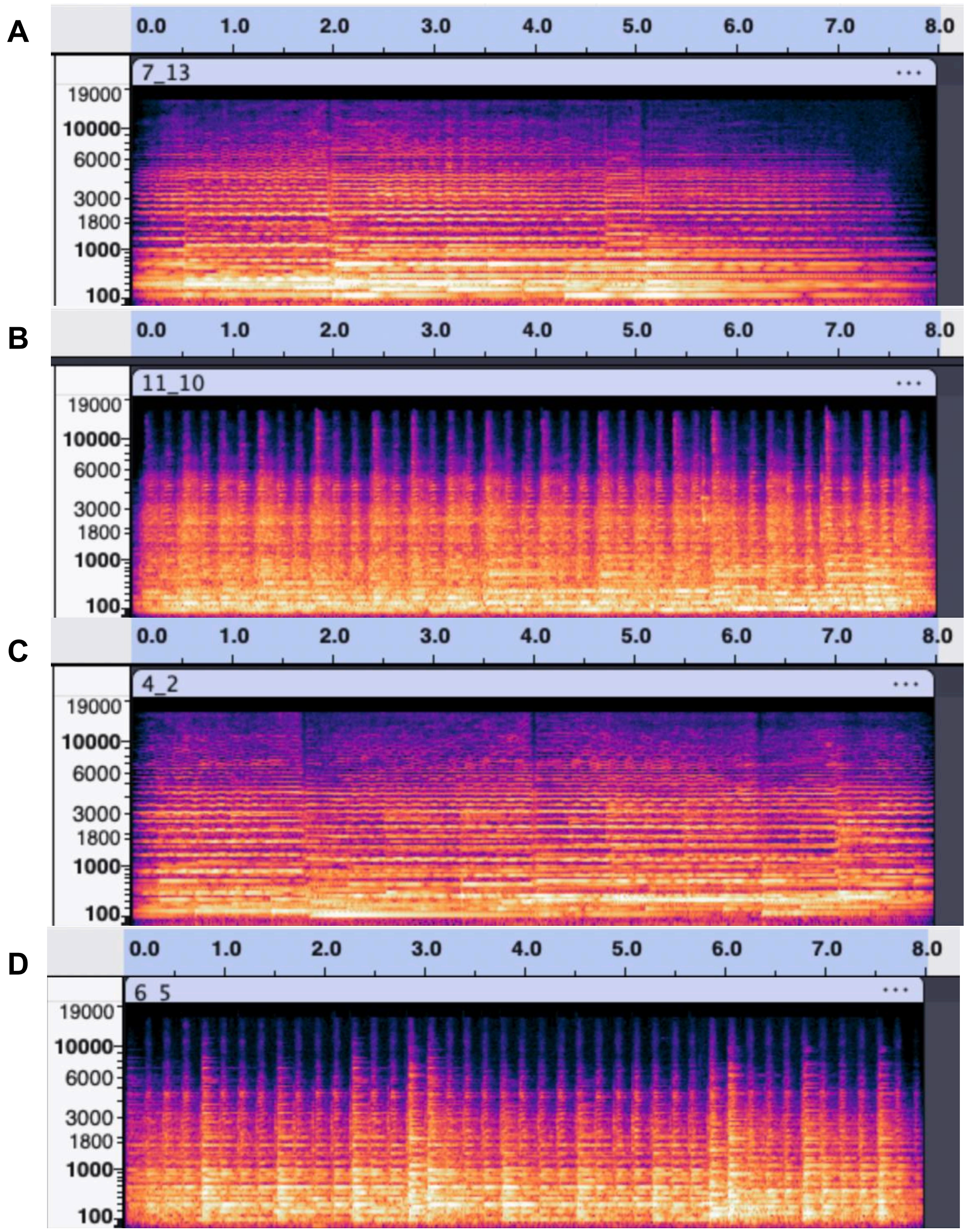


Figure 1. Spectrograms of four of the selected music stimuli with time (seconds) on horizontal scale and frequency (Hz) on vertical scale. **(A)** Negative valence stimulus that was identified as high arousal in the normed dataset but shows very little spectral flux and was therefore relabeled as low arousal. **(B)** Negative valence stimulus that was identified as high arousal in the normed dataset and shows high spectral flux and therefore retained its high arousal label. **(C)** Positive valence stimulus that was identified as low arousal in the normed dataset and shows low spectral flux and therefore retained its low arousal label. **(D)** Positive valence stimulus that was identified as high arousal for first half and low arousal for second half but shows high spectral flux throughout entire duration and was therefore relabeled as only high arousal.

The 10 emotion words used in this task (happy, joyful, excited, satisfied, relaxed, sad, anxious, upset, gloomy, scared) were chosen based on frequently used terms used in previous studies on emotional granularity (Diener et al., 1995; Barrett et al., 2001; Tugade et al., 2004; Kashdan et al., 2010; Erbas et al., 2018; Kalokerinos et al., 2019; Nook et al., 2021a; Vedernikova et al., 2021), along with emotions elicited by music (Eerola & Saari, 2025; Hevner, 1936). Pilot data (n = 61) indicated that, across all the emotion words selected, there was no difference between the magnitude of emotion elicited by music versus pictures with the selected stimuli (i.e., emotional words selected were not biased to be experienced more in response to either music or pictures). The stimuli used in this pilot were the same as the ones used in the present study.

Procedure

Participants completed the study on Gorilla, an online behavioral research platform, and Qualtrics, an online survey platform. Informed consent was obtained in accordance with the IRB-approved protocol 31-8-23 at Northeastern University. After consenting on Gorilla, online participants completed a headphone check (Woods et al., 2017) to ensure that they could hear the musical stimuli properly. Participants were then given instructions on how to complete the emotion rating task. They were told that each picture or music clip would appear for eight seconds and that they should look at the image for all eight seconds or listen to the entirety of the music clip and then rate the ten emotions shown on the screen afterwards based on how much they experienced that emotion while looking or listening. They were then presented with two practice stimuli: one OASIS picture stimulus (not included in the actual set of stimuli) followed by an emotion word response rating screen, and one music stimulus (not the same as any of the actual music stimuli but from the same compositions in Sachs et al. (2023)) followed by an emotion response rating screen. After confirming that the practice was completed, they were then presented with 16 affective musical excerpts (eight negatively- and eight positively-valenced) and 16 OASIS images (eight negatively- and eight positively-valenced) for eight seconds each. A schematic of the emotion rating task is shown in Figure 2.

Presentation of these stimuli was randomized across stimulus type (i.e., visual and musical stimuli were presented randomly in the same block together). After the presentation of each stimulus, participants rated the degree to which they felt five positively-valenced emotions (happy, satisfied, excited, joyful, relaxed) and five negatively-valenced emotions (gloomy, upset, scared, sad, anxious) on a 0-100 scale, with 0 meaning "no experience of that emotion at all" and 100 meaning "maximum experience of that emotion." This randomized presentation continued until the end of the 32 stimuli, at which point participants were redirected to Qualtrics, where they completed a series of self-report questionnaires, including the Connor-Davidson Resilience Scale (CD-RISC; Connor & Davidson, 2003), Beck Depression Inventory-II (BDI-II; Beck et al., 1996), and State-Trait Anxiety Inventory for Adults (STAI; Spielberger, 1983), as well as basic demographic questions.

At the end of the questionnaires, they were redirected to the third part of the task: the adaptive Musical Emotion Discrimination Test (aMEDT; MacGregor et al., 2023). This task involves listening to 18 pairs of short musical stimuli, where for each pair of stimuli, participants were asked to choose which stimulus expresses a certain emotion more (happy, angry, tender, sad, fearful). The aMEDT is adaptive in that a correct answer leads to the presentation of a pair of stimuli that are more difficult to discriminate between compared to the previous pair.

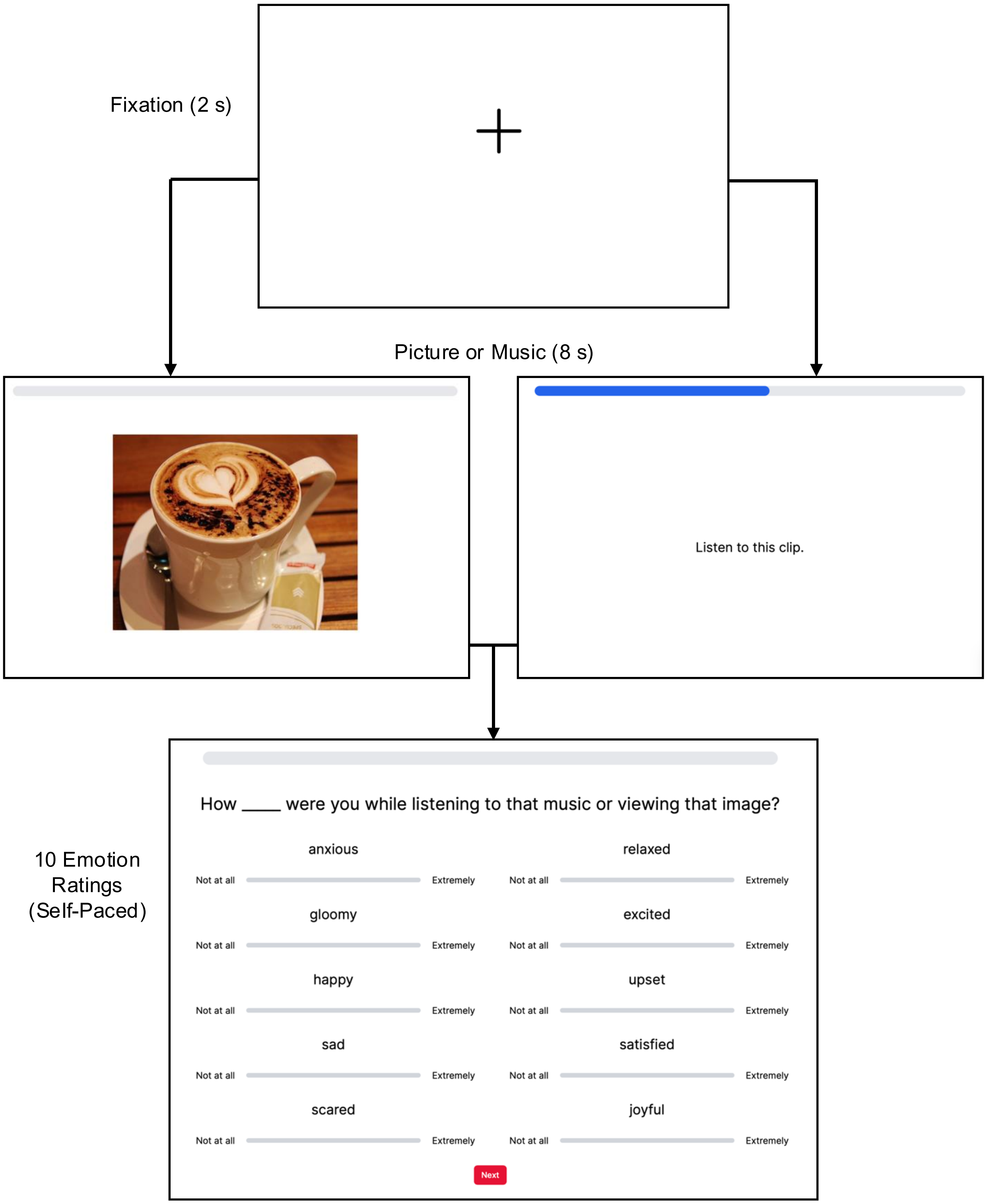


Figure 2. Design of the emotion rating task. Following a 2-s intertrial interval with a fixation cross, participants either viewed an image for 8 s or listened to a clip of music for 8 s. Participants then rated (self-paced) how anxious, gloomy, happy, sad, scared, relaxed, excited, upset, satisfied, and joyful they felt while either listening to the music or viewing the image.

Incorrect answers lead to the presentation of an easier pair of stimuli to discriminate between. Emotion discrimination is measured based on a computationally derived measure that considers both the number of correct answers on the test along with the difficulty of the items themselves. This measure ranges between –2.5 and 2.5, with more positive values representing a greater ability to discriminate between emotions in music.

Analysis Plan

Using the 0-100 scale emotion ratings, we calculated the intraclass correlation coefficient (ICC) of experienced emotion ratings as a measure of experienced emotional granularity in response to either music or visual stimuli (Barrett et al., 2001; Erbas et al., 2019; Nook et al., 2021a). ICC scores were separated by ratings of positively- and negatively-valenced emotion words, for a total of four ICCs per individual. ICCs were calculated using the *irr* package in R. Specifically, ICC(3,k) was calculated using the *icc* function, where ICC(3,k) is a two-way mixed effects model for consistency based on the average values of each emotion category at a 95% confidence level (Shrout & Fleiss, 1979). Use of ICC(3,k) is consistent with previous research (Nook et al., 2021a; Kalokerinos et al., 2019). Although negative ICCs are technically impossible, they are not unheard of in the context of emotional granularity. In some contexts, negative ICCs are removed. However, for us, given that negative ICCs would represent maximum granularity (extreme lack of correlation between an individual's emotions), ICCs with negative values were recoded as 0, which is consistent with prior emotional granularity studies (Hoemann et al., 2023). Since correlations are not usually normally distributed, ICCs were then Fisher *r-to-z* transformed, in accordance with previous research on emotional granularity (Barrett et al., 2001; Erbas et al., 2019). To make the granularity score more intuitive, scores were then multiplied by –1 such that higher values represented greater levels of emotion differentiation, with 0 representing maximum granularity (Erbas et al., 2019). Combined granularity scores were calculated from the average of an individual's positive and negative granularity, separated by stimulus type (i.e., music or images). This gave us a total of six granularity scores for each participant.

For our first hypothesis that there would be a positive correlation between emotional granularity scores in response to music and pictures, Pearson's product moment correlation coefficients were calculated for: positive granularity (music) and positive granularity (pictures), negative granularity (music) and negative granularity (pictures), and combined granularity (music) and combined granularity (pictures).

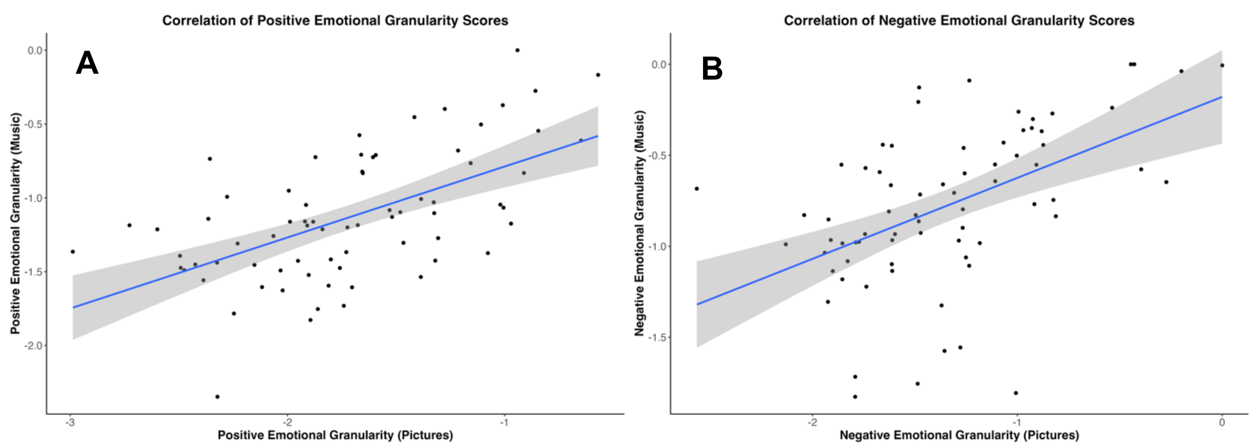
For our second hypothesis that the magnitude of granularity scores in response to music would be greater in magnitude than scores in response to pictures (in the same pairs as above), we conducted paired samples *t*-tests at a 95% confidence level.

To determine if there's a positive correlation between the ability to discriminate emotions in music (aMEDT score) and granularity in response to music, Pearson's product moment correlation coefficients were calculated for both positive and negative emotional granularity in response to music and aMEDT. Twelve participants were excluded from this analysis due to missing data on the aMEDT.

Finally, associations between granularity and mental health survey measures were also tested this way. Specifically, correlational tests were conducted between positive granularity (music) and resilience (CD-RISC score) and positive granularity (picture) and resilience, negative granularity (music) and depression (BDI-II score) and negative granularity (picture) and depression, and negative granularity (music) and anxiety (STAI score) and negative granularity (picture) and anxiety. Eight participants were excluded from these analyses due to missing survey data.

RESULTS

Positive emotional granularity scores in response to music were found to significantly positively correlated with positive granularity scores in response to pictures, ($r(70) = .58$, $p < .001$; Figure 3A). Negative emotional granularity scores were similarly positively correlated, ($r(70) = 0.51$, $p < .001$; Figure 3B), as was combined granularity, ($r(70) = 0.66$, $p < .001$; Figure 3C). Emotional granularity in response to music was greater for music compared to pictures for positive (music: $M = –1.13$, $SD = 0.43$, picture: $M = –1.72$, $SD = 0.53$, $t(71) = 11.16$ and $p < .001$), negative (music: $M = –0.78$, $SD = 0.44$, picture: $M = –1.34$, $SD = 0.50$, $t(71) = 10.28$ and $p < .001$), and combined (music: $M = –0.95$, $SD = 0.38$, picture: $M = –1.53$, $SD = 0.46$, $t(71) = 13.80$ and $p < .001$) granularity scores (Figure 4).



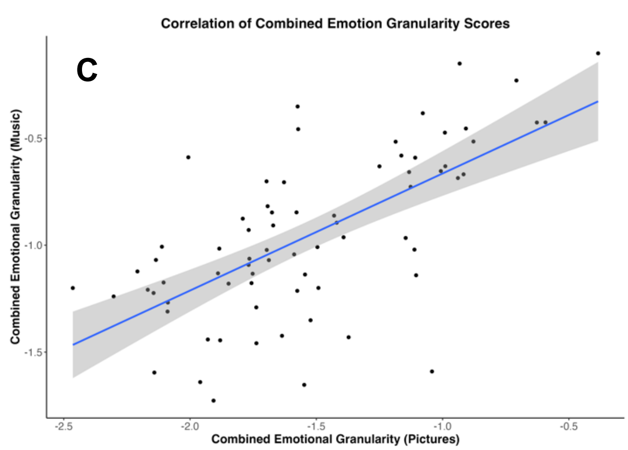


Figure 3. Study 1 scatter plots of correlations between granularity scores for positive emotions (**A**), negative emotions (**B**), and combined emotional granularity (**C**).

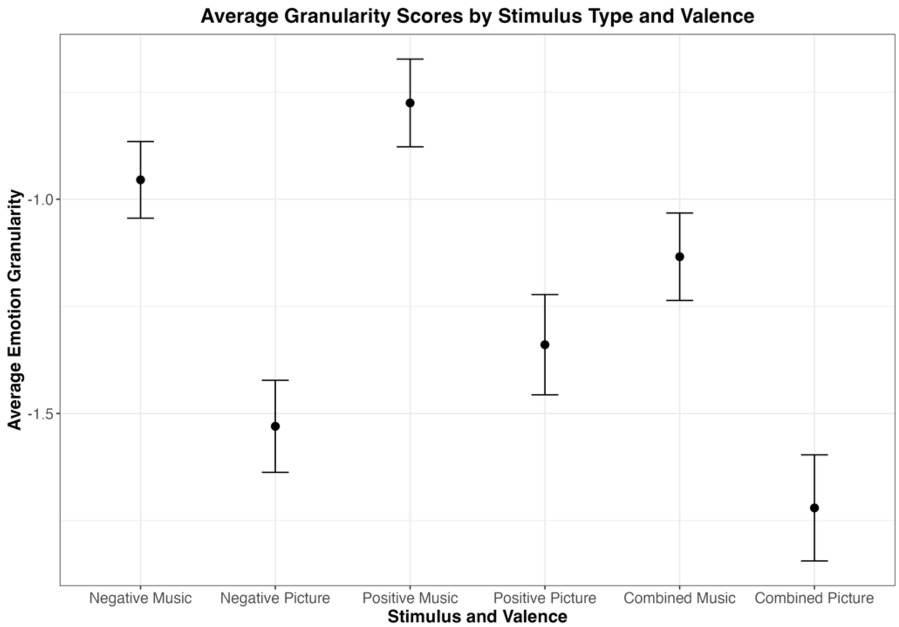


Figure 4. Study 1 average emotional granularity scores split by emotion valence (negative vs. positive) and stimulus type (picture vs. music). Error bars show 95% confidence intervals.

There was a significant positive correlation between negative emotion granularity in response to music and musical emotion discrimination ability scores, ($r(58) = .33$ and $p = .014$; Figure 5A), and combined emotional granularity with aMEDT scores, ($r(58) = .31$ and $p = .019$; Figure 5B). However, there was no correlation between positive emotion granularity in response to music and musical emotion discrimination ability, ($r(58) = .21$, $p = .12$).

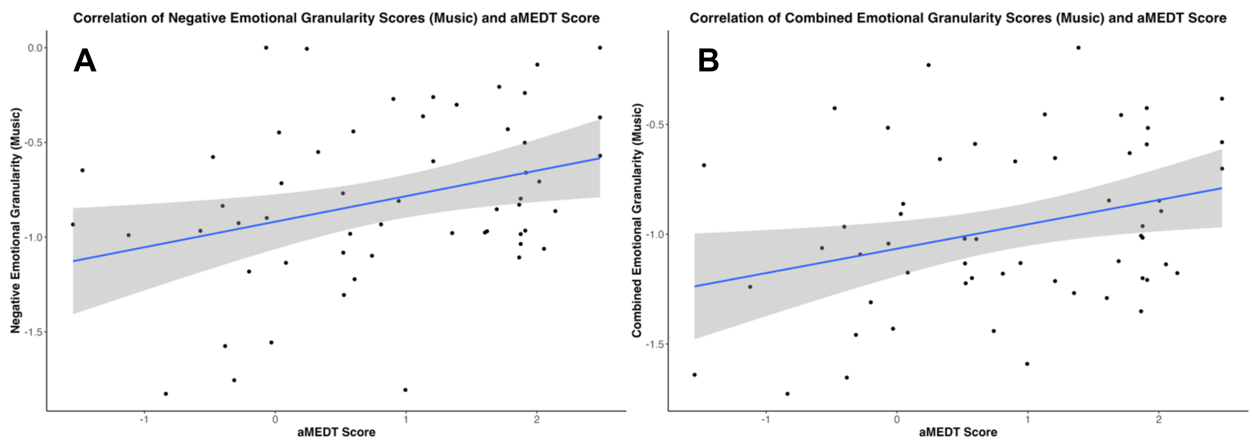


Figure 5. Study 1 scatter plot of significant positive correlations between **(A)** negative / **(B)** combined emotional granularity in response to music and musical emotion discrimination task score.
A. $r(58) = .33$, $p = .014$
B. $r(58) = .31$, $p = .019$

No significant associations were found between positive emotional granularity scores and resilience (CD-RISC), or negative emotional granularity scores and depression (BDI-II) or anxiety (STAI) (Table 2).

Table 2 Correlations with Mental Health Measures

Mental Health Measure:		**CD-RISC-10**	**BDI-II**	**STAI**
Granularity	**Stimulus Type**	n = 64	n = 64	n = 64
Positive	Music	.09		
	Picture	.09		
Negative	Music		0	–.08
	Picture		–.15	–.21

Bivariate correlations relating Connor-Davidson Resilience Scale (CD-RISC-10), Beck Depression Inventory-II (BDI-II) and State-Trait Anxiety Inventory (STAI) to measures of emotional granularity from the Study 1 sample. * p < .05, ** p <.01, *** p <.001

STUDY 2

INTRODUCTION

The neurological basis of emotional processing in both speech and music has been widely studied, with compelling evidence pointing to overlapping neural mechanisms. Listening to music activates emotion and reward-related brain circuits, including the mesolimbic dopaminergic system, a key pathway for reward and motivation, with implicated structures including the ventral and dorsal striatum, anterior cingulate cortex, orbitofrontal cortex, and secondary somatosensory cortex (Mas-Herrero et al., 2021; Salimpoor et al., 2011, 2013; Belden et al., 2023; Koelsch, 2014, 2020). The medial temporal lobe, including the amygdala and anterior hippocampus, as well as the ventromedial prefrontal cortex are also involved in evaluating emotional responses to music, reinforcing their roles in affective processing and controlling emotional responses (Blood & Zatorre, 2001; Dellacherie et al., 2008; Khalfa et al., 2008). The amygdala in particular plays an important role in the recognition of danger and fear in music, just as it does in non-musical contexts, as determined by patients with amygdala resections showing impaired recognition of fear-inducing music (Gosselin et al., 2005).

Further studies highlight the integration of sensory and affective cues in music and emotion perception. Baumgartner et al. (2006) demonstrated that emotional responses to visual stimuli were significantly enhanced when paired with music, suggesting that musical stimuli amplify the perception and experience of emotion. These findings align with research on emotional speech perception, in which prosodic cues—such as frequency, amplitude, and timing—engage a frontotemporal network, including the bilateral auditory cortices, superior temporal cortex, and inferior frontal gyrus (IFG) (Schirmer & Kotz, 2006; Dricu & Frühholz, 2016; Frühholz & Grandjean, 2013a, 2013b; Frühholz et al., 2016).

The Inferior Frontal Cortex

The inferior frontal cortex (IFC), including both the pars triangularis (BA45) and pars orbitalis (BA47), plays a critical role in processing emotional cues in both speech and music. In children, greater IFG connectivity with motor regions (primary motor, lateral premotor, and supplementary motor areas) has been linked to stronger emotional speech perception skills, emphasizing the role of the pars triangularis in integrating auditory and motor aspects of communication (Correia et al., 2019). Together, pars opercularis (BA44) and pars triangularis (BA45) constitute Broca's area, which is primarily responsible for language production and comprehension (Flinker et al., 2015). Studies on prosody perception indicate that the right IFC, particularly pars opercularis (BA44) and pars triangularis (BA45) may be specialized for decoding and evaluating emotional vocalizations (Buchanan et al., 2000; George et al., 1996; Wildgruber et al., 2005). In contrast, the left IFC (including BA44 and BA45) is more involved in syntactic and semantic processing (Friederici, 2012). However, some studies suggest bilateral IFC involvement in emotional prosody processing (Beaucousin et al., 2007; Frühholz et al., 2012; Kotz et al., 2003; Morris et al., 1999), while others have even found left IFC-specific activity in vocal emotion processing (Wildgruber et al., 2002; Adolphs et al., 2002; Roher et al., 2012).

Beyond the IFG, other frontotemporal and limbic regions contribute to emotional prosody processing. The bilateral fronto-opercular region is activated by prosodic speech containing emotional cues (Kotz et al., 2003). The anterior insula, a structure implicated in interoceptive awareness, also exhibits heightened responses to emotional vocalizations, underscoring its involvement in affective prosody processing (Morris et al., 1999). Additionally, emotional prosody has been linked to distinct right hemisphere activations in the posterior superior temporal sulcus (BA22), dorsolateral prefrontal cortex (BA44/45), and orbitobasal frontal areas (BA47) (Wildgruber et al., 2005). While BA47 is in close proximity to the pars orbitalis, they are not entirely synonymous, though both are implicated in evaluating and integrating emotional information in speech and music.

Emotional Granularity and Neuroanatomical Correlates

Differences in emotional granularity are associated with differences in neural processing of emotional experiences, with high granularity potentially being associated with stronger executive control of resources for consistent processing of affective stimuli (Lee et al., 2017). Individuals with degeneration of the frontal and temporal lobes show activity in more brain regions involved in the resting-state functional connectivity associated with emotional processing, suggesting that this lack of control of resources for emotion processing is related to a loss of functional specificity within emotional processing networks (Canu et al., 2022).

Individual differences in emotional granularity—the ability to distinguish between nuanced emotional states—have recently been linked to IFC cortical thickness. Greater cortical thickness in the right and left lateral orbitofrontal cortex, with extension into the dorsal anterior insula, has been associated with higher emotional granularity in older adults (Lukic et al., 2023). Given the IFC's role in cognitive control, behavioral inhibition, and emotion regulation (Aron et al., 2014; Dörfel et al., 2014; Li et al., 2021; Ochsner et al., 2004; Phan et al., 2005; Picó-Pérez et al., 2019), this structural relationship suggests that greater IFC integrity may support more nuanced emotional processing. Moreover, emotion labeling and meaning-making—both of which engage the IFC, particularly BA45/47—play a crucial role in deriving meaning from musical and verbal emotional cues (Brooks et al., 2017; Goldin et al., 2008; Hariri et al., 2000; Lieberman et al., 2005, 2007; Phan et al., 2005; Torre & Lieberman, 2018).

Music provides a unique and ecologically valid model for studying emotion in the brain, offering a controlled yet naturalistic means of eliciting affective responses. Unlike language, which conveys explicit semantic meaning, instrumental music can express emotion through structural and auditory features alone, making it an ideal tool for investigating neural responses to emotional stimuli without lexical confounds. The same neural circuits involved in emotional prosody and vocal affect—such as the IFG (BA44/45/47), superior temporal cortex (BA22), anterior insula, and orbitofrontal cortex—are also recruited during musical emotion perception (Wildgruber et al., 2005; Kotz et al., 2003; Morris et al., 1999). Given correlations that have been found being emotional granularity and emotion perception (i.e., recognizing the emotions expressed by facial expressions of other people) (Israelashvili et al., 2019; Erbas et al., 2016), there may be similar correlations between musical emotional granularity and musical emotion perception.

Some distinctions have been found between the specific affective state induced by music and the regions of the brain activated during that affective experience. Listening to positively-valenced classical music shows activity in BA44, BA45, the ventral and dorsal striatum (involved in reward experience and movement), anterior cingulate and anterior superior insula, and parahippocampal gyrus, while negatively-valenced music activates the hippocampus, amygdala, and parahippocampal gyrus, which are all implicated in the appraisal and processing of emotions (Koelsch et al., 2006; Mitterschiffthaler et al., 2007). Even listening to unfamiliar instrumental music passively shows activation in the subcallosal cingulate gyrus, prefrontal anterior cingulate, hippocampus, anterior insula, and nucleus accumbens (Brown et al., 2004).

Furthermore, the interplay between motor and auditory regions in music perception mirrors the mechanisms underlying speech prosody processing. The motor system, particularly the IFG, premotor cortex, and supplementary motor area, is engaged not only in vocal production but also in emotional speech and music perception, reinforcing the sensorimotor integration hypothesis—the idea that our ability to perceive and interpret emotional sounds is shaped by the same neural mechanisms involved in producing them (Correia et al., 2019; Patel & Iversen, 2014).

By examining how music evokes emotions and engages reward, limbic, and cognitive control networks, researchers can gain deeper insights into the fundamental neural mechanisms underlying human emotional experience. As research continues to bridge the gap between music, speech, and emotional processing, music may be a powerful tool for exploring how the brain encodes, interprets, and regulates emotion.

Current Study

In the current study we aimed to replicate hypotheses 1 and 2 from Study 1. We additionally hypothesized that we would replicate the positive correlation between emotional granularity and cortical thickness of the inferior frontal cortex cortical thickness (Lukic et al., 2023), using the same granularity task and musical emotion discrimination task as the first study but with the addition of structural magnetic resonance imaging.

MATERIALS AND METHODS

Data Collection

Participants

Study 2 consisted of 50 participants who all completed the study in-person at Northeastern University's Interdisciplinary Science and Engineering Complex as part of a broader experimental protocol. Participants were recruited from the Greater Boston area. Demographic data for the sample are shown in Table 2. All participants gave written informed consent and completed an MRI pre-screening phone call and pre-entry screening form.

Table 3 Study 2 Sample Demographics

Demographic	Study 2 sample (n = 50)
Age	
Mean (SD)	21 (1.32)
Range	18–24 years
Sex	
Male	22 (44%)
Female	28 (56%)
Gender	
Man	22 (44%)
Woman	27 (54%)
Non-binary	1 (2%)
Race/Ethnicity	
American Indian or Alaska Native	0 (0%)
Asian	15 (30%)
Black or African American	2 (4%)

Hispanic or Latino	0 (0%)
Native Hawaiian or Other Pacific Islander	0 (0%)
White	21 (42%)
Two or more races	12 (24%)

Demographic information for the Study 2 sample

Materials

The same emotion rating task and aMEDT from Study 1 were administered in Study 2.

Procedure

Participants completed the study in two separate sessions on separate days. The aMEDT was one of the tasks completed on the first day, and the emotion rating task and MRI were part of the second day. In the MRI, patients remained awake and watching short films while structural scans were completed.

4 of the participants were individuals that were sent the emotion rating task and aMEDT as optional follow-up tasks after having previously participated in a study at the MIND Lab prior to the start of data collection for this study. Those 4 completed the tasks online, while the other 46 completed the tasks in the MIND Lab space in-person.

MRI Data Acquisition

Neuroimaging was acquired using a Siemens Magnetom 3 T MR scanner with a 64-channel head coil at Northeastern University. T1 images were acquired using a magnetization prepared rapid gradient echo sequence, with one T1 image acquired every 2400 msec, for a total task time of approximately 7 min. Sagittal slices (0.8 mm thick, anterior to posterior) were acquired covering the whole brain (TR = 9.9 msec, echo time = 4.6 msec, flip angle = 2°, field of view = 256, voxel size = 0.8 × 0.8 × 0.8 mm3). Anatomical images were obtained using a T1-weighted image.

Analysis Plan

MRI Preprocessing

Results included in this manuscript come from preprocessing performed using fMRIPrep 24.0.0 (Esteban et al. (2019); Esteban et al. (2018); RRID:SCR_016216), which is based on Nipype 1.8.6 (K. Gorgolewski et al. (2011); K. J. Gorgolewski et al. (2018); RRID:SCR_002502).

The T1-weighted (T1w) image was corrected for intensity non-uniformity (INU) with N4BiasFieldCorrection (Tustison et al., 2010), distributed with ANTs 2.5.1 (Avants et al., 2008, RRID:SCR_004757), and used as T1w-reference throughout the workflow. The T1w-reference was then skull-stripped with a *Nipype* implementation of the antsBrainExtraction.sh workflow (from ANTs), using OASIS30ANTs as target template. Brain tissue segmentation of cerebrospinal fluid (CSF), white-matter (WM) and gray-matter (GM) was performed on the brain-extracted T1w using fast (FSL (version unknown), RRID:SCR_002823, Zhang, Brady, and Smith, 2001). An anatomical T2w-reference map was computed after registration of 3 T2w images (after INU-correction) using mri_robust_template (FreeSurfer 7.3.2, Reuter, Rosas, and Fischl, 2010). Brain surfaces were reconstructed using recon-all (FreeSurfer 7.3.2, RRID:SCR_001847, Dale, Fischl, and Sereno, 1999), and the brain mask estimated previously was refined with a custom variation of the method to reconcile ANTs-derived and FreeSurfer-derived segmentations of the cortical gray-matter of Mindboggle (RRID:SCR_002438, Klein et al., 2017). Volume-based spatial normalization to one standard space (MNI152NLin2009cAsym) was performed through nonlinear registration with antsRegistration (ANTs 2.5.1), using brain-extracted versions of both T1w reference and the T1w template. The following template was selected for spatial normalization and accessed with *TemplateFlow* (24.2.0, Ciric et al., 2022): *ICBM 152 Nonlinear Asymmetrical template version 2009c* [Fonov et al. (2009), RRID:SCR_008796; TemplateFlow ID: MNI152NLin2009cAsym].

ROI Cortical Thickness Analysis

Anatomical data preprocessing was done through FreeSurfer using a T1-weighted image and recon-all for cortical surface reconstruction. This returned measures of cortical thickness and subcortical volume measures. The Destrieux atlas (aparc.a2009s) was used to isolate the inferior frontal cortex ROIs, given that the Destrieux atlas is parcellated into 148 ROIs (Figure 6), while the Desikan-Killiany atlas (default for FreeSurfer aparc_stats) is parcellated into 68 ROIs. Specific ROIs in the inferior frontal cortex were selected based on those analyzed in Lukic et al. (2023): the posterior inferior frontal gyrus, comprising of pars opercularis (BA44) and pars triangularis (BA45), the lateral orbitofrontal cortex, comprising of pars orbitalis (BA47), BA12, and BA11, and the dorsal anterior insula. The Destrieux atlas includes BA44, BA45, and BA47 explicitly and were analyzed as such. The other regions were approximated using the broader orbitofrontal gyrus thickness for BA12, lateral sulcus and H-shaped orbital sulcus for BA12, and the larger gyrus of the insula and superior circular sulcus of the insula for the dorsal anterior insula, for a total of eight ROIs from the atlas (Figure 7). Parcellation statistics of cortical thickness for both hemispheres for these regions were analyzed for Pearson's correlations with all six granularity scores for participants.

Study 1 Replication

The emotion rating task and aMEDT were analyzed as in Study 1 in order to replicate the results of Study 1 with the additional structural correlations of Study 2. The 4 participants mentioned in Participants completed both tasks online after having already completed their two sessions. Our final sample size for the aMEDT was 48 due to missing data from 2 participants.

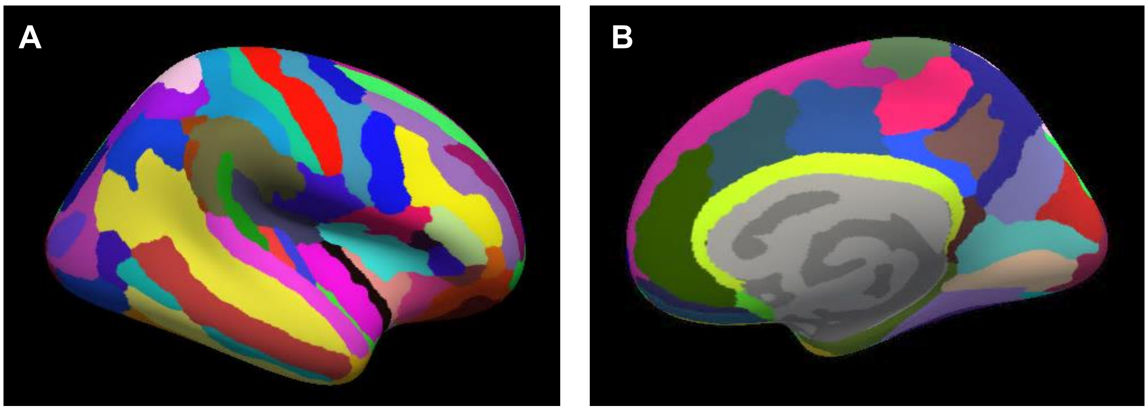


Figure 6. (A) Right hemisphere Freeview visualization of Destrieux atlas structural parcellation with 148 ROIs (default color labels). **(B)** Right hemisphere medial view of atlas visualized in **(A)**.

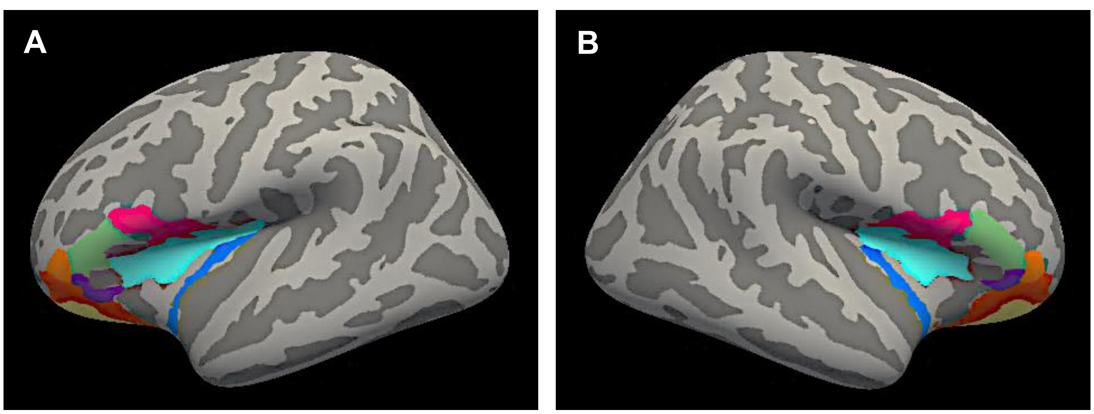


Figure 7. ROIs from Destrieux atlas: (1) Pars opercularis (BA44) (magenta), (2) pars triangularis (BA45) (green), (3) pars orbitalis (purple), (4) long insular gyrus and central sulcus of the insula (blue), (5) superior segment of the circular sulcus of the insula (cyan), (6) lateral orbital sulcus (orange), (7) orbital gyri (red), (8) H-shaped orbital sulci (yellow) of the **(A)** left hemisphere and **(B)** right hemisphere.

RESULTS

Positive emotional granularity scores in response to music were significantly positively correlated with positive granularity scores in response to pictures, ($r(48) = .65$, $p < .001$; Figure 8A). Negative emotional granularity scores were similarly positively correlated, ($r(48) = .62$, $p < .001$; Figure 8B), as was combined granularity, ($r(48) = .73$, $p < .001$; Figure 8C). Emotional granularity in response to music was greater for music compared to pictures for positive (music: $M = -0.99$, $SD = 0.48$, pictures: $M = -1.59$, $SD = 0.55$, $t(49) = 9.86$ and $p < .001$), negative (music: $M = -0.64$, $SD = 0.40$, pictures: $M = -1.38$, $SD = 0.49$, $t(49) = 13.28$ and $p < .001$), and combined (music: $M = -0.81$, $SD = 0.38$, pictures: $M = -1.48$, $SD = 0.47$, $t(49) = 14.67$ and $p < .001$) granularity scores (Figure 9).

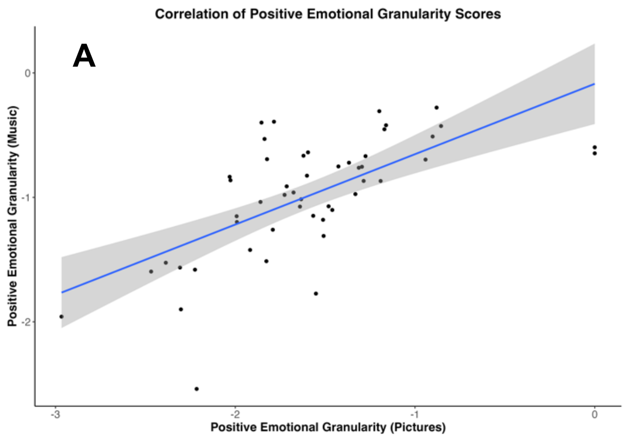
There were no significant correlations between aMEDT scores and positive emotion granularity in response to music, ($r(46) = -.07$, $p = .62$), negative emotion granularity in response to music, ($r(46) = -.21$ and $p = .15$), or combined emotional granularity in response to music, ($r(46) = -.15$ and $p = .29$).

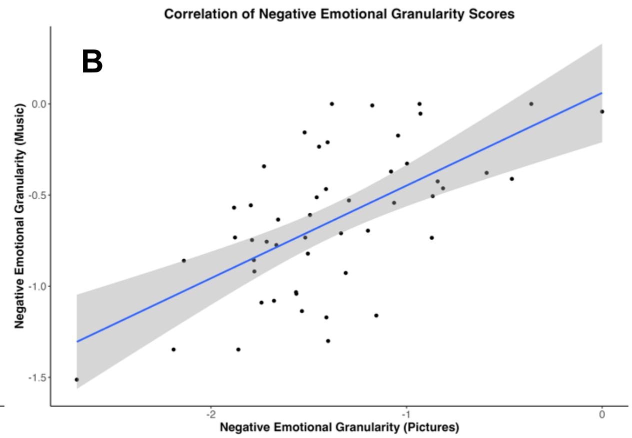
With the eight ROIs we identified, a positive correlation was found between the cortical thickness of the right hemisphere BA45, pars triangularis, and negative emotional granularity in response to music, $r(48) = .28$ and $p = .047$ (Figure 10). The right pars triangularis is shown in green in Figure 11. Correlations between granularity scores and all ROIs of both hemispheres are shown in Table 4.

Table 4 Structural Correlations with Granularity

		Granularity					
		Positive		Negative		Combined	
	Stimulus Type	Music	Picture	Music	Picture	Music	Picture
ROI	**Hemisphere**						
Pars opercularis	Right	.19	.08	.18	.03	.21	.06
	Left	–.19	–.06	.06	0	–.09	–.04
Pars triangularis	Right	.10	.07	.28*	.07	.21	.08
	Left	.07	.05	.05	.01	.07	.04
Pars orbitalis	Right	–.01	–.21	–.05	–.25	–.03	–.25
	Left	.05	0	.12	.08	.10	.04
Long insular gyrus and central sulcus of the insula	Right	–.09	–.07	–.03	.12	–.07	.02
	Left	–.04	.07	.07	.26	.01	.18
Superior segment of the circular sulcus of the insula	Right	.07	.04	.16	.06	.13	.06
	Left	–.15	–.14	–.06	–.11	–.12	–.14
Lateral orbital sulcus	Right	–.01	–.03	–.09	0	.06	–.01
	Left	.05	–.02	.06	.01	.06	0
Orbital gyri	Right	–.05	–.14	–.09	–.17	–.08	–.17
	Left	–.21	–.25	–.20	–.09	–.24	–.19
H-shaped orbital sulci	Right	.17	.17	.05	.08	.02	.14
	Left	–.09	–.15	–.11	–.17	–.12	–.18

Bivariate correlations relating the eight ROIs to measures of emotional granularity from the Study 2 sample. * $p < .05$, ** $p < .01$, *** $p < .001$





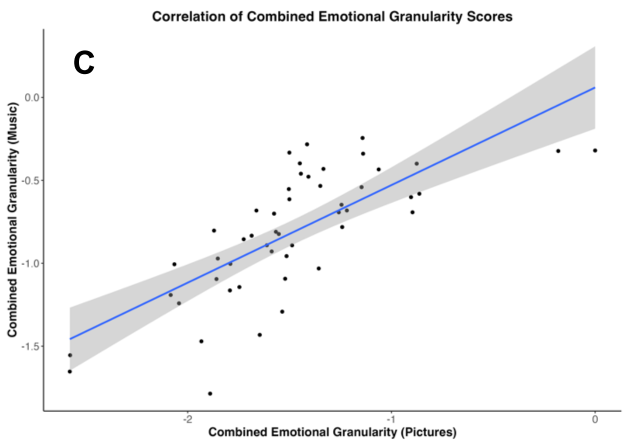


Figure 8. Study 2 scatter plots of correlations between granularity scores for positive emotions (**A**), negative emotions (**B**), and combined emotional granularity (**C**).

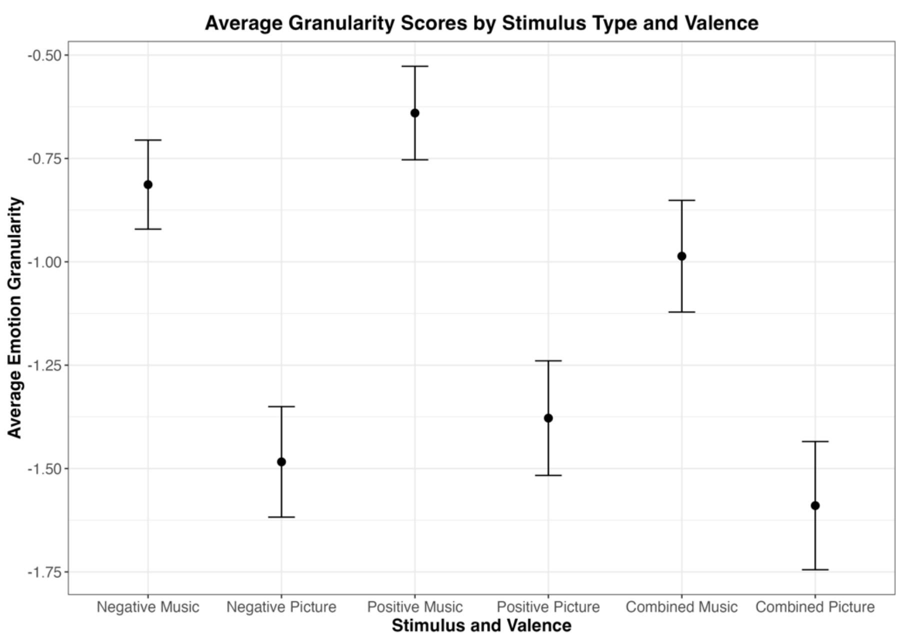


Figure 9. Study 2 average emotional granularity scores split by emotion valence (negative vs. positive) and stimulus type (picture vs. music). Error bars show 95% confidence intervals.

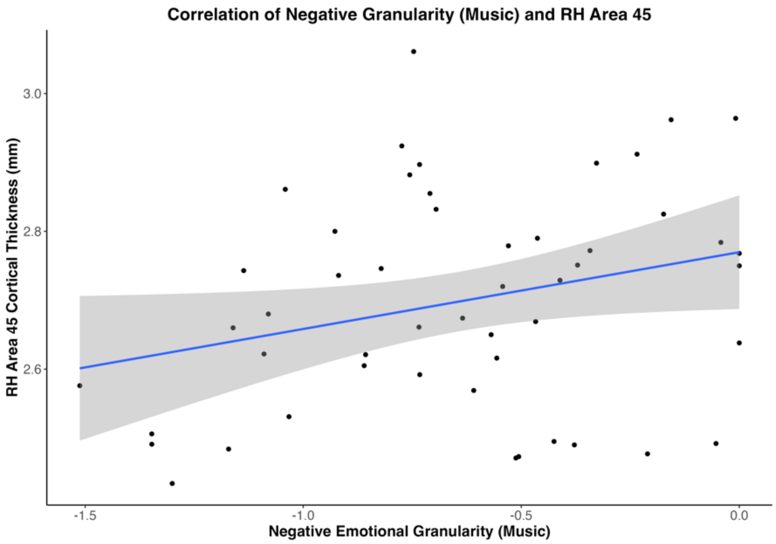


Figure 10. Study 2 scatter plot showing positive correlation between right hemisphere Area 45 (pars triangularis) cortical thickness and negative emotional granularity in response to music, $r(48) = .28$, $p = .047$.

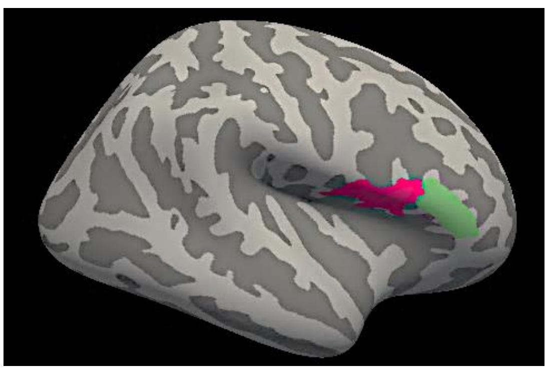


Figure 11. Right pars triangularis (BA45) (green) and pars opercularis (BA44) (magenta) from Destrieux atlas parcellation.

DISCUSSION

In the present study, we examined emotional granularity in response to music and picture stimuli. Consistent with our first hypothesis, we found a significant positive correlation between emotional granularity in response to music and in response to picture stimuli, suggesting that the construct measured via static images is similarly captured through music. Supporting our second hypothesis, emotional granularity was significantly higher for music than for picture stimuli. In Study 1, we observed a significant positive relationship between negative emotional granularity in response to music and musical emotion discrimination ability, partially supporting our third hypothesis; however, this association was not replicated in Study 2, suggesting that emotional differentiation and musical emotion perception may rely on distinct processes. Lastly, contrary to our fourth hypothesis, we did not find significant correlations between positive emotional granularity and resilience or between negative emotional granularity and depressive or anxious symptoms. However, structural MRI data in Study 2 revealed a positive correlation between cortical thickness in the right pars triangularis (BA45) and negative emotional granularity in response to music, partially replicating prior findings linking emotional granularity to inferior frontal cortex cortical thickness (Lukic et al., 2023). These results underscore music's potential as a more ecologically valid tool for studying emotion differentiation and highlight the need for further research into the neural mechanisms underlying emotional granularity.

Emotional granularity in response to music was significantly positively correlated with emotional granularity in response to picture stimuli. This suggests that the psychological construct measured via images is similar to that using music. Prior research has typically examined emotional granularity using static visual stimuli (e.g., Nook et al., 2018; Erbas at al., 2018), and our findings indicate that music can serve as a valid alternative for assessing this phenomenon.

Emotional granularity was significantly higher for music than for picture stimuli. This finding suggests that music's temporally unfolding nature allows for more nuanced differentiation of emotional states. This aligns with prior research demonstrating that music provides a richer emotional experience than static stimuli (Baumgartner et al., 2006; Juslin & Laukka, 2003), reinforcing the idea that music's dynamic and temporally unfolding nature may allow for more nuanced emotional differentiation. The continuous nature of music may provide listeners with additional contextual cues for emotion differentiation, whereas pictures offer only a significant moment in time, which may limit individuals' abilities to process general affect into specific emotions. The finding of higher granularity for music is also consistent with previously raised concerns regarding the ecological validity of static stimuli in granularity research (Thompson et al., 2021). Using music as a stimulus may be a step toward more ecologically valid assessments of emotional granularity, potentially serving as an alternative to experience sampling methods.

Our hypothesis that musical emotional discrimination ability would correlate with emotional granularity received mixed support. In Study 1, we observed a significant positive correlation between negative emotional granularity in response to music and musical emotion discrimination ability. However, this association was not replicated in Study 2. The inconsistency between the two studies suggests that while emotion perception ability and differentiation share some common mechanisms, they may not be entirely overlapping. This aligns with existing musical emotion research on perceived emotion versus felt emotion, where the emotions perceived in musical pieces do not necessarily coincide with the emotions felt by listeners (Kawakami et al., 2013).

Prior research also suggests that emotion perception in music relies on learned associations between acoustic features and emotional categories (Juslin & Laukka, 2003), whereas emotional granularity involves an individual's ability to introspectively differentiate their own emotional experiences (Barrett et al., 2001). For example, in the stimuli presented in the aMEDT, excerpts intended to be "angry" were generally at a louder dynamic with accented articulations (sometimes marcato, sometimes staccato) and bright overtones, whereas "happy" excerpts were at a loud dynamic with more legato phrasing and less harsh overtones. It is entirely possible to learn these characteristics through methods that don't require a connection to one's own emotional states, such as through formal musical training. This discrepancy aligns with findings that the ability to differentiate one's own emotional experiences is not necessarily correlated with the ability to accurately perceive and identify emotions depicted by others in external scenarios (Gregory et al., 2020). Future studies should further investigate whether these abilities rely on different cognitive or neural resources.

We did not find significant correlations between emotional granularity and measures of resilience, depression, or anxiety. This stands in contrast to prior research showing that higher positive emotional granularity is associated with resilience (Tugade et al., 2004) and that higher negative emotional granularity negatively correlated with depression (Willroth et al., 2020) and anxiety (Seah et al., 2020; Erbas et al., 2014)**.** One issue lies in how individuals make use of emotion labels for their emotional experiences. Research has indeed shown that a significantly lower ability to identify and describe one's emotions, known as alexithymia (Sifneos, 2010), is associated with challenges with cognitive reappraisal of emotional experiences (Swart et al., 2009), worse mental health symptoms (Leweke et al., 2011; Taylor et al., 1997), and poorer therapeutic outcomes (Ogrodniczuk et al., 2011). However, research has also found that assigning a specific label to an emotional experience may “crystallize” one’s affective experience and make it more difficult to reappraise the situation (Nook et al., 2021b). Therefore, while some individuals may use emotion labels as a means for identifying specific emotion regulation mechanisms, others may experience emotion labels as impeding emotion regulation rather than facilitating it. Other studies find that affect labeling acts as a form of implicit emotion regulation where labeling may not necessarily feel like an active regulatory process, but still has significant effects (Torre & Lieberman, 2018). These discrepancies suggest that there is a need for not only measuring individuals’ own differentiation abilities but also providing them with the emotion regulation tools to use those abilities to their advantage. This highlights the importance of specific targeted therapeutic interventions in facilitating practical uses of emotion differentiation.

However, it is worth noting the difference in methodologies between the present study and those used in Seah et al. (2020), Erbas et al. (2014), and Willroth et al. (2020)—all of which measured emotional granularity through experience sampling. Given the difficulties with ecological validity when measuring emotional granularity with standardized stimulus response tasks as opposed to experience sampling, it is possible that the correlations with mental health measures found in these previous studies reflect methodological differences. The challenge of maintaining high ecological validity with standardized stimulus response tasks may not be one that will be overcome simply by changing the types of stimuli used. However, that isn’t to say that these tasks cannot be improved to be at least somewhat more representative of daily experiences of emotions. Given music’s ability to unfold over time and bring listeners through different affective states, as well as our findings in this study, music may be an effective step forward with improving the methodologies for studying the complexities of emotional granularity.

The positive correlation between cortical thickness in the right pars triangularis (BA45) and negative emotional granularity in response to music, partially replicating previous findings linking emotional granularity to inferior frontal cortex cortical thickness (Lukic et al., 2023). The inferior frontal cortex has been implicated in the controlled retrieval of semantic knowledge (Lau et al., 2008) and plays a critical role in emotion labeling and regulation (Brooks et al., 2017; Lieberman et al., 2005, 2007). The left inferior frontal gyrus specifically is involved in the selection of semantic knowledge (Thompson-Schill et al., 1997). The right pars triangularis, in particular, has been associated with higher-order language and semantic processing (Levy & Wagner, 2011), which may explain its relationship with emotional granularity.

The role of the right versus left pars triangularis has been disputed, given that some studies on prosody perception indicate that the right BA44 and BA45 may be specialized for decoding and evaluating emotional vocalizations (Buchanan et al., 2000; George et al., 1996; Wildgruber et al., 2005), with the left BA44 and BA45 being more involved in syntactic and semantic processing (Friederici, 2012), while others have found bilateral IFC involvement in emotional prosody processing (Beaucousin et al., 2007; Frühholz et al., 2012; Kotz et al., 2003; Morris et al., 1999). Future studies should analyze the activity levels of both the right and left pars triangularis while listening to music and completing an emotional granularity task to determine whether this lateralization of function is indeed the case. In either case, the right pars triangularis still plays a role in selection and retrieval of affective labels and given that emotional differentiation relies on an individual's ability to precisely label their emotional states (Barrett et al., 2001), these findings support the notion that individual differences in emotional granularity may be tied to structural differences in the inferior frontal cortex.

Our results did not show survive correction for multiple comparisons, and correlations with other inferior frontal cortex regions were not significant. However, Lukic et al. (2023) collected data over the course of 8 weeks with participants completing daily experience surveys, a form of experience sampling that is known to be more ecologically valid than stimulus response tasks. The higher ecological validity of this kind of emotional granularity study may explain part of the discrepancy (i.e., our lack of correlations for other IFC regions). Additionally, given that Lukic et al. (2023) used a different atlas for parcellation there may have been methodological issues with the Destrieux parcellation we used that made it more difficult to find significant correlations with the left pars triangularis and potentially other IFC regions. For example, the distinction between pars triangularis and pars opercularis is not always clear (as can be seen by the proximity of pars triangularis to pars opercularis in Figure 11).

Our findings contribute to the growing literature on emotional granularity by demonstrating that music can be an effective tool for assessing emotion differentiation. The higher granularity observed for music suggests that musical stimuli may offer a more ecologically valid alternative to static images, potentially addressing limitations of previous research that relied solely on picture-based tasks. Additionally, our results highlight the need for further investigation into the relationship between emotion differentiation and neural structures, particularly in the inferior frontal cortex.

Future research should explore whether music-based granularity assessments provide stronger predictions for real-world emotional regulation and mental health outcomes than traditional static stimuli. One way to do so would be to conduct both an experience sampling and stimulus response study with the same sample of participants, as in Erbas et al. (2019), to find the correlation between granularity as measured by experience sampling versus granularity measured through a stimulus response task and determine if there is a stronger correlation between experience sampling-based granularity and granularity with music stimuli or picture stimuli. Doing so will help to clarify the ecological validity of granularity as measured with music, potentially allowing us to further understand the relationship between granularity and mental health. Furthermore, future studies should explore the correlation between not only musical emotional granularity and internal emotion regulation, but also granularity and external emotion regulation methods (i.e., helping others with the intention of regulating one's own negative emotions). Given that granularity and external regulation methods have been studied in non-Western contexts (Jeong et al., 2022), this would provide insight into the cross-cultural validity of music as a means of measuring emotional granularity.

This study expands our understanding of emotional granularity by demonstrating its consistency across different stimulus modalities and highlighting the advantages of music as an assessment tool. While our findings provide important insights into the neural correlates of emotional granularity, they also underscore the need for further research into the ecological validity of different measurement approaches. As affective science continues to evolve, integrating music into granularity research may offer new avenues for understanding the complexities of emotion differentiation and its role in emotion regulation.

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