Synchronized Activation of Brain Waves by Singing Bowl Beating Sounds

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Research Article

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Abstract

This study aims to verify if the beating sound of a singing bowl synchronizes and activates brain waves. The singing bowl sound used in this experiment strongly beats at the frequency of 6.68 Hz, while it decays exponentially and lasts for about 50 sec. Brain waves were measured for 5 min at the F3 and F4 region of the 17 subjects who heard the beating singing bowl sounds. Experimental results showed that the increases (up to ~ 251 %) in the spectral magnitudes of the brain waves were dominant at the beat frequency, compared to those of any other clinical brain wave frequency bands. The observed synchronized activation of the brain wave at the beating sound frequency supports that the singing bowl sound may effectively facilitate meditation and relaxation, considering that the beat frequency belongs to theta waves which increases in the relaxed meditation state.

I. Introduction

A singing bowl is a bowl-shaped percussion instrument[1]. The singing bowl has a peculiar feature that it sounds as well as beats, lasting for a long time after playing[2]. The singing bowl sound has often used to reduce the degree of tension, anxiety, and depression[3]. The singing bowl sound is known to facilitate physiological and psychological responses to meditation[2, 4]. Although the singing bowl sound is reported to give positive effects in meditation or alternative medicine, the mechanism for its psychoacoustic effects remains unclear.

It is presumed that the singing bowl sound may play a critical role for the beneficial responses of the brain through its strong beat. Suppose the brain waves be activated and synchronized at the beat frequencies located in theta waves, the brain is likely shifted to relaxed meditation state[1]. Meditation effects that evoke psychophysiological changes may result in increases in the theta waves[5−9]. Yet, no systematic study on such synchronized activation has been reported. The present study aims to examine if the singing bowl beating sound gives rise to a significant increase in the brain waves (electroencephalogram, EEG) being dominant at the beating frequency.

Ii. Methods

In this experiment, the changes in the spectral magnitude of the brain waves were monitored while the subjects heard the singing bowl sound. The singing bowl sound was recorded to measure its beating spectral property. The experimental setup, tools and the procedure are shown in Fig. 1.

2.1 Singing bowl sound

Figure 1a illustrates a schematic overview of the experimental tools and space, including the relative location between a singing bowl and the subject. A singing bowl (Best Himalaya, Nepal) with 260 mm in diameter and 115 mm in depth was used in the experiment (Fig. 1b). A cylindrical mallet with 192 mm in height and 48 mm in diameter (Best Himalaya, Nepal) was used to hit the percussion instrument of the singing bowl (Fig. 1c). Each percussion produces the sound modulated with a strong beat that lasts for about 50 sec.

The singing bowl sound was recorded using a mobile sound analysis system (NoiseBook, 4820MHS II, Head Acoustics). The frequency characteristics of the recorded sound were analyzed using FFT in MATLAB. In order to give the spectral property of the low frequency beating phenomenon of the singing bowl sound, we first reconstructed the envelope of the recorded sound signal using Hilbert transform. The frequency spectrum of the envelope was then plotted in the frequency range (0 Hz ~ 50 Hz) employed in the clinical EEG.

2.2 Brain wave measurements

The brain waves were recorded at the F3 and F4 positions of the international standard 10–20 system on the left and right sides of the dorsolateral prefrontal cortex (DLPFC), known to be sensitive to brain activity during meditation[5,8,10−14]. The EEG signals were acquired using an EEG measurement instrument (LXE1104, Laxtha, Rep. Korea) via wet electrodes (Fig. 1d). The measured EEG signals were stored on a PC in digital form with the sampling rate to 256 Hz. The participants in this study comprised 17 healthy adults with normal EEG findings without any specific diseases. The experiment was conducted under the approval of Jeju National University Hospital IRB (JEJUNUH 2018-10-010).

Figure 1e presents a flow chart of the entire experiment which takes about 700 sec. The subjects laid down on a comfortable bed chair. After the electrodes were attached, they closed their eyes for approximately 5 min in a relaxed posture. When a stable EEG was observed, the EEG was recorded for 50 seconds. After that, the singing bowl was played 6 times for 5 min at intervals of 50 sec, and at the same time, the brain waves were recorded. After the sixth round of playing the percussion instrument, an additional EEG was measured for 50 sec without listening to the singing bowl sound. All experiments were conducted with the subjects who had their eyes closed.

2.3 EEG analysis

The measured time history of the brain waves was converted into the spectral magnitude or power of each clinical frequency band of EEG via FFT. The clinical frequency bands are divided into the five spectral regions of delta (0 Hz ~ 4 Hz), theta (4 Hz ~ 8 Hz), alpha (8 Hz ~ 13 Hz), beta (13 Hz ~ 30 Hz), and gamma (30 Hz ~ 50 Hz). The spectral powers of the brain waves were compared between before and after the singing bowl meditation to examine changes in the brain waves of the subjects. In order to test the temporal response of brain waves to the singing bowl sound, temporal variations in changes of the magnitude of each spectral band of EEG were monitored at the time interval of 50 sec. The spectral band powers of each subject were normalized to the total spectral power (0 Hz ~ 50 Hz) to eliminate the variability of the degree of subject-to-subject EEG activity.

Iii. Results

The measured time history of the singing bowl sounds (top) and brain waves (middle) are presented in Fig. 2. The three bottom panels magnify the brain waves recorded at the characteristic temporal locations (beginning, halfway, and end) of the experiment, illustrating that the magnitudes of the brain waves increase with time and are significantly larger at the end of the experiment than those in the beginning. The increase was apparent in the low frequency components, as seen in the magnified figures. This type changes in EEG are known to be common in psychological relaxation or meditation[5].

3.1 Temporal and spectral characteristics of the singing bowl sound

Fig 3 shows a typical measured waveform of the singing bowl sound. It gradually diminishes in amplitudes for more than 40 seconds after hitting the percussion instrument and persists for approximately 50 seconds (Fig. 3a). A part of the waveform (marked by 'A') was expanded in the time axis to reveal its low frequency variation of the sound which is called as a beat (Fig. 3b). It was observed that the beat repeated at an interval of approximately 0.15 second.

Fig. 3c is the frequency spectrum of the singing bowl sound. The fundamental frequency (marked in 'B') that determines the pitch of the singing bowl sound was found to be 482.61 Hz. This frequency corresponds to B4 note in the musical scale. As seen in Fig. 3c, the singing bowl sound contains not only the fundamental frequency but also additional spectral components. The spectral components were observed at 773.15 Hz, 1102.56 Hz, 1464.81 Hz, and 1870.86 Hz, corresponding to the musical scales near to G5, C#6, F#6, and A#6, respectively. The number and magnitude of these spectral components determine the tonal property of the singing bowl sound. In addition, as seen in the box of 'B' in Fig. 3c, an additional frequency component (relatively small but significant) appears near the fundamental frequency (482.61 Hz). The minute frequency difference of 6.68 Hz between them causes beating phenomenon.

In order to calculate the frequency spectrum of the beat, we reconstructed its time domain signal using Hilbert transform, plotted in Fig. 3b as the envelope of the singing bowl sound. The envelope, Fig. 3d is the frequency spectrum of the beat rhythm plotted in the frequency range of 0 Hz~50 Hz, used in clinical brain waves. As shown in Fig. 3d, the strongest beat was observed to occur at 6.68 Hz, while a pair of minor beats appeared at the either side from about 1 Hz of 15 Hz. Note that the frequency of the strongest beat is located in the theta wave band (4 Hz~8 Hz), well observed in meditation. Fig. 3e is the time-frequency representation of the beat signal, showing the temporal variations of the multiple beat frequencies. The spectrogram was calculated using a short time FFT with a window length of 4 sec and at the time resolution of 0.5 sec. As expected, it is clearly seen that the strongest beat is shown at 6.68 Hz. Its loudness was maximum in the beginning of playing the singing bowl (t=0) and started to decrease rapidly from 10 sec until 30 sec. The minor multiple beats are seen at the frequency of near 10 Hz, 13.3 Hz, 16.2 Hz, and 36 Hz, disappearing within 10~20 sec.

3.2 Spectral magnitudes of brain waves

Fig. 4 shows the temporal changes in the spectral power of the measured brain waves, plotted at every 50 sec for which the singing bowl was repeatedly played. The seven spectral bands were considered in the study, including the five clinical frequency bands (delta: 0 Hz~4 Hz, theta: 4 Hz~8 Hz, alpha: 8 Hz~13 Hz, beta: 13 Hz~30 Hz, and gamma: 30 Hz~50 Hz), the entire frequency range (0 Hz~50 Hz) and the beat frequency (6.68 Hz). The mean and standard error of the spectral magnitude of the brain waves recorded for the 17 individuals are plotted at the temporal middle of each 50 se c singing bowl sound (t = 25, 75, 125, 175, 225, 275, 325, and 375 sec). The initial monitoring time ti = 25 sec represents the temporal middle of the 50 sec with no sound before the first singing bowl sound, and the final time tf = 375 sec is that after the last (6^{th}) singing bowl sound. Note that the dotted and solid lines represent the measurement locations of the F3 and the F4, respectively. The ranges of the vertical axis were set in the 50 %~170 % of the overall mean values measured in the F4, so that they are all different. The spectral magnitude of the brain waves measured in the F4 were observed to be similar (Fig. 4e,f) or slightly larger (Fig. 4a~d,g) than those measured in the F3. However, there was no statistically significant difference observed between the measurement locations (F3 and F4) in all the frequency bands(Fig. 4). The ranges of the minimum to the maximum p values are presented in Fig. 4. and they are shown to be large enough for admitting that the location effects may not be significant. The data collected at each monitoring time are tested for their statistical normality using Shapiro-Wilk test.

The spectral magnitude of the delta and theta waves were shown to significantly increase with time (Fig 4a and Fig 4b). The increase was found to be the largest at the beat frequency (Fig. 4f). The beta and gamma waves did not show significant changes, while the gamma wave had variability larger than the beta wave (Fig. 4d,e). In contrast, the alpha wave initially increased a bit for 100 sec, followed by continuous decreases with time(Fig 4c). The magnitude of the overall frequency band (0 Hz~50 Hz) increased for the initial 100 sec, and it remained almost unchanged until the second noticeable increase at t = 275 sec, followed by decrease to the end of the experiment (Fig. 4g).

3.3 Synchronized activation of brain waves at the beat frequency

The spectral magnitude of each frequency band of brain waves shown in Fig. 4 are different one another in its initial value. This makes it difficult in comparing their temporal changes one another. To remove the effect of the initial value difference, the magnitude of each frequency band needs to be normalized to the initial value. In addition, the magnitude of the measured brain waves varies from subject to subject. The spectral power of a particular clinical frequency bands is often expressed as a ratio (in %) to the total power of the overall frequency range (0 Hz~50 Hz), to compensate for the differences by subjects.

A new parameter of the spectral magnitude of brain waves was introduced to effectively remove the effects of not only the initial value difference but also the subject dependence. Let M(fb,t) be the spectral magnitude of a frequency band of the brain wave at a time t. The new parameter A(fb,t) was introduced in the present study and defined in Eq.1, which is the magnitude of a frequency band of the brain wave normalized to its initial value and to the magnitude of the overall frequency range.

$$A(fb,t)(in\ \%) = \frac{<M(fb,t)\ /\ M(fb,ti)>}{<M(overall,t)\ /\ (M(overall,ti)>} * 100 \quad (1)$$

where fb represents the frequency band; t is the time variable; ti stands for the initial time that is 25 sec in the present study as illustrated in Fig. 4. The numerator of the right hand side of Eq.1 represents the temporal history of the magnitude of each frequency band relative to its initial value, while the denominator is the temporal magnitude of the overall frequency band relative to its initial value. The A(fb,t) stands for the rate of changes in the spectral magnitude of each frequency band that is normalized to that of the whole frequency range (0 Hz~50 Hz).

In order to compare more effectively the temporal changes in the magnitude of each frequency band of the brain wave, we averaged the values measured from the two locations of F3 and F4. This unification was justified by the statistical test that the spectral magnitudes of every frequency band are not different between the two locations for the entire experimental duration, as the maximum and the minimum p values are presented in Fig. 4.

Fig. 5 shows A(fb,t) in %, the rate of changes in the spectral magnitude of each frequency band ((a) delta: 0 Hz~4 Hz, (b) theta: 4 Hz~8 Hz, (c) alpha: 8 Hz~13 Hz, (d) beta: 13 Hz~30 Hz, (e) gamma: 30 Hz~50 Hz, (f) beat: 6.68 Hz), normalized to that of the whole frequency range (0 Hz~50 Hz) and averaged with the data measured at the two locations of F3 and F4 for the 17 subjects. The temporal changes were plotted at every 50 sec for the time from ti = 25 sec to tf = 375 sec, and the error bar represents the standard error. The data are provided in Table 1, together with the p values resulted from the statistical test on each temporal change to the initial value at t=ti. The p value (at t= tf) after the experiment is presented Fig. 5, and, if it is not the minimum value, the minimum is also provided at its time location.

Table 1. Temporal variations (in %) in the spectral band brain wave magnitudes relative to their initial values(0 sce~50 sec), normalized to those of the overall frequency band, and averaged the data measured at the two positions (F3, F4) of the subjects (N=17) who heard the strongly beating singing bowl sounds repeated 6 times at every 50 sec for t=50 sec~350 sec. (†: maximum change)

Time (sec)		Delta wave		Theta wave		Beat Frequency		Alpha wave		Beta wave		Gamma wave	
		changes in EEG (%)	p	changes in EEG (%)	p	changes in EEG (%)	p	changes in EEG (%)	p	changes in EEG (%)	p	changes in EEG (%)	p
Before exp.	0~50	100	-	100	-	100	-	100	-	100	-	100	-
experiment	50~100	93.52	0.014	103.16	0.176	163.90	0.006	103.69	0.137	98.48	0.248	87.99	0.000
	100~150	100.09	0.985	108.57	0.015	144.40	0.160	97.69	0.411	97.54	0.280	85.18	0.000
	150~200	100.37	0.933	106.85	0.037	227.66	0.006	97.57	0.533	99.16	0.579	85.53	0.000
	200~250	102.71	0.641	108.09	0.031	199.67	0.032	95.47	0.275	98.78	0.586	84.10	0.000
	250~300	109.62	0.220	116.16	0.003	251.98†	0.021	87.40	0.003	95.19	0.067	85.65	0.006
	300~350	117.95	0.029	114.34	0.004	182.19	0.001	89.07	0.010	95.09	0.062	81.86 †	0.000
After exp.	350~400	135.18†	0.001	117.07†	0.002	157.06	0.049	85.28 †	0.005	93.75 †	0.012	90.41	0.047

As expected, the rate of changes increase the most at the beat frequency. with time (Fig. 5f). Among the clinical frequency bands, the increase rate was the largest in the delta wave (135.18 %, p=0.001), followed by the theta wave (117.07 %, p=0.002). In those two waves located in the low frequency ranges the rate of changes in the spectral magnitude increase with time, whereas they decrease with time in the high frequency ranges including alpha, beta and gamma waves. The tendency of the changes was kept to be extended during the silent time after the last singing bowl sound, except the gamma wave and the beat frequency. This trend implies that the largest changes are observed after the last singing bowl sound rather than when the subjects heard the last singing bowl sound. This is why the p value was the minimum at t = 375 sec rather than at t=325 sec (Figures 5a~d). At the beat frequency, however, the largest increase in the spectral magnitude was observed at the time when the subjects heard the 5^{th} singing bowl sound just before the final one. This would be understood as an extension of the preceding repeated pattern of the (large and rapid) jump and (small and slow) fall, and it is expected to have the spectral magnitude larger than the previous maximum if the subjects may hear the additional (7^{th}) singing bowl sound after the last one.

Fig. 6 compares the maximum rate of the relative changes in the spectral magnitude of each spectral band (A(fb,t) in %), together with the frequency spectrum of the beat of singing bowl sound. The rate of the increase is predominant at the beat frequency, which reaches 251.98 % (p=0.021) of its initial value at the time (t = 275 sec) approaching to the end of the experiment. This implies that brain waves are most effectively synchronized at its beat frequency and activated by the singing bowl sound. Among the five clinical EEG frequency bands, the delta wave rose up the most to 135.18 % (p = 0.001) from its initial state, followed by the theta wave with a rise to 117.07 % (p = 0.002). In contrast, the other three spectral bands decrease after the experiment. The gamma wave was down to 81.86 % (p = 0.000) from its initial state, the alpha wave down to 85.28 % (p = 0.005), and the beta wave down to 93.75 % (p = 0.012).

Iv. Discussion

The singing bowl used in this study produces a sound that lasts for more than 50 seconds at one time of play and has a strong beat at the frequency of 6.68 Hz. When the subjects were listening to the singing bowl sound, the spectral magnitudes of their brain waves were shown to increase with time at low frequencies (≤ 8 Hz, delta and theta waves), whereas they decreased with time at the high-frequencies (> 8 Hz, alpha, beta and gamma waves) (Figs. 4 and 5). Among the five clinical spectral bands, the increase rate was the highest in the delta wave (135.18 %, p = 0.001), followed by the theta wave (117.07 %, p = 0.002). Under the present experimental condition that the subjects heard the 6 repeating singing bowl sound for 300 sec, the largest increase rate (251.98 %, p = 0.021) was observed at the beat frequency of the singing bowl sound (Table 1). This result suggests that, when the subjects were listening to the singing bowl sound, their brain waves are activated and effectively synchronized at the beat frequency.

The beat frequency of the singing bowl sound used in this study belongs to the theta wave spectral band. Numerous studies have observed psychophysiological changes due to the effects of meditation as an increase in theta waves[5–9,15–22]. The present finding that the brain wave is synchronized and activated at the beat frequency located in the theta wave may serve as an academic basis that a singing bowl sound can be used in meditation. In the future study, it would be of interest to consider the beat frequency located in the other clinical spectral bands.

In many studies on meditation and brain waves, delta waves were observed to increase in the prefrontal cortex[23], as measured at the same location used in the present study. Tei et al (2009) compared the activity of delta waves using a low resolution electromagnetic tomography (LORETA), when people either meditate (Qigong) or just rest under their eyes closed (control group)[24]. In the frontal lobe of the subject who meditated, delta waves were significantly different and stronger than those of the control group. In the present study, delta waves were shown to slightly decrease immediately after the 1st singing bowl sounding, followed by the continuous increase to the highest increase rate (135.18 %) among the five clinical brain waves.

In the present study, the changes in the brain wave activity were compared to the initial state (Figs. 4 and 5) rather than a conventional test between the experimental and control groups. This approach enables us to remove subject dependent effects as well as to provide the temporal response in brain waves to the testing sound. Note that, this study monitors brain waves for the limited time of 400 sec from 50 sec before the 1st singing bowl sound to 50 sec after the last (6th) singing bowl sound. As shown in Fig. 5a ~ d, the changes in brain waves were kept to extend even in the silent condition after the last singing bowl sound. As discussed in the previous Sect. 3.3 on the brain wave activity at the beat frequency (Fig. 5f), it is interesting to test what if the subjects hear the additional (7th) singing bowl sound. It is of interest to see if the pattern of the (large and rapid) jump and (small and slow) fall would repeat and if the spectral magnitude would increase compared to the present maximum value observed at the 5th singing bowl sound. A future study is suggested to include the temporal information when the maximum rate of the increase in brain waves is achieved.

The reduction in alpha waves is known to be a common phenomenon in the entire range of relaxation therapy[25]. Numerous prior studies have reported a decrease in the alpha waves in yoga or transcendental meditation[7, 8, 18, 21, 26, 27]. Various studies have also reported a decrease in alpha waves by approximately 50 % due to an increase in theta waves in the first stage of sleep[25, 28]. In the present study, the spectral magnitudes of alpha waves were smaller than those at rest before the experiment, and became decreased steadily as the subjects started to hear the singing bowl sound, reaching the 85.28 % of the initial states at the end of the experiment. The observed continuous decrease with time in alpha waves is attributed to the effect of the singing bowl sound that may induce the subjects to relax or meditate.

The gamma wave activity to meditation is controversial. Some studies showed a decrease in gamma waves during meditation[23], while the other studies reported an increase in gamma waves[29–31]. The present study shows that the gamma waves continuously decreased by up to about 12 %~18 % during when the subjects were listening to the singing bowl sound. However, the gamma wave was observed to rise again approaching to the initial state as the subjects stopped hearing the sound. It should be noted that the present study employs the singing bowl sound whose beat frequency is located in theta waves and, in the future study, it would be of interest to look at the gamma wave response to the singing bowl sound whose beat frequency is located in the gamma waves.

The present study was based on the brain waves measured at limited locations (F3 and F4). The measurement locations of the F3 and F4 are known to be sensitive to brain activity during meditation[5,8,10,12–14,32–34], and they would be taken as the reasonable locations for the singing bowl meditation of the present study. Further studies with measurements at various positions are required to expand and generalize the observed synchronized activation of the brain waves. In addition, the present results were obtained from a relatively small number of subjects (N = 17). Fortunately, Shapiro-Wilk test confirmed the normal distributions of the measured data, which ensured the reliability of the statistical tests performed present study.

The beat of the singing bowl sound is determined by the size, material, and structure of the instrument. The various singing bowls used in meditation are classified in accordance with the fundamental frequencies of their sounds as musical key tones. The fundamental frequency of the singing bowl used in the present experiment was approximately 480 Hz, which musically corresponds to B4. As shown in Fig. 3c, the singing bowl sound used in this study was composed of multiple harmonic components at 773.15 (G5), 1102.56 (C#6), 1464.81 (F#6), and 1870.86 Hz (A#6). The tonal property of the singing bowl is not affected by the manner of playing and the sound volume. Nevertheless the sound intensity and tonal properties are important psychoacoustical parameters[35] which are expected to affect the brain waves independently. In the present experiment, an arbitrary single singing bowl was chosen and the playing method and the sound intensity were not precisely controlled. A follow-up study is suggested to explore the interesting aspects of how the synchronized activation of the brain waves relates with the playing techniques and the intensity of the beating sound, for the singing bowls with various key tones.

V. Conclusions

The beat frequency of the singing bowl sound used in this study was measured to belong to the theta wave which is known to rise during meditation. In this experiment, the brain waves of the subjects who heard the singing bowl sound were observed to get activated in a few minutes dominantly at its strong beat rhythm. The study claims an experimental evidence that the singing bowl sound likely activates the brain wave that is effectively synchronized at its beating rhythm. This underpins that the strongly beating singing bowl sound facilitates meditation, relaxation and psychological stability.

Declarations

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Contributions

S.C.K. : designed the study, conducted this research, analyze the data. M.J.C : designed the study, supervision, writing-review, editing and project administration. All authors contributed in research paper writing.

Ethics declarations

Competing interests

The authors declare no competing interests.

Additional information

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Figures

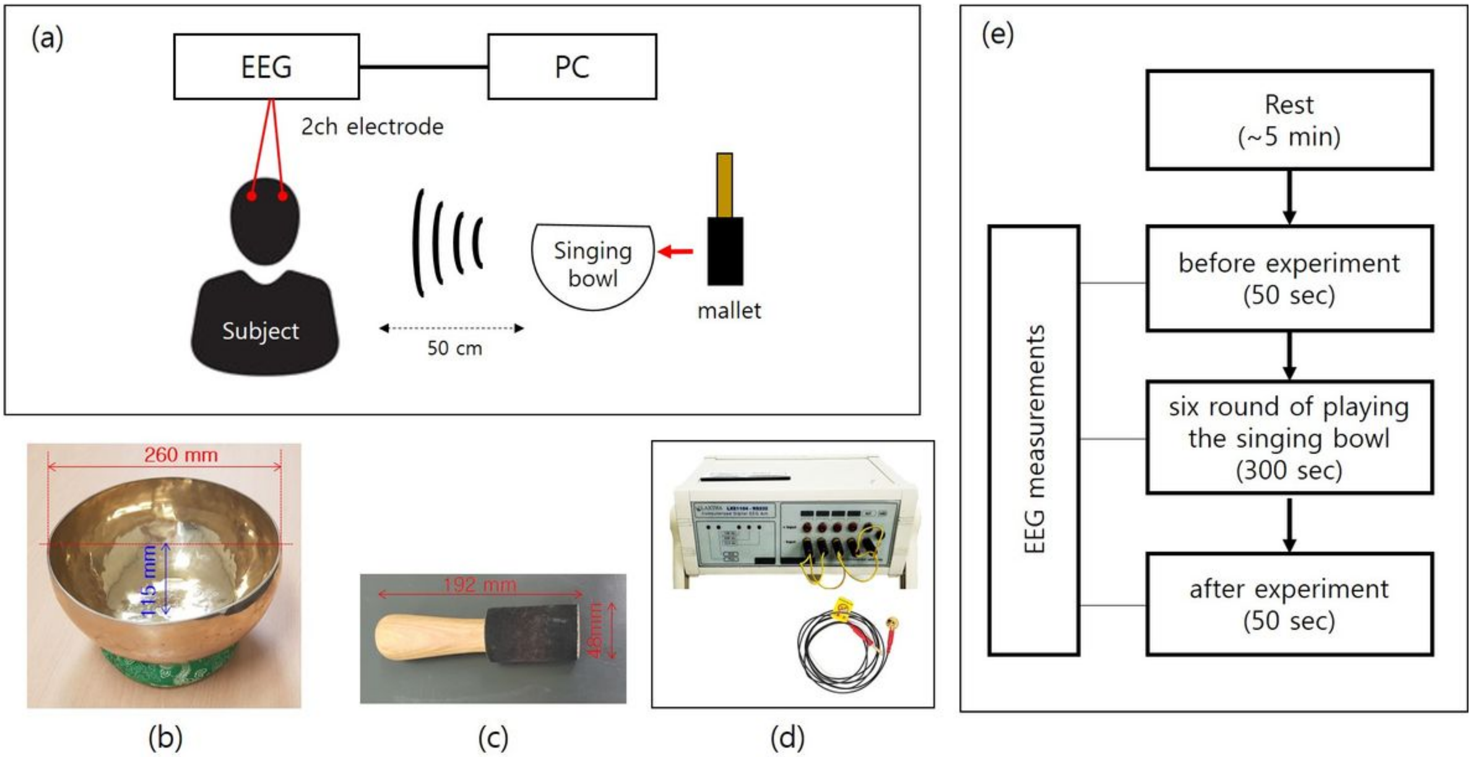

Figure 1

Experimental setup and method: (a) schematic illustration of the experimental space and method, (b) singing bowl, (c) mallet, (d) EEG measurement device with a wet electrode, and (e) experimental procedure.

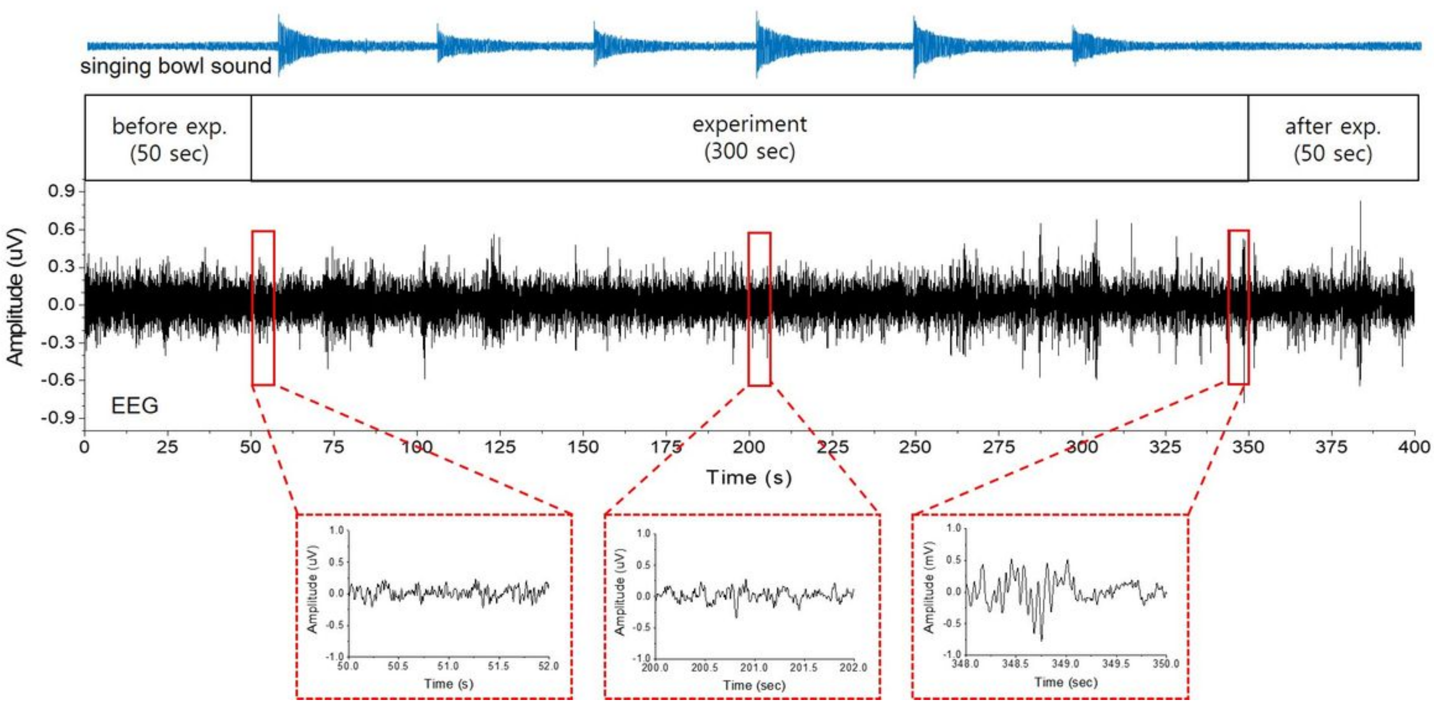

Figure 2

The temporal history of the repeating singing bowl sound (top) and the brain wave (middle) of the subject listening to the singing bowl sound. The bottom three panels magnify the brain waves in the time axis, recorded at the beginning, in the middle, and at the end of the experiment.

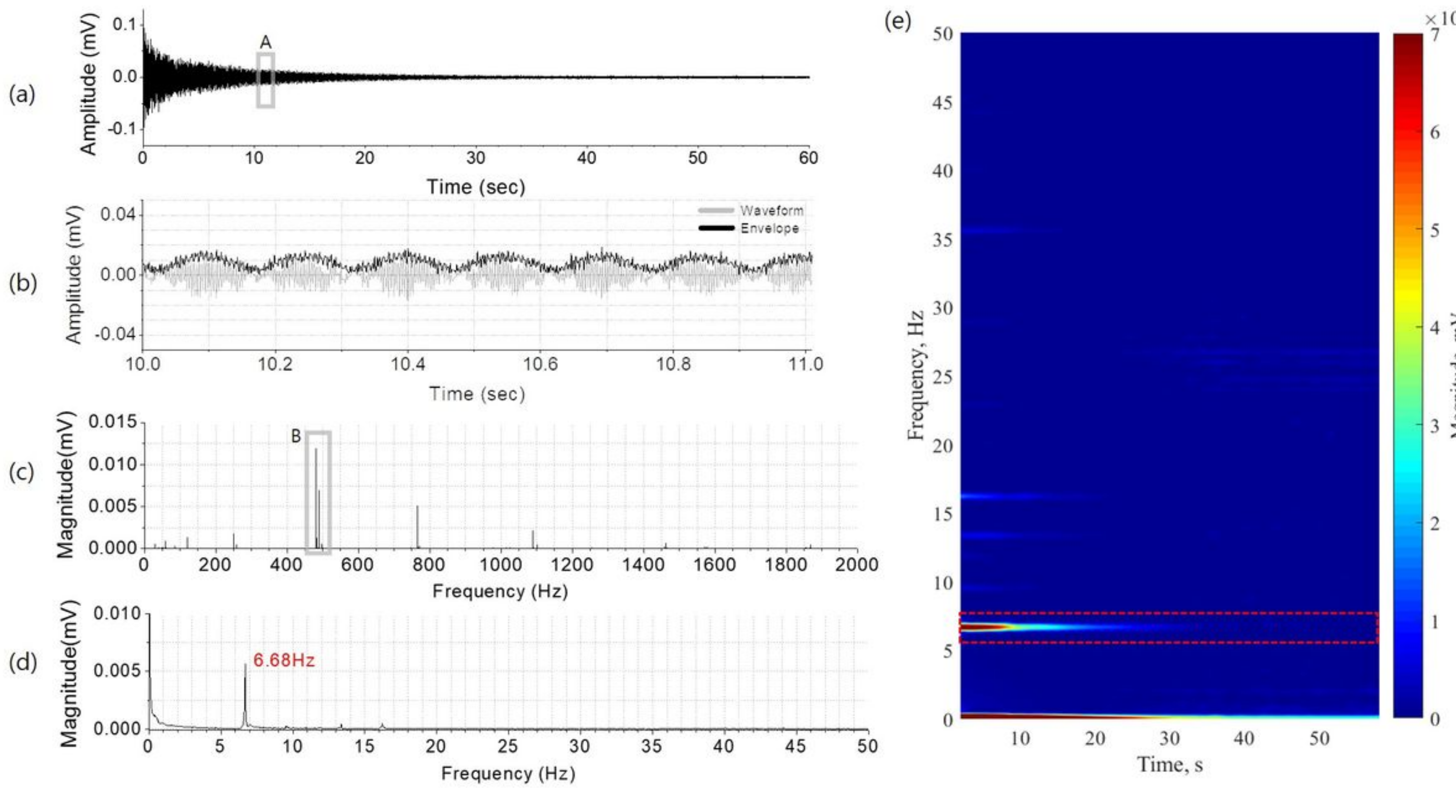

Figure 3

A typical singing bowl sound plotted in the time and frequency domain: (a) the waveform, (b) a part of the waveform in the box of A magnified to display clearly the envelope, (c) the frequency spectrum of the entire singing bowl sound waveform, (d) the frequency spectrum of the envelope, and (e) the time-frequency representation of the envelope calculated with a window length of 4 seconds at the time interval of 0.5 sec.

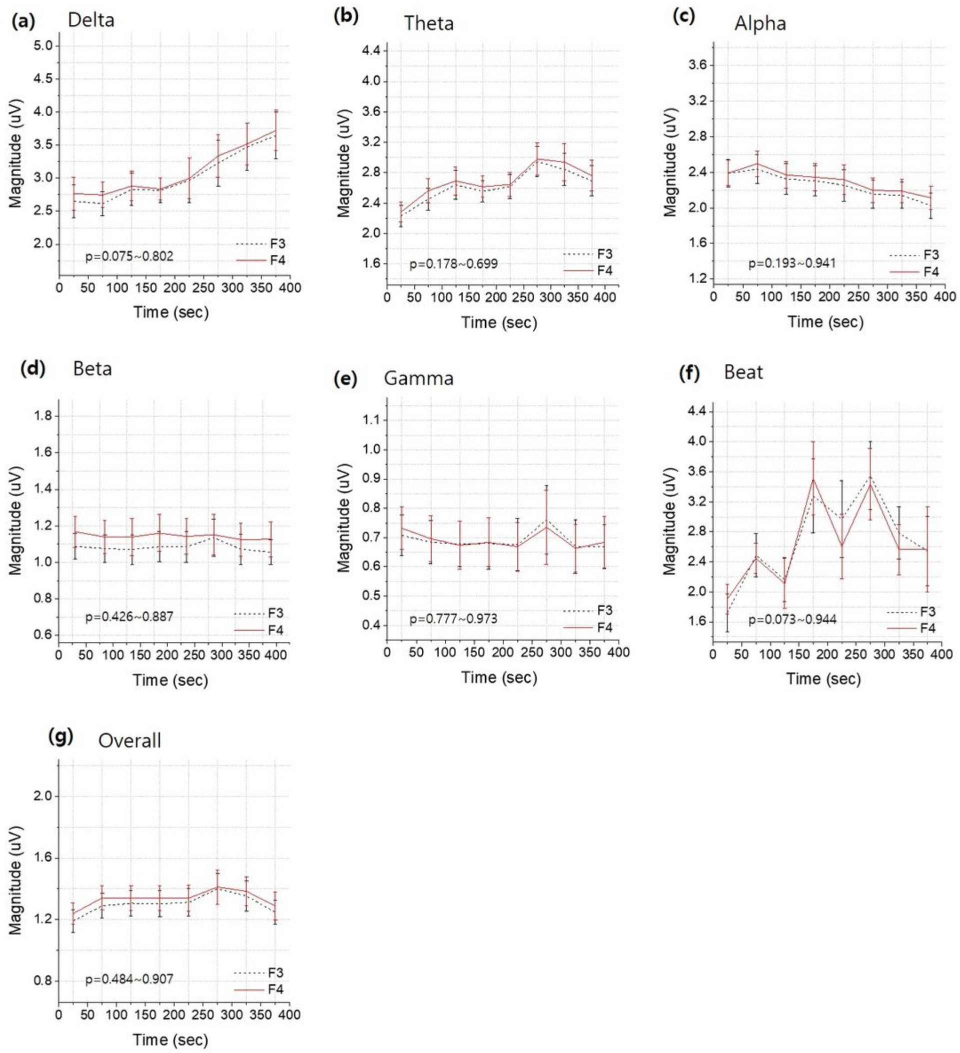

Figure 4

Temporal variations in the magnitudes of each spectral band of the EEG signals measured in the F3 and F4 of the 17 subjects, plotted at every 50 sec: (a) delta (0 Hz~4 Hz), (b) theta (4 Hz~8 Hz), (c) alpha (8 Hz~13 Hz), (d) beta (13 Hz~30 Hz), (e) gamma (30 Hz~50 Hz), (f) beat (6.68 Hz), and (g) overall (0 Hz~50 Hz). Note that the ranges of p values are presented for the statistical test between the measurement locations (F3 and F4), and the error bars represent the standard errors.

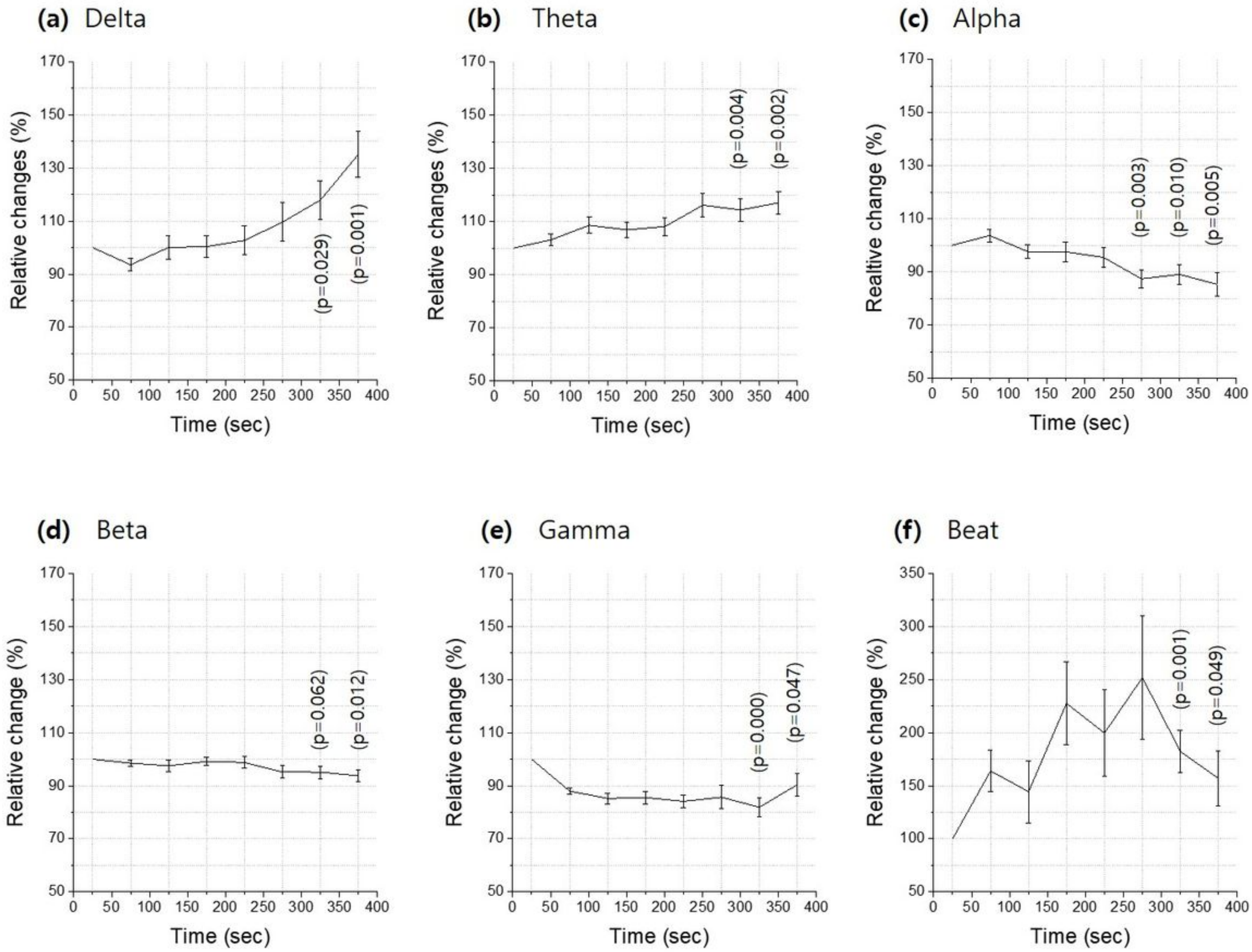

Figure 5

Temporal variations (in %) of each spectral band brain wave magnitude relative to its initial value and normalized to that of the overall frequency band, averaged with data measured at the two positions (F3 and F4) from the subjects (N=17) who heard the strongly beating singing bowl sounds repeated 6 times at every 50 sec for t=50~350 sec, plotted at every 50 sec: (a) delta (0~4 Hz), (b) theta (4~8 Hz), (c) alpha (8~13 Hz), (d) beta (13~30 Hz), (e) gamma (30~50 Hz), (f) beat (6.68 Hz), (f) beat: 6.68 Hz. Note that the ranges of p values are presented for the statistical test on the changes from initial states, and the error bars represent the standard errors.

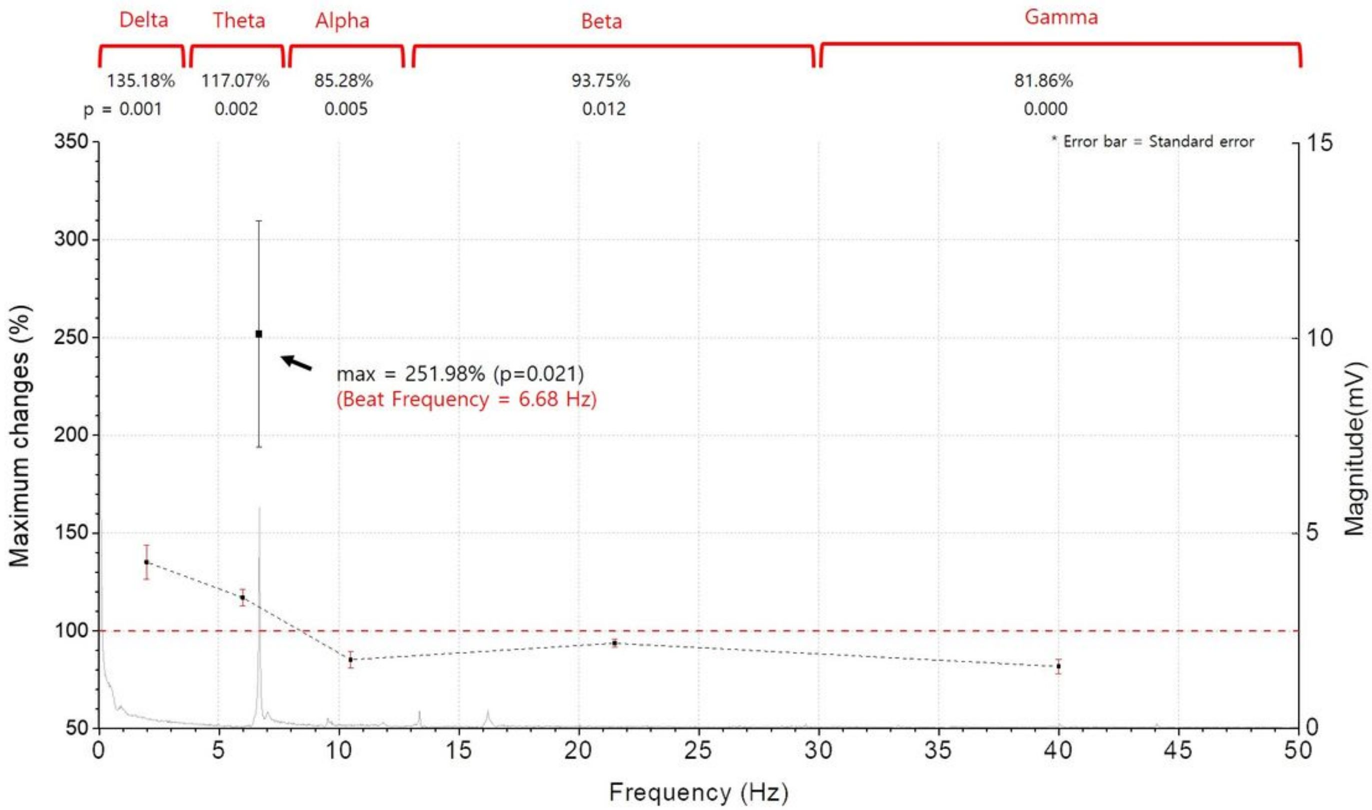

Figure 6

Maximum changes in the EEG spectral magnitudes (in %) relative to the initial states in the five clinical frequency bands and at the beat frequency (6.68 Hz), obtained from the subjects (N=17) who heard the strongly beating singing bowl sounds repeated 6 times at every 50 sec, plotted on the top of the frequency spectra of the singing bowl sound.