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ORIGINAL ARTICLE

Alteration of gastric myoelectrical and autonomic activities with audio stimulation in healthy humans

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Abstract

Objective. Cold or emotional stress was reported to affect gastric myoelectrical activity. The aim of this study was to investigate the effects of music or noise on gastric myoelectrical activity and autonomic function in healthy volunteers. ***Material and methods***. The study was performed in 10 fasted healthy volunteers and included 30 min at baseline, 30 min of classical music via headphones and 30 min of loud household noises via headphones. The electrogastrogram (EGG) readings were recorded simultaneously with the electrocardiogram (ECG) recording. ***Results***. Both classical music and noise altered the regularity of gastric slow waves. The percentage of normal 2–4 cycles/min (cpm) waves was reduced from 77.9 ± 4.7% at baseline to 66.9 ± 5.4% during music ($p < 0.006$) and 67.7 ± 5.4% during noise ($p < 0.05$). The reduction was attributed to a significant increase in bradygastria (15.8 ± 3.9% versus 9.8 ± 2.6%, $p < 0.04$) with the music and a significant increase in arrhythmia (7.4 ± 1.6% versus 2.0 ± 1.1%, $p < 0.02$) with the noise. The dominant frequency and power of the EGG were, however, not altered with either music or noise. Neither music nor noise had any effect on the autonomic function assessed by the heart rate variability. ***Conclusions***. Audio stimulation, with both music and noise, alters the rhythmicity of gastric slow waves. Classical music seems to increase bradygastria, whereas, household noise may increase arrhythmia. The effect of audio stimulation on the gastric slow wave does not seem to involve sympathetic or vagal efferent pathways assessed by the spectral analysis of heart rate variability.

Key Words: *Autonomic function, electrogastrography, gastric myoelectrical activity, gastric slow waves, gastrointestinal motility, heart rate variability*

Introduction

Gastric myoelectrical activity (GMA) plays an important role in the regulation of gastric motility [1]. There are two types of myoelectrical activities in the human stomach: slow waves and spike potentials [2]. Slow waves are present all the time and originate near the junction of the proximal one-third and distal two-thirds of the gastric corpus. The frequency of the normal slow wave is about 3 cycles per minute (cpm) or 0.05 Hz in humans [2]. Spike potentials are directly associated with antral contractions. The antral muscles contract when slow waves are superimposed with spike potentials. The frequency and propagation of the antral contractions are determined by the gastric slow waves.

The gastric slow waves can be recorded by using electrodes placed on the surface of the abdomen [3,4]. This non-invasive, easily reproducible technique is termed electrogastrography (EGG). When appropriately recorded, the dominant frequency of the EGG could accurately reflect the frequency of the gastric slow waves and the relative amplitude change from EGG could reflect gastric contractility [5]. The EGG method is attractive to researchers because it is noninvasive and does not disturb the on-going activity of human stomach. Electrogastrography has been applied to investigate GMA in both normal subjects and patients [5–10].

Music may induce a pleasant feeling, whereas noise may induce discomfort or even stress to an audience [11,12]. It has been reported that cold or emotional stress can affect GMA [13–16], but it is not known whether audio stimulation has any effects on GMA. A study by Camilleri & Ford suggests the involvement of the autonomic nervous system in the

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effect of stress on the gastrointestinal system [17]. Yin et al. reported the role of both sympathetic and vagal pathways in the inhibition of GMA induced by emotional stress [16]. Involvement of the vagal pathway in the effect of stress on gastrointestinal motility has also been reported by others [18,19]. Spectral analysis of heart rate variability (HRV) provides a non-invasive and quantitative assessment of vagal activity, and it is not only frequently used in cardiac research but also applied in gastrointestinal research [20–22].

The aims of this study were to investigate the effect of audio stimulation on GMA assessed by EGG and vagal activity assessed by the spectral analysis of HRV in healthy volunteers and possible differences in effect between pleasant classical music and annoying household noise.

Material and methods

Subjects

The study comprise 10 healthy volunteers (4 F, 6 M, age 25–47 years, mean 38.3 years). None of the subjects had any gastrointestinal diseases or symptoms or a history of gastrointestinal surgery. All of the women were studied during their follicular phase of the menses in order to minimize possible hormonal influences [23]. No medications were used by the participants, with the exception of oral contraceptives. The study was approved by the Institutional Review Board at University of Texas Medical Branch in Galveston, Texas. Written consent was signed by all the subjects before entering the study.

Study protocol

After a fast of 6 h or more, the EGG and ECG recordings were made in each subject for 30 min in the fasting state and in supine position. Then loud classical music was played to each subject via a headphone for 30 min, followed with another 30-min period during which a tape containing loud household noise was played. The volume of the music or noise was set at the highest level tolerated by the subjects. The classical music consisted of pieces of violin music played by Perlman; whereas the noise consisted of household noises including the opening of a garage door, operation of a vacuum cleaner, noises from tapping various kitchen utensils, etc. It was hypothesized that noise would affect gastric myoelectrical and autonomic activities and the effect might be prolonged and thus it was always played during the last 30-min period. The subjects were asked to stay awake, not to talk or read, and to remain as still as possible during the entire 90-min recording period to minimize their movements and obviate motion artifacts.

Electrogastrogram

Surface EGG was applied to measure GMA. Before the electrodes were put in place, the abdominal surface where the electrodes were to be placed was shaved, if hairy, and cleaned with sandy skin-prep jelly (Omni Prep; Weaver and Aurora, Colo., USA) to reduce impedance. The skin was rubbed with sandy skin-prep jelly until pinkish. Three silver-silver chloride ECG electrodes (Red Dot; 3M Health Care, St. Paul, Minn., USA) were placed on the abdominal skin. Two epigastric electrodes were connected to yield a bipolar EGG signal. The other electrode was used as a reference. The bipolar EGG signal was derived from electrodes 1 and 2 and was amplified using a portable EGG recorder (Digitrapper EGG; Medtronic-Synectics, Shoreview, Minn., USA) with low and high cut-off frequencies of 1 and 18 cpm, respectively. On-line digitization with a sampling frequency of 1 Hz was performed using a built-in 8-bit analog-to-digital converter and digitized samples were stored on the recorder.

Electrocardiogram

The HRV data were obtained from the electrocardiogram (ECG) recording. The ECG was recorded from three surface electrodes: the right-arm electrode on the manubrium of the sternum, the left-arm electrode at the surface marking of the V5 position (just above the 5th interspace in the anterior axillary line) and the ground electrode at the right chest. The ECG signal was first amplified using a UFI amplifier (UFI model 2283 ft/I, Morro Bay, Calif., USA) and digitized at a sampling frequency of 6000 Hz with the sound card installed on the PC and down-sampled to 500 Hz before the detection of R-R intervals. The detection of R-R interval, interpolation of the R-R interval data and spectral analysis of HRV were performed using software previously developed and validated in the lab [24].

Analysis of the EGG

The EGG data stored on the recorder were downloaded to an IBM 486 personal computer and subjected to computerized spectral analysis using a program previously developed by one of the authors in our laboratory [25]. The pattern of the EGG was characterized by several quantitative parameters, including the dominant frequency, dominant power and percentage of normal 2–4 cpm slow waves (see Figure 1). The following parameters were calculated from the EGG.

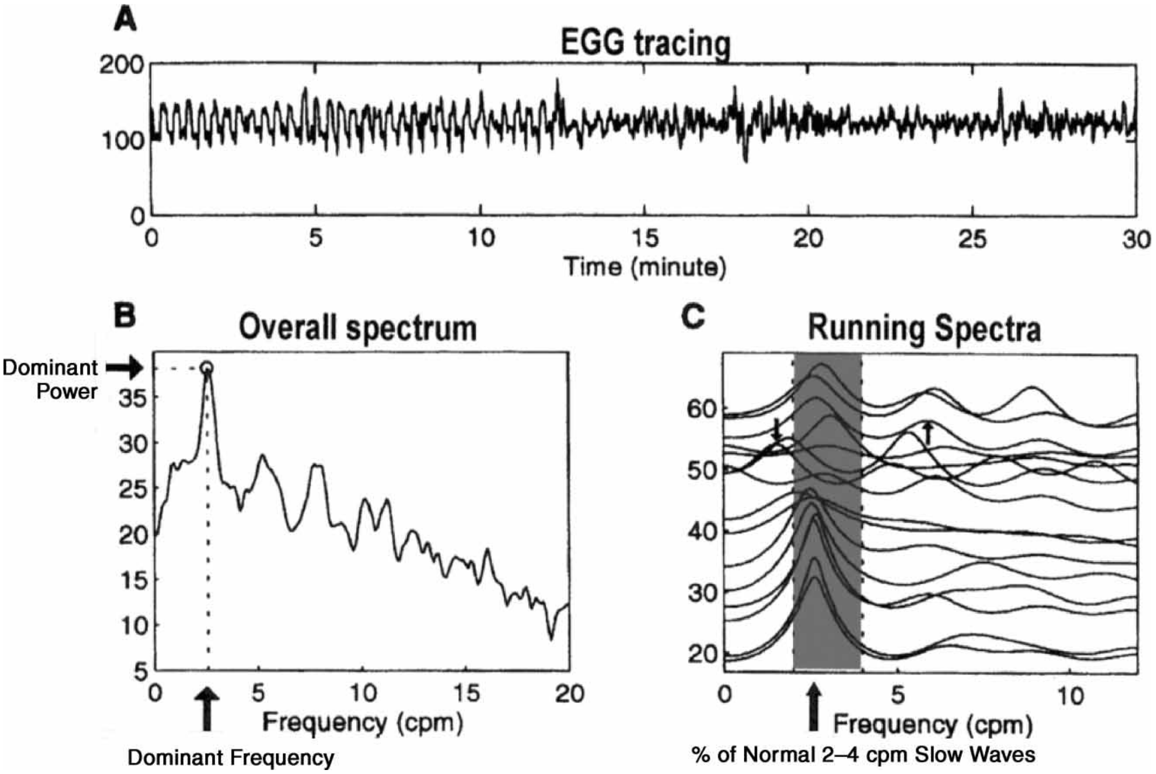

Figure 1. Recording and analysis of gastric myoelectrical activity. A. Tracing of EGG. B. Power spectrum: the peak values were defined as the dominant frequency and dominant power. C. Running spectrum: the segment of data was defined as normal if its dominant peak was in the frequency range of 2–4 cpm.

Dominant frequency and power of the slow waves. The frequency at which the power spectrum of an entire recording had a peak power in the range of 0.5 to 9.0 cpm was defined as the dominant frequency. The power corresponding to the dominant frequency in the power spectrum was defined as the dominant power.

Instability coefficient of dominant frequency (ICDF) and dominant power (ICDP). The ICDF was used to measure the stability of the dominant frequency, defined as the ratio between the standard deviation and the mean of dominant frequency: ICDF = SD/MEAN. The ICDF reflects variation in EGG-dominant frequency over the whole recording period and is not subject-dependent [8]. Similarly, the ICDP was used to test the stability of the dominant power and was defined as the ratio between the standard deviation and the mean of dominant power. A lower value of ICDF or ICDP is indicative of a more stable dominant frequency or dominant power.

Percentage of normal slow waves. This parameter specifies the regularity of gastric slow waves and was computed using the adaptive running spectral analysis method [8]. In this method, the gastric myoelectrical recording was divided into 1-min segments and the power spectrum of each 1-min recording was derived using the previously validated adaptive spectral analysis method [8,26]. The 1-min segment of the recording was defined as normal if its power spectrum had a clear peak in the 2–4 cpm frequency range. Otherwise, it was defined as dysrhythmia. The percentage of normal gastric slow waves was determined by computing the ratio between the number of normal segments and the total number of segments.

Percentage of gastric dysrhythmia. The percentage of gastric dysrhythmia was defined as the percentage of time during which gastric dysrhythmia was present in the EGG. Gastric dysrhythmia includes bradygastria, tachygastria and arrhythmia. This parameter reflects the abnormalities of gastric slow waves. It was computed in a similar way for the calculation of the percentage of normal gastric slow waves. Bradygastria was defined if the peak power of the 1-min EGG segment was within the range of 0.5–2 cpm, tachygastria if the peak power was within the range of 4–9 cpm and arrhythmia if there was no dominant peak in the 0.5–9 cpm range [8]. The above analyses were performed for the entire 30 min of the baseline, music and noise periods. To further assess the specificity of possible changes in the EGG, the analyses were repeated using an interval of 15 min on the last 15-min data during music and the first 15-min data during noise.

Analysis of heart rate variability

Overall power spectral analysis was applied to extract the sympathovagal parameters low frequency (LF) and high frequency (HF) [24]. The power in the LF band (0.04 to 0.15 Hz) represents mainly sympathetic or adrenergic activity and some parasympathetic activity. The power in the HF band (0.15 to 0.50 Hz) represents purely parasympathetic or vagal activity. LF was defined as the area under the curve in the frequency range of 0.04–0.15 Hz and HF was defined as the area under the curve in the frequency range of 0.15–0.50 Hz. The ratio of LF/HF reflects the balance between sympathetic activity and vagal activity. To fine-tune possible alternations, the above analyses were repeated on the HRV data at intervals of 5 min, 10 min and 15 min.

Statistical analysis

All data were presented as means ± SE. ANOVA was used for comparison of each parameter at baseline, classical music and noise periods. A paired Student's *t*-test was applied to investigate the difference in each of the EGG parameters and the parameters of HRV between baseline and audio stimulation. ANOVA was used to compare the difference between the three recording periods. The results were regarded as significant when the *p*-value was less than 0.05.

Results

Effects of audio stimulations on gastric slow waves

Both classical music and noise altered the regularity of gastric slow waves (Figures 2 and 3) The percentage of normal 2–4 cpm gastric slow waves was reduced from 77.9 ± 4.7% at baseline to 66.9 ± 5.4% during music ($p < 0.006$) and 67.7 ± 5.4% during noise ($p < 0.05$). The difference in the reduction of the percentage of normal gastric slow waves between the music and noise was that, with the music stimulation, the decrease was mainly attributable to a significant increase in bradygastria (15.8 ± 3.9% versus 9.8 ± 2.6%, $p < 0.04$); whereas, with the noise stimulation, the decrease was mainly attributable to a significant increase in arrhythmia (7.4 ± 1.6% versus 2.0 ± 1.1%, $p < 0.02$) (Figure 4). To further prove that these changes were specific to the type of audio stimulation, the EGG data during the last 15-min period with music and the first 15-min period with noise were analyzed with a 15-min interval, and the results were found to be similar to those obtained from the entire 30-min analysis; that is, the change in the regularity of gastric slow waves was mainly attributable to bradygastria (16.1 ± 3.2%, $p < 0.01$ versus baseline) during the last 15 min of music but mainly attributable to arrhythmia (10.3 ± 2.4%, $p < 0.01$ vs. baseline) during the first 15 min of noise intervention.

However, neither music nor noise resulted in any significant changes in the dominant frequency or power of the slow waves or the instability coefficient of the dominant frequency or dominant power. At baseline, the dominant frequency and power of the EGG were 2.89 ± 0.04 cpm and 31.17 ± 1.09 dB, respectively. These values were not altered with either music (2.93 ± 0.04 cpm and 28.1 ± 1.5) or noise (2.80 ± 0.08 cpm and 30.0 ± 1.38). There was

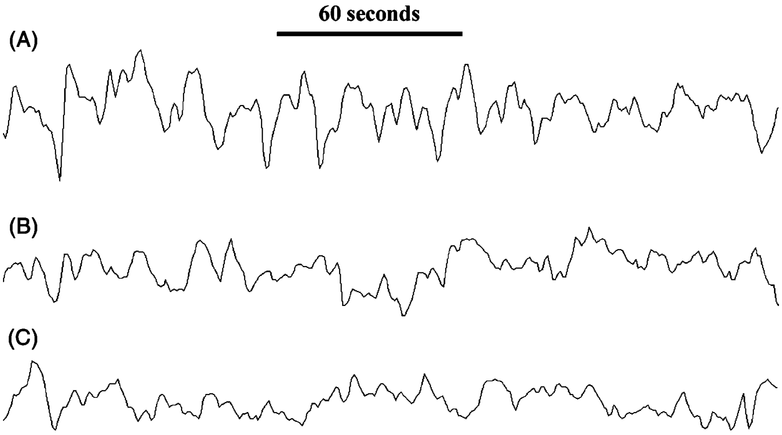

Figure 2. EGG tracings recorded from one subject. A. Normal gastric slow waves at baseline before audio stimulation. B. Recordings of EGG tracings during audio stimulation with music period. C. Recordings of EGG tracings during audio stimulation with noise period.

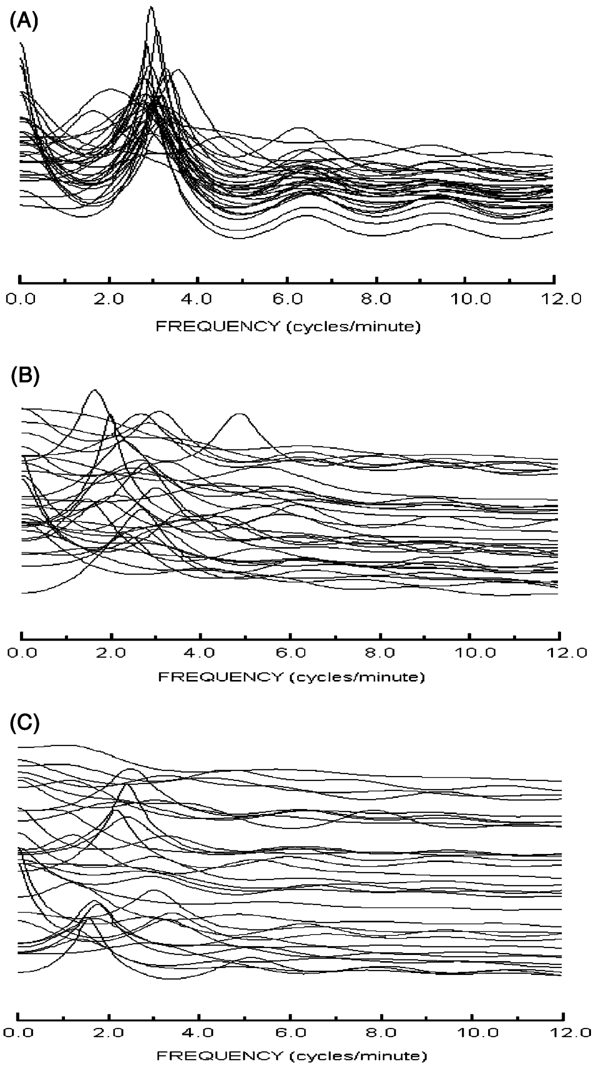

Figure 3. Running spectra of the EGG tracings. A. Running spectra of the EGG tracings at baseline before audio stimulation. B. Running spectra of the EGG tracings during audio stimulation with music. It can be seen that some spectral peaks are shifted to the left (bradygastria) in comparison with baseline. C. Running spectra of the EGG tracings during audio stimulation with noise. Fewer spectra (or more arrhythmia) are seen, compared with the baseline recording.

no significant difference in the instability coefficient of the dominant frequency among the baseline (0.33 ± 0.03), classical music (0.37 ± 0.04) and noise (0.36 ± 0.04) periods ($p > 0.05$). Neither was there any difference in the instability coefficient of dominant power among the baseline (0.19 ± 0.01), classical music (0.19 ± 0.01) and noise (0.20 ± 0.02) periods ($p > 0.05$).

Effects of audio stimulation on heart rate variability

None of the HRV parameters was altered by audio stimulation. No differences were noted among the three periods of control, music and noise in heart rate (67.8 ± 0.7 beats/min, 65.3 ± 0.4 beats/min and 65.4 ± 0.3 beats/min, NS), LF/HF (1.4 ± 0.1, 1.6 ± 0.1 and 1.6 ± 0.1, NS) or HF (0.47 ± 0.01, 0.42 ± 0.01 and 0.40 ± 0.01, NS). Neither the spectral analysis of the HRV using intervals of 15 min, 10 min or 5 min revealed any statistically significant differences in LF/HF or HF.

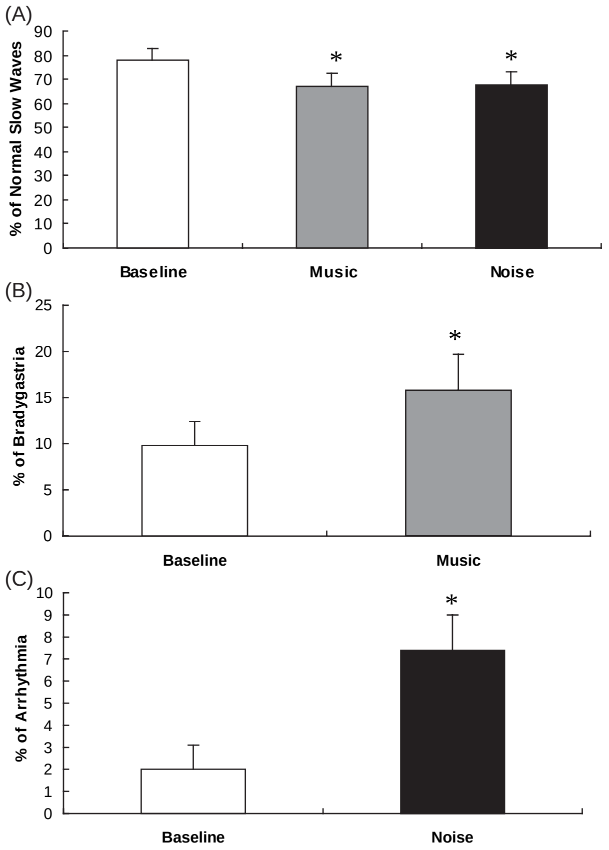

Figure 4. Effects of audio stimulation on the rhythmicity of gastric slow waves. A. The percentage of normal 2–4 cpm waves was significantly reduced during music ($p < 0.006$) and noise ($p < 0.05$) in comparison with baseline. B. Bradygastria was significantly increased during the music period. C. Noise significantly increased arrhythmia. *$p < 0.05$ versus baseline by paired Student's t-test.

Discussion

In this study, we have found that audio stimulation, whether music or noise, alters the rhythmicity of gastric slow waves, and the alternations did not seem to be associated with the vagal efferent activity or sympathovagal balance.

While there have been a large number of studies investigating the effect of stress on gastrointestinal motility, there have been few studies investigating the effect of stress on GMA. Cold stress was reported to inhibit gastric and duodenal motility and delay gastric emptying [13]. It was also reported to suppress the normal 3 cpm gastric slow waves [14] and the suppression seemed to be associated with the alteration in sympathetic activity [15]. A recent study reported that emotional stress induced by watching a horror movie inhibited normal gastric slow wave activities and the inhibition was accompanied by simultaneous alterations in both sympathetic and vagal activities [16]. In this study, we investigated the effect of audio stress on GMA and sympathovagal activity. To the best of our knowledge, this study was the first of its kind. One previous study investigated the effect of pre-recorded music (broad frequency noise) on gastrointestinal motility and peptides in dogs [27]. It was found that the acoustic stress induced a transient delay in gastric emptying, delayed the recovery of the migrating motor complex and enhanced the feeding-induced release of gastrin, pancreatic polypeptide and somatostatin.

In this study, an alteration in gastric slow waves was noticed during the audio stimulations. Both music and household noise reduced the percentage of normal gastric slow waves. The reduction in the normal slow waves was attributed to an increase in bradygastria with the music. However, with the household noise, this reduction was attributed to an increase in arrhythmia. The difference between bradygastria and arrhythmia has been reported in a number of earlier studies [28,29]. In one study, the origins of various patterns of gastric dysrhythmia (tachygastria, bradygastria and arrhythmia) were carefully investigated in a canine model [29]. It was found that tachygastria originated from an ectopic pacemaker located in the antrum, propagated retrogradely, and was correlated with gastric hypomotility. Similarly, arrhythmia was found to be associated with the absence of gastric contractions. Bradygastria, however, was found to originate from the normal pacemaker located in the corpus and propagated distally [29]. That is, bradygastria is caused by a decrease in frequency of the normal pacemaker. The correlation of bradygastria with gastric hypomotility has not been established. Instead, bradygastria has been reported to be associated with gastric contractions with a reduced frequency [30,31]. Based on these previous studies, it was postulated that the reduction in the percentage of normal gastric slow waves associated with the classical music in this study was attributable to a decrease in the frequency of the normal pacemaker, whereas the household noise increased the percentage of gastric arrhythmia and impaired the rhythmicity of the pacemaker. Since arrhythmia is related to the absence of gastric contractions, the stress-induced higher percentage of arrhythmia may cause hypomotility of the stomach. The different changes in gastric slow waves observed during music and noise are believed to be specific to the type of audio intervention, i.e. music or noise. In this study, the limitation is that the two audio interventions were not randomized and were applied back-to-back without a washout period, and hence, time effects could not be definitively ruled out. There was a concern with such a design that the effect of the first intervention might be carried over to the second intervention. However, the findings of the study seemed to rule this possibility because there was a significant increase in bradygastria when music was applied and this was changed into arrhythmia when music was replaced with noise.

Autonomic function assessed by the spectral analysis of HRV was found to be unchanged with audio stimulations in this study. The activity of the autonomic nervous system, especially the parasympathetic activity, can be assessed in the frequency domain using spectral analysis of the HRV derived from the electrocardiogram. The spectral analysis of the HRV is a well-established methodology for the non-invasive assessment of parasympathetic activity and sympathovagal balance [32,33]. Using the same method of spectral analysis of HRV, one previous study reported an increase in sympathetic activity and a decrease in vagal activity with emotional stress, and these alterations were associated with simultaneous inhibition of gastric slow waves [16]. In this study, however, neither vagal nor sympathetic activity was found altered with the audio stimulation, suggesting the involvement of other mechanisms that need further investigation. To study possible transient changes in vagal and sympathetic activities, the HRV data were also analyzed using shorter intervals of 15-, 10- and 5-min. No transient changes were noted in any of the HRV parameters when the music or noise intervention was initiated.

Music therapy has been used to lower blood pressure, decrease heart rate, stimulate peripheral vasodilatation and induce relaxation and decrease stress [34–37]. Central mechanisms were reported to be involved in music therapy [38,39]. Music can induce positive emotions and diminish stress. Pleasurable music can stimulate the frontal (left-anterior) brain and activate parts of the limbic system, e.g. the cingulate gyrus [38]. However, harsh or unpleasant music activates right parahippocampus and amygdala (related to fear and anxiety) [34]. The decrease in the rate of the gastric slow wave observed in this study is consistent with the previous findings. Further studies are needed to elucidate the mechanisms involved in such a change.

In conclusion, audio stimulation, both music and noise, alter the rhythmicity of gastric slow waves. Classical music seems to increase bradygastria, whereas household noise induces gastric arrhythmia. Vagal efferent nerves do not seem to be involved in these alterations as assessed by the spectral analysis of HRV.

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