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# Effects of audio stimulation on gastric myoelectrical activity and sympathovagal balance in healthy adolescents and adults

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## Abstract

**Aim:** The primary aim of this study was to investigate the effects of different audio stimulations on gastric myoelectrical activity and sympathovagal balance in adolescents compared with adults.

**Methods:** The study was performed in 11 adults and 12 adolescents. Each subject underwent two sessions, one for classical music, and the other for noise. Each session consisted of 30 min of baseline, 30 min of fasting audio stimulation, a test meal, 30 min of fed audio stimulation, and 30 min of recovery. Electrocardiogram and electrogastrogram were both recorded throughout each session.

**Results:** (i) In the fasting state, both classical music and noise impaired gastric slow wave activity in adolescents. In adults, noise had no effects while classical music moderately improved slow wave rhythmicity. (ii) In the fed state, neither noise nor music had any effects on gastric slow waves. (iii) In the fasting state, both noise and music increased the sympathovagal balance in adolescents; in adults only noise had such an effect. (iv) The test meal increased the sympathovagal balance in all groups.

**Conclusions:** Gastric slow waves and the sympathovagal balance are more strongly affected by audio stimulation in adolescents than in adults. The test meal normalizes the audio stimulation-induced differences between the groups.

## Introduction

Gastric myoelectrical activity (GMA) is one of the key factors in the regulation of gastric motility.[1] Two major types of myoelectrical activity are present in the human stomach: slow waves and spikes potentials.[2] Slow waves are occurring at all times, originating around the junction of the proximal one-third and distal two-thirds of the gastric corpus. The normal frequency of gastric slow waves is about three cycles per minute (cpm) and in the range of 2–4 cpm in humans.[2] Spike potentials are directly related to the presence of antral contractions. When spike potentials superimpose onto slow waves, the antral muscles contract. The frequency and propagation of the antral contractions are determined by gastric slow waves.

Gastric slow waves can be recorded using a non-invasive, easily reproduced technique known as electrogastrography (EGG). In this method, electrodes placed on the surface of the abdomen record GMA, which can be amplified for analysis.[3,4] EGG is attractive to researchers because its non-invasive nature does not disturb the naturally occurring activity in the human stomach. When performed correctly, the dominant frequency of the EGG accurately reflects the frequency of gastric slow waves while the change in dominant power reflects gastric contractility.[5] The EGG method has been applied to investigate GMA in both healthy subjects and patients.[5–10]

Different forms of audio stimulation can trigger varying responses in listeners. Peaceful, enjoyable music can induce relaxation, while aggravating noises might cause stress and adversely affect a listener.[11–13] Research has shown that various forms of audio stimulation can alter heart rate variability (HRV), and that the effects of rock music are similar to those of noise.[14] The literature shows that different forms of stress, including cold or emotional, alter GMA.[15–19] Previous research has also indicated that both a relaxing classical tape and a stressful noise tape affect GMA in healthy, fasting adult subjects.[20] A study in dogs showed that acoustic stress delayed gastric emptying and altered postprandial GMA.[21] However, the effects of audio stimulation on post-prandial GMA in humans remain largely unknown, as do any differences between age demographics. Research has indicated that noise stress can cause various negative physiologic effects, and that children are more vulnerable to these effects.[22] It is hypothesized that adolescents will be more susceptible to the effects of audio stress than adults because of the adolescents being psychologically immature relative to the adults.

There is evidence that both the sympathetic and vagal pathways play a role in the effects of stress on GMA.[18,23–25] In contrast, a previous study on audio stress in healthy adults found involvement from neither the sympathetic nor the vagal pathway.[20] Spectral analysis of HRV allows for accurate, non-invasive observations of autonomic nervous system activity.[26–28]

The primary aim of this study was to investigate the different effects of audio stimulation on GMA of adolescents and adults, as assessed by the EGG method, and on autonomic functions, as assessed by the spectral analysis of HRV. The study was also designed to explore different responses caused by classical music and household noises.

## Methods

### Subjects

Eleven healthy adult volunteers (6F, 5M, ages 23–45 years, mean age 36.5 years) and 12 healthy teenage volunteers (8F, 4M, ages 13–18 years, mean age 15.4 years) were recruited. None of the subjects showed any symptoms of gastrointestinal diseases and none had a history of gastrointestinal surgery. No medications were used by the subjects, with the exception of oral contraceptives. Written consent was obtained from all subjects prior to the study; parent consent was also obtained for all teenage subjects. The study was approved by the Institutional Review Board at the University of Texas Medical Branch in Galveston, Texas and the VA Medical Center, Oklahoma City, Oklahoma.

### Protocol

The study consisted of two sessions (one with household noises, one with classical music) in a randomized order on separate days. Subjects were told to fast for at least 6 h before arriving for the session. Once the subject arrived, he was asked to lie in a supine position while electrocardiogram (ECG) and EGG signals were recorded for 30 min in the fasting state as a baseline. After this period, headphones were given to the subject and the household noise tape was played for 30 min. The subject was told to set the volume at the highest tolerable level. The tape was stopped at the end of this section and the subject was given a test meal (467 kcal) to consume within 30 min. Once the meal was completed, another 30 min was recorded with the household noise tape. Finally, the headphones were removed and another 30 min was recorded in silence. The second session was identical in procedure, except classical music replaced the household noise tape and the subject was allowed to set the volume to his own preference. The household noise tape included the clattering of pots and pans, alarm clocks, sounds made by children's toys, vacuum cleaners, etc.; the classical music was a series of violin pieces performed by Perlman. Subjects were asked to remain awake, silent, and to avoid excessive movement throughout the recording period to prevent the presence of motion artifacts. The test meal was 467 kcal in total and consisted of a turkey sandwich (3 slices of bread, 4 slices of turkey, 330 kcal), a cookie (80 kcal), and orange juice (120 mL, 57 kcal).

### Electrogastrogram

Gastric myoelectrical activity was recorded by surface EGG. The abdominal area where the three electrodes were to be placed was shaved, if necessary, and cleaned with abrasive skin-prep jelly (Nuprep, D.O. Weaver & Co., Aurora, CO, USA) to reduce impedance. The jelly was rubbed on the skin until the skin turned pinkish. The area was dried, and then blue electrode gel (Signa gel, Parker Laboratories, Inc., Orange, NJ, USA) was applied to improve signal conductivity. Three silver-silver chloride EGG electrodes (Red Dot; 3M Health Care, St. Paul, MN, USA) were attached to the prepared abdominal area. Two epigastric electrodes (one at the midline between xiphoid process and the umbilicus and the other 5 cm away 45 degrees to the upper-left of the subject) were used to yield a bipolar EGG signal while the third electrode served as a reference. The EGG signal obtained from the electrodes was amplified using a multi-channel EGG recorder (Medtronic-Synectics, Shoreview, MN, USA) at UTMB and a portable EGG recorder (Digitrapper EGG; Medtronic-Synectics, Shoreview, MN, USA) at the VA Medical Center in Oklahoma City. Online digitization was performed, using a sampling frequency of 1 Hz and data were stored on a personal computer (PC).

### Electrocardiogram

The ECG was recorded to yield the HRV data. Three ECG surface electrodes were attached as follows: the right-arm electrode at the manubrium of the sternum, the left-arm electrode on the surface marking of the V5 position (just above the fifth interspace in the anterior axillary line), and the ground electrode at the right chest. Skin preparation was identical to EGG electrodes. The ECG signal was amplified by a UFI amplifier (UFI model 2283 ft/I, Morrow Bay, CA, USA) and digitized with a sampling frequency of 6000 Hz using the sound card on the PC. The signal was then down-sampled to 500 Hz before analysis. The R-R interval detection and interpolation of R-R interval data and the spectral analysis of the HRV data were all performed using software previously developed and validated in the lab.[29]

### Assessment of the appreciation of audio stimulation

Subjects' appreciation during each period of audio stimulation was recorded and graded. These included stress level (0: no stress; 10: most stressful), intolerance level (0: completely tolerable, 10: most intolerable), and relaxation level (0: no feeling of relaxation; 10: most relaxing).

### Analysis of EGG

The EGG data were all stored on an IBM 486 PC. Each session was divided into four 30-min segments (baseline, fasting stimulation, fed stimulation, recovery) and computerized spectral analysis was performed on the data using an existing program previously developed validated in the lab.[30] The signal from the EGG was described by several quantitative parameters, including dominant frequency, dominant power, and percentage of normal 2–4 cpm slow waves. The observed parameters from the EGG signal were as follows.

#### Dominant frequency and power of slow waves

The frequency, in the range of 0.5–9.0 cpm, at which the power spectrum of the analyzed section had a peak power, was defined as the dominant frequency. The dominant frequency measured by the EGG has been shown to be equal to the frequency of gastric slow waves as measured by implanted serosal electrodes. The corresponding peak power at this dominant frequency was defined as the dominant power of the EGG. Change in the dominant power has been shown to reflect gastric contractility.[5]

#### Percentage of normal slow waves

This parameter reflects the normality of gastric slow waves and was determined as the percentage of time when normal 2–4 cpm slow waves were present over each 30-min period. This percentage was computed by using an adaptive running spectral analysis method where the EGG recording was divided into non-overlapping 1-min segments and the power spectrum of each individual segment was derived using a previously validated spectral analysis.[9,31] If a 1-min segment had a clear peak in the 2–4 cpm frequency range, it was defined as normal; if not, it was defined as gastric dysrhythmia.

#### Percentage of gastric dysrhythmia

Gastric dysrhythmia can be divided into three different categories: bradygastria, tachygastria, and arrhythmia. All three forms represent abnormalities of the gastric slow waves. Calculation of each form was done in a similar fashion to the percentage of normal slow waves. If the peak power of a 1-min segment was between 0.5 and 2 cpm, it was defined as bradygastria; between 4 and 9 cpm was tachygastria. Arrhythmia was defined when there was no dominant peak in the 0.5–9 cpm frequency range.

### Analysis of ECG

The ECG recordings were stored on a PC and divided into the same four 30-min segments as the EGG recordings. The HRV signal was derived from the ECG signal by detection and interpolation of R-R intervals. Power spectral analysis was then performed on the segmental HRV data to derive sympathetic and vagal activities.

#### Average heart rate

Average heart rate was the average number of recorded beats per minute over an entire 30-min segment. The standard deviation of HR was also calculated to observe the stability of average heart rate.

#### Sympathetic and vagal activity

The spectral analysis of the HRV is an established method for non-invasive assessment of parasympathetic activity and sympathovagal balance.[32,33] The power in the low frequency (LF) band (0.04–0.15 Hz) primarily represents sympathetic activity, along with some parasympathetic, or vagal activity. The power in the high frequency (HF) band (0.15–0.50 Hz) represents solely 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 to HF shows the balance between sympathetic and vagal activity.

### Statistical analysis

All data are presented as mean ± SE. Analysis of variance (ANOVA) was performed to assess any difference among three or more segments of data. When a significant difference was noted with ANOVA, the paired Student's *t*-test was applied to examine the differences in each of the parameters between baseline and audio stimulation, music and noise, fasting and fed, or adolescents and adults. Results were considered statistically significant when $P \leq 0.05$.

## Results

### Gastric slow waves

Results showing the effects of noise and music are presented in Table 1 and Figs 1–3. The adolescents and the adults showed similar percentages of normal 2–4 cpm slow waves at baseline (Noise session: 71.34 ± 4.59% *vs* 80.31 ± 5.51%, $P > 0.05$; Music session: 72.11 ± 4.26% *vs* 76.33 ± 5.00%, $P > 0.05$). In the adolescents, noise played in the fasting state significantly reduced the percentage of normal slow waves from 71.34 ± 4.59% to 65.85 ± 4.25% ($P < 0.05$, Figs 1,2), whereas classical music did not significantly alter normal slow waves but resulted in a significant increase in tachygastria (15.23 ± 4.69% *vs* 21.82 ± 4.41%, $P < 0.05$). In the adults, classical music in the fasting state moderately increased normal slow waves from 76.33 ± 5.00% to 81.94 ± 5.41% ($P = 0.07$, Figs 1,3), which was primarily attributed to a decrease in arrhythmia (4.86 ± 1.61% *vs* 1.81 ± 0.83%, $P < 0.05$). Noise in the fasting state had no effects on the gastric slow waves in the adults.

Differences were noted in the gastric slow waves between the adult group and the adolescent group. The adult group had significantly higher percentages of normal slow waves than the adolescent group during the fasting stimulation stage for both classical music (81.94 ± 5.41% *vs* 67.38 ± 5.2%, $P < 0.05$) and noise (81.21% ± 3.93 *vs* 65.85 ± 4.25%, $P < 0.05$) (see Table 1 and Fig. 4).

The test meal significantly increased the percentage of normal slow waves for the adolescent group during the noise session (65.85 ± 4.25% *vs* 72.27 ± 4.52%, $P < 0.05$), which was mainly attributable to a decrease in tachygastria (17.88 ± 2.55% *vs* 10.12 ± 2.87%, $P < 0.05$). Feeding did not significantly alter normal slow waves in any other group/sessions. However, feeding did abolish the difference in the percentage of normal slow waves between adults and adolescents in both classical and noise sessions, suggesting that the effects of audio stimulation on the gastric slow waves were limited to the fasting state.

When the comparison was made in the audio stimulation-induced changes in the percentage of normal slow waves between adult and adolescent groups, the difference was significant for classical music (+5.61 ± 3.47% for adults, –4.73 ± 3.68% for adolescents, $P < 0.05$) and moderate for noise (+0.92 ± 2.92%

**Table 1** Effects of audio stimulation on electrogastrography parameters

| | Baseline | Fasting | Fed | Recovery |
|---|---|---|---|---|
| % Normal 2–4 cpm slow waves | | | | |
| Teens noise | 71.34 ± 4.59 | 65.85 ± 4.25* | 72.27 ± 4.52** | 69.32 ± 4.20 |
| Teens music | 72.11 ± 4.26 | 67.38 ± 5.20 | 64.49 ± 5.10 | 61.17 ± 5.04 |
| Adults noise | 80.31 ± 5.51 | 81.21 ± 3.93 | 76.36 ± 3.93 | 69.85 ± 3.92 |
| Adults music | 76.33 ± 5.00 | 81.94 ± 5.41 | 72.90 ± 3.00 | 76.69 ± 3.14 |
| % Bradygastria | | | | |
| Teens noise | 10.49 ± 2.32 | 12.94 ± 2.46 | 15.96 ± 3.00 | 17.00 ± 2.19 |
| Teens music | 9.67 ± 1.83 | 8.97 ± 2.37 | 14.43 ± 3.16 | 17.24 ± 2.67 |
| Adults noise | 6.03 ± 1.74 | 7.32 ± 1.72 | 7.92 ± 1.49 | 14.31 ± 2.36 |
| Adults music | 9.04 ± 2.54 | 6.74 ± 2.55 | 13.65 ± 2.28 | 11.96 ± 2.01 |
| % Tachygastria | | | | |
| Teens noise | 14.39 ± 2.68 | 17.88 ± 2.55 | 10.12 ± 2.87** | 15.04 ± 2.82 |
| Teens music | 15.23 ± 4.69 | 21.82 ± 4.41* | 17.48 ± 3.37 | 18.01 ± 2.72 |
| Adults noise | 11.87 ± 4.03 | 10.05 ± 2.58 | 12.39 ± 3.46 | 13.19 ± 2.66 |
| Adults music | 9.78 ± 2.63 | 9.51 ± 2.80 | 9.98 ± 2.12 | 8.54 ± 2.31 |
| % Arrhythmia | | | | |
| Teens noise | 3.75 ± 1.03 | 3.33 ± 0.91 | 1.65 ± 0.65 | 3.47 ± 1.23 |
| Teens music | 3.00 ± 0.96 | 1.84 ± 0.71 | 3.60 ± 0.73 | 3.33 ± 0.70 |
| Adults noise | 1.78 ± 0.68 | 1.43 ± 0.50 | 3.34 ± 1.38 | 2.64 ± 0.75 |
| Adults music | 4.86 ± 1.61 | 1.81 ± 0.83* | 3.47 ± 0.91 | 2.77 ± 1.30 |
| Dominant frequency (cpm) | | | | |
| Teens noise | 2.90 ± 0.05 | 2.74 ± 0.08* | 3.07 ± 0.11** | 3.08 ± 0.09 |
| Teens music | 2.84 ± 0.12 | 2.87 ± 0.09 | 3.01 ± 0.08 | 3.14 ± 0.08** |
| Adults noise | 2.94 ± 0.08 | 2.99 ± 0.05 | 3.04 ± 0.10 | 3.14 ± 0.06** |
| Adults music | 2.95 ± 0.09 | 2.95 ± 0.06 | 3.04 ± 0.08 | 3.14 ± 0.05** |
| Dominant power (dB) | | | | |
| Teens noise | 30.18 ± 0.62 | 29.96 ± 0.84 | 31.89 ± 0.95 | 31.89 ± 1.04 |
| Teens music | 30.33 ± 0.52 | 29.79 ± 0.71 | 30.00 ± 1.12 | 30.86 ± 1.07 |
| Adults noise | 31.43 ± 1.06 | 31.07 ± 1.03 | 32.33 ± 1.38 | 30.77 ± 0.45 |
| Adults music | 30.05 ± 1.04 | 29.79 ± 0.80 | 32.02 ± 1.34** | 31.32 ± 1.41 |

*$P \leq 0.05$ *vs* baseline. **$P \leq 0.05$ *vs* fasting.

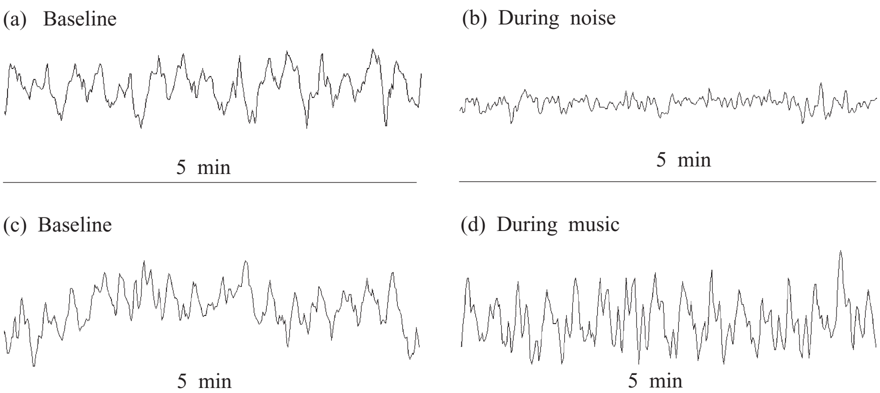


**Figure 1** Typical electrogastrography (EGG) tracings recorded from one adolescent and one adult in fasting state. (a) Baseline EGG in an adolescent. (b) EGG during audio stimulation (noise) in the same adolescent showing impairment in slow waves. (c) Baseline EGG in an adult. (d) EGG during audio stimulation (music) in the same adult showing an improvement in slow waves.

for adults, $-5.49 \pm 3.01\%$ for adolescents, $P = 0.07$). These results indicated that both classical music and noise affected the age groups to varying degrees.

The noise stimulation significantly lowered dominant frequency in the adolescent group ($2.90 \pm 0.05$ cpm *vs* $2.74 \pm 0.08$ cpm, $P < 0.05$) but did not affect the adult group. Classical music did not alter dominant frequency in either group. After consuming the meal, the dominant frequency significantly increased during the first or second 30-min session in both age groups for both forms of audio stimulation (see Table 1). In both the adolescent and adult groups, dominant power was unaffected by audio stimulation in both sessions. At baseline, there was no difference in dominant power between the adolescent and adults groups. During the classical music session, consumption of the

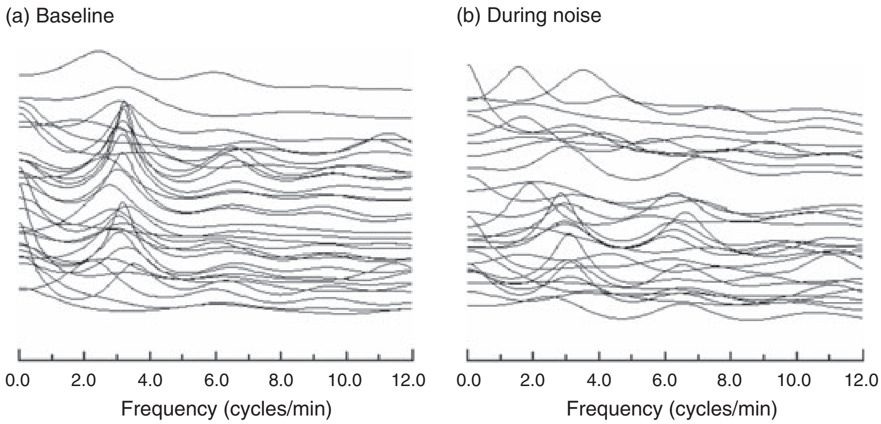


**Figure 2** Running spectra of the electrogastrography (EGG) in an adolescent in the noise session in fasting state. (a) Running spectra of the EGG at baseline before audio stimulation (noise) in an adolescent. (b) Running spectra of the EGG during audio stimulation (noise) in the same adolescent. There were less spectral peaks in the frequency range of 2–4 cpm (decreased percentage of normal slow waves) during noise stimulation in the adolescent.

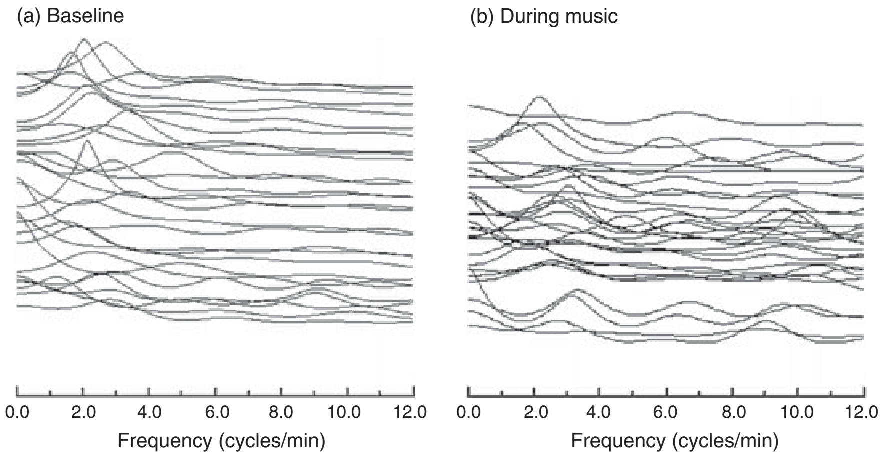


**Figure 3** Running spectra of the electrogastrography (EGG) in an adult in the music session in the fasting state. (a) Running spectra of the EGG at baseline before audio stimulation (music) in an adult. (b) Running spectra of the EGG during audio stimulation (music) in the same adult. There were more spectral peaks in the frequency range of 2–4 cpm during the music period, suggesting an increase in the percentage of normal slow waves.

test meal significantly increased dominant power in adults (29.79 ± 0.80 *vs* 32.02 ± 1.34, $P = 0.05$) but did not affect adolescents. Conversely, during the noise session, consumption of the test meal moderately increased dominant power in adolescents (29.96 ± 0.84 *vs* 31.89 ± 0.95, $P = 0.07$) but did not affect adults.

## Heart rate variability

As shown in Table 2, the adolescent group had a higher average heart rate than the adult group during any measurement periods. Neither music nor noise altered heart rate in either group from their baseline values. Consumption of the meal did significantly increase the heart rate with respect to baseline and it did not return to the baseline value during the recovery stage (see Table 2).

There was no difference in sympathovagal balance (LF/HF ratio) between the adult and adolescent groups at baseline and the values were all close to 1 (see Table 2). As shown in Table 2 and Fig. 5, in the adolescent group, the LF/HF ratio was significantly increased by both noise stimulation (0.96 ± 0.15 *vs* 1.17 ± 0.12, $P = 0.05$) and classical music (0.99 ± 0.23 *vs* 1.34 ± 0.32, $P = 0.01$). In adults, LF/HF ratio increased significantly during the noise stimulation (0.93 ± 0.13 *vs* 1.19 ± 0.13, $P < 0.002$) but was not affected by classical music. Consumption of the meal further increased the LF/HF ratio for each group. This effect was readily apparent in the adult group during both the classical (1.67 ± 0.20 *vs* 1.09 ± 0.13, $P < 0.0004$) and noise sessions (1.61 ± 0.23 *vs* 1.19 ± 0.13, $P = 0.04$). In adolescents, the effect was also immediate during the noise session (1.58 ± 0.25 *vs* 1.17 ± 0.12, $P = 0.05$) but was delayed in classical session, with the effect occurring between the post-prandial stimulation stage and the recovery stage (1.25 ± 0.22 *vs* 1.67 ± 0.38, $P = 0.05$). Neither sympathetic activity (LF) alone nor vagal (HF) activity alone was significantly altered during either audio stimulation session (see Table 2). Instead, it appeared that the increase in LF/HF ratio resulted from the combination of a small increase in LF activity corresponding to a similar decrease in HF activity. This was also true between pre- and post-prandial stages in each group.

## Appreciation of audio stimulation

Surprisingly, no differences were noted in the appreciation of audio stimulation between the adults and adolescence. Both groups of subjects felt stressed with the noise but relaxed with the music. As shown in Table 3, in the fasting state both groups rated a stress level of about 7.4% and intolerability of about 6.0% with noise and a relaxation level of 8.5%. These values were not significantly altered in the fed state.

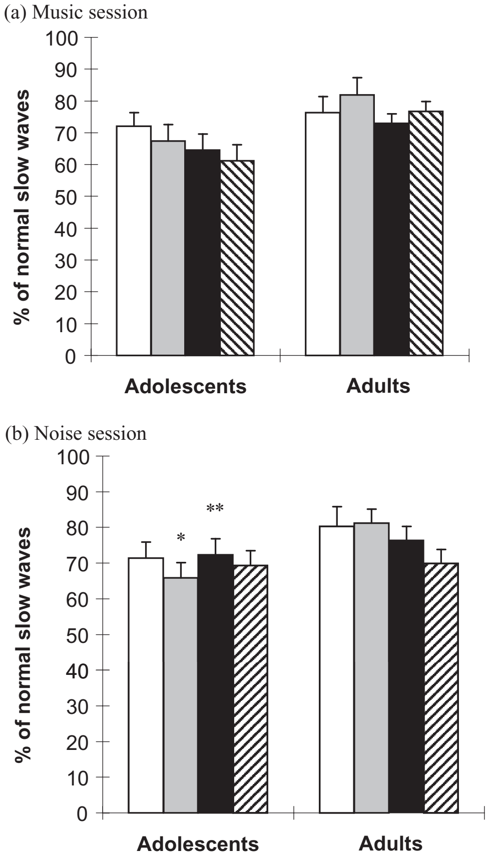


**Figure 4** Effects of audio stimulation on percentage of normal slow waves in adolescents and adults. (a) Effects of music on percentage of normal slow waves. (b) Effects of noise on percentage of normal slow waves. *$P < 0.05$ *vs* Baseline, **$P < 0.05$ *vs* Fasting. Baseline (□): baseline recording without stimulation; fasting (▢): fasting state with stimulation; fed (■): first 30-min post-prandial period with stimulation; recovery (▧): second 30-min post-prandial period without stimulation.

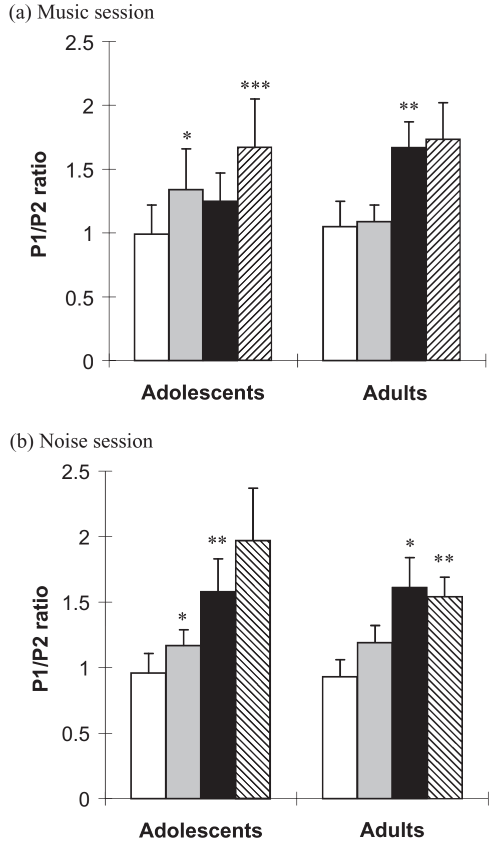


**Figure 5** Effects of audio stimulation on sympathovagal balance (LF/HF ratio) in adolescents and adults. (a) Effects of music on the LF/HF ratio. *$P \leq 0.05$ *vs* Baseline, **$P \leq 0.05$ *vs* Fasting, ***$P < 0.05$ *vs* Fed. (b) Effects of noise on the ratio. *$P < 0.05$ *vs* Baseline, **$P < 0.05$ *vs* Fasting. Baseline (□): baseline recording without stimulation; fasting (▢): fasting state with stimulation; fed (■): first 30-min post-prandial period with stimulation; recovery (▨): second 30-min post-prandial period without stimulation.

## Discussion

In this study, we found that: (i) noise impaired gastric slow waves in the adolescents but not in the adults; music impaired gastric slow waves in adolescents but enhanced gastric slow waves in adults; (ii) meal consumption abolished the audio stimulation-induced alterations in gastric slow waves, suggesting that the effects of the audio stimulations are manifested only in the fasting state but not in the fed state; (ii) noise resulted in an increase in sympathovagal balance in both adolescents and adults, whereas music increased the sympathovagal balance in adolescents but not in adults; and (iv) the test meal increased the sympathovagal balance in both groups of subjects.

Studies examining the effects of audio stress on human gastric slow waves have been limited. While some research has been done on the effects of various types of stress on healthy volunteers, little work has been done concerning the differences between adults and adolescents. Research has shown that different types of audio stimulation have different effects on listeners.[14] This difference may be due in part to personal preferences of the listeners. Because adolescents are thought to be less psychologically mature than adults, we wanted to explore the differences of audio stimulation between the two groups.

This study revealed that noise was able to impair normal slow waves in adolescents but not in adults. This finding supports the hypothesis that adolescents are more susceptible to audio stress than adults. Although adolescents did not consider the noise to be more disruptive than adults did, the noise strongly affected them (see Table 3), suggesting the involvement of unknown mechanisms, such as education, religion, life/social experience, and/or even hormones, other than feelings. Both groups disliked the noise and found it stressful, but only adolescents' gastric slow waves were affected. This seems to suggest that adults are more capable of coping with stressful situations.

Conversely, classical music improved normal slow waves in adults but impaired them in adolescents. In adults, the increase in normal slow waves was mainly credited to a decrease in arrhythmia. In adolescents, the decrease was primarily attributed to an

**Table 2** Effects of audio stimulation on heart rate variability

| | Baseline | Fasting | Fed | Recovery |
|---|---|---|---|---|
| Heart rate(beats/min) | | | | |
| Teens noise | 69.84 ± 2.74 | 70.04 ± 2.51 | 75.56 ± 2.23*** | 78.80 ± 2.62 |
| Teens music | 72.64 ± 2.90 | 72.80 ± 3.11 | 77.76 ± 3.25*** | 80.45 ± 3.28 |
| Adults noise | 63.06 ± 2.05** | 62.53 ± 1.70** | 67.10 ± 1.59**, *** | 69.43 ± 1.89** |
| Adults music | 61.88 ± 1.78** | 60.22 ± 1.89** | 66.08 ± 1.65**, *** | 67.63 ± 2.40** |
| Sympathovagal balance (LF/HF ratio) | | | | |
| Teens noise | 0.96 ± 0.15 | 1.17 ± 0.12* | 1.58 ± 0.25*** | 1.97 ± 0.40 |
| Teens music | 0.99 ± 0.23 | 1.34 ± 0.32* | 1.25 ± 0.22 | 1.67 ± 0.38**** |
| Adults noise | 0.93 ± 0.13 | 1.19 ± 0.13* | 1.61 ± 0.23*** | 1.54 ± 0.15 |
| Adults music | 1.05 ± 0.20 | 1.09 ± 0.13 | 1.67 ± 0.20*** | 1.73 ± 0.29 |
| Sympathetic activity (LF) | | | | |
| Teens noise | 0.18 ± 0.05 | 0.18 ± 0.05 | 0.18 ± 0.04 | 0.22 ± 0.06 |
| Teens music | 0.12 ± 0.03 | 0.14 ± 0.04 | 0.12 ± 0.03 | 0.15 ± 0.04 |
| Adults noise | 0.07 ± 0.02 | 0.08 ± 0.02 | 0.10 ± 0.02 | 0.08 ± 0.01 |
| Adults music | 0.08 ± 0.02 | 0.09 ± 0.02 | 0.11 ± 0.03 | 0.09 ± 0.02 |
| Vagal activity (HF) | | | | |
| Teens noise | 0.21 ± 0.06 | 0.21 ± 0.07 | 0.23 ± 0.12 | 0.26 ± 0.12 |
| Teens music | 0.18 ± 0.06 | 0.17 ± 0.05 | 0.17 ± 0.06 | 0.20 ± 0.08 |
| Adults noise | 0.08 ± 0.02 | 0.07 ± 0.01 | 0.07 ± 0.01 | 0.06 ± 0.01 |
| Adults music | 0.09 ± 0.02 | 0.09 ± 0.02 | 0.07 ± 0.02 | 0.06 ± 0.01 |

$^{*}P \leq 0.05$ *vs* baseline; $^{**}P < 0.05$ *vs* teens; $^{***}P \leq 0.05$ *vs* fasting; $^{****}P < 0.05$ *vs* fed.
HF, high frequency; LF, low frequency.

**Table 3** Effects of audio stimulation on stress, intolerance, and relaxation levels

| | Stress level | Intolerance level | Relaxation level |
|---|---|---|---|
| Fasting | | | |
| Teens noise | 7.42 ± 0.45 | 5.83 ± 0.74 | 3.50 ± 0.60 |
| Adults noise | 7.36 ± 0.51 | 6.36 ± 0.72 | 2.64 ± 0.64 |
| Teens music | 1.92 ± 0.69 | 1.58 ± 0.64 | 8.42 ± 0.43 |
| Adults music | 1.64 ± 0.49 | 0.73 ± 0.27 | 8.55 ± 0.43 |
| Fed | | | |
| Teens noise | 7.00 ± 0.55 | 5.67 ± 0.70 | 4.17 ± 0.66 |
| Adults noise | 7.45 ± 0.47 | 6.73 ± 0.57 | 2.82 ± 0.62 |
| Teens music | 2.00 ± 0.48 | 1.92 ± 0.57 | 7.92 ± 0.46 |
| Adults music | 2.09 ± 0.46 | 1.27 ± 0.38 | 8.27 ± 0.45 |

increase in tachygastria. Previous research examined the origins of the three types of gastric dysrhythmia (bradygastria, tachygastria, arrhythmia) in a canine model.[34,35] Tachygastria was found to originate from an ectopic pacemaker in the antrum and to propagate retrogradely. Both tachygastria and arrhythmia were associated with gastric hypomotility. Bradygastria originated in the normal pacemaker and propagated distally. The results in this study seem to suggest that audio stress alters gastric rhythmicity because it affects the antral ectopic pacemaker, but not the normal pacemaker. Since arrhythmia and tachygastria are both associated with gastric hypomotility, audio stress may impair or inhibit gastric contractions.

Both groups rated the music as relaxing, yet the music had nearly the same effect on adolescents as the noise did. This leads to two primary possibilities: (i) audio stimulation, whether enjoyable or not, adversely affects gastric slow waves in adolescents; (ii) adolescents felt social pressure to enjoy the classical music, so they gave the music higher scores on the rating sheet even though they did not enjoy the classical music any more than the noise tape. Musical therapy can decrease heart rate, lower blood pressure, stimulate peripheral vasodilatation, and induce relaxation and decrease stress.[36–39] The central nervous system was found to play a role in the effects of music therapy.[40,41] When audio stimulation is enjoyable, the frontal lobe is stimulated and parts of the limbic system are activated.[41] Meanwhile, stressful audio stimulation activates the amygdala (related to fear and anxiety) and the right parahippocampus.[38] Further research must be done to understand the specific mechanisms of audio stimulation and the central nervous system.

The test meal was able to abolish the alterations to normal slow waves caused by the audio stimulation in both groups. This effect occurred even though there were no significant differences in percentage of slow waves between the pre- and post-prandial stages in any individual group. This corresponds with previous research indicating that a meal does not significantly alter normal slow waves.[42,43] In the adult group, the test meal caused non-significant decreases in the percentage of normal slow waves in both the classical music and noise sessions. In the adolescent group, the meal caused a non-significant increase during the noise session and a non-significant decrease in the music session. It is possible that, rather than always causing an increase or decrease, consumption of a meal causes the percentage of normal slow waves to revert to its original baseline value, nullifying the effects of the audio stimulation.

Although the heat rate was significantly higher in the adolescents, sympathovagal balance (LF/HF ratio) was similar in adults and adolescents at baseline and all values were close to 1. Noise stimulation significantly increased LF/HF ratio in both groups, while classical music significantly increased the ratio in adolescents but did not affect adults. An increase in LF/HF ratio results from a combination of increased sympathetic activity and decreased vagal activity, so these results are consistent with previous research showing that emotional stress increased sympathetic activity and decreased vagal activity.[18] Higher sympathetic activity indicates increased heart rate and higher blood pressure, while decreased vagal activity may be associated with decreased gastric motility. The noise tape was reported to be very stressful by both adults and adolescents, which corresponds to the increased sympathovagal balance. In adolescents, classical music caused an increase in sympathovagal balance in spite of low stress ratings. This is consistent with the gastric slow wave findings in this study which showed that classical music lowered percentage of normal slow waves in adolescents. While adults were not physiologically or psychologically affected by classical music, adolescents showed increasing sympathetic activity and decreasing normal slow waves, which contradicts their own ratings of the classical music. The test meal caused an immediate increase in LF/HF ratio in all groups except the adolescent classical music session where the effect was delayed for 30 min. This increase in sympathetic activity can be observed in the heart rate measurements, which significantly increased in all groups after the test meal (see Table 2). These results correspond with previous research that found sympathovagal balance increased post-prandially.[18,44]

This study supports the efficacy of classical music therapy as a method of improving gastric slow wave rhythmicity. However, the patients being treated must be psychologically mature for the therapy to actually have positive effects. In addition, findings from this study suggest that prolonged exposure to stressful noise would cause negative consequences for both GMA and HRV. Further studies would be needed to assess the long-term effects of these consequences.

In conclusion, both classical music and noise stimulation disrupt slow wave activity and increase sympathovagal balance in adolescents. In adults, only noise causes these effects, while classical music actually enhances gastric slow waves. The test meal also further increased the sympathovagal balance. The test meal cancelled out the effects of the audio stimulation on the gastric slow waves, indicating that the effects exerted by audio stimulation may only occur in the fasting state.

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