ScienceDirect

International Journal of Psychophysiology
Volume 94, Issue 3, December 2014, Pages 399-406

Analysis of EEG activity in response to binaural beats with different frequencies

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Abstract

When two coherent sounds with nearly similar frequencies are presented to each ear respectively with stereo headphones, the brain integrates the two signals and produces a sensation of a third sound called binaural beat (BB). Although earlier studies showed that BB could influence behavior and cognition, common agreement on the mechanism of BB has not been reached yet. In this work, we employed Relative Power (RP), Phase Locking Value (PLV) and Cross-Mutual Information (CMI) to track EEG changes during BB stimulations. EEG signals were acquired from 13 healthy subjects. Five-minute BBs with four different frequencies were tested: delta band (1 Hz), theta band (5 Hz), alpha band (10 Hz) and beta band (20 Hz). We observed RP increase in theta and alpha bands and decrease in beta band during delta and alpha BB stimulations. RP decreased in beta band during theta BB, while RP decreased in theta band during beta BB. However, no clear brainwave entrainment effect was identified. Connectivity changes were detected following the variation of RP during BB stimulations. Our observation supports the hypothesis that BBs could affect functional brain connectivity, suggesting that the mechanism of BB–brain interaction is worth further study.

Introduction

When a sound with a steady intensity and frequency was presented to one ear and another with the same intensity but slightly different frequency, the brain would produce pulsations in the amplitude and localization that is the same with the perceived sounds, which are known as “binaural beat” or “binaural tone” (Dove, 1841, Oster, 1973).

The binaural beat (BB) has a fundamental frequency and a modulation frequency. For example, if a pure tone of 550 Hz was displayed in one ear and 560 Hz in the other, the BB would have a fundamental frequency of (550 + 560)/2 = 555 Hz with a modulation frequency of 10 Hz. The frequency difference between the two sounds must be small (≤ 30 Hz) for the BB to occur; otherwise, the two tones would be captured by the two ears separately, and no beat would be perceived. It was suggested that tones with a frequency from 200 to 900 Hz were more effective in provoking BB than those exceed 1000 Hz (Licklider et al., 1950, Wahbeh et al., 2007, Pratt et al., 2010). Moreover, the probability of detecting the BB was maximized around 500 Hz (Perrott and Nelson, 2005).

It has been reported that many physiological and psychological processes can be altered by BB. For example, it can help one to reduce self-reports of anxiety, to deepen relaxation meditation and to improve hypnotic susceptibility (Le Scouarnec et al., 2001, Lavallee et al., 2011, Brady and Stevens, 2000). In addition, BB can help one to relax (Foster, 1990) and improve one's memory ability, as well as alertness and vigilance status. BB is also helpful in mental concentration and psychomotor performance, leading to good feelings (Kennerly, 1996, Lane et al., 1998, Sornson, 1999). With all those importance in application, however, agreements have not been reached regarding the mechanism of BB. Some researchers (such as Brady and Stevens, 2000, Schwarz and Taylor, 2005, Karino et al., 2006) tended to believe the hypothesis of brainwave entrainment effect or also known as Frequency Follow Response (Marsh et al., 1970), which is similar to what will occur during stimuli such as light oscillating at a stable frequency or acoustics such as human speech or consistent tones (Silberstein et al., 1990, Aiken and

Picton, 2008, Krishnan et al., 2004).

The basic theoretical assumption was that the human brain had a tendency to change its dominant EEG frequency towards the frequency of external stimulus by entraining the brain to synchronize neural activity with BB stimuli or other external stimulations. However, other studies did not achieve similar observations (Stevens et al., 2003, Wahbeh et al., 2007, Goodin et al., 2012, Vernon et al., 2012). Goodin et al. (2012) assessed theta (7 Hz) and beta (16 Hz) bands in 2-min BB carrier tone. They reported no significant differences in cortical frequency power during the period of BB stimulation compared to using a white noise signal. Consistently, Vernon et al. (2012) found no significant change in EEG from BB stimulation with alpha (10 Hz) and beta (20 Hz) frequencies. One of the reasons that the power of EEG did not change in these studies might be their short-duration of stimulation (ten 1-minute segments). Another reason may be that the 'averaging' processor that they used in EEG power calculation over a long period of time wiped out possible changes. Besides the brainwave entrainment effect, there might be other hypothesis for the mechanism of behavior and cognition changes under BB stimulations. For example, functional connectivity of the brain, not just brainwave oscillation, may change under BB stimulation. To evaluate the functional connectivity of different brain regions, we calculated the phase-locking value (PLV), and cross-mutual information (CMI) between different cortical areas, using EEG signals. CMI and PLV have been widely used to study the brain functions in complex diseases such as schizophrenics, Alzheimer's disease (AD) and self-determinant motor task (Na et al., 2002, Jeong et al., 2001, Lu et al., 2011) or cognitive tasks (Lehmann et al., 2006, Rose and Büchel, 2005). Although mechanisms of stimuli induced short-lasting functional connectivity changes of the brain have been studied using EEG or MEG signals, there has been no report studying the information transmission variations in brain networks using BB stimulation.

Different to previous studies, we extended the duration of BB stimulations to 5 min to study possible induced brainwave entrainment effect. Moreover, we focused on the changes of relative power (RP) instead of power, and tracking the EEG changes over time, instead of 'averaging' it, to avoid losing information. In addition, we used new methods—PLV and CMI—to test the connectivity variations during BB stimulations.

Section snippets

Subjects

We recruited 13 right handed healthy subjects from Tianjin University (6 male and 7 female, aged from 19 to 26). The subjects were informed that they cannot take any products containing caffeine, alcohol or drugs during the week before the experiment. In addition, they were

corrected permutation statistics based on pair-wised *t*-tests. After RRP calculation, we obtained the topographical images of different bands at different time periods. Fig. 2 shows the results under delta BB, theta BB and beta BB, and Fig. 3 shows the results under alpha BB. The RP values and other details of electrodes were shown in Table 1. For better comparison, we presented the power spectral density...

Discussion and conclusion

When exposed to 5-minute BBs (delta (1 Hz), theta (5 Hz), alpha (10 Hz) and beta (20 Hz)), the relative power of dominant EEG frequency of 13 subjects showed no enhancement. Our results didn't support the brainwave entrainment effect or FFR hypothesis that the human brain had a tendency to change its dominant EEG frequency under BB stimulations. Different to previous work (Stevens et al., 2003, Wahbeh et al., 2007, Goodin et al., 2012, Vernon et al., 2012), we extended the duration of BB...

Acknowledgments

This research was supported by the National Natural Science Foundation of China (No. 51377120, 81222021, 31271062, 61172008, 81171423, 51007063), the National Key Technology R&D Program of the Ministry of Science and Technology of China (No. 2012BAI34B02) and the Program for New Century Excellent Talents in University of the Ministry of Education of China (No. NCET-10-0618)....

References (50)

V.K. Yeragani *et al.*
Decreased coherence in higher frequency ranges (beta and gamma) between central and frontal EEG in patients with schizophrenia: a preliminary report
Psychiatry Res. (2006)

L. Torsvall *et al.*
Sleepiness on the job: continuously measured EEG changes in train drivers
Electroencephalogr. Clin. Neurophysiol. (1987)

C. Summerfield *et al.*
Coherent theta-band EEG activity predicts item–context binding during encoding
Neuroimage (2005)

D.W.F. Schwarz *et al.*
Human auditory steady state responses to binaural and monaural beats
Clin. Neurophysiol. (2005)

H. Pratt *et al.*
A comparison of auditory evoked potentials to acoustic beats and to binaural beats
Hear. Res. (2010)

S.H. Na *et al.*
EEG in schizophrenic patients: mutual information analysis
Clin. Neurophysiol. (2002)

E.L. Merrin *et al.*
EEG coherence in unmedicated schizophrenic patients
Biol. Psychiatry (1989)

E. Maris *et al.*
Nonparametric statistical testing of EEG- and MEG-data
J. Neurosci. Methods (2007)

C.F. Lu *et al.*
Reorganization of functional connectivity during the motor task using EEG time–frequency cross mutual information analysis
Clin. Neurophysiol. (2011)

D. Lehmann *et al.*

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