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Effects of instrumental music on the activation of Robert Plutchik's basic emotions

Efeitos da música instrumental na ativação das emoções básicas de Robert Plutchik

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ABSTRACT

This study aimed to investigate the basic emotions proposed by Robert Plutchik and the timbre of instruments from four instrument families (strings, electrophone, percussion, and wind), without isolating any other dimension of sound, considering that previous studies have highlighted the relevance of timbre for the perception of emotions. In four meetings, an average of 38 participants out of a total of 67, of both sexes, aged between 16 and 71, listened to an hour of solo instrumental music and then filled in a questionnaire containing the eight basic emotions, and shared their experiences as a group. The Kruskal-Wallis H-test showed a value of p = 0.002, indicating that different families of instruments activate different emotions, thus confirming the hypothesis of this study. The results revealed that there was no single instrument activating a single emotion and showed a circular relationship between the instrument families and emotions: surprise and anticipation were activated by the German zither-strings and the wind-clarinet; fear and anger were activated by the wind-clarinet, the electrophone-theremin, and the marimba percussion; displeasure and trust were activated by the marimba percussion and the German zither-strings; sadness and joy were activated by the German zither-strings, the electrophone-theremin, and the marimba percussion. The compatibility of the data obtained in this study with data from previous studies provides new insight into the importance of instrument timbre, and it offers a central basis for further research into other aspects of music involved in the activation of emotions.

Keywords: Basic emotions. Instrumental music. Robert Plutchik.

RESUMO

O objetivo deste estudo foi investigar as emoções básicas propostas por Robert Plutchik e o timbre de instrumentos de quatro famílias instrumentais (cordas, eletrofone, percussão e sopro), sem o isolamento de qualquer outra dimensão do som, considerando que estudos prévios salientam a relevância do timbre para a percepção das emoções. Em quatro encontros, 38 participantes em média, de um total de 67, entre 16 e 71 anos e de ambos os sexos, ouviram uma hora de música instrumental solo e preencheram, a posteriori, um questionário que continha as oito emoções básicas, além de compartilharem suas experiências em grupo. O teste H de Kruskal-Wallis apresentou o valor de p = 0,002, indicando que famílias instrumentais diferentes ativam emoções diferentes, de modo a confirmar a hipótese deste estudo. Os resultados revelaram que não há um instrumento que ative uma única emoção e demonstraram uma relação circular entre as famílias instrumentais e entre as emoções: as emoções surpresa e antecipação foram ativadas pelas cordas-cítara alemã e pelo sopro-clarinete; as emoções medo e raiva foram ativadas pelo sopro-clarinete, pelo eletrofone-teremim e pela percussão-marimba; as emoções desgosto e confiança foram ativadas pela percussão-marimba e pelas cordas-cítara alemã; as emoções tristeza e alegria foram ativadas pelas cordas-cítara alemã, pelo eletrofone-teremim e pela percussão-marimba. A compatibilidade dos dados do presente estudo com os dados de estudos prévios permite um novo olhar sobre a importância do timbre instrumental e oferece uma base fulcral para novas investigações de outros aspectos da música, envolvidos na ativação das emoções.

Palavras-chave: Emoções básicas. Música instrumental. Robert Plutchik.

INTRODUCTION

Music is inseparable from human beings. It is present in moments of joy and sadness, in times of illness, wars, spiritual searches, and romantic pursuits. As Morley (2003) discusses in his thesis "The Evolutionary Origins and Archaeology of Music", there is an intertwining of music with the path of humanity.

There is an ever-growing number of studies that reveal connections between music and emotions, as evidenced by an altimetric study of scientific production from 1970 to 2019 conducted by Moreira and Tsunoda (2022), which shows the total number of citations of articles on music and emotions over this period: 27 (1970-1979), 75 (1980-1989), 157 (1990-1999), 710 (2000-2009), 2609 (2010-2019).

Västfjäll (2001) analyzed research showing that music can alter moods and emotions. In another sense, Eerola and Vuoskoski (2013) have emphasized that the study of music and emotion is a field in which much can be advanced to understand all aspects of emotional experiences.

The choice of this research topic was motivated by experiences working with a group of participants created to welcome people diagnosed with cancer, which was later divided into two groups that began to welcome people who suffered from some type of psychological distress.

Previous studies that used music as a therapeutic tool, such as EMDR (Eye Movement Desensitization and Reprocessing), discovered and developed by psychologist Francine Shapiro (Laliotis et al., 2021), and Brainspotting Therapy, discovered and developed by Dr. David Grand (Grand, 2013), also contributed to the choice of this theme.

Interest in this theme arose, in particular, from the possibilities that music offers for collective work, its use by the general population, and the multiple possibilities it offers in the field of research.

Stimuli used in research on music and emotions differ from the instrumental music that is available to the general public through the internet. Hence, the relevance of this study, in addition to providing slightly broader knowledge on the subject, stems from its use of musical pieces available on YouTube.com, which is a highly accessible platform. In this regard, emphasis was also placed on the selection of sound sources. Therefore, in the context of this research, reference to the timbre of a given instrument family is linked to the definition of timbre, which characterizes it as the permanent element, the element that is common to all

sound objects that come from the same instrument (Schaeffer, 2003).

Timbre can structure music and is a characteristic that stands out in auditory events (Menon et al., 2002). Studies on timbre indicate that both cerebral hemispheres are involved in timbre processing. Smalley (1994) questions the viability of a notion of timbre based on his experience with electroacoustic music and states that timbre encompasses all characteristics related to sound, including loudness. Hailstone et al. (2009) found that there is an interrelationship between timbre and the perceptive and affective dimensions.

Emotions and music have been the focus of countless investigations, as highlighted in several systematic reviews. Lun et al. (2024) conducted a bibliometric review covering music therapy and anxiety from 1993 to 2023. Wang, Wu and Yan (2023) carried out a systematic review and meta-analysis on the effect of music therapy on elderly people with depression. Bruna, Fioravante and Kreither (2022) conducted a systematic review where they explored the ability of musical stimuli to generate or modify emotional states. Furthermore, Magraner, Marín-Liébana and Nicolás (2022) examined in a systematic review the effects of music education on the emotional development of adolescents aged ten to 18. And yet there is still limited research on the relationship between emotions and instrument families.

Studies that investigate the ability of a musical instrument to activate emotions can contribute to a greater understanding of the emotions evoked when listening to music, to a greater awareness of the dynamics of emotions, and to the identification of musical stimuli that trigger emotions. This allows for the use musical stimuli according to personal choices.

For this research, the basic emotions proposed by Robert Plutchik (1982, 1991, 2003) were selected. His classification of emotions is currently being used in the field of robotics (Qi et al., 2019) and in several studies on this topic. Plutchik (1982, 2003) proposes the existence of 48 emotions, which form 24 pairs of opposing emotions, resulting in two groups: 12 pairs of basic emotions and 12 pairs of combined emotions. In his view, basic emotions consist of four pairs of emotions in three levels of intensity, all with polar opposites: grief and ecstasy; sadness and joy; pensiveness and serenity; astonishment and vigilance; surprise and anticipation; distraction and interest; hate and terror; anger and fear; annoyance and apprehension; loathing and admiration; displeasure and trust; boredom and acceptance.

Plutchik (2003), a psychologist who developed the psychoevolutionary theory of emotions, assumed that emotions played an adaptive role in helping organisms deal with the main survival issues posed by the environment. His theory was based on the supposition that there are eight basic emotional dimensions, which were defined within an adaptive and evolutionary framework, with bipolar dimensions: destruction (anger, hate) and protection (fear, panic); incorporation (acceptance, trust) and rejection (disgust, revulsion); reproduction (joy, elation) and reintegration (sadness, grief); exploration (interest, expectation) and orientation (surprise, astonishment). In an analogy to the color wheel, he developed the wheel of emotions, in which he demonstrated how emotions are polarized and can vary in degree of intensity and combine to form new emotions.

The instruments selected for this study on the effects of instrumental music on the activation of basic emotions, as conceptualized by Plutchik (1982), were the German zither (a string instrument), the theremin (an electrophone), the marimba (a percussion instrument), and the clarinet (a wind instrument).

The goal was to investigate the effects of exposure to different timbres (specifically from the strings, electrophone, percussion, and wind families) in the activation of Robert Plutchik's basic emotions.

MATERIALS AND METHODS

The study was developed with the use of an exploratory descriptive method, through qualitative and quantitative approaches, and with a non-experimental design. Data were collected within a longitudinal research which involved using music as a therapeutic resource. Particularly for the preparation of this article, and with the aim of providing it with a theoretical background, a literature review on emotions (in Plutchik's perspective) and how they are impacted by music was conducted. Only quantitative data were selected for this study. The ethical principles established for human research, as recommended by the Declaration of Helsinki, were complied with and the study was duly approved by the Ethics Committee under the following protocol: CAAE 58651616.4.0000.0109.

Research began after participants read and signed the Informed Consent Form in which they agreed to participate and authorized the use of the data collected and the sharing of experiences during the process. A total of 67 people participated in the study, with an average of 38 participants on each instrument (strings-German zither, electrophone-theremin, percussion-marimba, and wind-clarinet). Many participants were regulars and participated in more than one meeting, but others failed to attend some meetings due to unforeseen circumstances in their daily lives.

The following criteria were used to include subjects in the research: the person had acknowledged that they were experiencing some sort of psychological distress; they had joined the group out of their own free will; they had to be over 12 years of age and to have time available to participate in the project. The exclusion criteria were: pregnant women; people who needed some form of restraint; and people who were under psychological care from other professionals or who lacked lucidity and the ability to understand the process.

The research aimed to answer some questions: "Is it possible that the musical timbre of a given instrument activates certain emotions in a different way from those operated by other instruments? Thus, would music also have the power to help give new meaning to emotions, processing psychic trauma?"

Data were collected through a questionnaire with multiple answers and open questions. From this point forward, the experiences when listening to the sound of 40 musical instruments were evaluated over a period of 28 months. For this study in particular, four instruments that presented the highest absolute frequencies in basic emotions at the medium level were selected: zither (47), clarinet (46), theremin (41), and marimba (36).

In terms of field research, participants were limited to those already present and those who later signed up for the emotional support and traumatic experience processing group, coordinated by the psychologist who was conducting the research. The research took place at the Psychology Clinic, where the psychologist was already following up the group. Every Wednesday, participants could pick from three shifts to participate in the research: morning, afternoon, and evening. While listening to the music, the recommended response was to remain in a state of observation, mindful of everything that emerged at that moment, including physical sensations, images, memories, experiences, or emotions.

At each meeting, participants were directed to quiet rooms with white walls and dimmed lighting. To listen, each person assumed the most comfortable position for them: either

sitting on sofas, chairs, or lying on mats or beds. After an hour of uninterrupted listening, the researcher gave them instructions to get out of the state they were in. After a short break, participants sat in a circle to fill out the questionnaires and, when everyone had completed this part, the group began sharing their experiences. As soon as the meeting ended, participants placed the questionnaires in a cabinet drawer and then took part in the coffee break, a special moment for everyone to gather and socialize.

At the end of the meeting, the psychologist investigated the state of each participant. Those who were sensitive to the music, presenting some physical discomfort or emotional disturbance, received individualized guidance according to their needs. There were two determining criteria for choosing the music used in the study: it had to be instrumental only and played on a single instrument since the aim was to investigate the possible emotions triggered by instrumental music available on the internet for the general population.

The selected musical pieces for each instrument were played on a portable stereo using a flash drive, at a comfortable sound level, every week and in one-hour sessions. To select the music for each instrument, a search was conducted on YouTube.com. Noises, voices, claps, and pauses were cut using the online app Audio Cutter. The selections had their loudness normalized using the audio editor Audacity. The musical samples that were chosen and used for the study were grouped according to the instruments on which they were played: string instrument (Table 1); electrophone (Table 2); percussion instrument (Table 3); and wind instrument (Table 4).

The results obtained from the questionnaires were entered into the database. First, the absolute frequencies of the emotions were calculated for each of the four musical instruments. After that, the relative statistical frequencies of each emotion were estimated in the same way according to the instrument family.

This study aimed to do a quantitative analysis of the data with a trust level set at 95%. To test the hypotheses in the evaluation of equality or difference in the distribution of the collected data, the Kruskal-Wallis test was considered appropriate, given the significance level of 5%.

The statistical tests were performed with the support of the calculator www.statskingdom.com. The one-way ANOVA test was carried out, which used the Levene test to assess homoscedasticity. The population variances were considered equal (p-value = 0.371). The power of the Levene test was considered weak (0.11). The size of the groups is considered similar; the proportion between the largest and the smallest group was one. The ANOVA test is considered robust to the assumption of homogeneity of variances when the group sizes are similar. For this reason, the non-parametric Kruskal-Wallis ANOVA test was adopted (Vilela, 2014)

RESULTS AND DISCUSSION

Participants were between 16 and 71 years old. The average age was 43 years. The mode was 38 years old. The median was 45 years. In total, 16.42% (11) were male and 83.58% (56) were female.

The relative frequencies in percentages of the instrument families in the activation of Plutchik's (1982) basic emotions at the medium level are presented in Table 5 and Figure 1.

It was found that the emotions of joy and anticipation were activated by the strings; trust was activated by the wind instrument; displeasure was activated by the strings and percussion; fear and anger were activated by the wind instrument and the electrophone; surprise was activated by the strings and sadness was activated by the electrophone. Further details can be found in Figure 1 and Table 6.

The data in Table 6 are illustrated in Figure 2 and refer to the relative frequencies in percentages of Plutchik's (1982) basic emotions at the medium level, activated by the instrument families.

Correlations between pairs of emotions in the Kruskal-Wallis test are listed in Table 7.

The comparison between the pairs of emotions anticipation and fear and between the emotions fear and anger showed highly significant differences in the classification of the means in the Kruskal-Wallis test. The comparison between the pairs of emotions joy and fear, anticipation and trust, and trust and anger showed significant differences in the classification of the means.

Dunn's post hoc test, using a Bonferroni-corrected alpha of 0.0018, indicated that the mean classifications of the pairs of emotions anticipation and fear and fear and anger were significantly different, as shown in Table 8.

Table 9 shows the descriptive analysis data: normality, mean, standard deviation, lower quartile, median, and upper quartile, as well as the sum of the R classification, from the Kruskal-Wallis test.

Sadness was the only emotion that did not meet the criteria for normality set by the Shapiro-Wilk test.

The Kruskal-Wallis H test evidenced a significant difference between the various groups of emotions, with an average classification rank of 9.5 for joy; eight for anticipation; 25.38 for trust; 14.5 for displeasure; 29 for fear; 8.38 for anger; 14 for surprise, and 23.25 for sadness. The degree of freedom was seven. The H test was 22.3 and the p-value = 0.002.

Timbre is a characteristic that allows the identification of a sound source (Caclin et al., 2006). In this study, sound sources refer to musical instruments. As defined by McAdams and Giordano (2014, p. 113), "timbre is a set of auditory attributes that have been characterized through multidimensional scaling of dissimilarity ratings". Furthermore, these authors state that timbre is one of the most important perceptive means for identifying and locating a sound source.

According to Patterson, Gaudraim and Walters (2010, p. 4), "with regard to timbre, instruments in a given family have similar physical shapes, are made of similar materials, and are excited in similar ways". As a result, they produce tones with similar characteristics, thus allowing the recognition of the instrument family.

The following theoretical contributions have investigated, in addition to timbre, the major and minor modes, as well as time and the relationship between time and mode. Eerola, Friberg and Bresin (2013) and Ramos, Bueno and Bigand (2011) defend the additivity criterion to explain the contributions of each aspect of sound.

Studies have found relationships between emotions and the major and minor modes. Laurier, Lartillot, Eerola and Toiviainen (2009) evaluated the emotions of sadness and joy in excerpts from film soundtracks, while Justus, Gabriel and Pfaff (2018) evaluated these same emotions in the clarinet and flute. The results of these studies indicated that joy is activated by the major mode and sadness by the minor mode.

Hunter, Schellenberg, and Schimmack (2008) utilized commercially available recordings in their studies. In their research from 2010, Hunter, Schellenberg, and Schimmack (2010) employed the timbres of various wind instruments (specifically, the clarinet and flute) as well as of string instruments (such as the violin and cello). Similarly, Ladinig and Schellenberg (2012) also worked with commercially available audio. All of these

researchers explored the relationship between the emotions of happiness and the factors of mode and tempo. They concluded that joy and happiness are associated with the major mode and fast tempo, whereas sadness is activated by the minor mode and slow tempo.

Table 1
Selected musical pieces performed on a string instrument (German zither).

Musical piece	Composer YouTube link	Instrumentalist
As Times Goes By	Herman Hupfeld https://www.youtube.com/watch?v=KzrRMui4NA4	Andy Goessling
Asturias	Isaac Albeniz https://www.youtube.com/watch?v=nUuaqPc3th0	Johannes Schubert
Auf der Alm, da gibt's koa Sünd	Traditionelles Volkslied https://www.youtube.com/watch?v=h3UUTtEfpB4	Rudi Knabl (waldteufel78)
Berchtesgadener Jodelwalzer	Rudi Knabl https://www.youtube.com/watch?v=SP9DzA5zWCQ	Dieter Vensler
Die Singende Zither" - Marsch	Georg Freundorfer https://www.youtube.com/watch?v=dEuEtrdRX9o	Dieter Vensler
Ein Abend am Traunsee	Hans Frank https://www.youtube.com/watch?v=rB47XMXWPKA	Dieter Vensler
Fernando played by Etienne de Lavaulx on a 5 chord Zither	Björn Ulvaeus, Benny Andersson and Stig Anderson https://www.youtube.com/watch?v=qaos6xg14So	Etienne de Lavaulx (Testa David)
Glocken aus Salzburg	Rudi Knabl https://www.youtube.com/watch?v=j68g68V7IRY	Dieter Vensler
Grüße aus Faistenau (Marsch)	Dieter Vensler https://www.youtube.com/watch?v=urr-q4w1jPU	Dieter Vensler.
Hallelujah	Leonard Cohen https://www.youtube.com/watch?v=v7Ufvw4WoHs	Ruth B.
Im Prater blüh'n wieder die Bäume	Robert Stolz https://www.youtube.com/watch?v=Y3BJF4SRcas	Anton Karas (Raic Josip)
Largo from the lute concerto in D major	Antonio Vivaldi https://www.youtube.com/watch?v=hyHd4rDUd5g	Etienne de Lavaulx
Ma Liberté	Serge Reggiani https://www.youtube.com/watch?v=wIR-D5kVzfo	Etienne de Lavaulx
Mein Hut der hat drei Ecken	Traditionelles Volkslied https://www.youtube.com/watch?v=HjKUkhhduxI	Rudi Knabl (waldteufel78)
Mein Matzleinsdorf	Anton Karas https://www.youtube.com/watch?v=3LNMB-9IpZM	Anton Karas (Hotwotta)
Memory (from Cats)	Andrew Lloyd Webber https://www.youtube.com/watch?v=G-lv4kPDwUI	Etienne de Lavaulx
River Flows In You	Yiruma (Lee Ru-ma) https://www.youtube.com/watch?v=N2SMtkZk138	Florian Stölzel
Romanze in A-dur op. 27	Otto Erbes https://www.youtube.com/watch?v=dd4zTroAiCM	Johannes Schubert
That Dear Old Song	Anton Karas https://www.youtube.com/watch?v=1DbtFzhsJuE	Anton Karas (Pekka)
Variations on Pachelbel's Canon	Johann Pachelbel https://www.youtube.com/watch?v=UPCGOHjBuNU	Etienne de Lavaulx
Zither Amazing Grace	John Newton https://www.youtube.com/watch?v=cKr_pr2qHCU	Engelbert L. (Robert Leitner)

Source: The author.
Note. This table is based on sources from YouTube.

Table 2
Selected musical pieces performed on an electrophone (theremin).

Musical piece	Composer YouTube link	Instrumentalist
Andrew's Second Public Theremin Performance	Unidentified https://www.youtube.com/watch?v=0QosY0yavTk (0,21s–2min10s)	Andrew – Randy Finch (canal)
Bach: Goldberg - V 25	Johann Sebastian Bach https://www.youtube.com/watch?v=Z-9GGx9p2yo	Grégoire Blanc
Oraison pour Thérémin	Olivier Messiaen https://www.youtube.com/watch?v=t6FXpZw1YOA	Grégoire Blanc
The new old theremin	Unidentified https://www.youtube.com/watch?v=Nj30pD6F2ZU&t=451s (3min40s–9min,06s)	Lydia Kavina
Theremin	Unidentified https://www.youtube.com/watch?v=P-p5glK90gI	Lydia Kavina
Theremin: Le Cygne	Camille St Saens https://www.youtube.com/watch?v=h8L2VBU3PQU	Claude-Samuel Levine

Source: The author.
Note. This table is based on sources from YouTube.

Table 3
Selected musical pieces performed on a percussion instrument (marimba).

Musical piece	Composer YouTube link	Instrumentalist
Bourrée suite en Do Majeur BWV 1009	Johann Sebastian Bach https://www.youtube.com/watch?v=2C01aZEFlrM	Jean Geoffroy
Butterfly	Nils Rohwer https://www.youtube.com/watch?v=Fhpo7cYUVcY	Lorenzo Capasso
Caprice No. 24	Niccolò Paganini https://www.youtube.com/watch?v=1qN_FG1WqdQ	Johan Bridger
Fantasia in D min K397	Wolfgang Amadeus *Mozart* https://www.youtube.com/watch?v=M-0ge5EezkQ	Stanislao M. Spina
Grave sonate en La mineur BWV 1003	J.S Bach Johann Sebastian Bach https://www.youtube.com/watch?v=Ogna4XZvNao	Jean Geoffroy
Land	Takatsugu Muramatsu https://www.youtube.com/watch?v=YSmt-BNM5OU	Lorenzo Capasso
Notenbüchlein für Anna Magdalena	Johann Sebastian Bach https://www.youtube.com/watch?v=t0-ELYT617s	Koen Plaetinck
Over the Rainbow	Harold Arlen https://www.youtube.com/watch?v=JnmXmi4fb-8	Robert Oetomo
Prélude suite en Sol Majeur BWV 1007	Johann Sebastian Bach https://www.youtube.com/watch?v=2C01aZEFlrM	Jean Geoffroy
Toccata and Fugue in D Minor	Johann Sebastian Bach https://www.youtube.com/watch?v=e2SwhD5hbFU	Desmond Chan
Toccata for marimba	Anna Ignatowicz https://www.youtube.com/watch?v=1HZOM488Fv0	Noriko Tsukagoshi

Source: The author.
Note. This table is based on sources from YouTube.

In their studies, researchers found data that support the hypothesis that the perception of tempo precedes the perception of mode. Gerardi and Gerken (1995) used ascending and descending melodies; Gregory, Worrall and Sarge (1996) used the timbre of a piano; and Gagnon and Peretz (2003) used the timbre of a pan flute. Nurezlin (2017) investigated the effect of major and minor modes on the perception of happy and sad emotions, with piano music, in students aged between nine and 17. In this sense, her research presented data that indicate the absence of association and of a significant relationship between the major and minor modes and happy and sad emotions. Nevertheless, the relationship occurs between the fast tempo and happiness and between the slow tempo and sadness. The conclusions of this study show that tempo acts on the effects of major and minor modes on the perception of happy and sad emotions.

When investigating the Greek modes in relation to Plutchik's basic emotions at three intensity levels, Straehley and Loebach (2014) used pure tone sequences generated using a monophonic synthesizer in *Propellerhead's Reason* as musical stimuli. Joy, trust, and surprise stood out in the major modes; fear, anger, displeasure, sadness, and anticipation stood out in the minor modes.

Ramos et al. (2011) investigated the emotions of happiness, serenity, sadness, and fear/anger in the Greek modes using piano timbre at three different tempos (72, 108, and 184 bpm) and reached similar results: happiness was associated with a fast tempo and sadness was associated with a slow tempo. Sadness was replaced by serenity and happiness as the tempo

increased. Only in the Phrygian and Locrian modes, as the tempo increased, did sadness transform into fear/anger.

Table 4
Selected musical pieces performed on a wind instrument (clarinet).

Musical piece	Composer YouTube link	Instrumentalist
12 Duets for clarinets, K 487 – I-VI – ½	Wolfgang Amadeus Mozart https://www.youtube.com/watch?v=B23Ws3iFXG4	Michel Portal, Paul Meyer
Chaconne for clarinet	Johann Sebastian Bach https://www.youtube.com/watch?v=L0_B1GydZpo	Gabriele Galvani
Chromatic Fantasy for solo clarinet – BWV 903.a	Johann Sebastian Bach https://www.youtube.com/watch?v=zEggChq5zgo	John Gibson
Clarinet Duet - Sonatina	Richard Percival https://www.youtube.com/watch?v=u2AYTLU-Zy8	Richard Percival
Duet for two clarinets H 638	Carl Philipp Emanuel Bach https://www.youtube.com/watch?v=rA-RAhm4rQI	John Gibson
E lucevan la Stelle (from Tosca)	Giacomo Puccini https://www.youtube.com/watch?v=hK3aJa05450	José Gonzalez Granero
Partita III for solo violin in E major BWV 1006 - Preludio	Johann Sebastian Bach https://www.youtube.com/watch?v=WtvUv0ycnww	Michael Hodgkins
Quartet for the End of Time, Mvt III – The Abyss of the Birds	Olivier Messiaen https://www.youtube.com/watch?v=gQN58i3IdcY	Kestrel Curro
Sonata for two clarinets	Francis Jean Marcel Poulenc https://www.youtube.com/watch?v=dPBnJWxTU-c	André Moisan, Ronald Van Spaendonck
Sonata for solo violin in g minor, presto	Johann Sebastian Bach https://www.youtube.com/watch?v=3rfZ_A1jGqs	István Kohán
Three Progressive Clarinet Duets n.º 3 in C	Bernhard Henrik Crusell https://www.youtube.com/watch?v=C54791jUcC0	Carlos Casanova e Wolfgang Meyer
Tico-tico	José Gomes de Abreu (Zequinha de Abreu) https://www.youtube.com/watch?v=Eq-Reqh-VGE	Gershwin Sicily Clarinet Quartet

Source: The author.
Note. This table is based on sources from YouTube.

Table 5
Relative frequencies in percentages of instrument families in the activation of Plutchik's (1982) basic emotions at the medium level.

Emotions	Joy	Anticipation	Trust	Displeasure	Fear	Anger	Surprise	Sadness
F.M.I.				Rf (%)				
Strings	35.71	41.67	29.03	33.33	18.92	23.08	33.33	22.22
Electrophone	14.29	8.33	19.35	22.22	29.73	30.77	22.22	33.33
Percussion	21.43	16.67	19.35	33.33	21.62	15.38	16.67	22.22
Wind	28.57	33.33	32.26	11.11	29.73	30.77	27.78	22.22

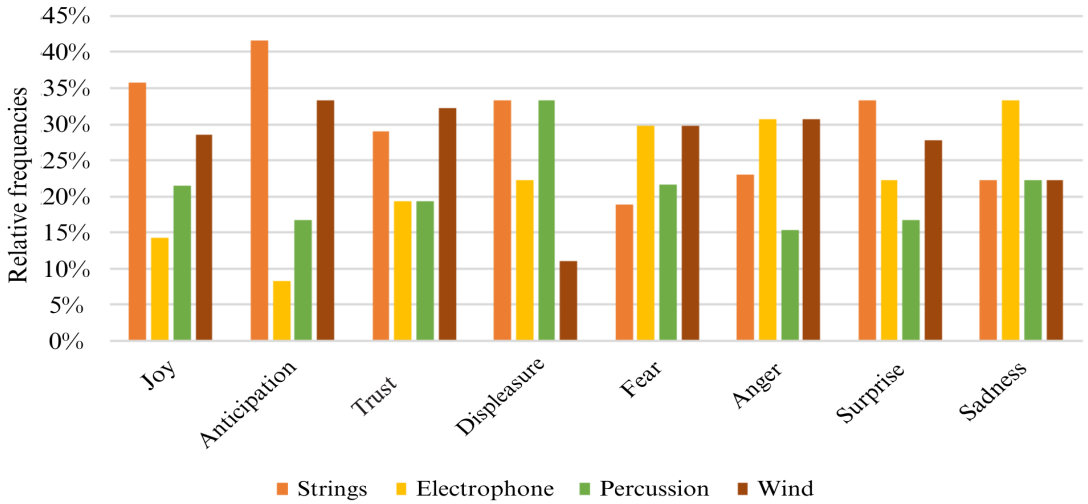
Source: The author.
Notes. F.M.I. – family of musical instruments; Rf (%) – relative frequencies in percentages.

Eerola et al. (2013) manipulated seven musical cues: musical structure, tempo, articulation, register, mode, dynamics, and timbre. Regarding timbre, the instruments used were the flute, the horn, and the trumpet. These authors concluded that the interactions between these cues are insignificant and that the way to explain the emotional effects of these cues is by the additivity criterion. Ramos et al. (2011), in their studies on mode and tempo, have concluded that both make independent contributions concerning emotional evaluation and that the data found fit the additive model.

The results of the aforementioned studies reveal that, regarding the emotions sadness and joy, tempo and mode are factors responsible for the difference in the activation of opposite emotions in the same musical instrument.

To discuss the results found in our research, six studies were selected: Behrens and Green (1993); Mohn, Argstatter and Wilker (2011); Argstatter (2016), who included four groups from different locations, namely: Germany, Norway, South Korea, and Indonesia; Lucassen (2006); Wu, Horner and Lee (2014); Chau, Wu and Horner (2014). Out of these studies, only three had a smaller number of participants than our study did: 25 participants in Lucassen (2006), 32 participants in Wu et al. (2014), and 34 participants in Chau et al. (2014).

Figure 1
Relative frequencies of instrument families in the activation of Plutchik's (1982) basic emotions at the medium level.



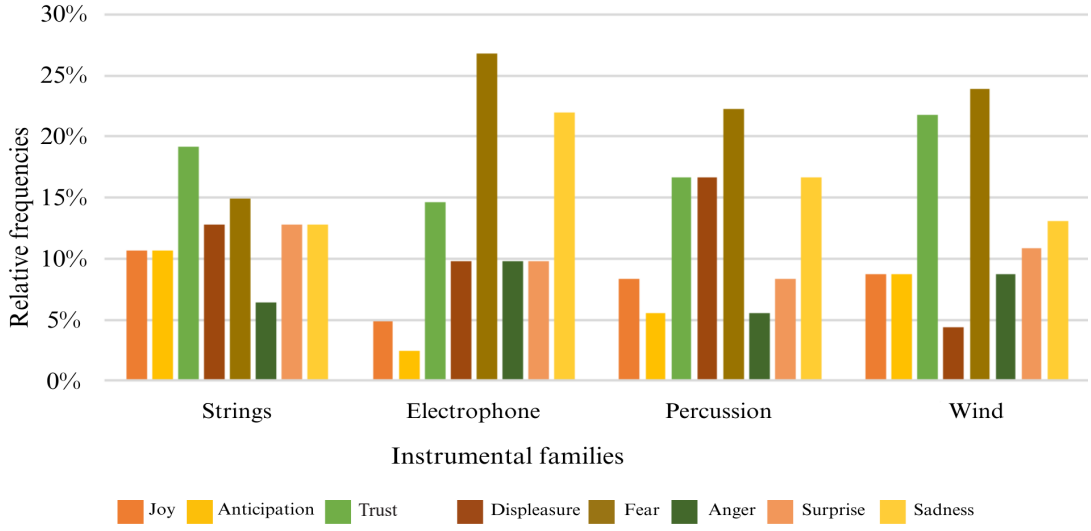
Source: The author.

Table 6
Relative frequencies of Plutchik's (1982) basic emotions at the medium level, activated by the different families of instruments.

F. M. I	Strings	Electrophone	Percussion	Wind
Emotions	Rf (%)			
Joy	10.64	4.88	8.33	8.70
Anticipation	10.64	2.44	5.56	8.70
Trust	19.15	14.63	16.67	21.74
Displeasure	12.77	9.76	16.67	4.35
Fear	14.89	26.83	22.22	23.91
Anger	6.38	9.76	5.56	8.70
Surprise	12.77	9.76	8.33	10.87
Sadness	12.77	21.95	16.67	13.04

Source: The author.
Notes. F. M. I – family of musical instruments; Rf (%) – relative frequencies in percentages.

Figure 2
Relative frequencies in percentages of Plutchik's (1982) basic emotions at the medium level, activated by the different families of instruments.



Source: The author.

Table 7
Correlations between pairs of emotions in the Kruskal-Wallis test.

Pair	MRD	Z	SE	Critical value	p-value	p-value/2
J – ANT	1.5	0.2291	6.5482	20.4546	0.8188	0.4094
J - C	-15.875	2.4243	6.5482	20.4546	0.01534	0.007668
J - D	-5	0.7636	6.5482	20.4546	0.4451	0.2226
J - F	-19.5	2.9779	6.5482	20.4546	0.002902*	0.001451
J - ANG	1.125	0.1718	6.5482	20.4546	0.8636	0.4318
J - SUR	-4.5	0.6872	6.5482	20.4546	0.4919	0.246
J - SAD	-13.75	2.0998	6.5482	20.4546	0.03575	0.01787
ANT - C	-17.375	2.6534	6.5482	20.4546	0.007969*	0.003984
ANT - D	-6.5	0.9926	6.5482	20.4546	0.3209	0.1604
ANT - F	-21	3.207	6.5482	20.4546	0.001341**	0.0006707
ANT - ANG	-0.375	0.05727	6.5482	20.4546	0.9543	0.4772
ANT - SUR	-6	0.9163	6.5482	20.4546	0.3595	0.1798
ANT - SAD	-15.25	2.3289	6.5482	20.4546	0.01987	0.009933
T - D	10.875	1.6608	6.5482	20.4546	0.09676	0.04838
T - F	-3.625	0.5536	6.5482	20.4546	0.5799	0.2899
T - ANG	17	2.5961	6.5482	20.4546	0.009428*	0.004714
T - SUR	11.375	1.7371	6.5482	20.4546	0.08237	0.04118
T - SAD	2.125	0.3245	6.5482	20.4546	0.7455	0.3728
D - F	-14.5	2.2143	6.5482	20.4546	0.0268	0.0134
D - ANG	6.125	0.9354	6.5482	20.4546	0.3496	0.1748
D - SUR	0.5	0.07636	6.5482	20.4546	0.9391	0.4696
D - SAD	-8.75	1.3362	6.5482	20.4546	0.1815	0.09073
F - ANG	20.625	3.1497	6.5482	20.4546	0.001634**	0.0008171
F - SUR	15	2.2907	6.5482	20.4546	0.02198	0.01099
F - SAD	5.75	0.8781	6.5482	20.4546	0.3799	0.1899
ANG - SUR	-5.625	0.859	6.5482	20.4546	0.3903	0.1952
ANG - SAD	-14.875	2.2716	6.5482	20.4546	0.02311	0.01155
SUR - SAD	-9.25	1.4126	6.5482	20.4546	0.1578	0.07889

Source: The author.

Notes. This table is based on calculator www.statskingdom.com; *significant values; **highly significant values; MRD – mean rank difference; J – joy; ANT – anticipation; T – trust, D – displeasure; F – fear; ANG – anger; SUR – surprise; SAD – sadness.

Table 8
Dunn's post hoc-test for multiple comparisons in Kruskal-Wallis.

Emotions	Anticipation	Trust	Displeasure	Fear	Anger	Surprise	Sadness
Joy	1.5	-15.88	-5	-19.5*	1.13	-4.5	-13.75
Anticipation	0	-17.38	-6.5	-21**	-0.38	-6	-15.25
Trust	-17.38	0	10.88	-3.63	17	11.38	2.13
Displeasure	-6.5	10.88	0	-14.5	6.13	0.5	-8.75
Fear	-21**	-3.63	-14.5	0	20.63**	15	5.75
Anger	-0.38	17	6.13	20.63**	0	-5.63	-14.88
Surprise	-6	11.38	0.5	15	-5.63	0	-9.25

Source: The author.

Notes. This table is based on calculator www.statskingdom.com; *significant values; **highly significant values.

In all groups, the number of women was higher than that of men, except for the studies by Wu et al. (2014) and Chau et al. (2014), which did not provide gender-related data. As for the age of the participants, except for the studies by Mohn et al. (2011), which did not include data on the participants' age, participants were younger than those who took part in our study, with an average age of 43.

Of the six studies, three used improvised music with solo instruments, which intended to arouse specific emotions to be recognized by the listeners: Behrens and Green (1993), Mohn et al. (2011) and Argstatter (2016), who included four groups from different locations. Lucassen (2006) used a single piece composed of specific characteristics for the study, which was played on all the instruments evaluated. Wu et al. (2014) used

stimuli consisting of eight sustained sounds of wind and bowed string instruments, which were obtained from the McGill and Prosonus sample libraries, with the exception of the trumpet, which was recorded at the School of Music from the University of Illinois, in Urbana-Champaign. As stimuli in the listening test Chau et al. (2014) used the sounds of non-sustained instruments and the sounds were from the McGill and RWC sample libraries.

Table 9
Normality, mean, standard deviation, quartiles 1, 2, 3, and sum of R ranks.

Emotions	Joy	Anticipation	Trust	Displeasure	Fear	Anger	Surprise	Sadness
Normality	1	0.9379	0.236	0.3818	0.236	0.3818	1	0.01716*
Mean	3.5	3	7.75	4.5	9.25	3.25	4.5	6.75
Standard deviation	1.29	1.83	2.06	1.91	2.06	0.96	1.29	1.5
Q1 - 25%	2.5	1.5	6	3	7.5	2.5	3.5	6
Q2 - 50% (Median)	3.5	3	7.5	5	9.5	3.5	4.5	6
Q3 - 75%	4.5	4.5	9.5	6	11	4	5.5	7.5
Sum of classification (R)	38	32	101.5	58	116	33.5	56	93

Source: The author.

Notes. This table is based on calculator www.statskingdom.com; *did not meet the normality assumption according to the Shapiro-Wilk test.

In all groups, music was recorded to be played for the research participants to listen to in an environment suitable for this activity. Music used as stimuli in the present study, grouped by the instrument on which they were played, were listened to for one hour, in four meetings and on different days. The instruments used in the studies investigated were: strings (electric bass, harp, guitar, violin, and cello); percussion (marimba, timpani, vibraphone, and xylophone); wind instruments (clarinet, bassoon, flute, oboe, saxophone, horn, French horn, trumpet, and tuba); keys (harpsichord and piano).

No previous studies were found that focused specifically on two instruments evaluated in the study that originated this article: German zither–strings and theremin–electrophone. One study included the clarinet and two included the marimba. The German zither represents the strings, the marimba represents the percussion and the clarinet represents the wind instruments. Results were analyzed according to the instruments in each category (string, wind, percussion, and electrophone).

Among all six studies selected for this discussion, the study that originated this article was the only one that offered participants support to help them in processing the emotions activated by musical stimuli on the day of the assessment and that allowed monitoring them during the post-assessment period.

Emotions Activated by the German Zither–Strings Family

In improvisations composed of vocals, timpani, trumpet, and violin to activate fear, anger, and sadness, the violin's results stood out in the score for sadness and fear in relation to the trumpet, timpani, and vocals, coming in third in the activation of anger (Behrens & Green, 1993). In the study that originated this article, there was a similarity in the emotion of fear/surprise, which was in third place in the German zither–strings, both in the category of instruments and in the category of emotions, as well as the low expressivity of anger in the German zither–strings, which came in last place in the classification of instruments.

Lucassen (2006) examined the results that listeners scored in a piece composed to be played on four different instruments and found that the cello was the instrument that most activated sadness. Regarding the other instruments evaluated, the German zither–strings came second in the activation of sadness.

In the article named "Timbre Features and Music Emotion in Plucked String, Mallet Percussion, and Keyboard Tones" (Chau et al., 2014), using as stimuli the sounds of eight instruments, lasting one second, from sample libraries, the participants compared all the instruments in pairs. The plucked string instruments were the harp, the guitar, and the violin. They stood out in activating the emotion of sadness in the following order: harp, guitar, and violin. The harp was the instrument that most activated the emotional state of fear and shyness, and the violin activated laughter. The emotional states of fear, shyness (which is linked to fear), and laughter (which is linked to joy) found similarities in our study: joy occupied the first position in the German zither–strings compared to the other instruments that were evaluated.

Wu et al. (2014) investigated the correspondence between musical emotion and timbre in sustained sounds of musical instruments. The stimuli consisted of sustained sounds from eight musical instruments, including wind and bowed string instruments: bassoon, clarinet, flute, horn, oboe, saxophone, trumpet, and violin. Each subject made pairwise comparisons of all eight instruments. During each test, subjects listened to a pair of sounds from different instruments and were asked to choose which sound most strongly aroused a given emotion. Among the eight instruments, four stood out: horn, clarinet, flute, and violin. The violin stood out for happiness. Regarding the emotional states of fear and joy, the violin ranked third. As evidenced by the aforementioned study, joy/happiness was in harmony with the data found in our research.

When analyzing the results found by Mohn et al. (2011) and Argstatter (2016), one concludes that, significantly, music composed to activate the emotions of happiness, displeasure, sadness, surprise, anger, and fear achieved its purpose as expected, except for displeasure, in the electric bass, which triggered fear and sadness; and in the cello, which triggered anger.

The studies mentioned here, involving research in the string category, point to their great potential for activating the emotions of sadness and joy/happiness and surprise/fear. The findings of these previous studies are in harmony with the results from the study that this article stems from, in the category of German zither–strings, which showed the activation of trust and anticipation, standing out from the other instruments evaluated.

Emotions Activated by the Theremin–Electrophone Family

Andrade (2013) compares the sound of the theremin, in the low register, with the sound of a cello, and, in the acute register, with the sound of a violin (wind instrument). The author describes the theremin as a sentimental instrument that completely

sublimates the expression of complaint or suffering, such as lamentation and moaning. Andrade's (2013) poetic view of the theremin sound corresponds to our findings, which indicated it as the sound that most prominently activated sadness.

Oliveira (2012) investigated the use of the theremin in the soundtracks of science fiction films from the early 1950s. He points out that, from the very beginning, the use of the theremin was linked to senses of strangeness and fear, usually brought about by some abnormal creature or supernatural forces. It thus became representative of the stranger, the grotesque, the abnormal, and of evil. The sound of the theremin, discovered by the film industry, has been fully associated with space travel, alien invasions, monsters, and attacks by grotesque creatures, arousing feelings of mystery, terror, and suspense.

In light of this, one finds a noticeable similarity with our study, which indicates the potential of the theremin sound in activating fear, as it stood out by coming in first in this category on the instruments evaluated. The theremin mainly activated the emotions of fear, anger, sadness, trust, displeasure, and surprise. Its least activated emotions were joy and anticipation.

Emotions Activated by the Marimba–Percussion Family

Lucassen (2006) assessed the scores assigned by listeners to a piece composed to be played on four different instruments and observed that joy (3.41) had the highest score on the marimba. Sadness (1.06) came in second, but with an insignificant score, surpassed by the cello, sax, and piano.

In studies using the sounds of eight instruments (lasting one second) from sample libraries as stimuli, participants compared all the instruments in pairs. Mallet percussion (marimba, xylophone, and vibraphone) was highly rated for emotions of happiness, joy, and laughter, with lower scores than the harpsichord. Percussion also came in second for sadness, preceded only by strings: harp, guitar, and violin (Chau et al., 2014).

In the study that originated this article, sadness ranked second in marimba percussion, reaching the same level found by Chau et al. (2014). In the studies by Chau et al. (2014), joy was surpassed only by the results of the harpsichord sound. Lucassen (2006) found a significant relationship between marimba and joy. In the research on which our analysis was based, considering all instruments that were evaluated, joy ranked third. Fear, trust, and displeasure were emotions that surpassed sadness and joy in marimba percussion.

According to Hornbostel-Sachs, instruments are divided into five categories: idiophones, membranophones, chordophones, aerophones, and electrophones. Idiophones and membranophones are a division of percussion instruments, based on the way the sound is produced (Lee, 2019). The marimba is considered an idiophone, and the tympanum is considered a membranophone. Behrens and Green (1993), in their investigations of improvised music created to activate sadness, anger, and the emotional state of fear, found a relationship between the tympanum and anger, with maximum scores for this emotion. However, no relationships were detected between marimba percussion and anger. Fear, on the other hand, stood out in first place in the marimba percussion in the research that motivated our study, though it was characterized by Plutchik (1982, 2003) as the opposite emotion of anger. In the general classification, fear was in a lower position than the theremin electrophone and the wind-clarinet. Fear in the marimba–percussion idiophone, found in our study, and anger in the tympanum–membranophone percussion, found by Behrens and Green (1993), both point to the possibility that the pair of opposing emotions fear/anger finds similarity in the instruments of the idiophone and membranophone categories.

The marimba–percussion activated the emotions of displeasure (tying with the German zither–strings), trust, fear, sadness, and joy, in a significant way. The emotions with the lowest level of activation were anger, surprise, and anticipation. Previous studies have reported similar results on the emotion of sadness.

Emotions Activated by the Clarinet–Wind Family

To activate the emotions of fear, anger and sadness, Behrens and Green (1993) used three improvisations performed on timpani, trumpet, violin and vocals. In this experiment, they found that the trumpet came in second for all of these emotions.

Lucassen (2006) evaluated the results that listeners scored for a piece he composed to be played on four different instruments and found that the saxophone activated sadness (2.18), joy (1.71), fear (1.12), and anger (0.76). In the investigations that inspired this article, in the category of instruments, the wind–clarinet activated, with emphasis, fear, trust, and sadness.

In the studies conducted by Wu et al. (2014), the following results were found: happiness was activated by the trumpet and clarinet; heroism, by the trumpet; sadness, fear, shyness, and depression were activated by the horn and flute; laughter and joy were activated by the clarinet and trumpet. In our study, joy and surprise ranked second in relation to the clarinet–wind instrument.

Gridley and Hoff (2006) question whether mirror neurons can account for the incorrect attribution of emotions in music. This phenomenon occurs when listeners of avant-garde jazz saxophonists mistakenly attribute feelings of anger to the music they hear, even though the musicians themselves claim to have translated other feelings into their music. One believes that the data found by the authors, which indicate that anger is among the emotions triggered by the wind instrument, may help explain this contradiction.

Wu et al. (2014) found a relationship between the emotional state of being frightened and the sounds of the horn and flute. In the studies by Mohn et al. (2011) and Argstatter (2016), the French horn, in improvised music for surprise, activated happiness. The French horn presented results compatible with those expected for the improvisation of sadness. When it comes to the other instruments evaluated, the clarinet–wind instrument ranked first in the activation of trust, also occupying the first position in the emotions of fear and anger–and tying with the theremin–electrophone. It also ranked second in activating the emotions of joy, anticipation, surprise, and sadness, tying with the strings and percussion. The clarinet–wind significantly activated the emotions of fear and anger, surprise, anticipation, trust, and joy. Its lowest activation potential was in the emotions of sadness and displeasure.

The studies cited here involving investigations into the wind instrument category point to its great potential for activating the emotions of joy, fear, anger, and surprise. The data found in previous studies are in line with our results.

In light of all that was discussed, it is worth noting that, in the case of the research that this paper is based on, data were observed from three angles: in the category of emotions, in the category of instruments, and the classification of emotions according to the four instruments (German zither–strings, theremin–electrophone, marimba–percussion, and clarinet–wind instrument). The German zither activated the emotions of surprise and anticipation, displeasure and trust, sadness, and joy. The emotions least activated by this instrument were fear and anger. The theremin mainly activated the emotions of fear,

anger, sadness, and trust. The marimba–percussion activated the emotions of displeasure (tying with the German zither-strings), trust, fear, sadness, and joy, in a significant way. The emotions with the lowest level of activation were anger, surprise, and anticipation. The clarinet–wind significantly activated the emotions of fear and anger, surprise and anticipation, trust and joy. Its lowest activation potential was observed in the emotions of sadness and displeasure.

The German zither–strings activated the pair of emotions of surprise and anticipation; the marimba–percussion activated displeasure and trust; the theremin–electrophone and the clarinet–wind activated fear and anger. This demonstrated that the same instrument can activate two emotions that are considered as opposites and confirms the theory of polar emotions proposed by Plutchik (2003).

Based on the analysis and discussion of the results, a summary was prepared with the sum of the relative frequencies in percentages of the pairs of opposite emotions, as listed in Table 10.

Table 10
Relative frequencies (%) of pairs of Plutchik's (1982) basic emotions at the medium level, according to families of musical instruments.

Emotions	Strings	Electrophone	Percussion	Wind
	Rf (%)			
Surprise	12.77	9.76	8.33	10.87
Anticipation	10.64	2.44	5.56	8.70
Surprise/anticipation	23.41*	12.20	13.89	19.57
Fear	14.89	26.83	22.22	23.91
Anger	6.38	9.76	5.56	8.70
Fear/anger	21.27	36.59*	27.78	32.61*
Displeasure	12.77	9.76	16.67	4.35
Trust	19.15	14.63	16.67	21.74
Displeasure/trust	31.92*	24.39	33.34*	26.09
Sadness	12.77	21.95	16.67	13.04
Joy	10.64	4.88	8.33	8.70
Sadness/joy	23.41	26.83*	25.00	21.74

Source: The author.
Notes. *Sum of pairs of emotions with significant values; Rf (%) – relative frequencies in percentages.

The results from the study that originated this article revealed that there is no single instrument that activates a single emotion. Data in Table 10 demonstrated a circular relationship between the instrument families and between the emotions: the emotions of surprise and anticipation were activated by the strings and wind instruments; the emotions of fear and anger were activated by the wind instruments, the electrophone, and percussion; the emotions of displeasure and trust were activated by the percussion and strings; the emotions of sadness and joy were activated by the strings, the electrophone, and percussion.

In order to consider the intimate relationship between music and emotion, one hopes that further research on the theory of emotions may shed light on the process of activation of emotions by music. On the other hand, having the power to activate emotional experiences, music serves as a perfect tool for bringing new understandings to the field of the theory of emotions.

This research was conducted under the hypothesis that music from different musical instruments–even without isolating variables–may trigger different emotions. The analysis of the results statistically confirmed this hypothesis, presenting strong evidence that instrumental musical pieces available to the general public point in the same direction as previous research.

CONCLUSION

By selecting an instrument from each instrument family, it was possible to obtain a sample of the activation of emotions, validated by statistical analysis of the data, which were consistent with previous research conducted with various specificity criteria. In a society permeated by music, recognizing the emotions elicited by each type of active instrument family can enable greater emotional awareness in the choice of music, to achieve the desired emotional states and understand the emotions activated by the music that is present in diverse environments.

Our results revealed that no instrument activates a single emotion and also demonstrated that there is a circular relationship between the families of instruments and between the emotions: the emotions of surprise and anticipation were activated by the German zither–strings and the clarinet–wind instrument; the emotions of fear and anger were activated by the clarinet–wind instrument, the theremin–electrophone, and the marimba–percussion. On the other hand, the emotions of displeasure and trust were activated by the marimba–percussion and the German zither–strings; the emotions of sadness and joy were activated by the German zither–strings, the theremin–electrophone, and the marimba–percussion.

The compatibility of the data from this study with those from previous research offers a new perspective on the significance of instrumental timbre. It also provides a foundational basis for further investigations into other elements of music that are involved in the activation of emotions. Nevertheless, this study had limitations, including the absence of an assessment for other characteristics that influence emotional activation, as well as the lack of criteria for music selection. For instance, it did not consider variations in major and minor modes or different tempos on the same instrument.

For future studies, we recommend expanding the sample size to better control for variables in research conducted within

clinical settings. Additionally, we suggest exploring other characteristics of sound, always seeking to identify factors that may determine which pairs of emotions are activated at intense, medium, and light levels. It is also important to identify which factors affect the activation of pairs of opposing emotions.

COMPETING INTERESTS
The authors declare that there are no conflicts of interest.

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The authors declare that they have no financial interests.

AUTHOR CONTRIBUTIONS
Conceptualization: R. C. C. F. *Data curation*: R. C. C. F. *Formal analysis*: R. C. C. F. *Investigation*: R. C. C. F. *Methodology*: R. C. C. F. *Project administration*: R. C. C. F. *Visualization*: R. C. C. F. *Writing the initial draft*: R. C. C. F. *Revision and editing of writing*: R. C. C. F.

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