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On The Relationship between Key Signatures and Music-Induced Emotions

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ABSTRACT

Music induces emotions, and emotions affect people's behavior and mental health. This study investigates how different musical key signatures influence listeners' emotions. A survey was conducted to gather data on emotional responses to various music pieces, followed by an Analysis of Variance (ANOVA) to identify statistical differences across key signatures. We focus on three major keys (C major, E-flat major, and E major) and three minor keys (C-sharp minor, F minor, and G minor). There are several main findings from the experimental study. First, certain keys are associated with specific emotions. For example, C major is linked to feelings of simplicity and brightness, while C-sharp minor evokes darkness and pain. Second, there is a correlation between the number of black notes in a key signature and the intensity of negative feelings. In particular, C major (with no black notes) is the most positively perceived among tested major keys, whereas G minor (with two black notes) is the least negatively perceived among tested minor keys. Third, lower pitches generally induce more negativity. This trend is especially pronounced in minor keys, with C-sharp minor (lowest pitch) eliciting the most negative emotions among tested minor keys, compared to G minor (highest pitch), which is the least negative. These findings provide empirical support for the connection between musical features and emotional responses, enhancing our understanding of music cognition theory and offering guidance on choosing suitable music for target emotions in therapeutic practice.

Keywords: Music cognition, emotions, key signatures, music therapy, ANOVA

1. Introduction

Why is a song like Leonard Cohen's *Hallelujah* played so commonly at weddings, Christmas, and many other celebratory events? What makes John Lennon's *Imagine* such an anthem for promoting world peace? Similarly, why does Beethoven's well-known *Moonlight Sonata* sound so dark and painful? Music evokes different emotions in people, and many factors of musical structure (melody, rhythm, etc.) influence this emotional effect.

The relationship between music and emotions has been widely studied. This topic is important because it is an essential part of music theory; furthermore, a clearer understanding of this relationship

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can provide guidance in utilizing music for beneficial purposes, such as developing music therapies for diseases like Alzheimer's and autism. Since there are many facets that make up a musical composition, one can approach the topic from different perspectives. Despite the existence of extensive literature, a careful search shows that the impact of key signatures on emotions is underexplored. In particular, there are surprisingly limited studies that collect data to conduct quantitative analysis. This paper aims to advance our understanding of the role of key signatures using rigorously designed experiments.

A survey was designed to collect data for this research. The survey focuses on three major and three minor keys selected from the twenty-four keys. For each mode (major or minor), the author recorded three short, thirty-second music excerpts using the three selected keys. The survey contains questions asking participants to rank their feelings after listening to the excerpts and to provide open-ended comments. Different dimensions of emotions have been considered in the survey design, such as simplicity/pureness and darkness/gloominess. A total of 290 people of different ages and levels of musical experience participated in the survey. After the data was collected, it was exported to Excel and analyzed using the add-in data analysis toolkit. Specifically, we used the single-factor analysis of variance (ANOVA) to test the statistical differences between the emotions induced by different keys.

We highlight three main findings from the experimental study. First, some keys convey certain emotions significantly stronger than other keys. Specifically, C major induces the most simplicity and positivity; C-sharp minor induces the most negativity, pain, and darkness; and F minor induces the most anger. This helps explain why John Lennon's *Imagine* (in C major) is known as an anthem for world peace and why Beethoven's *Moonlight Sonata* (in C-sharp minor) sounds so dark and painful. Second, for both major and minor categories, there is a negative correlation between the number of black notes in a key signature and how positive the key's induced emotion is. Throughout the paper, black notes refer to the black-colored keys on the piano. For instance, C major (zero black notes) is more positive than E-flat major (three black notes) and E major (four black notes); C-sharp minor (four black notes) and F minor (four black notes) are more negative than G minor (two black notes). Finally, lower pitch correlates with more negative emotions, especially for the minor keys. From the data, C-sharp minor (lowest pitched clip) conveys the most negativity, darkness, and pain; in contrast, G minor (highest pitched clip) conveys the least amount of the above three dimensions.

The rest of the paper is organized as follows. Section 2.0 reviews the related literature on this topic. Section 3.0 describes the research method and survey design. The results are presented in Section 4.0. Lastly, Section 5.0 concludes the paper and proposes directions for future research.

2. Literature review

Widely regarded as the universal language, music has been a powerful means of human expression throughout history, evoking various emotions within listeners. The relationship between music and emotions has been extensively explored by both musicians and researchers. For example, Zentner et al. (2008) conducted an experimental study to examine music's emotional rewards and reported that music is an effective means of mood induction. Similarly, Silva et al. (2021) show that listeners respond excitedly to exciting excerpts of music and calmly to calm excerpts despite being unfamiliar with the pieces, showing that some connection between musical structure and the brain must be present. Lundqvist et al. (2009) study whether music evokes genuine emotional responses in listeners (the emotivist position) or whether listeners merely perceive emotions expressed by the music (the cognitivist position). Their experimental results support the emotivist position. Extensive reviews of this line of literature can be found in Juslin & Laukka (2004) and Sloboda (2005).

There are many factors in musical structure (e.g., melody, rhythm, pitch, and mode) that may affect the relationship between music and the induced emotions. The literature has shown that these factors can convey distinct human emotions. For instance, Juslin (1997) manipulates musical features such as tempo and sound level in excerpts of the same melody, attempting to express emotions such as happiness and sadness. His participants' ability to correctly match the emotions to the excerpts indicates a correlation between these musical factors and the emotion conveyed. Collier & Hubbard (2001) further examine the impact of ascending and descending musical scales on listeners' perceived happiness, brightness, and other feelings. A comprehensive review of related studies can be found in Juslin & Sloboda (2001).

This paper focuses on the emotional effect of a specific musical factor: key signature. There are existing theories about distinct feelings linked to key signatures, known as key characteristics. For example, many musicians believe the key of C major is marked by simplicity and pureness (Steblin, 2002). However, in the vast literature on the relationship between music and emotions, relatively few studies are devoted to investigating the connection between musical key signatures and the emotions they induce. While researching this issue, it is also crucial to consider the modern adoption of equal temperament tuning for the piano, which features evenly spaced tone values between the keys, lessening the auditory and characteristic distinctions between key signatures.

Before equal temperament, many music theorists and notable composers, including Beethoven, Mozart, and Handel, agreed that keys had distinguishable characteristics (Young, 1991). Furthermore, several musicians defined their own views of each key characteristic, the most noteworthy being composer Christian Schubart's affective key characteristics in *Ideen zu einer Ästhetik der Tonkunst* (Schubart & DuBois, 2004). There have also been studies that tried to determine differences in key signatures. Composer Jean-Phillippe Rameau took key signatures not generally used by the public and characterized them uniquely (Rameau, 1971). According to Young (1991), an anonymous author described an experiment in *Journal de Trévoux* in 1718 where the audience felt the same emotion for the same key signature even when it was transposed a semitone higher. Although the above findings were primarily personal judgments before the modern equal temperament, they still serve as a valuable reference for this research, especially given the relatively small changes made by modern equal temperament.

After the adoption of equal temperament, some scholars use qualitative measures to reach conclusions on key characteristics. Vernon (1942) claims that the complexity of the key causes its differences: Key signatures with more sharps and flats are richer or more mysterious, while fewer sharps and flats mean more pureness and vigor. Helmholtz (1954) utilizes the acoustic properties of music and the human ear to explain the differences in key signatures. Steblin (1983) examines the key characteristics in the eighteenth and early nineteenth centuries using a historical approach. Arnn (1983) offers a book review of the work by Steblin (1983). More recently, researchers have adopted experimental studies to investigate the impact of key signatures in music. For example, Egmond & Boswijk (2007) explore the role of musical training on the perception of keys. Their experiments suggest that musical training is not a reliable predictor for a listener's performance in a tonic identification task.

A search of the literature shows that surprisingly limited studies are dedicated to differences among key signatures and how they affect the relationship between music and emotions, especially those with quantitative evidence and data support. This research aims to contribute to this literature by using experimental and statistical methodologies. There are several major differences between our paper and the existing studies. First, a novel experiment was designed to test the distinctive perceptions of participants of several music pieces with different keys/modes. Second, this research investigates not only the different perceptions between keys, but also those within modes under selected emotion types. Third, there are interesting, even surprising, findings that have not been reported in the previous literature. These findings may help explain why composers have used certain music keys and why some compositions are well-known for specific circumstances (for example, Leonard Cohen's *Hallelujah*, mentioned in the introduction).

Lastly, this paper examines humans' perception of music, which is therefore related to the literature that develops the underlying cognitive mechanisms of emotional responses to music. For instance, Brower (2000) proposes a cognitive theory of music meaning. Juslin & Västfjäll (2008) argue there is a lack of underlying mechanisms in studying musical emotions. In particular, they conclude that music evokes emotions through mechanisms that are not unique to music and that studying musical emotions could benefit the entire field of emotion studies by providing novel paradigms for emotion induction. By using functional neuroimaging with parametric analyses, Trost et al. (2012) attempt to map aesthetic music emotions in the brain. This is a vital research area because establishing scientific mechanisms behind music-induced emotions may help develop effective music therapies. For example, Arroyo-Anlló et al. (2019), who studied music and emotions in Alzheimer's disease, found a global impairment of music competencies in patients with cognitive and emotional troubles. Bleibel et al. (2023) use randomized controlled trials to evaluate the effect of music therapy on cognitive functions in patients with Alzheimer's disease. They show that compared to control groups, there is an improvement in

cognitive functions for the treatment group that receives music therapy. Their findings confirm the potential benefits of music therapy as a complementary treatment option for Alzheimer's disease and the importance of continued investigation in this field. Although identifying the mechanism behind the music-induced emotions is beyond the scope of this study, a thorough understanding of the relationship between music (including key signatures) and emotion would provide useful guidance for cognitive and neuroscience researchers.

3. Data and methodology

We conducted a survey to collect the needed data for this research. The complete survey can be found in the appendix at the end of the paper. In this survey, we created two sets of audio clips and attached a few questions to each set. The first set of clips contains a thirty-second excerpt from the beginning of the prelude from Bach's Prelude and Fugue in C Major, Book I. Bach's Prelude was chosen because it is relatively neutral in terms of tempo, volume, and rhythm, which serves our purpose well. The author played this composition using three different key signatures: C major, E-flat major, and E major. The three audio clips in the survey are labeled Audio Clip #1, Audio Clip #2, and Audio Clip #3 (see appendix). We selected these three keys to test because the literature suggests the strongest consensus about the unique key characteristics of these three keys. For example, many authors described C major as simple and E major as bright. Thus, as a first step to understanding key signatures' relationship with emotions, we focus on these three major keys for concision. Expanding the research to cover additional key signatures is a promising direction for future research.

For each of the three music clips in a major key, we first asked listeners to rank how positive a feeling they perceived from the excerpt on a scale of 1 to 5, with 5 being the most positive. This is followed by a question to rank how negative they felt from each clip on a scale of 1 to 5, with 5 being the most negative. After these two questions, we collected listeners' feelings about the following three dimensions for each piece of music: simplicity/pureness, dreaminess/magical feeling, and brightness/brilliance. For each dimension, respondents ranked the three clips on a scale of 1 to 5. We focus on the above three emotions for the major keys for several reasons. First, despite the large variety of emotions, we can only test a limited number of them in a single study, considering the length of the survey and the scope of this research. Second, these emotions have been frequently cited in the literature (see, for example, Schubart & Dubois, 2004 and Steblin, 2002). Third, testing these emotions can help us address the research questions proposed in the introduction.

A similar design paradigm applies to the second set of audio clips. The second set of clips contains a thirty-second excerpt from the beginning of Beethoven's Moonlight Sonata, No. 14, which again is relatively neutral in terms of tempo, volume, and rhythm. The author played this composition using three different minor keys: C-sharp minor, F minor, and G minor. The three audio clips in the survey are labeled Audio Clip #4, Audio Clip #5, and Audio Clip #6 (see appendix). We selected these three minor keys to sharpen the focus of the research, the same rationale as that behind the major keys. Also, through the literature review, we found strong agreement among researchers about the key characteristics of these three keys.

For each music piece in a minor key, the first two questions about ranking positive and negative feelings from each clip follow the same format as the major keys. After these two questions, we collected listeners' feelings about each clip for three dimensions: pain/despair, darkness/gloominess, and anger/harshness. Again, these three dimensions were selected for similar reasons as cited above for the major keys.

The survey participants were recruited on the website *Prolific*, which specializes in recruiting research participants. This research aims to examine the effect of musical key signatures on the general population, not a specific population segment. Therefore, we used minimum screeners when recruiting research participants. However, we collected the following information from participants to help understand the sample representation. Specifically, when taking the survey, each participant first answered three demographic questions: (1) age, (2) whether or not they have musical experience, and (3) how many years of musical experience they have. After that, the participants listened to the audio clips and answered the above questions. In addition, the respondents were given opportunities to offer free-response comments on each set of audio clips. Again, the complete survey can be found in the appendix. Unreliable data points were excluded to ensure the accuracy and validity of our analysis. For

instance, we removed any data with a survey completion time of less than four minutes since it took about three minutes to play all six audio clips, not to mention the time for answering seventeen questions. There were N = 290 effective responses in total. We anonymized the participant data when reporting the research results.

Table 1.

Summary of statistics on survey participants.

Total	Age			Musical experience (years)				Open comments	
N = 290	18 or under	19-64	65 or over	0-1	2-4	5-10	11+	Yes	No
	1	284	5	135	79	40	36	158	132
	0.3%	97.9%	1.7%	46.6%	27.2%	13.8%	12.4%	54.5%	45.5%

All the survey responses were recorded and then exported to Excel for analysis. Table 1 provides a summary of the statistics on the survey respondents. We can see the distribution of the participants based on their age, music experience, and whether they left open-ended comments in the survey. Several observations are worth highlighting. First, most participants (97.9%) are between 19 and 64 years old. Second, nearly half of the participants (46.6%) have no or limited music experience (e.g., playing an instrument or taking music classes). We need to be mindful of the potential biases caused by these concentrated distributions of participant characteristics. Finally, about 54.5% of the respondents provided open-ended comments, which is helpful information in addition to the numeric ranking data.

4. Results and discussion

The collected survey data allows us to explore detailed relationships between key signatures and induced emotions. This section highlights three key findings from the experimental study. First, some tested key signatures evoke certain emotions more strongly than others. Second, the number of black notes in a key signature plays a role in its induced emotion. Third, the pitch of a music piece affects listeners' perceived emotions. We elaborate on these three results in the following subsections.

4.1 Emotions induced by different keys

The primary purpose of this research is to explore the relationship between musical keys and emotions. The experimental data indicates that several key signatures we tested scored significantly higher on certain emotions than other keys. We start with the three major keys: C major, E-flat major, and E major. A notable finding is that C major scores the highest of the three major keys in the simplicity/pureness and brightness/brilliance categories. It is also perceived as the least negative among the three major keys. To demonstrate this, Tables 2-4 provide the ANOVA results for the simplicity/pureness, dreaminess/magical, and brightness/brilliance rankings of the three major keys. The ANOVA analysis was conducted using the Data Analysis toolkit in Excel, with the single-factor option. Throughout the paper, we use the threshold P-value of 0.1 for statistically significant differences in results.

Table 2.

ANOVA results of the three major keys on the simplicity/pureness dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C Major	290	1116	3.848	1.285		
Eb Major	290	1041	3.590	0.810		
E Major	290	975	3.362	1.228		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	34.324	2	17.162	15.492	0.000	2.309
Within Groups	960.476	867	1.108			

Total	994.8	869				

Table 3.
ANOVA results of the three major keys on the dreaminess/magical dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C Major	290	1048	3.614	1.345		
Eb Major	290	1068	3.683	0.965		
E Major	290	1010	3.483	1.337		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.986	2	2.993	2.462	0.086	2.309
Within Groups	1053.972	867	1.216			
Total	1059.959	869				

Table 4.
ANOVA results of the three major keys on the brightness/brilliance dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C Major	290	1058	3.648	1.301		
Eb Major	290	1048	3.614	0.965		
E Major	290	1057	3.645	1.441		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.209	2	0.105	0.085	0.919	2.309
Within Groups	1071.286	867	1.236			
Total	1071.495	869				

From Table 2 on the simplicity/pureness dimension, we can see that C major's average rating of 3.848 is significantly higher than E-flat major's average rating of 3.590 and E major's average rating of 3.362. The P-value of 0.000 suggests that the average ratings from the three major keys are significantly different. To better understand the relationships between keys, we conducted a Bonferroni post-hoc test (pairwise t-tests with Bonferroni correction) for pairwise comparisons. The test shows that the C major key is significantly different from both the E-flat and E major keys on the simplicity/pureness dimension (the P-values are smaller than the Bonferroni-corrected threshold for both pairwise comparisons). Thus, it is clear that C major conveys a statistically much stronger sense of simplicity/pureness than the other two keys.

Table 3 shows the results for the three major keys on the dreaminess/magical dimension. The P-value of 0.086 indicates that the three major keys induce different dreaminess/magical emotions. The Bonferroni post-hoc test confirms that C major and E-flat major are statistically non-different, but E-flat major significantly dominates E major on this dimension.

The results for the brightness/brilliance dimension are given in Table 4. We can see that the average ratings for the three major keys are 3.648, 3.614, and 3.645, respectively. Although the C major key receives the highest average score, no significant differences exist among the three major keys. In fact, the large P-value of 0.919 suggests that the three major keys induce similar feelings on the brightness/brilliance dimension. The existing literature often describes E major as bright (e.g., Steblin, 2002). However, the survey data does not show a statistical difference in the brightness among the three major keys we tested. Nevertheless, it is worth noting that E major scored slightly higher than E-flat major on the brightness dimension, and there is a negligible difference between E major and C major.

We proceed to examine the emotions induced by the three minor keys: C-sharp minor, F minor, and G minor. It has been found that the C-sharp minor and F minor keys evoke more pain/despair, as well as more darkness/gloominess and anger/harshness than the G minor key. The results are presented in Tables 5-7. In all these tables, the P-value 0.000 indicates that the three minor keys induce significantly

different emotions. Close scrutiny shows that C-sharp minor and F minor received similar scores, which are higher than that of G minor, on all three emotional dimensions. So, we conducted a post-hoc analysis to disentangle the relationships. We find that for the pain/despair and anger/harshness dimensions, C-sharp minor and F minor are not statistically different; moreover, both of them are significantly different from G minor. For the darkness/gloominess dimension, C-sharp minor is significantly stronger than F minor, which in turn is significantly stronger than G minor based on the Bonferroni post-hoc test. Therefore, the data suggests that C-sharp minor induces the most darkness/gloominess among the three minor keys. Further, the C-sharp minor and F minor keys are similar along the pain/despair and anger/harshness dimensions, but still, they both induce significantly stronger emotions than the G minor key on these two dimensions.

Table 5.

ANOVA results of the three minor keys on the pain/despair feeling dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C# Minor	290	1009	3.479	1.731		
F Minor	290	997	3.438	0.987		
G Minor	290	882	3.041	1.334		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	33.90575	2	16.953	12.549	0.000	2.309
Within Groups	1171.262	867	1.351			
Total	1205.168	869				

Table 6.

ANOVA results of the three minor keys on the darkness/gloominess feeling dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C# Minor	290	1051	3.624	1.640		
F Minor	290	995	3.431	1.056		
G Minor	290	891	3.072	1.438		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	45.462	2	22.731	16.497	0.000	2.309
Within Groups	1194.631	867	1.378			
Total	1240.093	869				

Table 7.

ANOVA results of the three minor keys on the anger/harshness feeling dimension.

Groups	Count	Sum	Average	Variance		
C# Minor	290	877	3.024	1.878		
F Minor	290	891	3.072	1.285		
G Minor	290	749	2.583	1.483		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	42.234	2	21.117	13.634	0.000	2.309
Within Groups	1342.824	867	1.549			
Total	1385.059	869				

The above findings corroborate with the discussions in the past literature, especially the one pertaining to C major. It is somewhat accepted that C major evokes simple and pure emotions from listeners, and this relationship has been recognized by many musicians and composers, including

Christian Schubart in his famous list of key characteristics (Schubart & DuBois, 2004). Overall, these results about the C major, C-sharp minor, and other keys can deepen our understanding of key signatures and help us choose suitable keys for certain target emotions.

4.2 The role of black notes

Another major finding yielded by our experiment is that the induced emotion of a key signature is affected by its number of black notes. Again, black notes refer to the black-colored keys on the piano. Specifically, for both major and minor modes, more black notes typically correlate with a higher score in negative feelings.

Table 8 presents the ranking of the negative feelings induced by the major keys. We can see that C major, which has no black notes, has the lowest average rating of 1.459. In comparison, E-flat major (three black notes) and E major (four black notes) have much higher average scores of 1.676 and 1.679, respectively. The statistical significance is supported by the P-value of 0.004. A Bonferroni post-hoc test shows no statistical difference between E-flat major and E major. This could be explained by the fact that these two keys involve similar numbers of black notes (three vs. four). Consequently, the ANOVA analysis indicates that the C major key evokes significantly less negativity in the induced emotions than the other two major keys, which share similar negative ratings.

Table 8.

ANOVA results of the three major keys on the negative feeling dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C Major	290	423	1.459	0.754		
Eb Major	290	486	1.676	0.877		
E Major	290	487	1.679	0.876		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.271	2	4.636	5.546	0.004	2.309
Within Groups	724.710	867	0.836			
Total	733.982	869				

Table 9 lists the negative feeling ratings for the three minor keys. The ANOVA analysis shows that the three minor keys induce significantly different negative feelings (P-value = 0.077). A Bonferroni post-hoc test shows that the difference between C-sharp minor and F minor is not statistically different, nor is the difference between the F minor and G minor keys. However, the test indicates that the C-sharp minor key evokes a significantly stronger negative feeling than the G minor key.

Table 9.

ANOVA results of the three minor keys on the negative feeling dimension.

Groups	*Count*	*Sum*	*Average*	*Variance*		
C# Minor	290	889	3.066	1.854		
F Minor	290	866	2.986	1.612		
G Minor	290	819	2.824	1.647		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.779	2	4.390	2.575	0.077	2.309
Within Groups	1477.731	867	1.704			
Total	1486.510	869				

We may use black notes as a potential explanation for Table 9. The C-sharp minor, F minor, and G minor keys have four, four, and two black notes, respectively. The common number of black notes could explain the statistically non-different negative feelings induced by C-sharp minor and F minor. Not surprisingly, the C-sharp minor key (four black notes) evokes a significantly more negative feeling than the G minor key (two black notes), probably due to the difference in the number of black notes. Since F

minor also has more black notes than G minor, one may expect the F minor key to induce a stronger negative feeling than the G minor key. However, the Bonferroni post-hoc test indicates the difference between F minor and G minor is not statistically significant. We will revisit this discrepancy and offer a possible explanation in the following subsection.

Section 4.1 compares the three minor keys (C-sharp minor, F minor, and G minor) on their induced feelings for three emotional dimensions: pain/despair, darkness/gloominess, and anger/harshness. In particular, Tables 5-7 demonstrate that the C-sharp minor and F minor keys tend to be similar (the only exception is the darkness/gloominess dimension, on which the C-sharp minor key is significantly stronger than the F minor key), and both induce significantly stronger emotions than the G minor key on these three dimensions. The black notes could have played a role in this result. That is, C-sharp minor and F minor have a similar effect on induced feelings, possibly due to the same number of black notes for the two minor keys. By contrast, the G minor key induces significantly less pain, darkness, and anger emotions because it has fewer black notes.

The above results and observations suggest that more black notes are typically tied to a more negative induced emotion, both for the major and minor keys. This theory has also been proposed in the previous literature. For example, Arnn (1983) notes that the intensity of emotion increases when more sharps or flats are present in the key signature. Vernon (1942) claims that keys with more black notes tend to be richer, more mysterious, and more melancholy than keys with more white notes. Helmholtz (1954) points out that black keys, because they are higher leverage on the keyboard, may have a different effect than white keys. This research offers empirical support for such a theory. The finding regarding black notes not only broadens our musical knowledge of the keys but also brings up a specific factor that should be considered for key or piece selection.

4.3 The moderating effect of pitch

The last finding we report from the experiment is that pitch might affect induced emotion, especially for minor keys. Specifically, the survey data shows that a lower pitch correlates with more darkness, pain, and negativity among the minor keys. As we have seen from Table 6 of minor keys' darkness/gloominess dimension, C-sharp minor (the lowest pitched clip) had the highest average darkness/gloominess score of 3.624, and G minor (the highest pitched clip) had the lowest average darkness/gloominess score of 3.072. The significance of the difference between these two minors is confirmed by the P-value of 0.000.

Likewise, in Table 5 for the pain/despair dimension, C-sharp minor has the highest pain/despair rating of 3.479, and G minor has the lowest pain/despair rating of 3.041. Moreover, in the negative feelings for minor keys table (Table 9), C-sharp minor had the highest negativity score at 3.066, and G minor had the lowest negativity score at 2.824. The statistical significance of these two results is supported by their P-values of 0.000 and 0.077, respectively.

Recall there is a discrepancy identified in Section 4.2 regarding the negative feelings induced by F minor and G minor. Since F minor has four black notes while G minor has only two, one might expect the F minor key to induce significantly more negative feelings than the G minor key. However, the post-hoc test indicates that these two minor keys are not statistically different on the negative feeling dimension. This might be explained by the similar pitches associated with the F and G minor keys. By contrast, despite sharing the same number of black notes as F minor, C-sharp minor has a much lower pitch than G minor, and thus, it induces significantly more negative feelings than G minor. These observations suggest that the pitch of a music piece plays a nontrivial role in the induced emotions. Although beyond the scope of this paper, analyzing the interaction between pitch and black notes would be a promising direction for future research.

The above evidence suggests that the pitch likely influences the negative feelings induced by minor keys. Specifically, a lower pitch tends to cause a more negative feeling. However, it is worth cautioning that the pitch effect could be one of many factors contributing to the induced emotions. Interestingly, we do not identify a similar effect of the pitch for the major keys. That is, pitch seems to have an insignificant impact on the emotions induced by major keys. This perhaps is due to factors such as piece selection, the pitch of the piece, or the different ways pitch affects major and minor keys. One plausible explanation for the different results between major and minor keys could be interval distance. That is, the interval distances between the three minor keys are greater than those between the three

major keys, which enhances the pitch effects on the minor keys. Further research is warranted to thoroughly test this hypothesis and investigate the pitch effect.

5. Conclusion

It is well-known that music evokes emotions. However, there is a lack of experimental studies that examine key signatures' role in music-induced emotions. This paper aims to deepen our understanding of the relationship between music and emotions, with a focus on key signatures. A survey was designed to collect data on listeners' feelings induced by music pieces played in different keys. There are several noteworthy findings from the experimental study. First, some keys convey certain emotions more than others, such as C major for simplicity and C-sharp minor for darkness and pain. Second, increasing black notes in a key signature correlates with stronger negative feelings. For example, C major, with the least black notes (zero), is the most positive among the tested major keys, and G minor, with the least black notes (two), is the least negative among the tested minor keys. Third, the pitch of the music might influence the induced emotion. In particular, the lower the clip's pitch, the more negative emotion the clip is associated with. This finding is especially true for minor keys, where C-sharp minor (the lowest pitched clip) induces the most negativity; in contrast, G minor (the highest pitched clip) induces the least negativity. This research is among the first to use rigorously designed experiments to advance our understanding of the role of key signatures in music-induced emotions. The findings supplement musical theory by providing empirical evidence of the association between specific key signatures and emotions.

Moreover, the results from this paper have many potential practical applications, especially in educational and therapeutic settings. For instance, they help explain why some famous pieces are commonly heard in various circumstances. Leonard Cohen's *Hallelujah*, which is in the key of C major, fits well for weddings or Christmas events because the key induces positive and pure emotions. Similarly, John Lennon's *Imagine* is also in C major, and its positive and pure feelings make it a suitable choice as an anthem for peace. Part of why Beethoven's *Moonlight Sonata* is so tragic and dark is due to the fact that it is in C-sharp minor, the key that induces negativity, darkness, and pain. From the therapeutic perspective, this study may inform music therapy practices for patients with specific emotional needs. Understanding the role of key signatures will help a therapist select effective music pieces to induce target emotions. In sum, the research findings contribute to our understanding of music and emotions from both theoretical and practical standpoints.

This research can be extended in several directions. First, more keys can be included in the experiment to offer a more complete picture of all twenty-four keys. Second, this research focuses on several commonly cited emotions in the literature. An extended study is warranted to examine additional types of emotions. Next, it would be interesting to investigate the effects of musical keys across different cultural contexts. Finally, the two music pieces used to test the major and minor modes are different, so a direct comparison of the data from the major keys and minor keys is problematic. However, playing the same music composition using both major and minor keys is challenging, if not impossible. Therefore, how to deal with this problem is also a promising direction for future research.

References

Arnn, J. D. (1983). Book Review of "A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries by R. Steblin." *Notes*, 40(2), 287–289.

Arroyo-Anlló, E. M., Dauphin, S., Fargeau, M. N., Ingrand, P., & Gil, R. (2019). Music and emotion in Alzheimer's disease. *Alzheimer's Research & Therapy*, 11(1), 69.

Bleibel, M., El Cheikh, A., Sadier, N. S., & Abou-Abbas, L. (2023). The effect of music therapy on cognitive functions in patients with Alzheimer's disease: a systematic review of randomized controlled trials. *Alzheimer's Research & Therapy*, 15, 65.

Brower, C. (2000). A cognitive theory of music meaning. *Journal of Music Theory*, 44(2), 323-379.

Collier, W. G., & Hubbard, T. (2001). Musical scales and evaluations of happiness and awkwardness: effects of pitch, direction, and scale mode. *American Journal of Psychology*, 114(3), 355-375.

Egmond, R., & Boswijk, M. (2007). The perception of key: The role of music training. *Music Perception*, 25(1), 31–42.

Helmholtz, H. (1954). On the Sensations of Tone (A. Ellis, Trans.). Dover Publications, Inc. (Original work published 1885).

Juslin, P. N. (1997). Can results from studies of perceived expression in musical performances be generalized across response formats? *Psychomusicology: A Journal of Research in Music Cognition*, 16(1-2), 77–101.

Juslin, P. N., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: a review and a questionnaire study of everyday listening. *Journal of New Music Research*, 33(3), 217-238.

Juslin, P. N., & Sloboda, J. A. (Eds.). (2001). Music and Emotion: Theory and Research. Oxford University Press.

Juslin, P. N., & Västfjäll, D. (2008). Emotional responses to music: the need to consider underlying mechanisms. *Behavioral and Brain Sciences*, 31(5), 559–575.

Lundqvist, L.-O., Carlsson, F., Hilmersson, P., & Juslin, P. N. (2009). Emotional responses to music: experience, expression, and physiology. *Psychology of Music*, 37(1), 61-90.

Rameau, J.-P. (1971). Treatise on Harmony. Dover Publications.

Schubart, C. F. D., & DuBois, T. (2004). On the human voice and the characteristics of the musical keys. *New England Review*, 25(1/2), 166–171.

Silva, I. C., Gouveia, A., Dalagna, G., Oliveira, J. M., Carvalho, P., Costa, R., & Gama, J. (2021). Music and emotion. *European Psychiatry*, 64(S1), S671–S672.

Sloboda, J. (2005). Exploring the Musical Mind: Cognition, Emotion, Ability, Function. Oxford University Press.

Steblin, R. (1983). A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries (Study in Music, 67). Ann Arbor: UMI Research Press.

Steblin, R. (2002). A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries. University of Rochester Press. Second Edition.

Trost, W., Ethofer, T., Zentner, M., & Vuilleumier, P. (2012). Mapping aesthetic musical emotions in the brain. *Cerebral Cortex*, 22(12), 2769–2783.

Vernon, P. E. (1942). The individuality of keys. *The Musical Times*, 83(1190), 105–107.

Young, J. O. (1991). Key, temperament and musical expression. *Journal of Aesthetics and Art Criticism*, 49(3), 235–242.

Zentner, M., Grandjean, D., & Scherer, K. R. (2008). Emotions evoked by the sound of music: characterization, classification, and measurement. *Emotion*, 8(4), 494-521.

Appendix to "On the Relationship Between Key Signatures and Music-Induced Emotions"

This appendix presents the survey used in the experimental study.

[Start of Survey]

1. What is your age? (Required)
   - 18 or under
   - 19-64
   - 65 and over
2. Do you have any musical experience (play an instrument, take classes, etc.) (Required)
   - Yes
   - No
3. If yes, how many years of musical experience do you have?
   - 0-1
   - 2-4
   - 5-10
   - 11+

Listen to these three snippets of audio. If you notice any differences in feelings, keep them in mind. If not, that's ok too.

Audio clip #1
Audio clip #2
Audio clip #3

4. On a 1-5 scale (5 being the most), rank how much positive vs. negative feeling you felt from the FIRST audio snippet: (Required)

	1	2	3	4	5
Positive feeling	o	o	o	o	o
Negative feeling	o	o	o	o	o

5. On a scale of 1-5, rank how much positive vs. negative feeling you felt from the SECOND audio snippet: (Required)

	1	2	3	4	5
Positive feeling	o	o	o	o	o
Negative feeling	o	o	o	o	o

6. On a scale of 1-5, rank how much positive vs. negative feeling you felt from the THIRD audio snippet: (Required)

	1	2	3	4	5
Positive feeling	o	o	o	o	o
Negative feeling	o	o	o	o	o

7. On a scale of 1-5, rank how much simplicity/pureness you felt from each of the audio clips: (Required)

	1	2	3	4	5
Clip 1	o	o	o	o	o
Clip 2	o	o	o	o	o
Clip 3	o	o	o	o	o

8. On a scale of 1-5, rank how much dreaminess/magical feeling you felt from each of the audio clips: (Required)

	1	2	3	4	5
Clip 1	o	o	o	o	o
Clip 2	o	o	o	o	o
Clip 3	o	o	o	o	o

9. On a scale of 1-5, rank how much brightness/brilliance you felt from each of the audio clips: (Required)

	1	2	3	4	5
Clip 1	o	o	o	o	o
Clip 2	o	o	o	o	o
Clip 3	o	o	o	o	o

10. Is there anything else you would like to add about the difference between these three clips?

Now, listen to these three snippets of audio. Again, keep in mind any differences in feeling you may hear.

Audio clip #4
Audio clip #5
Audio clip #6

11. On a scale of 1-5, rank how much positive vs. negative feeling you felt from the FIRST audio snippet: (Required)

	1	2	3	4	5
Positive feeling	o	o	o	o	o
Negative feeling	o	o	o	o	o

12. On a scale of 1-5, rank how much positive vs. negative feeling you felt from the SECOND audio snippet: (Required)

	1	2	3	4	5
Positive feeling	o	o	o	o	o
Negative feeling	o	o	o	o	o

13. On a scale of 1-5, rank how much positive vs. negative feeling you felt from the THIRD audio snippet: (Required)

	1	2	3	4	5
Positive feeling	o	o	o	o	o
Negative feeling	o	o	o	o	o

14. On a scale of 1-5, rank how much pain/despair you felt from each of the audio clips: (Required)

	1	2	3	4	5
Clip 1	o	o	o	o	o
Clip 2	o	o	o	o	o
Clip 3	o	o	o	o	o

15. On a scale of 1-5, rank how much darkness/gloominess you felt from each of the audio clips: (Required)

	1	2	3	4	5
Clip 1	o	o	o	o	o
Clip 2	o	o	o	o	o
Clip 3	o	o	o	o	o

16. On a scale of 1-5, rank how much anger/harshness you felt from each of the audio clips: (Required)

	1	2	3	4	5
Clip 1	o	o	o	o	o
Clip 2	o	o	o	o	o
Clip 3	o	o	o	o	o

17. Is there anything you would like to add about the difference between these three clips?

[End of Survey]