

REVIEW

Auditory stimulation and cardiac autonomic regulation

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Previous studies have already demonstrated that auditory stimulation with music influences the cardiovascular system. In this study, we described the relationship between musical auditory stimulation and heart rate variability. Searches were performed with the Medline, SciELO, Lilacs and Cochrane databases using the following keywords: "auditory stimulation", "autonomic nervous system", "music" and "heart rate variability". The selected studies indicated that there is a strong correlation between noise intensity and vagal-sympathetic balance. Additionally, it was reported that music therapy improved heart rate variability in anthracycline-treated breast cancer patients. It was hypothesized that dopamine release in the striatal system induced by pleasurable songs is involved in cardiac autonomic regulation. Musical auditory stimulation influences heart rate variability through a neural mechanism that is not well understood. Further studies are necessary to develop new therapies to treat cardiovascular disorders.

KEYWORDS: Auditory Stimulation; Autonomic Nervous System; Music.

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INTRODUCTION

A previous study from our group demonstrated that a portion of subjects with auditory deficit presented with cardiovascular disorders (1). The literature demonstrated that auditory stimulation with music is known to induce many psychological responses (2-4). However, the effects of music on physiological phenomena have not been as well studied. Auditory stimulation with music lowers the heart rate and blood pressure in humans (5) and spontaneously hypertensive rats (6), suggesting that music may affect cardiac autonomic function.

Cardiovascular responses are important for evaluating a patient's health (7-9). Heart rate variability (HRV) is a noninvasive method for investigating the autonomic nervous system (ANS), and it describes the oscillations of the intervals between consecutive heartbeats. This method is a conventionally accepted procedure to describe the fluctuations in the intervals between consecutive heartbeats (RR intervals), which are known to influence the sinus node (10). HRV may be analyzed with linear and nonlinear methods, and changes in those patterns provide information

on the adaptations of abnormal autonomic modulation and health impairments (11,12).

HRV analysis has received attention because it is related to highly irregular fluctuations of the heart rate and allows for better discrimination between normal and abnormal physiology (13). Moreover, previous studies have indicated that music therapy has positive effects on HRV in ill patients (14,15).

Elucidating physiological responses involved in musical auditory stimulation is important to investigate future therapies to prevent the development of cardiovascular disorders. Therefore, this study aimed to analyze existing data regarding the effects of musical auditory stimulation and heart rate variability to contribute to the understanding of this topic and to facilitate the development of new treatments based on auditory stimulation therapy with music.

METHODS

Search strategy and selection

Literature searches were performed between September 2011 and December 2011. The Medline (via PubMed), Lilacs and Cochrane databases were searched using the following subject keywords: "auditory stimulation", "autonomic nervous system", "music" and "heart rate variability". These words were defined by the Health Sciences Descriptors (DeCS) and their corresponding English versions, the Medical Subject Headings (MeSH).

The studies were selected by a reviewer and supervised by a senior reviewer. Based on the titles and abstracts, we

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excluded manuscripts that were not clearly related to the subject of the review. Subsequently, all of the selected titles and abstracts were submitted to a final evaluation, which considered the inclusion criteria. The reference lists were independently checked to identify studies of possible relevance that were not found in the electronic search.

We excluded literature reviews and studies that presented no abstract or full text in English. As inclusion criteria, we considered clinical trials and basic studies published between 2000 and 2010 that investigated the effects of musical auditory stimulation on the ANS.

RESULTS

The electronic search yielded a total of 1,751 references. Among these references, the first elimination round resulted in the exclusion of 1,632 titles and abstracts that were not clearly related to the subject of the review. The titles of the remaining 119 abstracts were submitted to a final evaluation that accounted for the inclusion criteria. An investigation of the reference lists confirmed the absence of relevant documents. Summaries of the five studies analyzed (6,16-19) were selected. Table 1 shows the levels of variability and the main results and conclusions of the studies included in this update.

DISCUSSION

In general, the analysis of texts selected for this review indicated that harmonic music is able to improve cardiac autonomic regulation. The literature on the effect of music on ANS activity in healthy subjects is quite large. In contrast, the literature on how musical auditory stimulation affects individuals with cardiovascular dysfunction is less developed. In this review, we reported published studies on the effects of musical auditory stimulation on heart rate variability.

The intensity of musical auditory stimulation is an important issue. In Lee et al. (19), white noise exposure above 50 dB enhanced sympathetic activity. They also found a strong correlation between the LF/HF ratio (low frequency-high frequency ratio) and noise intensity. The LF/HF ratio corresponds to the sympathetic-vagal balance (20). Thus, noise intensity was indicated to influence heart rate variability. The cardiovascular responses to sound may be conducted through many pathways, and one example is the startle response mediated by a brainstem circuit. The acoustic startle reflex, a well-known effect of loud sounds on the cardiovascular system, is described as the abrupt response of the heart rate and blood pressure to a sudden loud sound stimulation. The typical intensity used to elicit a

startle reflex is 110 dB, and this intensity is much louder than environmental noise. However, cardiac accelerative responses that habituated over trials were observed in subjects exposed to repeated 60 dB and 110 dB white-noise stimuli (21). The responses were regarded as a startle and defense response in humans or a fight/flight reaction in animals. The rise in the blood pressure and heart rate in response to acoustic startle stimuli indicates an autonomic function responding to the acoustic stimuli (22). Furthermore, cortical centers and subcortical processing centers were thought to be involved in the cardiovascular and hormonal responses to long-term stress activation by environmental noises, even though the noise intensity was as low as 53 dB (23).

Musical auditory stimulation was also investigated during stress situations (16). Another study cited in our review (16) tested whether physiological stress recovery was faster during exposure to pleasant nature sounds than noise. As a main finding, they suggested that nature sounds facilitate recovery from sympathetic activation after a psychological stressor. The mechanisms underlying the faster recovery could be related to positive emotions (pleasantness) evoked by the nature sound, as suggested by previous research using non-audio film stimuli (24). Other perceptual attributes may also influence recovery. In the study of Alvarsson et al. (16), ambient noise was perceived as less familiar than other sounds, presumably because it contained no identifiable sources. One may speculate that this lack of information might have caused increased mental activity and thereby an increased skin conductance level compared with the nature sound.

An effect of the sound pressure level may be observed in the difference between loud and quiet noise. Moreover, this difference is in line with previous psychoacoustic research (25) and is not a surprising finding considering the large difference (30 dBA) in the sound pressure level.

Auditory stimulation therapy with music was investigated in anthracycline-treated patients (15). Anthracycline is a compound known to induce cardiovascular disorders (15). Chuang and coworkers indicated that long-term music therapy improved heart rate variability in anthracycline-treated breast cancer patients (15). The findings of a previous study also suggest that the parasympathetic nervous system is activated by music therapy and appears to protect against congestive heart failure events in elderly patients with cerebrovascular disease and dementia by reducing the levels of both epinephrine and norepinephrine (26). Therefore, music therapy intervention may also help breast cancer patients control the progression and relieve symptoms of cardiac damage, which is a result of treatment

Table 1 - Main studies exploring the effects of auditory stimulation on cardiac autonomic regulation. LF/HF ratio: Low frequency/high frequency ratio; dB: decibel.

Authors and year	Main conclusions
Lee et al., 2010 (6)	White noise exposure over 50 dB increases sympathetic activity, and there is a strong correlation between the LF/HF ratio and the noise intensity.
Alvarsson et al., 2010 (17)	Sympathetic activation induced by psychological stress recovers more quickly during exposure to pleasant nature sounds than to unpleasant noise.
Chuang et al., 2011 (16)	Long-term music therapy improves heart rate variability in anthracycline-treated breast cancer patients.
Nakamura et al., 2007 (18)	Music reduces renal sympathetic nerve activity and blood pressure through the auditory pathway, the hypothalamic suprachiasmatic nucleus, and histaminergic neurons.
Salimpoor et al., 2011 (19)	Pleasure in response to music induces dopamine release in the striatal system.

with anthracycline-containing chemotherapy. As a main conclusion, Chuang et al. (15) suggested that regular music therapy appears to be useful for promoting autonomic function, although further research is necessary to determine whether more (or more frequent) sessions of music therapy intervention can promote and maintain autonomic function after music therapy is stopped.

To study the effects of musical auditory stimulation on cardiovascular responses in more detail, a previous investigation (17) studied the neural mechanism involved in this process in rats. A very elegant study performed by Nakamura et al. (17) indicated that in rats, musical auditory stimulation reduces renal sympathetic nerve activity and blood pressure through the auditory pathway, the hypothalamic suprachiasmatic nucleus, and histaminergic neurons. Moreover, the authors suggested that only certain types of music affect renal sympathetic activity and blood pressure in rats. Animals with bilateral lesions in the auditory cortex may discriminate a simple sound, suggesting that there is another auditory sensing pathway that is not mediated by the auditory cortex (27), but lesions of the cochlea or the auditory cortex eliminated music-induced changes in renal sympathetic activity and blood pressure (17), indicating that the changes to renal sympathetic activity and blood pressure depended on signaling through the auditory system.

In the same context, a recent investigation presented the first direct evidence that the intense pleasure experienced when listening to music is associated with dopamine activity in the mesolimbic reward system, including both the dorsal and ventral striatum (18). One explanation for this phenomenon is that it is related to the enhancement of emotions (28). The emotions induced by music are evoked, among other things, by temporal phenomena, such as expectations, delay, tension, resolution, prediction, surprise and anticipation (29). Indeed, Salimpoor et al. (18) found a temporal dissociation between distinct regions of the striatum while listening to pleasurable music. The combined psychophysiological, neurochemical and hemodynamic procedure used revealed that peaks of autonomic nervous system activity, which reflect the experience of the most intense emotional moments, are associated with dopamine release in the nucleus accumbens. This region has been implicated in the euphoric component of psychostimulants, such as cocaine (30), and is highly interconnected with limbic regions that mediate emotional responses, such as the amygdala, hippocampus, cingulate and ventromedial prefrontal cortex (31). In contrast, immediately before the climax of emotional responses, there was evidence for relatively greater dopamine activity in the caudate. This subregion of the striatum is interconnected with the sensory, motor and associative regions of the brain (31) and has typically been implicated in the learning of stimulus-response associations (31) and in mediating the reinforcing qualities of rewarding stimuli, such as food (32).

In summary, in this review, we presented important studies that aimed to clarify the effects of musical auditory stimulation on heart rate variability. The potential of using HRV induced by a musical auditory stimulus as a clinical indicator for evaluating and identifying health impairments involving autonomic changes is promising. This technique could be used as a tool for the early diagnosis and prognosis of autonomic dysfunction in subjects exposed to intense sounds for long periods. There are many potential clinical applications of this method in individuals with this condition.

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AUTHOR CONTRIBUTIONS

All of the authors participated in the revision of the manuscript. All of the authors determined the design, interpreted the text and drafted the manuscript. All of the authors read and approved the version submitted for publication.

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