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REVIEW

Music and the heart

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Music can powerfully evoke and modulate emotions and moods, along with changes in heart activity, blood pressure (BP), and breathing. Although there is great heterogeneity in methods and quality among previous studies on effects of music on the heart, the following findings emerge from the literature: Heart rate (HR) and respiratory rate (RR) are higher in response to exciting music compared with tranquilizing music. During musical frissons (involving shivers and piloerection), both HR and RR increase. Moreover, HR and RR tend to increase in response to music compared with silence, and HR appears to decrease in response to unpleasant music compared with pleasant music. We found no studies that would provide evidence for entrainment of HR to musical beats. Corresponding to the increase in HR, listening to exciting music (compared with tranquilizing music) is associated with a reduction of heart rate variability (HRV), including reductions of both low-frequency and high-frequency power of the HRV. Recent findings also suggest effects of music-evoked emotions on regional activity of the heart, as reflected in electrocardiogram amplitude patterns. In patients with heart disease (similar to other patient groups), music can reduce pain and anxiety, associated with lower HR and lower BP. In general, effects of music on the heart are small, and there is great inhomogeneity among studies with regard to methods, findings, and quality. Therefore, there is urgent need for systematic high-quality research on the effects of music on the heart, and on the beneficial effects of music in clinical settings.

Keywords Heart • Music • Emotion • Heart rate • Heart rate variability • Respiratory rate • Blood pressure • Depression

Introduction

Music is a powerful stimulus for evoking and modulating emotions as well as moods,[1–3] and is associated with activity changes in brain structures known to modulate heart activity, such as the hypothalamus, amygdala, insular cortex, and orbitofrontal cortex.[2,4,5] Effects of emotions and affective traits on heart activity are due to several pathways transmitting information into the cardiac nerve plexus, such as autonomic and endocrine pathways, blood pressure (BP), and blood gases.[5,6] On the other hand, cardiovascular afferent neurons provide the autonomic nervous system (ANS) with information about BP as well as the mechanical and chemical milieu of the heart.[7,8] Such sensory information modulates autonomic outflow, and contributes to emotional experience as interoceptive information.[9] Owing to these mechanisms, music-evoked emotions have effects on the regulation of regional heart activity, heart rate (HR), heart rate variability (HRV), BP, and respiratory rate (RR).

However, studies on effects of music on the heart have often yielded inconsistent results. These inconsistencies (in both healthy and clinical study groups) are probably due to the use of very inhomogeneous methods and musical stimuli used across studies. Note that the term ‘music’ itself refers to a great variety of musical genres and styles, all subsumed under the umbrella concept of music, and many studies did not clearly specify the particular style of music used, nor the particular emotional effects evoked by the musical stimuli. Thus, it is no wonder that music studies yield a variety of different physiological effects, given the great variety of musical stimuli. For example, use of (i) energizing (usually fast) or tranquilizing (usually slow) music, (ii) self-selected music (usually associated with memories and stronger pleasantness) or experimenter-selected music, (iii) beat-based music (usually with a drum set, e.g. Rock, Jazz, and Latin), or music that is not beat based but based on an isochronous pulse (e.g. most of classical music, which is often also characterized by distinct tension-resolution patterns that have particular emotional effects), or music not based on an isochronous pulse (e.g. many pieces of ‘ambient music’, meditation music, or ‘new age music’), (iv) music with or without lyrics, (v) active music making or passive music listening (and passive listening with or without the presence of a music therapist), and (vi) natural music (e.g. recorded from commercially available CDs) or artificial music stimuli (e.g. without variations in tempo and loudness in order to have maximum control over the acoustical stimulus).

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If participants bring their own music ('participant-selected music'), it is virtually impossible to control any of these variables. On the other hand, studies using experimenter-selected music suffer from a high risk of missing out on positive emotional effects (or even risk annoying the participant or the patient). To help overcoming methodological problems, we will provide methodological recommendations for future studies at the end of this review. Before we do so, we will first review effects of music on the heart in healthy subjects, and then review (potentially) beneficial effects of music in patients with heart disease.

Effects of music on the heart in healthy individuals

Although there are numerous inconsistencies between studies, there are also some consistent findings (summarized in *Table 1*), which we will review in following [studies included in this review were identified using the database Web of Science (Thomson Reuters, NY, USA) and the keywords 'music and HR' and 'music and HRV'; only studies with healthy participants were included; studies were excluded if they included fewer than 12 participants, if stimuli were <30 s, if there was no adequate control condition, or if data were not acquired during music listening].

Heart rate

Heart rate is regulated by numerous reflex-like circuits involving both brainstem structures and intra-thoracic cardiac ganglia, which are in turn under the influence of cortical forebrain structures involved in emotion such as hypothalamus, amygdala, insular cortex, and orbitofrontal cortex.[5] Activity of these forebrain structures can be modulated by music-evoked emotions.[1,2,4] Generally, emotional arousal is associated with a predominance of sympathetic ANS activity, thus leading to an increase in HR, whereas a predominance of parasympathetic ANS activity leads to a decrease of HR. Correspondingly, several studies report that listening to music evoking higher levels of emotional arousal is associated with higher HR than HR elicited by tranquilizing music,[10–18] and that exciting music is associated with higher RR than tranquilizing music.[10–15,19] A recent study reported that, if arousal is balanced, even considerable tempo differences (90 vs. 120 beats per minute) do not evoke changes inHR.[16] Thus, up to now, there is no evidence for entrainment of HR to musical beats.[20]

The increase of HR accompanying music-evoked emotional arousal is consistent with the observation that HR increases during music-evoked frissons (i.e. intensely pleasurable feelings with high-emotional arousal involving shivers and/or goosebumps, also referred to as 'chills').[21–26] This HR increase during musical frissons parallels an increase inRR[23–25] or respiratory depth.[21] A recent study found an HR increase following piloerection onset (i.e. onset of goosebumps) during a frisson, but no significant increase in HR during chills without piloerection.[26] Therefore, to measure reliable HR changes during music-evoked frissons, or 'chills', it is recommended to use objective measures of piloerection.[24]

Another relatively consistent effect of music is an increase in HR compared with silence,[13,16,27–35] although this change is small (usually about 1–2 beats per minute, thus considerably smaller than the respiratory sinus arrhythmia), often statistically not significant,[13,16,27,29,30] varying during music presentation,[32,35] and not consistent across studies.[11,17] Several studies also report an increase in RR in response to music (when compared with silence).[11,13,27,32] Interestingly, even simple isochronous auditory pulses (without melody, rhythm, or harmonies) can elicit such effects on HR[16] andRR.[32] This shows that the tactus (or 'beat') of music alone has a pivotal role in ANS responses to music.

Table 1 Summary of effects of music on heart rate, heart rate variability, and respiration

	HR	SDNN	Respiration
Exciting vs. tranquilizing music	↑	↓	↑
Musical frisson	↑		(↑)
Music vs. slience	(↑)	(↓)	(↑)
Pleasant vs. unpleasant music	(↑)		(↑)

Arrows in brackets indicate that only few studies are available, or that reliability across studies is only moderate.
HR, heart rate; HRV, heart rate variability; SDNN, standard deviation of NN intervals.

Heart rate variability

Similar to HR, HRV is modulated by limbic and paralimbic brain structures and is thus affected by emotional processes.[36] Consonant with the effects of music on HR, the HRV in terms of the standard deviation of the beat-to-beat intervals (SDNN) appears to be lower during exciting than tranquilizing music (probably because HRV is usually negatively correlated with HR),[16,17,19,37,38] and lower during music compared with silence (see also *Figure 1*).[16] However, these statements have to be treated with caution because surprisingly few music studies report SDNN data.

Likewise, only tentative statements can be made regarding frequency domain measures of the HRV. The high-frequency (HF) spectral power was reported to be lower during music than silence,[16,34] and lower during exciting music compared with less exciting music.[17,37] Similarly, the low-frequency (LF) spectral power was reported to be lower in response to exciting music compared with less exciting music,[38] or in response to music compared with silence.[16] Although the interpretation of LF and HF as measures of sympathetic and parasympathetic outflow has been challenged as being overly simplistic,[39] there is consensus that reductions of HF and LF during music listening reflect a modulation of both sympathetic and parasympathetic tone.

Inconsistent results have been reported regarding the LF to HF ratio.[13,16,34] As with studies on music and HR, the methods, the styles of the musical stimuli, and the quality of these studies vary greatly. Note that a stronger reduction in LF than in HF leads to a reduction in LF/HF, while a stronger reduction in HF than in LF leads to an increase in LF/HF. Also note that musical stimuli can have both exciting and relaxing effects: For example, already at the brainstem level, the musical beats of a piece of heavy metal music elicit visceromotor (autonomic) responses.[2] On the other hand, for a heavy metal enthusiast, such music can have stress-reducing effects

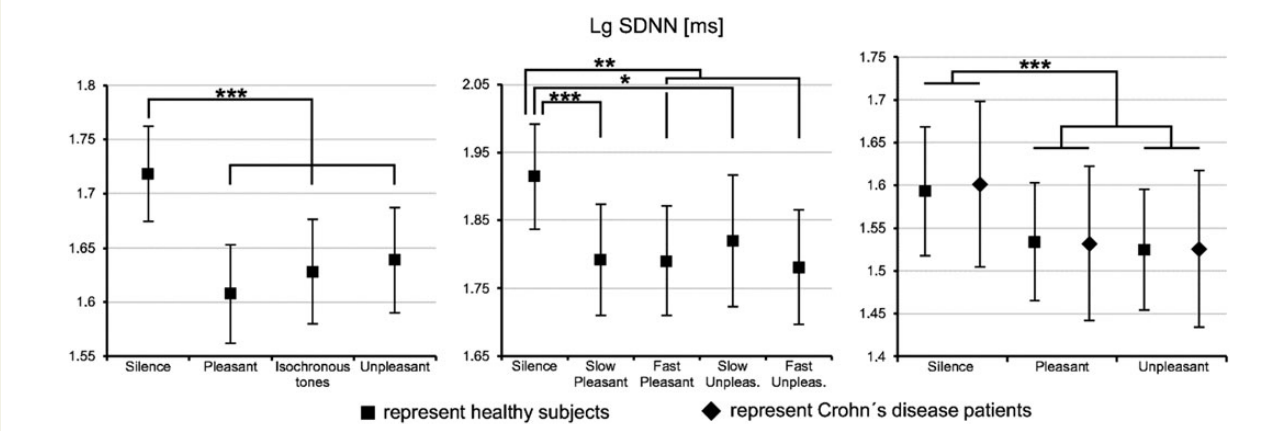

Figure 1 Effects of music on heart rate variability. The figure shows a decrease of HRV (SDNN) in response to music (pleasant, unpleasant) or isochronous tones compared with a rest condition (silence) in four independent groups of subjects (left panel: $n = 76$; middle panel: $n = 30$; right panel healthy subjects: $n = 32$; right panel Crohn's disease patients: $n = 19$). The left panel shows that HRV reduces even in response to isochronous tones (i.e. even by a simple tactus, or 'beat' without melody, harmony, or rhythm). The middle panel shows that similar HRV occurs in response to slower (90 beats per minute) and faster musical stimuli (120 beats per minute) when arousal is balanced (there was no significant difference in felt arousal between slow and fast music). Note that the valence of the music (felt pleasantness/unpleasantness) had no systematic effects on the HRV, and that HRV modulations by music were virtually identical for healthy individuals and patients with Crohn's disease (right panel). *Silence*: rest condition without music or any other stimulus; *pleasant*: pleasant music; *unpleasant*: unpleasant music; *isochronous tones*: sequences of ascending so-called Shepard-tones; *Lg SDNN*: logarithmized standard deviation of NN intervals. Filled squares (healthy subjects) and diamonds (Crohn's disease patients) indicate estimated marginal means with 95% confidence intervals. Figure modified with permission from Krabs *et al.*[16]

(including endocrine and immune changes).[40] Thus, music can elicit both exciting and relaxing effects at the same time, involving both autonomic and endocrine activity, making it challenging to pin down peripheral physiological effects of music to specific emotional processes. Future studies are necessary to specify how reduction of stress, relaxation, or activation with music contributes to changes in the spectral components of HRV.

Effects of music-evoked emotions on regional heart activity

To investigate effects of music on the heart, measures of regional activity of the heart might also be informative, in addition to HR and HRV. Regional cardiac function (such as conduction of excitation, conduction velocity, contractile force, coronary circulation, and aspects of cardiac valve function) is reflected in amplitudes and timing of electrocardiogram (ECG) waves. Regional heart activity is modulated by the activity of neurons within the cardiac nerve plexus, which are influenced by emotions and affective traits via several pathways: (i) Autonomic activity is transmitted into the cardiac nerve plexus by both parasympathetic and sympathetic nerve fibres.[41] As mentioned above, autonomic outflow to the heart is modulated by forebrain structures which are involved in music-evoked emotions.[2] Note that left and right brain hemispheric differences in emotions and affective traits[42] contribute to asymmetric autonomic outflow that modulates regional heart activity, due to innervation of the anterior surface of the heart by the right cardiac nerve, and of the posterolateral and posterior surface by the left cardiac nerve.[43,44] (2) Emotions (such as anxiety, stress, or relaxation) have effects on circulating hormones (such as adrenalin and angiotensin II).[40] (3) Blood pressure and blood gases are modulated by breathing frequency and breathing depth (which are affected by emotions).

In clinical groups, the diverse effects of affective traits on the heart have been demonstrated by a plethora of clinical and experimental evidence implicating anger, hostility, depression and anxiety in the occurrence of arteriosclerosis, coronary artery disease, hypertension, myocardial ischaemia and infarction, cardiac arrhythmia formation, and sudden cardiac death.[45] Thus, studying effects of music on the brain–heart-axis can potentially have great clinical significance. For example, it was shown that regional cardiac activity differs between individuals with flattened affect and normal controls,[46] and that a cardiac amplitude signature of flattened affect (see *Figure 2A*) is associated with reduced neural activity in the hippocampal formation in response to music.[6,46] Moreover, this cardiac amplitude signature appears to change slightly during musical frissons (see *Figure 2B*).[26] Thus, ECG amplitudes as electrophysiological markers of regional cardiac activity are highly promising and highly innovative parameters for future research on effects of (music-evoked) emotions on the heart, including potential preventive and therapeutic interventions.

Emotional valence

Some studies investigating the effects of emotional valence (i.e. pleasure or displeasure) evoked by music reported that compared with negative valence (displeasure), positive valence (pleasure) is associated with higher HR,[11,23,32,47] as well as higher electrodermal

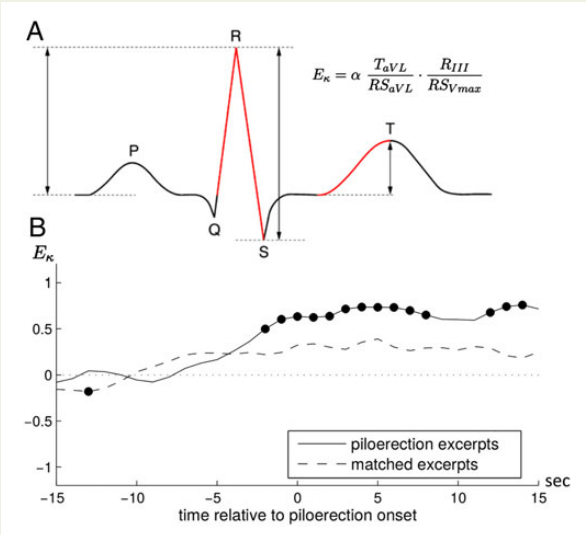

Figure 2 Effects of music on regional activity of the heart. (*A*) In addition to heart rate and heart rate variability, new approaches investigate effects of music on the regional activity of the heart as reflected in the amplitudes of ECG waves. For example, the computation of the ECG amplitudes indicated in red according to the formula shown in the right panel results in a value (E_κ) shown to be associated with flattened emotionality (low E_κ values correspond to flattened emotionality).[6,46] (*B*) During frissons with piloerection (evoked by music and film clips) E_κ values transiently increase (solid line) compared with when no frisson is experienced during the same stimuli (dashed line, black filled circles indicate significant differences from zero, 568 piloerection incidences were recorded from 25 individuals, E_κ was not correlated with HR).[26] The increase in E_κ during frissons reflects changes in the regional activity of the heart.

activity (EDA, a physiological marker of sympathetic activity),[11,16,23,48,49] and higher respiratory frequency.[32] However, often it is difficult to separate effects of pleasure from arousal effects,[23] and other studies did not demonstrate associations between the valence of music and HR,[16,50] nor EDA,[50,51] or HRV.[11,16] The combined findings suggest that HR and HRV are influenced more strongly by emotional arousal, rather than by felt pleasantness.[15] However, future studies are needed to specify the effects (and the size of effects) of music and music-evoked emotions on HR and HRV (see Methodological recommendations).

Effects of music in patients with heart disease

In patients with heart disease, as well as in other clinical groups, the reduction of anxiety with music is a relatively consistent finding (as will be reviewed below). The reduction of pain is also relatively consistent, but small. However, other physiological and clinical effects of music on the heart in studies with clinical groups (such as BP, wound healing, or duration of hospitalization) are inconsistent.

Anxiety

Four meta-analytic Cochrane reviews consistently reported that music can reduce anxiety in patients with coronary heart disease,[52] mechanically ventilated patients,[53] cancer patients,[54] and patients awaiting surgical procedures.[55] Based on these reviews, Bradt *et al.*[55] concluded that music interventions appear to provide a viable alternative to sedatives and anti-anxiety drugs for reducing anxiety. Supporting these findings, two further reviews report reduction of pre-[56] and perioperative[57] anxiety by music, as well as reduction of anxiety in patients receiving mechanical ventilatory support.[58] Although no meta-analysis is available on heart catheterization or coronary angiography, a meta-analysis by Bechtold *et al.*[59] reported anxiety reduction in patients undergoing colonoscopy. Thus, it is likely that music also reduces anxiety, thus increasing well-being, in patients undergoing coronary angiographic procedures. This notion is supported by a randomized controlled study on this topic.[60] Particularly relevant for heart patients is that the reduction in anxiety (i.e. psychological stress) with music is also associated with a reduction ofHR,[52,53,55] and perhaps of systolic BP[52] (but see also Bradt *et al.*[55] who reported effects on diastolic, but not systolic BP). However, it is important to note that all mentioned reviews suffer from a high risk of bias due to methodological weaknesses of the included studies (such as lack of blinding, small sample size, or lack of control stimuli). Therefore, there is dire need for high-quality studies on the effects of music on the heart in both healthy individuals and patients.

Blood pressure

The anxiety-reducing effects of music are probably also associated with (small) reductions in BP. In addition, music has been used in hypertensive patients to lower BP by guiding slow and regular breathing.[61] Such effects of music on BP are consistent with meta-analytic data indicating (small) reductions of RR and BP in patients due to music interventions.[54]

Pain

Another Cochrane meta-analysis reported pain-reducing effects of music in coronary heart disease patients,[52] consistent with two other Cochrane meta-analyses on the use of music for pain relief in patients.[54,62] However, the analyses state that the magnitude of the pain reduction is small[52,62] to moderate.[54] These effects are probably due to effects of music on brain opioid and oxytocin mechanisms[2,63] (associated with music-evoked activity changes within diencephalon-centred- and hippocampus-centred-affected systems).[2,64] Supporting this notion, a study by Nilsson reported an increase in oxytocin in response to soothing music during bed rest after open-heart surgery.[65]

Other potential effects and applications

In addition to the clinical settings mentioned above, music has been used to reduce anxiety and pain during chair-rest after open-heart procedure,[66] and after percutaneous coronary interventions in patients undergoing a C-clamp procedure.[67] Moreover, in addition to the studies showing reductions of anxiety and pain, a meta-analysis by de Niet *et al.*[68] (later substantiated by Kamioka *et al.*[69]) reported improvement of sleep quality due to music-assisted relaxation.

Music and depression

It is well established that depression and cardiovascular diseases (CVDs) are related. For example, patients with early-onset depression are at increased risk for developing CVD.[70] This adverse effect was present even when statistically correcting for cardiovascular risk factors, and even in the absence of a diagnosis of major depression. Depression increases the risk for CVD by 1.5–2 times in otherwise physically healthy individuals.[71] Correspondingly, depression is more common in patients with CVD such as stroke, heart failure, atrial fibrillation, and myocardial infarction.[72] Since several studies have demonstrated that pleasant music can activate the reward system (including the mesolimbic dopaminergic reward pathway)[2] music might also be useful in treating depression and CVD associated with depression. However, the evidence for beneficial effects of music therapy in the treatment of depression is surprisingly weak (mainly due to the lack of high-quality studies),[73] calling for more research in this area, in particular with regard to depression-related CVD.

Methodological recommendations

As reviewed above, there is great heterogeneity of methods and, correspondingly, of results of studies on effects of music on the heart. Moreover, many studies (in particular clinical studies) suffer from numerous methodological shortcomings. Therefore, the following recommendations are aimed at helping to overcome methodological problems in future research (see *Table 2* for summary).

(i) We advocate an accurate characterization of musical and acoustical features of the stimuli used. Stimuli, or stimulus sets, need to be characterized with regard to musical genre, tempo, instrumentation, loudness, and ideally also pulse clarity, variation of fundamental frequency, key strength, as well as spectral components (including sensory consonance/dissonance). Moreover, it is important to characterize the emotional impact of the stimuli to participants. This should at least comprise measures of felt valence (pleasantness/unpleasantness) and arousal/relaxation. Note that music can often evoke mixed emotions and that, although sadness is an emotion with negative valence, sad music is often perceived as positive.[74]

(ii) Although this is a hotly debated topic, we recommend using different sets of music prepared by the experimenter (e.g. Classic, Jazz, Country, etc.) from which participants can choose. Thus, music stimuli of different sets can be well matched (and acoustically as well as musically analysed and characterized), and there is a high likelihood that the music has positive valence for the participants. Note that in clinical practice, there are three major advantages if the physician 'prescribes' specially selected music (with a style according to the participant's taste and preference): (a) beneficial effects will be stronger due to additional placebo-effects (for pain see Cepeda *et al.*[62]), (b) the physician is less likely to be bothered by the music, and (c) the patient is not worried that the physician is bothered by the music.[75] Our recommendation comes with the caveat that participant-selected music is more appropriate when investigating very intense emotional reactions to music (such as frissons, or being moved to tears), because such reactions are in most individuals evoked only by very specific musical pieces.[21–26]

(iii) It is important to assess musical preferences for the intended listening situation. The emotional effects of a piece of music (and thus effects on the heart) also depend on the listening situation (such as the location or event where the music is perceived, and the fit of the music with a current mood).[74,76] For example, although an individual might have a strong preference for the music of Wagner, s/he might not want to listen to Wagner when lying on the operating table.

(iv) Clinical studies should include a control group with an acoustical control stimulus (e.g. to avoid placebo-effects or to ensure that effects in the music group are not simply due to perception of fewer threatening noises originating from the medical procedure). Possible control stimuli are audio books, or nature sounds such as breaking waves (the latter is particularly suited as a control stimulus if the musical stimulus is not based on an isochronous pulse). Moreover, studies should follow a double-blinded study design. The latter is often only possible with the use of headphones (so that the experimenter does not know which stimulus is presented).

(v) We recommend that clinical studies include (a) psychologically relevant outcome variables such as mood (which can be measured with the profile of mood states, POMS), anxiety (which can be measured with the state/trait anxiety inventory, STAI), and Pain (which can be measured with a visual analogue scale, VAS), and (b) economically relevant outcome variables (e.g. length of hospitalization, patient satisfaction, opioid intake, and requirements of sedative drugs).

Table 2 Methodological recommendations summary

- Use of music stimulus sets (e.g. Classic, Jazz, and Country) prepared by the experimenter, from which the participant can choose. The individual should not only have a general preference for a music set but a preference for this set taking the listening situation into account.
- Stimuli, or stimulus sets, need to be characterized with regard to musical (e.g. genre, tempo, instrumentation, key strength, and pulse clarity), acoustical (e.g. loudness, variation of fundamental frequency, and spectral components), and emotional features (e.g. felt valence, arousal/relaxation).
- In clinical studies inclusion of a control group with an acoustical control stimulus.
- Double-blinded study design (often only possible with the use of headphones).
- Inclusion of psychologically relevant outcome variables (mood/POMS, anxiety/STAI, pain/VAS).
- Inclusion of economically relevant outcome variables (e.g. length of hospitalisation, patient satisfaction, opioid intake, and requirements of sedative drugs).

Conclusions

Music has effects on the heart as indicated by the findings that HR, as well as RR, is higher (and HRV lower) during exciting music compared with tranquilizing music. Correspondingly, HR (and RR) increases during musical frissons, especially when associated with piloerection. It also appears that, compared with silence, music increases HR and RR, and that HR and RR are higher during pleasant than unpleasant music. New findings suggest that music also has effects on the regional activity of the heart, as reflected in changes of ECG amplitude patterns. In clinical settings, music can reduce pain and anxiety, associated with reductions in BP and RR. Thus, music is potentially a low-cost and safe adjuvant for intervention and therapy. However, the effects of music on the heart are small, and results of studies on this topic are often inconsistent. Therefore, there is pressing need for systematic high-quality research on the effects of music on the heart in both healthy individuals and patients.

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