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REVIEW
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Different Types of Sounds and Their Relationship With the Electrocardiographic Signals and the Cardiovascular System – Review

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Background: For some time now, the effects of sound, noise, and music on the human body have been studied. However, despite research done through time, it is still not completely clear what influence, interaction, and effects sounds have on human body. That is why it is necessary to conduct new research on this topic. Thus, in this paper, a systematic review is undertaken in order to integrate research related to several types of sound, both pleasant and unpleasant, specifically noise and music. In addition, it includes as much research as possible to give stakeholders a more general vision about relevant elements regarding methodologies, study subjects, stimulus, analysis, and experimental designs in general. This study has been conducted in order to make a genuine contribution to this area and to perhaps to raise the quality of future research about sound and its effects over ECG signals.

Methods: This review was carried out by independent researchers, through three search equations, in four different databases, including: engineering, medicine, and psychology. Inclusion and exclusion criteria were applied and studies published between 1999 and 2017 were considered. The selected documents were read and analyzed independently by each group of researchers and subsequently conclusions were established between all of them.

Results: Despite the differences between the outcomes of selected studies, some common factors were found among them. Thus, in noise studies where both BP and HR increased or tended to increase, it was noted that HRV (HF and LF/HF) changes with both sound and noise stimuli, whereas GSR changes with sound and musical stimuli. Furthermore, LF also showed changes with exposure to noise.

Conclusion: In many cases, samples displayed a limitation in experimental design, and in diverse studies, there was a lack of a control group. There was a lot of variability in the presented stimuli providing a wide overview of the effects they could produce in humans. In the listening sessions, there were numerous examples of good practice in experimental design, such as the use of headphones and comfortable positions for study subjects, while the listening sessions lasted 20 min in most of the studies.

Keywords: sound, music, noise, electrocardiogram, electrocardiography, signals

INTRODUCTION

Sound is a mechanical vibration which travels through an elastic medium, as a variation in the pressure exerted on the particles which comprise it (Hewitt, 2015). Sound can be perceived as pleasant or unpleasant, although the boundary that separates music and noise can be very thin and subjective. Most unpleasant sounds are several noise types, and, despite some elements and preferences, pleasant sounds are frequently related to music (Hewitt, 2015). However, the task of differentiating different types of music from noise becomes a question of esthetics, outside the scope of this document. Normally, noise (e.g., traffic and factory noises) is linked to unpleasant sounds; nonetheless, sometimes it is not directly associated with them (white noise or background noise, i.e., ambient sound; McDermott, 2012). On the other hand, music is associated with pleasant sounds (frequently music types as classical, relaxing, or sedative) although they are conditioned by preferences and familiarity (McDermott, 2012) or the listener's cultural association (McDermott et al., 2016). Regarding sound effects, research has shown sound produces effects on human health, in both physically and psychologically (Cowan, 2016). However, the effects on human health have not been fully understood and explained, or how sound may contribute to improve human beings quality of life.

As sound may generate both positive and negative effects on humans (Cowan, 2016), it may also contribute to the treatment of some diseases. It can also be a control instrument in such cases. Therefore, it is worth studying the relationship and effects of sound on human health (Koelsch and Jancke, 2015) and to address this topic in order to understand whether those effects are related to pleasant and unpleasant sounds (McDermott, 2012), or if they respond to specific structures of the sound. In general, previous work has shown that negative effects could be related to exposure to unpleasant sounds, such as noise (Basner et al., 2013), whereas in many cases, the positive effects could be related to interaction or to listening to pleasant sounds, such as music (Trappe, 2012; Mofredj et al., 2016).

Understanding these relationships may make it possible to achieve benefits in several areas. Thus, in health, it may be possible to prevent or reduce harmful effects which may be produced by exposure to harmful noises. Additionally, it may be possible to improve the use of music therapy in several physiological and psychological conditions such as hypertension, cardiovascular disease (Watkins, 1997), migraine, headaches, gastrointestinal ulcers, autism, dementia, depression, pain and stress management, and mental disorders (Montánchez Torres et al., 2016). Another important element of considerable interest currently is the relationship between the brain and the heart. Sound and music research may provide relevant tools to contribute to this topic, since music is a stimulus which can affect the whole brain and promotes interaction between its hemispheres. Improvements in health also have economic benefits, specifically in the health sector, since it is probable that application of sounds and music may able to reduce consumption of some medicines. Similarly, in the IT sector, topics related to emotions and relationships between people and machines may be improved where music could be a way to study them. Also, understanding the relationship between sound and humans and knowing the mechanisms related to how sound affects the human body could improve and promote new applications in emergent technologies, such as the Internet of things and virtual reality.

Some types of sound, such as noise, can also produce harmful effects whereas other types of sound, particularly music, can contribute to improving physiological and psychological health. However, it is not completely clear yet what the effects or the mechanisms of musical sounds are on the human body. Thus, it has been observed that exposure to noise increases BP and HR (Holand et al., 1999; Björ et al., 2007; Raggam et al., 2007; Goyal et al., 2010; Lee et al., 2010; Croy et al., 2013; Kraus et al., 2013; Osiris et al., 2014; Sim et al., 2015; Gallasch et al., 2016; El Aarbaoui et al., 2017), whereas music evokes emotions and has effects on mood, memory, stress levels, and anxiety. The effects of noise have also been seen on several of the body's systems, such as nervous, cardiovascular, respiratory, and endocrine, where it can influence physiological variables, such as respiration, HR, BP, and many more (Koelsch and Jancke, 2015).

Since the early 20th century, the effects produced by sounds, such as music, have been registered using measurement equipment (Hyde, 1924). Current technology can now be used to register the effects produced by different sound stimulus in more detail to move toward a clearer understanding of how the human body is affected by them. Considering the positive and negative effects of sounds on human health, it is important to carry out new research to reduce the negative effects and

Abbreviations: ANS, autonomic nervous system; BP, blood pressure; BPM, beats per minute; DBP, diastolic blood pressure; ECG, electrocardiography – electrocardiogram; EEG, electroencephalography – electroencephalogram; EMG, electromyography – electromyogram; GSR, galvanic skin response; HF, high-frequency power – HRV; HR, heart rate; HRV, heart rate variability; LF, low-frequency power – HRV; NN50, number of adjacent NN intervals which differ by at least 50 ms – HRV; RMSSD, root mean square of successive differences – HRV; SBP, systolic blood pressure; SDNN, SD of RR intervals; VLF, very low frequency power.

understand the ways in which we can take advantage of the positive effects.

Nevertheless, previous research has gaps which need to be addressed. One of the most important is related to the size of the sample. In many cases, the sample is very small and the conclusions do not allow us to make generalizations. However, as in much medical research, this problem has a complex solution. It is difficult to find a sample with all the necessary elements under control and wide homogeneity, such as, age, current diseases, gender, education level, conditions, and lifestyle.

Other difficulties are related to experimental design, specifically the control group. A lot of research has used a control group in silence, but in these situations, the effects obtained in all groups could be not compared since the control group does not have an auditory stimulus (Koelsch and Jancke, 2015). On the other hand, most of the previous reviews related to this topic have included very few studies, so it is difficult to have a wide view their common and uncommon results, and a general vision of their advances and gaps.

Focusing on this review, sound can be classified in different ways according to its characteristics. However, for this paper, it is important to differentiate between sounds that are pleasing to the ear, including music, and noise. In general, although music and noise are mixtures of different frequencies, pleasant sounds and music can be distinguished from noise. In the case of music, there is a certain order, its frequencies are discrete (separable) and rational (their relationships from simple fractions) with a discernible dominant frequency. This can be described mathematically by an infinite sum of sines and cosines multiplied by appropriate coefficients. On the other hand, noise has no set order. Its frequencies are continuous (each frequency will be present in some range) and random (described by a probability distribution) with no discernible dominant frequency.

In this paper, a systematic review is conducted in order to integrate research related to several sound types both pleasant and unpleasant, specifically noise and music. In this review, infrasound and ultrasound were not considered. Moreover, this paper seeks to include as much research as possible to create a more general vision about relevant elements regarding methodologies, study subjects, stimulus, analysis, and experimental designs in general. By doing so, it will be possible to find common elements and gaps in research between studies; common responses between different stimulus. Therefore, this review explores sound as a general element of particular aspects like noise and music types and their effects on physiological and psychological variables.

This approach differs from previous ones because here the stimuli are considered as a sound or auditory entity. In other studies, the effects of particular stimuli, such as noise or music, are only included. However, it is important to have a wide panorama in which it is possible to find common and different aspects among the outcomes and applied stimulus. Hence, this approach could contribute to the development of methodologies of future research related to the effects of sound on the human body.

Rationale

Nowadays, there has been an increase in research to understand the influence of sound, noise, and music on the human body, and in this case, electrocardiographic signals on the cardiovascular system. There is also a trend to study interaction between humans and the machine, where understanding, processing, and classifying emotions play an important role. In this case, music is a relevant tool because it can evoke emotions and memories through auditory memory. Thus, it is necessary to understand how music influences human physiology and psychology.

Objectives

The aim in this review is to understand previous research in this topic, in such a way that the main findings will be highlighted and research gaps and important issues will also be found to be considered in new studies related to this topic.

Research Questions

This review intends to answer the questions below:

1. How sound, noise, and music influence electrocardiographic signals and the cardiovascular system?

Four secondary questions were formulated related to the sample, the sound types, the listening sessions, and the tools for analysis:

1. Which characteristics related to gender, age, health condition, and size have the samples considered in the selected studies?
2. What types of sounds have been used most frequently?
3. What characteristics do the listening sessions have in the selected studies?
4. What mathematical, processing, and analysis tools have been used to analyze the results?

MATERIALS AND METHODS

This section describes the review methodology. Thus, details of participants, interventions, and comparators are shown. In addition, it explains the review protocol, search strategy and register, and inclusion and exclusion criteria. It also lists the data sources, studies' sections, and data extraction.

Participants, Interventions, and Comparators

The search, assessment, and selection of documents were performed independently by four research groups from different universities. In this case, researchers belonging to IPEM Institute for Systematic Musicology, Ghent University, SIDICO and SIFIEX – Universidad del Cauca, and PSI – Universidad del Valle participated in this review. Within each group, there were one or more researchers who participated in search, selection, evaluation, or analysis of documents independently. At the end of the review, a comparison was made between results obtained by each one of the researchers. Decisions were made

about non-concordant results (such as inclusion and exclusion criteria and paper selection) between the research groups. The information was then extracted and synthesized to respond to the formulated research questions. Finally, the results, analysis, and conclusions were organized in a document for the drafting of this article.

Systematic Review Protocol

The systematic review in this paper followed some sequential steps so that they can be reproduced in further research. First, searches about the topic were made in different databases and carried out following the same procedures to establish the same search conditions. Thus, the same filters and inclusion–exclusion criteria were used. Second, classification by categories of searched documents was made to find an answer to the research question raised. At this point, a reading of these documents was done and those which did not satisfy all inclusion criteria were discarded. Next, the documents collected by each group of researchers were collected together in a unique database and duplicates were removed. Finally, the selected documents were read and analyzed independently by each group of researchers and subsequently conclusions were established between them. In this way, the proposed review protocol allows carrying out a more complete search with less risk of bias and which can be reproduced in several contexts.

Search Strategy

The search strategy was made through an initial selection of keywords and construction of three different search equations. In order to search the documents, the following keywords were used: ECG, EKG, electrocardiogram, electrocardiography, electrocardiograph, sound, noise, and music. With keywords, they were constructed three search equations, which are referenced as SE1, SE2, and SE3:

SE1. TITLE-ABS-KEY [sound* AND (electrocardiogra* OR ecg OR ekg)]
SE2. TITLE-ABS-KEY [music* AND (electrocardiogra* OR ecg OR ekg)]
SE3. TITLE-ABS-KEY [nois* AND (electrocardiogra* OR ecg OR ekg)].

In these cases, an asterisk (*) was used as a wildcard element; for instance, "electrocardiogra*" includes results relate to electrocardiogram, electrocardiography, or electrocardiograph. Furthermore, logical operators were used, such as AND to restrict and OR to extend the search. This way, with these keywords, logical operators, and search equations, documents were searched using selected databases.

Search Register

Search register was made individually in each research group, and in the final stage, an average was taken with the registers. Initially, a unique search in Scopus with first search equation was made and 3457 documents published between 1912 and 2017 were found. In this search, it was noted that the first big peak in publications happened in the 1970s, when there was an increase in research into this topic. However, most of the research into this area was published between 1999 and 2017, with a peak in 2015. This paper focuses on only the most recent studies, between 1999 and 2017. Thus, documents published before 1999 were filtered. The amount of papers per year in Scopus related to sound and music is graphed in **Figure 1**.

Inclusion Criteria

In this review, the inclusion criteria relate to: document types, language, and year of publication. Stimuli and variables of interest were considered. Thus, document types included were those produced as original and review papers written in English, Spanish, or Portuguese and published between 1999 and 2017. Additionally, the human population according to the exclusion criteria and studies related to the influence of listening to sound on electrocardiographic signals or variables of cardiovascular system were considered uniquely. Moreover, documents relating to HR and HRV were included. There is a particular interest in research with an experimental design which includes sound reproduction. In these types of studies, subjects hear an acoustic or auditory stimulus and their effects on electrocardiographic signals or the cardiovascular system are studied.

Exclusion Criteria

As in inclusion criteria, document types, population sample, stimuli, and experimental design were considered. Documents with opinions, points of views, or anecdotes were discarded. In addition, studies with subjects younger than 18 years, children, newborns, and fetuses were discarded. Also, research with study subjects in a state of depression or with pathologies such as dementia, cognitive disability, disorders of consciousness, cerebrovascular disease, and vegetative state were discarded. In the same way, studies in which visual stimuli were presented were discarded. Therefore, research which presented stimuli with video or moving images were discarded. Studies which

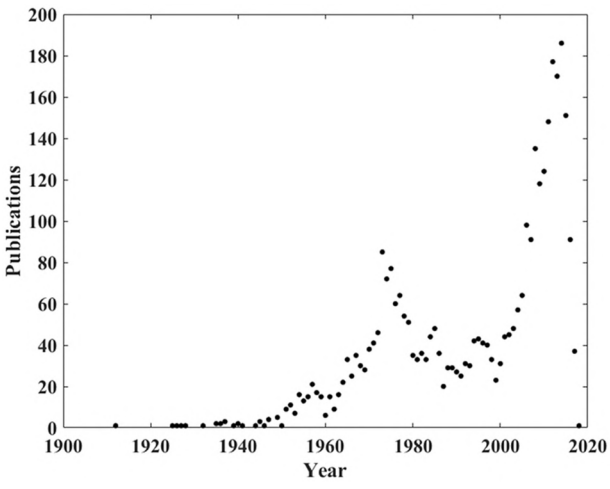

FIGURE 1 | Amount of papers per year in Scopus and related to sound and music.

considered active music therapy where subjects make music in any way were excluded. This way, with these exclusion criteria, researchers excluded research which deviated from the analysis and the conclusions related to the main topic and research question.

Data Sources, Studies' Sections, and Data Extraction

To answer the proposed questions, a search in several scientific literature databases was made. A search was carried out in databases relating to engineering, medicine, and psychology. Databases like IEEE, PubMed, and Frontiers were consulted. Moreover, Scopus as a general database was consulted. Searching databases from different disciplines allowed us to have different viewpoints and perspectives.

RESULTS

After presenting the methods to carry out this review, the obtained results are shown. The selected studies in this review present some characteristics with significant variability. Thus, the observed effects, the most common elements, and some differences between research are presented. First, characteristics of samples used in the selected studies are shown. Then, a section about different stimuli provided in included research is presented. Once the presentation has occurred, the results relating to stimuli show the listening sessions' characteristics. After this, mathematical, processing, and analysis tools often used in selected research are revealed. Lastly, the more common measured variables in this review are presented.

Flow Diagram of the Studies Retrieved for the Review

Figure 2 shows the flow diagram of the studies retrieved for the review from the selected databases with a number of documents.

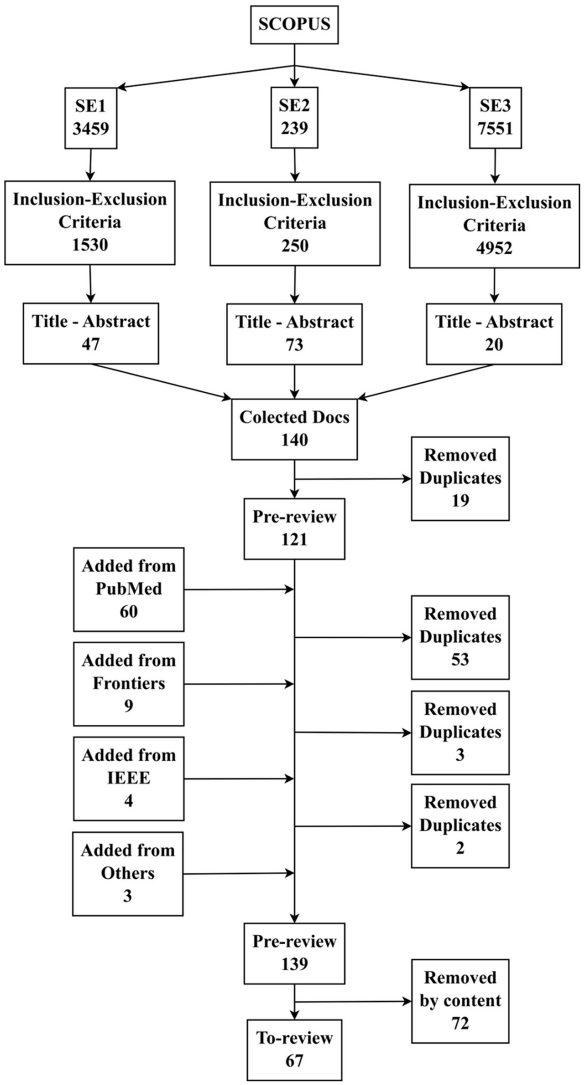

FIGURE 2 | Flow diagram of the studies retrieved for the review.

Effects of Stimuli

Selected research in this review has provided some effects with slight trends between them. Changes observed in measured variables as a result of presented stimuli are shown in **Figure 3**. In this case, general and significant changes in some variables as a product of exposure to stimuli are noted. However, most of these changes did not present a trend in most cases, with the exception of noise studies where both BP (Holand et al., 1999; Tomei et al., 2000; Sancini et al., 2012; Osiris et al., 2014; Sim et al., 2015; Gallasch et al., 2016) and HR (Holand et al., 1999; Raggam et al., 2007; Goyal et al., 2010; Croy et al., 2013; Kraus et al., 2013; Osiris et al., 2014; Gallasch et al., 2016) increase or tended to increase. Additionally, an increased risk of myocardial infarction (MI) was noted as levels of noise intensity increased (Babisch et al., 1993).

Another element to note is related to changes in common variables between different stimuli. HRV (HF and LF/HF) changes with both sound (Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015; Ishimitsu et al., 2017) and noise (Lee et al., 2010; Kraus et al., 2013; Oh et al., 2015; Gallasch et al., 2016; Walker et al., 2016; El Aarbaoui et al., 2017) stimuli, whereas GSR changes with sound (Martin-Soelch et al., 2006; Bidin et al., 2016) and musical (Wagner et al., 2005; Kim and André, 2008; Goshvarpour et al., 2016a) stimuli. Moreover, LF also showed changes with exposure to noise (Lee et al., 2010; Cho et al., 2011; Kraus et al., 2013; Oh et al., 2015; Walker et al., 2016; El Aarbaoui et al., 2017). Here, it is important to note that both sound and musical stimuli can affect memory and emotions. Perhaps they are related to GSR and HRV, particularly HF, which has been linked with the parasympathetic nervous system, whereas noise can affect both stress and anxiety levels; they are possibly related with BP and HR.

Sample Characteristics

In this review, the selected research presents a great diversity of samples. Most frequently characteristics in used samples are shown in **Figure 4**. It is possible to see that most selected

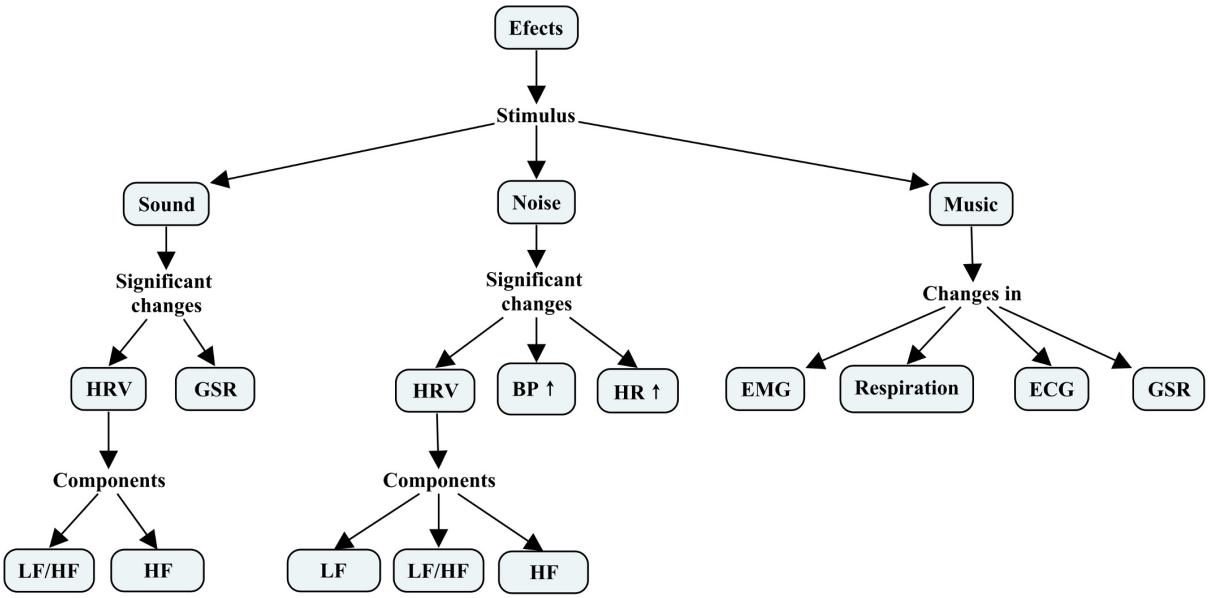

FIGURE 3 | Changes observed in measured variables as a result of presented stimuli. HRV, heart rate variability; GSR, galvanic skin response; LF, low-frequency power – HRV; HF, high-frequency power – HRV; HR, heart rate; BP, blood pressure; ECG, electrocardiography – electrocardiogram; EMG, electromyography – electromyogram.

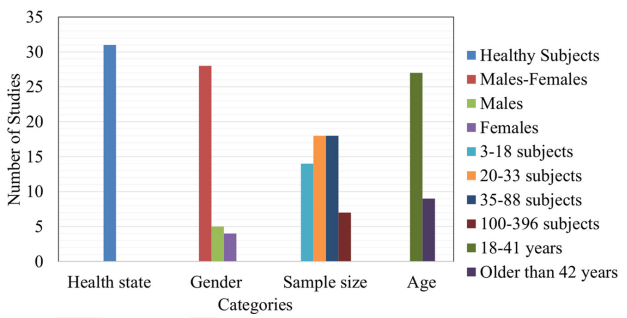

FIGURE 4 | Most frequently characteristics in used samples.

studies used a sample with healthy subjects (Holand et al., 1999; Martin-Soelch et al., 2006; Uclés et al., 2006; Koelsch et al., 2007; Kasprzak, 2010; Lee et al., 2010; Dousty et al., 2011; Sancini et al., 2012; Chen et al., 2014b; Naji et al., 2014b; Pérez-Lloret et al., 2014; da Silva and Backs, 2015; Krabs et al., 2015; Nardelli et al., 2015; Nozaki et al., 2015; Sim et al., 2015; Watanabe et al., 2015; Nakajima et al., 2016; El Aarbaoui et al., 2017; Goshvarpour et al., 2017; Ishimitsu et al., 2017). Samples are also used with a combination of males and females (Martin-Soelch et al., 2006; Björ et al., 2007; Koelsch et al., 2007; Lee et al., 2010; Orini et al., 2010; Kraus et al., 2013; Naji et al., 2014b; da Silva and Backs, 2015; Nozaki et al., 2015; Bidin et al., 2016; El Aarbaoui et al., 2017; Goshvarpour et al., 2017). There were few studies with just males (Tomei et al., 2000; Cho et al., 2011; Gupta and Gupta, 2015; Walker et al., 2016) or just females (Binns-Turner et al., 2011; Rhomberg et al., 2014; Nakajima et al., 2016; Abedi et al., 2017). With respect to the sample size, many of the studies used a size between 20 and 33 (Holand et al., 1999; Thayer and Faith, 2001; Chang et al., 2004; Martin-Soelch et al., 2006; Björ et al., 2007; Kasprzak, 2010; Krantz et al., 2010; Binns-Turner et al., 2011; Cho et al., 2011; Dousty et al., 2011; Croy et al., 2013; Naji et al., 2014b; Pérez-Lloret et al., 2014; Nardelli et al., 2015; Nozaki et al., 2015; Al-Galal et al., 2016; Abedi et al., 2017) or 35 and 88 (Tomei et al., 2000; Kenntner-Mabiala et al., 2007; Koelsch et al., 2007; Raggam et al., 2007; Graham et al., 2009; Orini et al., 2010; Sancini et al., 2012; Rhomberg et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Hajizadeh et al., 2015; Krabs et al., 2015; Sim et al., 2015; Watanabe et al., 2015; Gallasch et al., 2016; Goshvarpour et al., 2016a, 2017; El Aarbaoui et al., 2017) subjects. There were few studies with a sample larger than 100 subjects (Thayer and Faith, 2001; Yuan et al., 2005; Uclés et al., 2006; Goyal et al., 2010; Kraus et al., 2013; Osiris et al., 2014; Tan et al., 2015). Similarly, most of the research considered subjects between 18 and 41 (Yuan et al., 2005; Björ et al., 2007; Kenntner-Mabiala et al., 2007; Goyal et al., 2010; Kasprzak, 2010; Lee et al., 2010; Orini et al., 2010; Cho et al., 2011; Croy et al., 2013; Rhomberg et al., 2014; da Silva and Backs, 2015; Nardelli et al., 2015; Oh et al., 2015; Watanabe et al., 2015; Goshvarpour et al., 2016a, 2017; Ishimitsu et al., 2017), and a few studies used subjects older than 42 (Holand et al., 1999; Gupta and Gupta, 2015) as part of the sample.

Type of Sounds, Noise, and Music

As well as sample characteristics, the studies considered have different types of sound stimuli. Thus, most used stimuli in selected research according to categories of sound (S), noise (N), and music (M) are shown in **Figure 5**. There, it is noted that both

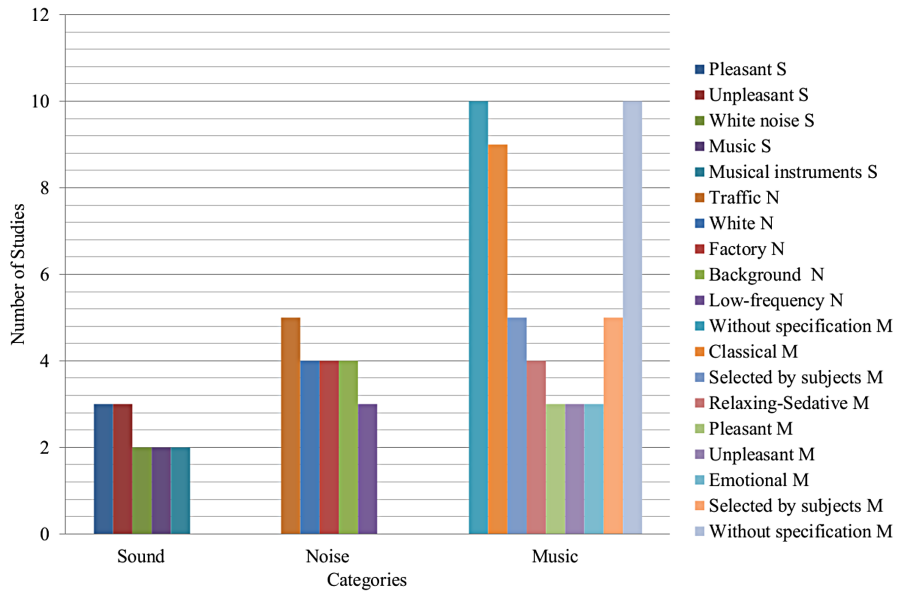

FIGURE 5 | Most used stimulus in selected research according to categories of sound (S), noise (N), and music (M).

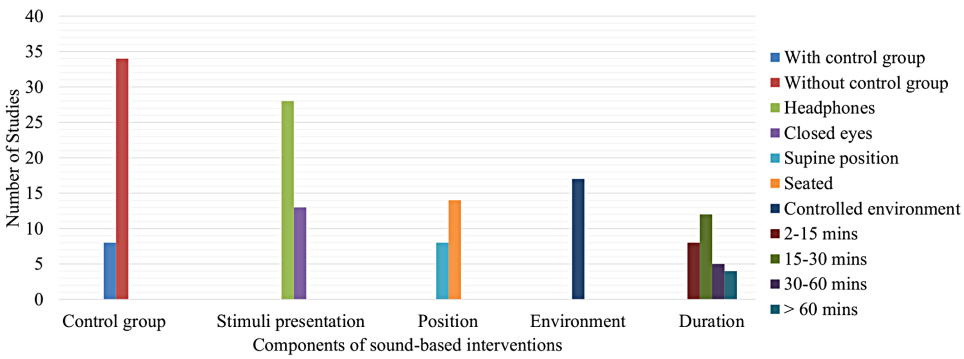

FIGURE 6 | Most frequently characteristics in the listening sessions.

pleasant (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nardelli et al., 2015) and unpleasant (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nardelli et al., 2015) sound were the most used stimuli in sound research; traffic (Yuan et al., 2005; Raggam et al., 2007; Graham et al., 2009; Sim et al., 2015; Gallasch et al., 2016), white (Holand et al., 1999; Uclés et al., 2006; Björ et al., 2007; Lee et al., 2010), factory (Tomei et al., 2000; Goyal et al., 2010; Sancini et al., 2012; Osiris et al., 2014), background (Holand et al., 1999; Chen et al., 2014b; Sim et al., 2015; El Aarbaoui et al., 2017), and low-frequency (Chen et al., 2014a,b; Walker et al., 2016) noises were used with more frequency in noise studies, whereas classical (Thayer and Faith, 2001; Chang et al., 2004; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Binns-Turner et al., 2011; Naji et al., 2014b; Pérez-Lloret et al., 2014; Gruhlke et al., 2015; Nakajima et al., 2016) and relaxing or sedative music (Dousty et al., 2011; Pérez-Lloret et al., 2014; Tan et al., 2015; Al-Galal et al., 2016) were most used in music research. It is important to observe that classical music was the most used stimulus. Some studies considered music selected by study subject, and in many cases, specifications about the music used were not given.

Listening Session Characteristics

In the same way as stimuli and sample, the listening sessions present a wide diversity due to the nature of the research. Most frequently characteristics in the listening sessions are shown in **Figure 6**. In most of the cases, it is not considered a control group (Holand et al., 1999; Wagner et al., 2005; Martin-Soelch et al., 2006; Koelsch et al., 2007; Kim and André, 2008; Lee et al., 2010; Cho et al., 2011; Niu et al., 2014; Osiris et al., 2014; da Silva and Backs, 2015; Nardelli et al., 2015; Nozaki et al., 2015), just few studies had a control group (Tomei et al., 2000; Yuan et al., 2005; Binns-Turner et al., 2011; Sancini et al., 2012; Gupta and Gupta, 2015; Sim et al., 2015; Tan et al., 2015). In much of the research, stimuli were presented through headphones (Holand et al., 1999; Martin-Soelch et al., 2006; Uclés et al., 2006; Björ et al., 2007;

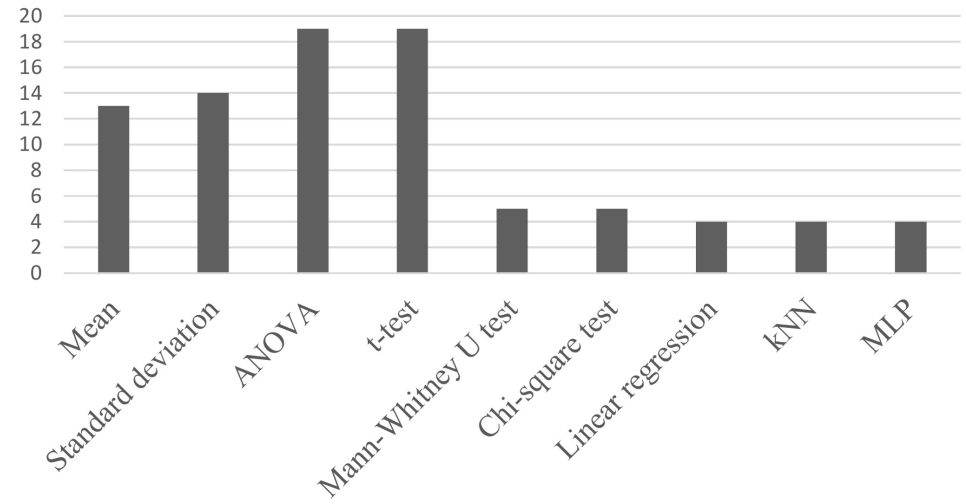

FIGURE 7 | Analysis tools used with most frequency in the selected researches.

Kim and André, 2008; Lee et al., 2010; Naji et al., 2014b; da Silva and Backs, 2015; Nardelli et al., 2015; Oh et al., 2015; Watanabe et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b; Ishimitsu et al., 2017). It is interesting to note that some studies asked subjects to close their eyes (Naji et al., 2014b; Nardelli et al., 2015; Nozaki et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b) to concentrate on presented stimulus. A seated position was also used (Martin-Soelch et al., 2006; Björ et al., 2007; Lee et al., 2010; Cho et al., 2011; Naji et al., 2014b; Pérez-Lloret et al., 2014; Nardelli et al., 2015; Sim et al., 2015; Watanabe et al., 2015; Al-Galal et al., 2016; Nakajima et al., 2016; Ishimitsu et al., 2017) more frequently with respect to a supine position (Holand et al., 1999; Hajizadeh et al., 2015; Goshvarpour et al., 2016a, 2017; Abedi et al., 2017). Moreover, in some cases, some environmental elements were controlled (Björ et al., 2007; Sancini et al., 2012; Naji et al., 2014b; Nardelli et al., 2015; Nozaki et al., 2015; Sim et al., 2015; Watanabe et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016b). Another element to note is related to the length of the listening sessions. Many studies had a listening time between 15 and 30 min (Chang et al., 2004; Uclés et al., 2006; Kasprzak, 2010; Das et al., 2015; Nardelli et al., 2015; Tan et al., 2015; Goshvarpour et al., 2016a,b, 2017). Others lasted between 2 and 15 min (Kim and André, 2008; Krantz et al., 2010; Dousty et al., 2011; Pérez-Lloret et al., 2014; Rhomberg et al., 2014; Hajizadeh et al., 2015; Nakajima et al., 2016; Abedi et al., 2017). Only a few listenings lasted between 30 and 60 min (Cho et al., 2011; Gruhlke et al., 2015; Gupta and Gupta, 2015; Nozaki et al., 2015; Bidin et al., 2016), or more than 60 min (Björ et al., 2007; Binns-Turner et al., 2011; Osiris et al., 2014; Walker et al., 2016).

Mathematical, Processing, and Analysis Tools

In the selected studies for this review, diverse mathematical, processing, and analysis tools were used. The most frequently used analysis tools in the selected studies are shown in **Figure 7**. There, common statistical tools are observed as mean (Tomei et al., 2000; Koelsch et al., 2007; Sancini et al., 2012; Naji et al., 2014b; Niu et al., 2014; Tan et al., 2015; Gallasch et al., 2016; Walker et al., 2016) and SD (Tomei et al., 2000; Koelsch et al., 2007; Krantz et al., 2010; Sancini et al., 2012; Naji et al., 2014b; Niu et al., 2014; Osiris et al., 2014; Walker et al., 2016), which are used frequently; moreover, the most frequent used elements are considered to compare between groups, such as ANOVA (Wagner et al., 2005; Martin-Soelch et al., 2006; Björ et al., 2007; Lee et al., 2010; Wong et al., 2010; Cho et al., 2011; Naji et al., 2014b; da Silva and Backs, 2015; Watanabe et al., 2015) and *t*-test (Holand et al., 1999; Koelsch et al., 2007; Binns-Turner et al., 2011; Sancini et al., 2012; Osiris et al., 2014; Hajizadeh et al., 2015; Bidin et al., 2016). Tools with less frequently used, such as Mann–Whitney *U*-test (Lee et al., 2010; Orini et al., 2010; Chen et al., 2014b; Sim et al., 2015; Tan et al., 2015), Chi-square test (Sancini et al., 2012; Sim et al., 2015; Tan et al., 2015), linear regression (Sancini et al., 2012; Sim et al., 2015), and classification elements as k-nearest neighbors (kNN; Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014) and multilayer perceptron (MLP; Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Al-Galal et al., 2016).

Measured Variables

In this review, studies were selected which researched the effects of music on several physiological variables, especially those related to the cardiovascular system, and psychological variables. The most used physiological and psychological variables in selected researches are shown in **Figure 8**. According to search criteria, it is noted that most studies measured the ECG signal (Wagner et al., 2005; Björ et al., 2007; Koelsch et al., 2007; Kim and André, 2008; Orini et al., 2010; Sancini et al., 2012; Osiris et al., 2014; da Silva and Backs, 2015; Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015; El Aarbaoui et al., 2017) In the same way, in many cases, the variables derived from ECG as

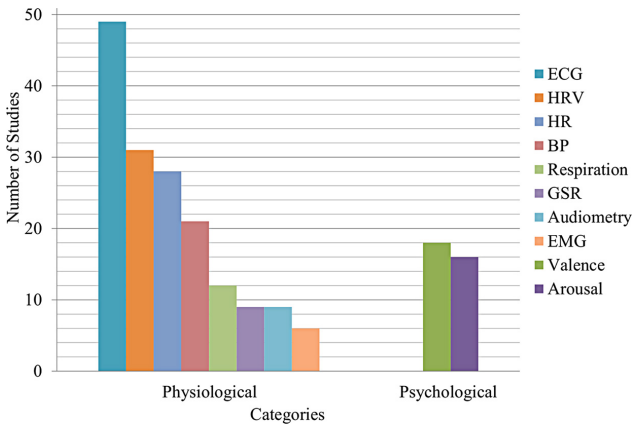

FIGURE 8 | Most used physiological and psychological variables in the selected researches. ECG, electrocardiography – electrocardiogram; HRV, heart rate variability; HR, heart rate; BP, blood pressure; GSR, galvanic skin response; EMG, electromyography – electromyogram.

HR (Martin-Soelch et al., 2006; Kim and André, 2008; Kasprzak, 2010; Lee et al., 2010; Binns-Turner et al., 2011; Cho et al., 2011; Sancini et al., 2012; Kraus et al., 2013; da Silva and Backs, 2015; Nozaki et al., 2015; Goshvarpour et al., 2016a, 2017) and HRV were selected (Björ et al., 2007; Koelsch et al., 2007; Kim and André, 2008; Orini et al., 2010; Kraus et al., 2013; Niu et al., 2014; Nardelli et al., 2015; Sim et al., 2015; Bidin et al., 2016; El Aarbaoui et al., 2017; Ishimitsu et al., 2017). In addition, other physiological variables, such as BP (Kasprzak, 2010; Sancini et al., 2012; Osiris et al., 2014; Rhomberg et al., 2014; Nakajima et al., 2016) and respiration (Wagner et al., 2005; Raggam et al., 2007; Kim and André, 2008; Graham et al., 2009), were contemplated, as well as GSR (Wagner et al., 2005; Martin-Soelch et al., 2006; Kim and André, 2008; Bidin et al., 2016), audiometry (Björ et al., 2007; Sancini et al., 2012), and EMG (Wagner et al., 2005; Martin-Soelch et al., 2006; Kim and André, 2008) with less frequency. On the other hand, the most used psychological variables were valence and arousal (Thayer and Faith, 2001; Martin-Soelch et al., 2006; Kenntner-Mabiala et al., 2007; da Silva and Backs, 2015; Nardelli et al., 2015). Here it is important to note how psychological variables were measured with less frequency than physiological variables. Thus, it is important to consider the psychological elements in future research.

DISCUSSION

Summary of Main Findings

In this section, the main findings according to physiological and psychological responses and its stimuli are presented. It is important to observe that the psychological elements are used in a reduced way respect to physiological variables.

Sample Characteristics

In studies related to sound, most of them considered normal or healthy subjects (Martin-Soelch et al., 2006; Kasprzak, 2010; da Silva and Backs, 2015; Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015; Ishimitsu et al., 2017); with respect to the sample size, most studies had a sample between 10 and 27 subjects (Nardelli et al., 2015; Nozaki et al., 2015; Bidin et al., 2016; Ishimitsu et al., 2017) and others between 30 and 52 subjects (Martin-Soelch et al., 2006; Kasprzak, 2010; Watanabe et al., 2015). Most research considered a sample with a mix of males and females (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nozaki et al., 2015; Bidin et al., 2016), and the subjects aged between 18 and 35 (Kasprzak, 2010; da Silva and Backs, 2015; Nardelli et al., 2015; Watanabe et al., 2015; Ishimitsu et al., 2017). Here, most of the studies did not have a control group (Martin-Soelch et al., 2006; Kasprzak, 2010; da Silva and Backs, 2015; Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015; Bidin et al., 2016; Ishimitsu et al., 2017).

In research related to noise, most considered normal or healthy subjects (Holand et al., 1999; Yuan et al., 2005; Uclés et al., 2006; Raggam et al., 2007; Lee et al., 2010; Cho et al., 2011; Sancini et al., 2012; Croy et al., 2013; Chen et al., 2014a,b; Sim et al., 2015; Walker et al., 2016; El Aarbaoui et al., 2017), and others with hypertension (Holand et al., 1999; Sancini et al., 2012; El Aarbaoui et al., 2017). The sample size varied widely among the studies. There were studies with samples between 10 and 25 subjects (Holand et al., 1999; Björ et al., 2007; Lee et al., 2010; Cho et al., 2011; Croy et al., 2013; Chen et al., 2014a,b; Oh et al., 2015; Walker et al., 2016), between 36 and 88 subjects (Tomei et al., 2000; Raggam et al., 2007; Graham et al., 2009; Sancini et al., 2012; Sim et al., 2015; Gallasch et al., 2016; El Aarbaoui et al., 2017), and between 100 and 396 subjects (Yuan et al., 2005; Uclés et al., 2006; Goyal et al., 2010; Kraus et al., 2013; Osiris et al., 2014). Most of the studies used a mix of males and females (Holand et al., 1999; Yuan et al., 2005; Uclés et al., 2006; Björ et al., 2007; Raggam et al., 2007; Graham et al., 2009; Lee et al., 2010; Croy et al., 2013; Kraus et al., 2013; Oh et al., 2015; El Aarbaoui et al., 2017) and other studies considered only males (Tomei et al., 2000; Cho et al., 2011; Walker et al., 2016). The age variable in the sample was wide, with subjects from 18 to 46 years (Holand et al., 1999; Yuan et al., 2005; Björ et al., 2007; Goyal et al., 2010; Lee et al., 2010; Cho et al., 2011; Croy et al., 2013; Oh et al., 2015), and studies with subjects with broader age ranges, between 18 and 62 years (Graham et al., 2009), 19 and 50 years (Raggam et al., 2007), 17 and 41 years (Uclés et al., 2006), and 34 and 74 years (El Aarbaoui et al., 2017). In these studies, some had a control group (Tomei et al., 2000; Yuan et al., 2005; Goyal et al., 2010; Sancini et al., 2012; Sim et al., 2015) but most did not (Holand et al., 1999; Uclés et al., 2006; Lee et al., 2010; Cho et al., 2011; Croy et al., 2013; Osiris et al., 2014; Oh et al., 2015; Gallasch et al., 2016).

In research related to music, most studies used a sample with normal or healthy subjects (Etzel et al., 2006; Koelsch et al., 2007; Dousty et al., 2011; Naji et al., 2014b; Pérez-Lloret et al., 2014; Rhomberg et al., 2014; Gupta and Gupta, 2015; Krabs et al., 2015; Nakajima et al., 2016; Abedi et al., 2017; Goshvarpour et al., 2017). Moreover, some studies considered subjects with several health conditions (Binns-Turner et al., 2011; Rhomberg et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Krabs et al., 2015). It is important to note that some studies did not provide a subject specification (Thayer and Faith, 2001; Wagner et al., 2005;

Wong et al., 2010; Niu et al., 2014). With respect to sample size, it was noted that the sample size varies between 3 and 18 subjects (Thayer and Faith, 2001; Etzel et al., 2006; Kim and André, 2008; Das et al., 2015; Goshvarpour et al., 2016b; Nakajima et al., 2016), 20 and 28 subjects (Thayer and Faith, 2001; Chang et al., 2004; Krantz et al., 2010; Naji et al., 2014b; Pérez-Lloret et al., 2014; Al-Galal et al., 2016; Abedi et al., 2017), 30 and 44 subjects (Thayer and Faith, 2001; Kenntner-Mabiala et al., 2007; Binns-Turner et al., 2011; Dousty et al., 2011; Rhomberg et al., 2014; Goshvarpour et al., 2016a, 2017), and 60 and 125 subjects (Thayer and Faith, 2001; Koelsch et al., 2007; Orini et al., 2010; Gruhlke et al., 2015; Gupta and Gupta, 2015; Hajizadeh et al., 2015; Krabs et al., 2015; Tan et al., 2015). Moreover, most research has had a sample with age ranges between 18 and 41 years (Chang et al., 2004; Kenntner-Mabiala et al., 2007; Kim and André, 2008; Orini et al., 2010; Dousty et al., 2011; Naji et al., 2014b; Rhomberg et al., 2014; Das et al., 2015; Hajizadeh et al., 2015; Goshvarpour et al., 2016a,b, 2017; Nakajima et al., 2016; Abedi et al., 2017), and other studies had a broader age range, 31–74 years (Etzel et al., 2006; Gupta and Gupta, 2015), 18–65 years (Tan et al., 2015), and 20–57 years (Krantz et al., 2010). Many studies also considered a sample with males and females (Chang et al., 2004; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Koelsch et al., 2007; Krantz et al., 2010; Orini et al., 2010; Naji et al., 2014b; Hajizadeh et al., 2015; Krabs et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017), and others with just males (Gupta and Gupta, 2015) or females (Binns-Turner et al., 2011; Rhomberg et al., 2014; Nakajima et al., 2016; Abedi et al., 2017). In these cases, most research did not have a control group (Chang et al., 2004; Wagner et al., 2005; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Koelsch et al., 2007; Kim and André, 2008; Orini et al., 2010; Wong et al., 2010; Naji et al., 2014b; Niu et al., 2014; Rhomberg et al., 2014; Das et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017; Nakajima et al., 2016; Abedi et al., 2017) and only a few considered a control group (Binns-Turner et al., 2011; Gupta and Gupta, 2015; Tan et al., 2015).

Most studies considered samples with healthy subjects. Therefore, it is interesting to determine whether healthy subjects respond to sound stimuli in different ways to people with health problems and to investigate how health issues can interfere with reactions to sound stimuli. A lack of control group was also noted in most research, probably due to samples with few subjects which could obstruct both data analysis and conclusion extraction related to stimuli effects. Another point to note is that a lot of research had a sample made up of males and females. Therefore, it will be interesting to establish if males and females are affected by sound stimuli in different ways. If that is the case, it should be taken into account in future research. In studies related with music, it is noted in some studies that there was a sample with a wide age range. In such cases, we can consider how the musical perception, appreciation, and hence the registered effects of different people might be affected by their generations' tastes (Yang and Kang, 2005). Thus, sample is an important restriction in experimental design for researches in the health area. A sample could present limitations both in its size as in its characteristics, as age and gender, among others.

Types of Sounds, Noise, and Music

In studies with sounds, it has been observed that most studies used pleasant (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nardelli et al., 2015) and unpleasant sounds (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nardelli et al., 2015), as well as white noise (da Silva and Backs, 2015; Nozaki et al., 2015); however, other sounds, such as neutral (Martin-Soelch et al., 2006), pure tone (da Silva and Backs, 2015), daily life sounds (Nozaki et al., 2015), wasp buzzing (Ishimitsu et al., 2017), engine sound (Ishimitsu et al., 2017), drum sound (Watanabe et al., 2015), Tibetan singing bowls (Bidin et al., 2016), and some types of music, such as classical and house music, have been applied (Ishimitsu et al., 2017). In studies with noise, most studies took into account traffic noise (Yuan et al., 2005; Raggam et al., 2007; Graham et al., 2009; Sim et al., 2015; Gallasch et al., 2016), background noise (Holand et al., 1999; Chen et al., 2014b; Sim et al., 2015; El Aarbaoui et al., 2017), white noise (Holand et al., 1999; Uclés et al., 2006; Björ et al., 2007; Lee et al., 2010), factory noise (Tomei et al., 2000; Goyal et al., 2010; Sancini et al., 2012; Osiris et al., 2014), and low-frequency noise (Chen et al., 2014a,b; Walker et al., 2016). Additionally, noises such as impulsive noise (Holand et al., 1999; Uclés et al., 2006), train noise (Croy et al., 2013; Gallasch et al., 2016), and various noise intensities (Chen et al., 2014a,b) were applied among others (Uclés et al., 2006; Cho et al., 2011; Kraus et al., 2013; Oh et al., 2015; Sim et al., 2015; Walker et al., 2016). In research related to music, most studies used classical music (Thayer and Faith, 2001; Chang et al., 2004; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Binns-Turner et al., 2011; Naji et al., 2014b; Pérez-Lloret et al., 2014; Gruhlke et al., 2015; Nakajima et al., 2016), relaxing or sedative music (Dousty et al., 2011; Pérez-Lloret et al., 2014; Tan et al., 2015; Al-Galal et al., 2016), emotional music (Goshvarpour et al., 2016a,b, 2017), pleasant music (Koelsch et al., 2007; Orini et al., 2010; Krabs et al., 2015), and unpleasant music (Koelsch et al., 2007; Orini et al., 2010; Krabs et al., 2015); also, new age music and Persian music were taken into account (Binns-Turner et al., 2011; Naji et al., 2014b; Pérez-Lloret et al., 2014; Abedi et al., 2017), among other kinds of music or stimulus (Thayer and Faith, 2001; Etzel et al., 2006; Koelsch et al., 2007; Krantz et al., 2010; Orini et al., 2010; Binns-Turner et al., 2011; Dousty et al., 2011; Pérez-Lloret et al., 2014; Rhomberg et al., 2014; Das et al., 2015; Gruhlke et al., 2015; Hajizadeh et al., 2015; Krabs et al., 2015). It is important to note that many studies used music selected by study subjects (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Pérez-Lloret et al., 2014; Rhomberg et al., 2014), and other studies did not give enough information about the music used (Wagner et al., 2005; Koelsch et al., 2007; Kim and André, 2008; Niu et al., 2014; Rhomberg et al., 2014; Tan et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017).

In studies related to sound and noise, it was noted that there was a considerable variety in the stimuli. In these cases, the use of daily life sounds and noises is highlighted since it is possible be aware of their positive or negative consequences on humans. Regarding research carried out with music, it is important to note how several types of music have been used, including music selected by study subjects. It is worth mentioning

that in studies with little information about the music used, it is hard to associate it with the registered effects. At this point, this paper encourages future research to promote the use of artificial and electronic music, where possible to control its components efficiently. That way, conclusions regarding the produced effects could provide more information and increase confidence levels. Hence, stimuli used in the selected studies present a great variety stimulus providing a general vision about its effects on the study subjects.

Listening Session Characteristics

In studies associated with sound, most of them used headphones (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nardelli et al., 2015; Watanabe et al., 2015; Ishimitsu et al., 2017), in other studies, subjects were seated (Martin-Soelch et al., 2006; Nardelli et al., 2015; Watanabe et al., 2015; Ishimitsu et al., 2017), and some research controlled some environmental elements (Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015). Moreover, listening sessions lasted between 20 and 60 min (Kasprzak, 2010; Nardelli et al., 2015; Nozaki et al., 2015; Bidin et al., 2016).

In studies with noise, most used headphones (Holand et al., 1999; Uclés et al., 2006; Björ et al., 2007; Lee et al., 2010; Oh et al., 2015) and others used loudspeakers (Croy et al., 2013; Gallasch et al., 2016; Walker et al., 2016). In some studies, subjects were seated (Björ et al., 2007; Lee et al., 2010; Cho et al., 2011; Sim et al., 2015; Gallasch et al., 2016). Many studies had a control for environmental elements (Tomei et al., 2000; Björ et al., 2007; Sancini et al., 2012; Croy et al., 2013; Sim et al., 2015; Gallasch et al., 2016; Walker et al., 2016). With respect to the length of the listening sessions, most of researches had a period between 20 and 100 min (Uclés et al., 2006; Cho et al., 2011; Chen et al., 2014a,b; Gallasch et al., 2016; Walker et al., 2016).

In studies related to music, most of them used headphones (Chang et al., 2004; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Kim and André, 2008; Binns-Turner et al., 2011; Dousty et al., 2011; Naji et al., 2014b; Rhomberg et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Hajizadeh et al., 2015; Krabs et al., 2015; Tan et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017; Nakajima et al., 2016). Here, it is important to note that some studies did not provide information about stimulus presentation (Thayer and Faith, 2001; Wagner et al., 2005; Wong et al., 2010; Niu et al., 2014; Das et al., 2015; Abedi et al., 2017). With respect to the stimulus volume, in some cases, the amplifier volume was controlled by the subject (Binns-Turner et al., 2011; Naji et al., 2014b; Goshvarpour et al., 2016b, 2017; Abedi et al., 2017) whereas in other cases, it was fixed or controlled by the research members (Etzel et al., 2006; Krantz et al., 2010; Orini et al., 2010; Dousty et al., 2011; Pérez-Lloret et al., 2014). With regard to the subjects' position, in many cases, subjects were in supine position (Chang et al., 2004; Dousty et al., 2011; Hajizadeh et al., 2015; Krabs et al., 2015; Goshvarpour et al., 2016a, 2017; Abedi et al., 2017) but in other cases were seated (Naji et al., 2014b; Pérez-Lloret et al., 2014; Gupta and Gupta, 2015; Al-Galal et al., 2016; Nakajima et al., 2016). One element to note is that, in many studies, subjects had their eyes closed (Orini et al., 2010; Dousty et al., 2011; Naji et al., 2014b; Gupta and Gupta, 2015; Hajizadeh et al., 2015; Krabs et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017; Abedi et al., 2017). Also, some studies controlled the environmental elements (Dousty et al., 2011; Naji et al., 2014b; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017; Nakajima et al., 2016). In many cases, the listening period was between 3 and 13 min (Kim and André, 2008; Krantz et al., 2010; Dousty et al., 2011; Pérez-Lloret et al., 2014; Rhomberg et al., 2014; Hajizadeh et al., 2015; Nakajima et al., 2016; Abedi et al., 2017), and also, in other cases, this period was longer, between 20 and 60 min (Chang et al., 2004; Das et al., 2015; Gruhlke et al., 2015; Gupta and Gupta, 2015; Tan et al., 2015; Goshvarpour et al., 2016a,b, 2017).

In this section, it was noted that most studies used headphones to present stimuli. This is a good method since headphones reduced the perception of external stimuli which could negatively affect research outcomes. Additionally, through the use of headphones, the stimuli are presented in a more intimate way. With respect to the position of study subjects, it is critical that their position allows them to concentrate or focus in the listening of the stimuli comfortably. Thus, the seated position and the supine position used in many music studies are ideal. So, where possible it is also important to control environmental elements in the experiment room in such a way that it does not distract people in the study, as happened in some selected studies. It is important to note that in some studies with music, subjects had their eyes closed, eliminating the effects of visual stimuli. This is a valuable element to replicate in future studies related to sound stimuli. Finally, it is noted that most of the selected studies had a minimum listening time session of 20 min. This is a crucial factor which requires critical assessment and discussion between specialists in the health area to determine the minimum listening session time to guarantee the presence of the effects produced by sound stimuli.

Mathematical, Processing, and Analysis Tools

Regarding studies with sound, it was noted that ANOVA (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Watanabe et al., 2015) and the Wilcoxon signed-rank test (Nardelli et al., 2015; Watanabe et al., 2015; Bidin et al., 2016) were the most used statistics tools. In studies related to noise, the most used analysis tools were ANOVA (Holand et al., 1999; Björ et al., 2007; Raggam et al., 2007; Lee et al., 2010; Cho et al., 2011; Croy et al., 2013; Chen et al., 2014a,b; Gallasch et al., 2016), *T*-test (Holand et al., 1999; Tomei et al., 2000; Yuan et al., 2005; Sancini et al., 2012; Croy et al., 2013; Osiris et al., 2014), Chi-square test (Tomei et al., 2000; Yuan et al., 2005; Sancini et al., 2012; Sim et al., 2015), linear regression (Yuan et al., 2005; Graham et al., 2009; Sancini et al., 2012; Sim et al., 2015), Mann–Whitney *U*-test (Lee et al., 2010; Chen et al., 2014b; Sim et al., 2015), and common statistical elements, such as mean (Tomei et al., 2000; Sancini et al., 2012; Gallasch et al., 2016; Walker et al., 2016) and SD (Tomei et al., 2000; Sancini et al., 2012; Osiris et al., 2014; Walker et al., 2016). In research related to music, several statistical tools were taken into account, among them ANOVA (Wagner et al., 2005; Kenntner-Mabiala et al., 2007; Wong et al., 2010; Naji et al., 2014b; Pérez-Lloret et al., 2014; Gruhlke et al., 2015; Krabs et al., 2015), *T*-test (Koelsch et al., 2007; Binns-Turner et al.,

2011; Rhomberg et al., 2014; Gupta and Gupta, 2015; Hajizadeh et al., 2015; Tan et al., 2015) and paired *t*-test (Krantz et al., 2010; Dousty et al., 2011; Gruhlke et al., 2015; Hajizadeh et al., 2015), Shapiro–Wilk statistic (Krabs et al., 2015; Tan et al., 2015; Nakajima et al., 2016), and common elements in statistics, such as mean (Chang et al., 2004; Koelsch et al., 2007; Dousty et al., 2011; Naji et al., 2014b; Niu et al., 2014; Pérez-Lloret et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Tan et al., 2015) and SD (Chang et al., 2004; Koelsch et al., 2007; Krantz et al., 2010; Dousty et al., 2011; Naji et al., 2014b; Niu et al., 2014; Pérez-Lloret et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Tan et al., 2015). Moreover, some elements of machine learning and digital signal processing were employed, including kNN (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014), MLP (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Al-Galal et al., 2016), and support vector machine (Naji et al., 2014b; Abedi et al., 2017; Goshvarpour et al., 2017).

Most of the studies presented in this section used ANOVA to analyze data along with some classic statistical tools such as *T*-test. However, in studies with music, other analysis elements, such as machine learning and digital signal processing, were used. This trend in the use of analysis tools is in great part due to the fact that many studies in health are developed using classic statistics. This paper encourages the application of new data analysis techniques in future research relating to sound stimuli and its effects, such as machine/statistical learning and data mining.

Measured Variables

With regard to measured variables, because this review was focused on ECG signals, most studies considered ECG signals and some derived variables as HR and HRV. Thus, ECG was measured in studies with sound (da Silva and Backs, 2015; Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015), noise (Tomei et al., 2000; Yuan et al., 2005; Uclés et al., 2006; Björ et al., 2007; Raggam et al., 2007; Graham et al., 2009; Goyal et al., 2010; Lee et al., 2010; Cho et al., 2011; Sancini et al., 2012; Croy et al., 2013; Chen et al., 2014a,b; Osiris et al., 2014; Oh et al., 2015; Gallasch et al., 2016; Walker et al., 2016; El Aarbaoui et al., 2017), and music (Thayer and Faith, 2001; Chang et al., 2004; Wagner et al., 2005; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Koelsch et al., 2007; Kim and André, 2008; Krantz et al., 2010; Orini et al., 2010; Wong et al., 2010; Binns-Turner et al., 2011; Dousty et al., 2011; Naji et al., 2014b; Niu et al., 2014; Pérez-Lloret et al., 2014; Rhomberg et al., 2014; Das et al., 2015; Hajizadeh et al., 2015; Krabs et al., 2015; Tan et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017; Nakajima et al., 2016; Abedi et al., 2017). In the same way, HR was present in research with sound (Martin-Soelch et al., 2006; Kasprzak, 2010; da Silva and Backs, 2015; Nozaki et al., 2015; Bidin et al., 2016), noise (Holand et al., 1999; Raggam et al., 2007; Goyal et al., 2010; Lee et al., 2010; Cho et al., 2011; Sancini et al., 2012; Croy et al., 2013; Kraus et al., 2013; Walker et al., 2016), and music (Chang et al., 2004; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Kim and André, 2008; Binns-Turner et al., 2011; Dousty et al., 2011; Rhomberg et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Krabs et al., 2015; Tan et al., 2015; Goshvarpour et al., 2016a, 2017; Nakajima et al., 2016). It also occurred with HRV in research in sound (Nardelli et al., 2015; Nozaki et al., 2015; Watanabe et al., 2015; Bidin et al., 2016; Ishimitsu et al., 2017), noise (Björ et al., 2007; Lee et al., 2010; Cho et al., 2011; Kraus et al., 2013; Chen et al., 2014a,b; Oh et al., 2015; Sim et al., 2015; Gallasch et al., 2016; Walker et al., 2016; El Aarbaoui et al., 2017), and music (Chang et al., 2004; Etzel et al., 2006; Koelsch et al., 2007; Kim and André, 2008; Krantz et al., 2010; Orini et al., 2010; Naji et al., 2014b; Niu et al., 2014; Pérez-Lloret et al., 2014; Das et al., 2015; Krabs et al., 2015; Tan et al., 2015; Nakajima et al., 2016; Goshvarpour et al., 2017). In these cases, it is can be seen that ECG is the measured variable, which has a broader frequency in most research.

Respiration was another variable measured in a lot of research. This variable was measured both in studies with noise (Raggam et al., 2007; Graham et al., 2009; Goyal et al., 2010; Croy et al., 2013), such as music (Thayer and Faith, 2001; Wagner et al., 2005; Etzel et al., 2006; Kenntner-Mabiala et al., 2007; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014). Although, respiration was observed in much research it was not as frequent as ECG or its derived variables.

In addition to respiration and ECG variables, other elements were considered for measuring or observation. Thus, in studies related to noise, the variables BP (Holand et al., 1999; Tomei et al., 2000; Goyal et al., 2010; Lee et al., 2010; Sancini et al., 2012; Chen et al., 2014a,b; Osiris et al., 2014; Sim et al., 2015; Gallasch et al., 2016; Walker et al., 2016) and electrooculography (Holand et al., 1999; Uclés et al., 2006; Croy et al., 2013) were used. Moreover, it is important to note that some research used audiometry (Tomei et al., 2000; Björ et al., 2007; Lee et al., 2010; Cho et al., 2011; Sancini et al., 2012; Croy et al., 2013; Chen et al., 2014a,b; Gallasch et al., 2016). Additionally, in studies with music, the measured variables, such as GSR (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014; Krabs et al., 2015; Goshvarpour et al., 2016a,b), EMG (Thayer and Faith, 2001; Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014), and BP (Chang et al., 2004; Binns-Turner et al., 2011; Rhomberg et al., 2014; Gruhlke et al., 2015; Nakajima et al., 2016), were used.

Most studies took into account the measurement of physiological variables as well as some psychological elements, such as valence and arousal. Thus, valence (Thayer and Faith, 2001; Wagner et al., 2005; Kenntner-Mabiala et al., 2007; Koelsch et al., 2007; Kim and André, 2008; Orini et al., 2010; Wong et al., 2010; Naji et al., 2014a,b; Niu et al., 2014; Krabs et al., 2015; Nardelli et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b) and arousal (Thayer and Faith, 2001; Wagner et al., 2005; Kenntner-Mabiala et al., 2007; Kim and André, 2008; Wong et al., 2010; Naji et al., 2014a,b; Niu et al., 2014; Krabs et al., 2015; Nardelli et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b) were measured in studies with music. These variables were also measured in studies with sound (Martin-Soelch et al., 2006; da Silva and Backs, 2015; Nardelli et al., 2015). In this way, these studies reveal that both valence and arousal represent important variables relating to human psychology.

In this point, it is important to note that many studies where HRV was considered used some elements relating to digital signal processing, due to the natural analysis of this signal. Thus, in

many cases elements such as Fourier or wavelet transform, power spectrum, linear, and frequency analysis are used. Finally, with respect to ECG acquisition, in most cases where the ECG signal was used, it was acquired from a device with three electrodes (Holand et al., 1999; Etzel et al., 2006; Martin-Soelch et al., 2006; Uclés et al., 2006; Raggam et al., 2007; Graham et al., 2009; Goyal et al., 2010; Croy et al., 2013; Nardelli et al., 2015; Oh et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017; Abedi et al., 2017).

Physiological Variables

In studies related to sound, it is noteworthy that there are just a small number of studies, but they vary significantly. In these cases, they considered different sound stimuli and produced responses which differ from each other. As a result, it is a difficult task to find both common outcomes and relationships between effects and observed variables. However, some common elements related to HRV were observed. Thus, it should be emphasized that both HF (Nardelli et al., 2015; Nozaki et al., 2015; Ishimitsu et al., 2017) and LF/HF ratio (Watanabe et al., 2015; Ishimitsu et al., 2017) were shown as indicators for different stimuli. In addition, it was noted that GSR (Martin-Soelch et al., 2006; Bidin et al., 2016) represents an element which presents variation against diverse sound stimuli. Here, a lack of clarity regarding influence of auditory stimuli on HR is noted. Hence, in studies relating to sound, it is evidenced that both HRV and GSR present variations influenced by sound stimuli, but HR is an element on which further research is worth being carried out.

From studies reviewed on the influence of noise, the results found do not establish a trend. Nevertheless, in this case, there are some repetitive elements between some studies. Thus, it can be seen that BP (SBP or DBP) increases or tends to increase (Holand et al., 1999; Tomei et al., 2000; Goyal et al., 2010; Sancini et al., 2012; Osiris et al., 2014; Sim et al., 2015; Gallasch et al., 2016). This behavior is also evident in HR (Holand et al., 1999; Raggam et al., 2007; Goyal et al., 2010; Croy et al., 2013; Kraus et al., 2013; Osiris et al., 2014; Gallasch et al., 2016). Other elements that have shown changes regarding noise exposure are HF, LF, and LF/HF ratio. Nonetheless, in HF and LF, there is no marked trend between studies. Thus, the LF/HF ratio has shown an increase (Lee et al., 2010; Kraus et al., 2013; El Aarbaoui et al., 2017) compared to noise exposure. On the other hand, in HF, there was both an increase (Lee et al., 2010; Cho et al., 2011; Oh et al., 2015; El Aarbaoui et al., 2017) and a decrease (Kraus et al., 2013; Gallasch et al., 2016; Walker et al., 2016) with exposure to noise. This same behavior is seen in LF, where (Lee et al., 2010; El Aarbaoui et al., 2017) a decrease is shown (Cho et al., 2011; Oh et al., 2015; Walker et al., 2016). Thus, these studies demonstrate that both BP and HR are affected by noise, but outcomes related with HRV elements are not clear. Despite these findings regarding noise and its effects, it is necessary to expand research about the psychophysiological response of the stress produced by noise.

Regarding research related to music, studies classifying emotions evoked by listening to music show further evidence of a relationship between emotions, music, and some physiological variables. For classification, the physiological variables which were considered with more frequency were ECG signal (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Naji et al., 2014b; Niu et al., 2014; Hajizadeh et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b) and GSR (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014; Goshvarpour et al., 2016a,b), as well as EMG and respiration (Wagner et al., 2005; Kim and André, 2008; Wong et al., 2010; Niu et al., 2014), in addition to others which were used with a lesser extent. Consequently, these variables are linked very much with emotions in general as well as listening to music.

In addition to ECG, GSR, EMG, and respiration, it should be noted that the studies observed do not allow us to establish accurately if music is an influence on HR or HRV. Therefore, it was noted that HR presented an increase (Kenntner-Mabiala et al., 2007; Krabs et al., 2015) and also a reduction (Chang et al., 2004; Etzel et al., 2006) in different research. In this case, it is difficult to draw a conclusion on this point since stimuli between the studies had different characteristics. This is therefore another element to be developed in future research.

Besides ECG (the most frequently acquired signal), there were other registers, such as respiration and BP. Therefore, it is important to consider ECG signals and other variables related directly with the cardiovascular system, as well as others which are not, such as GSR. All registers may support or to contribute to findings in the variable of interest. Thus, with more registers covering the entire cardiovascular system, there will be a greater possibility of finding a relationship between cause and effect in a particular variable, such as ECG in this particular case.

Psychological Variables

As well as physiological variables, it is important to know how psychological variables are affected by auditory stimuli. In this review, it was noted that valence and arousal were the psychological variables used the most to model emotional states evoked by sounds and music. However, they were not considered in studies with noise. In addition to these variables, other elements such as personality and anxiety were considered to a lesser extent. Thus, although psychological elements have an important role in auditory perception, they had been not included in research in a rigorous way.

Valence or arousal dimensions were used to classify emotions (Wagner et al., 2005; Kim and André, 2008; Naji et al., 2014a,b; Niu et al., 2014; Nardelli et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b). Some studies showed which emotion differentiation was easier in arousal than valence dimension (Wagner et al., 2005; Niu et al., 2014). Another aspect to note was that pain perception can be affected by musical tempo through the arousal of the listener. Pain ratings were highest for fastest tempos (Kenntner-Mabiala et al., 2007). Thus, emotions may be represented throughout valence and arousal. Moreover, music tempo might influence the perception of pain.

With respect to personality, emotions, and physiological response to auditory stimuli (Martin-Soelch et al., 2006), it was observed that the personality trait anxiety had an influence in response to affective stimuli, whereas in (da Silva and Backs, 2015) interaction of affective valence, sounds with cardiac response were observed. In the same way, in this case (Koelsch et al., 2007), a correlation between emotional personality and

ECG amplitude was found. In addition to ECG (Al-Galal et al., 2016), EEG signals were registered where both ECG and EEG changed emotional valence from negative to positive after listening to Quranic recitation. However, relaxing music changed arousal state and valence in EEG in a positive way, whereas relaxing music produced a negative change in the ECG signal. As a result, these studies show an influence of auditory stimuli on cardiac function, where in some cases, an ECG signal was registered throughout. Elements, such as emotions and personality, may also affect the ECG signal. In this sense, there could be evidence of a relationship between the brain and the heart.

Finally, it is important to note that (Kim and André, 2008) the arousal change was related to GSR and EMG, whereas valence was linked to ECG and respiration. On the other hand, in Krabs et al. (2015), it was found that the emotional valence of music affects ANS activity. In these cases, it is noted how valence and arousal may affect the physiological variables related to the cardiovascular system in different ways.

It is pertinent to highlight that both valence and arousal were the most registered psychological variables in the selected studies. However, it is necessary to extend research focused on other aspects, such as anxiety and personality. Research with personality as an observed variable is probably less common, due to the complexity of its evaluation and conclusions over obtained results (Martin-Soelch et al., 2006; Koelsch et al., 2007). Moreover, there is a lot of debate around this topic and it can add complexity to the studies that may arise. In this sense, anxiety could be also a useful element to consider in future research.

Scientific Disciplines for Documents Sourced in This Paper

In this review, studies from different scientific fields were included. The research chosen is associated with areas such as music therapy, work hygiene, music's influence on the heart's parameters, and affective sounds. The scientific disciplines from which these studies are selected are shown in **Table 1**. This paper has shown that the effects of sound on humans have been studied from diverse viewpoints, ranging from music therapy to work hygiene. However, the latter has been considered with more frequency. In the same way, **Figure 9** summarizes how the effects of sound, noise, and music on the human body may be studied from different aspects. These factors may impact both the mind and emotions as much as the body. This may be observed both psychologically and as a medical response. Hence, sound may be used to produce different outcomes in areas from music therapy and arts to work hygiene.

TABLE 1 | Scientific disciplines for documents sourced in this paper.

Scientific domain	Documents
Music therapy	Watkins, 1997; Binns-Turner et al., 2011; Dousty et al., 2011; Pérez-Lloret et al., 2014; Rhomberg et al., 2014; Gruhlke et al., 2015; Gupta and Gupta, 2015; Krabs et al., 2015; Tan et al., 2015; Bidin et al., 2016; Montánchez Torres et al., 2016
Work hygiene	Tomei et al., 2000; Yuan et al., 2005; Uclés et al., 2006; Björ et al., 2007; Raggam et al., 2007; Graham et al., 2009; Goyal et al., 2010; Kasprzak, 2010; Sancini et al., 2012; Croy et al., 2013; Kraus et al., 2013; Chen et al., 2014a,b; Osiris et al., 2014; Oh et al., 2015; Gallasch et al., 2016; Nakajima et al., 2016; Walker et al., 2016; El Aarbaoui et al., 2017; Ishimitsu et al., 2017
Music influence on heart parameters	Hyde, 1924; Holand et al., 1999; Chang et al., 2004; Etzel et al., 2006; Krantz et al., 2010; Lee et al., 2010; Cho et al., 2011; Das et al., 2015; Koelsch and Jancke, 2015; Nozaki et al., 2015; Sim et al., 2015; Watanabe et al., 2015; Abedi et al., 2017
Affective sounds	Thayer and Faith, 2001; Wagner et al., 2005; Martin-Soelch et al., 2006; Kenntner-Mabiala et al., 2007; Koelsch et al., 2007; Kim and André, 2008; Orini et al., 2010; Wong et al., 2010; Naji et al., 2014a,b; Niu et al., 2014; da Silva and Backs, 2015; Hajizadeh et al., 2015; Nardelli et al., 2015; Al-Galal et al., 2016; Goshvarpour et al., 2016a,b, 2017

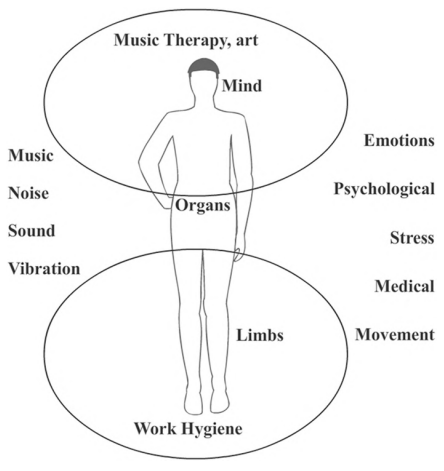

FIGURE 9 | Influence of sound, noise, and music on the human body.

Limitations

One limitation in this review is related to the number of revisers. We think that in order to carry out the best review on this topic, it is necessary to have a multidisciplinary team with several researchers in each of the areas, such as medicine, cardiology, psychology, music or music therapy, engineering, and statistics. Moreover, it is also considered that this may also introduce the possibility of bias in the selection of papers included in this review.

CONCLUSION

In this review, some relevant characteristics between selected studies were seen. Despite the differences between the outcomes of selected studies, some common elements were found among them. Thus, in noise studies where both BP and HR increased or tended to increase, it was noted that HRV (HF and LF/HF) changes with both sound and noise stimuli, whereas GSR changes with sound and musical stimuli. Furthermore, LF also showed changes with exposure to noise. In many cases, samples represented a limitation in experimental design, where in diverse

studies, there was a lack of a control group. Regarding stimuli, there was a great variability in the presented stimuli providing a wide overview of the effects they could produce on humans. In the listening sessions, some elements which represent good practices in experimental designs were observed, such as the use of headphones, comfortable positions for study subjects, and control of environmental elements. Moreover, a minimum length of listening session of 20 min was found in most of the research. However, this variable needs critical review and standardization for future research. The use of classic statistics had a dominant role in most studies. New data analysis tools should also be included. Besides ECG, in some studies, registers for other variables of the cardiovascular system were acquired which may support findings about the interest variables. It is important to mention that selected studies do not provide enough evidence about the influence of sound over ECG signal. In this sense, new research needs to be carried out which allow us to make conclusions about this topic. In this way, this review aims to provide elements which can contribute to improving quality in future research about sound and its effects over ECG signals.

An important point to consider is the extensive variability in the research characteristics. Thus, there is little homogeneity among the elements, such as stimulus, sample, and experimental design in studies with sound, noise, and music. The variations in these characteristics hinder the possibility to draw a complete conclusion with respect to the relationships between causes and effects. However, despite these variations, it was possible to observe some of the elements which were often present.

In sound and noise studies, it was noted that HF and HF/LF ratio HRV were elements with variations according to the provided stimuli. In the same way, GSR was an element which presented variations with sound stimulus and served as an element in classifying emotions in research with music.

This review shows that there is a genuine need to continue with research related to the influence of sound, noise, and music on psychophysiological variables. It is known that noise can affect several aspects in humans, both psychological and physiological. However, studies of this review do not show a common trend. Therefore, it is important to consider future research to observe and understand the response to different types of noises, such as traffic noise.

In addition, it is important to highlight that future research needs to have a strict experimental design as well as to provide a complete report or publication about its outcomes. Thus, it is essential to bear in mind the suggestion to include stimuli with different characteristics in control groups. It is advisable to avoid control groups in silence or without some stimulus. In this way, it is necessary to understand the human response to stimulus with of a different nature, such as several types of sounds, noise, and music (Koelsch and Jancke, 2015).

To complement this review, we suggest reading the review "Music and the heart" by Koelsch and Jancke (2015). The authors provide methodological recommendations for future research related to music (although many of them are suitable for research with sound and noise).

It is important to take into account the Consolidated Standards of Reporting Trials (CONSORT; CONSORT, 2017) for randomized controlled trial designs, the Transparent Reporting of Evaluations with Non-randomized Designs (TREND; Trend Statement CDC, 2017) for non-randomized designs, Reporting Guidelines for Music-based Interventions (Robb et al., 2011) for music-based intervention studies, and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009) for reviews.

KEY CONCEPTS

Sound

In general, sound may be defined as a mechanical vibration which travels through an elastic medium, like a variation in the pressure exerted on the particles which comprise it, and can be perceived by the ear or any device with this aim.

Music

In the case of music, there is a certain order. The frequencies which compose it are discrete (separable) and rational (their relations form simple fractions) with a discernible dominant frequency. It can also be described mathematically by an infinite sum of sines and cosines multiplied by appropriate coefficients.

Noise

On the other hand, noise has no set order, the frequencies which comprise it are continuous (each frequency may be present in some range) and random (described by a probability distribution) with no discernible dominant frequency.

Electrocardiogram

Electrocardiogram (ECG or EKG) is one of the main physiological measures for medical diagnosis and can be used to detect a large amount of cardiac abnormalities and pathologies; in addition to diagnosis, ECG is very important for the analysis and monitoring of cardiac function.

Signals

A signal is a varying phenomenon that differs with time (though it can vary with another parameter, such as space) and can be measured.

AUTHOR'S NOTE

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AUTHOR CONTRIBUTIONS

RV-C, EI-Á, FM-B, LvN, and HL-C supervised the entire process and revised the manuscript. EI-Á designed the systematic review, reviewed all the studies, and extracted the information from the eligible documents. FM-B analyzed the data and prepared the figures and tables. EI-Á, RV-C, and FM-B wrote the paper. All authors reviewed and approved the manuscript.

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