VIII Congresso Ibero-americano de Acústica
acústica 2012
1-3 outubro
Évora - Portugal

EFFECTS OF BINAURAL STIMULATION IN ATTENTION AND EEG

Adela Crespo[1], Manuel Recuero[1], Gerardo Galvez[1,2], Adrián Begoña[1]

[1]Centro de Acústica Aplicada y Evaluación no Destructiva, Consejo Superior de Investigaciones Científicas (CAEND-CSIC) C/ Serrano 144, Madrid (Spain)
adela.crespo@csic.es
manuel.recuero@upm.es
gerardo.galvez@csic.es
adrian.begona@csic.es

[2]Centro de Tecnología Biomédica, Universidad Politécnica de Madrid (CTB-UPM)
Campus de Montegancedo – Pozuelo de Alarcón (Spain)
gerardo.galvez@ctb.upm.es

Abstract
When two pure tones of slightly different frequency are presented separately to each ear, the listener perceives a third single tone with amplitude variations at a frequency that equals the difference between the two tones, this perceptual illusion is known as binaural auditory beat. There are anecdotal reports that suggest that the binaural beat can entrain EEG activity and may affect the arousal levels, although few studies have been published.

There is a need for double-blind, well-designed studies in order to establish a solid foundation for these sounds, as most of the documented benefits come from self-reported cases that could be affected by placebo effect. As BB's are a cheap technology (it even exists a free open source programmable binaural-beat generator on the internet named Gnaural), any achievement in this area could be of public interest. The aim in our research was to explore the potential of BB's in a particular field: tasks that require focus and concentration. In order to detect changes in the brain waves that could relate to any particular improvement, EEG recordings of a small sample of individuals were also obtained.

In this study we compare the effect of different binaural stimulation in 7 EEG frequency ranges, 78 participants were exposed to 20 min binaural beat stimulation. The effects were obtained both qualitative with cognitive test and quantitative with EEG analysis. Results suggest no significant statistical improvement in 20 min stimulation.

Keywords: Binaural auditory beats, attention, frequency following response.

PACS no. 43.66.Pn

1 Introduction

Binaural waves stimulation at different frequencies has been used in the past two decades in the treatment of many diseases and also to modify different states such as pain, relaxation, meditation, anxiety and also to improve attention and memory.

Binaural tones are subjective auditory sensations, which occur as a result of receiving two tones of slightly different frequencies with a low frequency. Binaural waves were discovered by Heinrich Wilhelm Dove in 1839.

The binaural hearing beats, occurring in the brain stem in response to auditory stimulation produced by two pure tones of slightly similar frequency, each in a different ear. The upper grove located in the brainstem is responsible for interpreting the phase difference, what is called binaural tone [1]. For example if we issue a 110 Hz tone in the right ear and another 115 in the left ear, the phase difference between the two be 5 Hz, this is the binaural tone [2].

It appears that the ability to hear binaural beats is due to the evolutionary result of assimilation; many advanced species can be detected and depends on the size of the skull.

The binaural tones are the result of neuronal firing overlapping at an appropriate level of the auditory path, coming from the right and left ear. The binaural tones show how neuronal firing in the auditory nerve, maintains the phase information of the received signal [3], [4]. The route of the auditory nerve to the brain allows the exchange of information coming from both sides, before the sound reaches the cortex, ensuring conscious listening. This exchange occurs at least in two areas of the auditory nerve: in the upper olive grove body, small mass of gray matter located in the ventral pontine reticular system (in charge of contralateral integration of auditory system) and transfers it to other area, the inferior colliculus [5]. The two signals arriving from different ears are connected in the brain, resulting in a third signal called binaural tone [4],[6].

Listening to binaural beats provides the information to the network system, also called diffuse activation system, a large area of the brain that looks like a network, makes decisions about the clarity, concentration and awareness. If internal stimuli (feelings, behaviors or beliefs) or external (perceived by the senses), are not in conflict with information willing, the reticular system modifies the activity of brain waves, adjusting these to the frequency binaural tone. This is a natural function of homeostasis. The brain regulates automatic body functions to maintain homeostasis. The reticular system tries to maintain homeostasis in a natural way, controlling and maintaining sustainable states of brain wave activity all the time (unless you get external or internal information). Thanks to the fact that the frequency characteristics of the auditory signal and the frequency of brain waves are similar, the reticular system begins processing the information coming from the auditory signal, believing that the information coming in binaural tone comes of brain wave activity [7], [8]. The term used for this synchronization process in the literature is "entrainment".

With the development of EEG, it became increasingly clear that certain frequencies can induce changes in the EEG, for instance binaural waves in the range delta (1-4Hz) is associated with sleep, which is in the range theta (4-8 Hz) relate to a slow brain activity, while those that are in the range alpha are associated with awake states (8-13 Hz). The binaural beats in the beta range (16-24 Hz) occur in states of alertness and concentration [2].

Foster (1991) examined the effects of stimulation in the alpha range [9], combined with neurofeedback in this range. The results of this study suggest that the combination of the binaural tones with neurofeedback, result in increased production of alpha comparing with only application with neurofeedback, but also the group received only binaural stimulation waves, had higher alpha production than any of the groups. Lane et al. (1998) provide evidence on the frequency response of runoff to 7 Hz and its direct effect on psychomotor development and mood [2] .

C. Kasprzak (2011), experiment the effect of a binaural wave in 20 subjects [4]. The carrier frequency was 100 Hz, 73 dB SPL and 20 minutes of binaural stimulation. In this study, positive statistical results are obtained on the modification of cortical arousal with binaural frequencies binaural. Also found an entrainment at 10 Hz for 4 of the subjects.

Among the many applications that are commercially, binaural waves seem to help achieve deeper and faster. Meditation techniques are used to achieve altered states of consciousness, developing awareness and perception, reduce stress and increase a positive attitude[10]. We found specific patterns in the EEG of meditators when compared with subjects who have never meditated as well when compared against baseline state [11].

Lavallee C and S Koren (2011) conducted a study with 8 subjects, half were expert meditators and half rookies, and were subjected to two different binaural stimulation, 7 Hz to facilitate meditation and the other 15 Hz to hinder meditation [12]. The results evidenced that novices have less power theta and increased gamma in 15 Hz condition. This result suggest experienced meditators have developed techniques over the years of practice, to maintain a deep state of meditation while blocking external stimuli[12].

Susan Kennel (2010) studied the effectiveness of binaural stimulation to reduce symptoms of teen's inattention. The study confirmed the utility of binaural waves. It was a randomized, double blind and placebo control study with 20 young people who listened to 20 min stimulation, 3 times per weeks during 3 weeks. They used TOVA, Color Trails test and Homework Problem Checklist to evaluate the cognitive change. They didn't fins significant attention results despite the *feedback* from parent was very positive [13].

There were similar studies found positive results on attention tasks [2].

There is need for double-blind, well-designed studies in order to establish a solid foundation for these sounds, as most of the documented benefits come from self-reported cases that could be affected by placebo effect. As BB's are a cheap technology (it even exists a free open source programmable binaural-beat generator on the internet named Gnaural), any achievement in this area could be of public interest. The aim in our research was to explore the potential of BB's in a particular field: tasks that require focus and concentration. In order to detect changes in the brain waves that could relate to any particular improvement, EEG recordings of a small sample of individuals were also obtained.

2 Materials and methods

2.1 Study Design

This study is a randomized, double blind, placebo controlled exploratory pilot investigation in order to determine the effect of two different binaural beat stimulations in the ranges theta and beta therefore establish the start methodology to continue research in this area of interest.

We divided in two experiments A and B, in ***Experiment A*** we measure the improvement in Attention with different test meanwhile in ***Experiment B*** we measure de EEG modifications.

2.2 Setting a Sample

Experiment A: We recruit 60 general public from Madrid, included men and women (28 females and 32 males; mean (±s.d.) age 28.9±4.3 years) who were naive to binaural beat stimulation and who consented to participate. Exclusion criteria were neurological disease and left handed. They were informed about the general goal of the research and rules of their particular experiment, and completed an audiometric test to assure they suffered no major hearing loss.

Experiment B*:* we recruit 18 general public from Madrid (5 females and 13 males, age 26.6±7, 49), who were naive to binaural beat stimulation and who consented to participate. Exclusion criteria were neurological disease, right handed. They were informed about the general goal of the research and rules of their particular experiment, and completed an audiometric test to assure they suffered no major hearing loss.

2.3 Procedures

Experiment A: Participants were blindly allocated to one of three groups according to a predetermined computer-generated random sequence. They listened for 20 minutes via standard headphones to a commercial binaural audio beat (Binaural commercial Group, n=20), an identical soundtrack without these tones (Placebo Group, n=20), or a self-made audio including several layers of BB's (Binaural experimental Group, n=20) (Fig. 1). The commercial beat audio had the BB's embedded in a fluctuating pink noise that was used also in the self-made audio (that noise was all the Placebo Group listened to). All were instructed to relax and listen with closed eyes in a comfortable position. After 20 minutes the participants were asked to open their eyes and, without removing the headphones, were requested to complete three different tasks: the Test on differences perception[14], used to evaluate attention and perceptive skills; the 5 digit test, used to measure the processing speed of the subjects and their ability to direct and switch their attention control and the EMAV-2, used to measure sustained attention and quality of attention.

When the three tests were completed, headphones were removed and participants were questioned about any unusual feeling during the course of the experiment.

Experiment B: Participants were blindly allocated to one of three groups according to a predetermined computer-generated random sequence. They listened for 20 minutes via standard headphones to a commercial binaural beat audio (Binaural commercial Group, n=6), an identical soundtrack without these tones (Placebo Group, n=6), or a self-made audio including several layers of BB's (Binaural experimental Group, n=6). EEG was used in this study, as we were interested in changes evoked by BB's, data from 3-min period prior to listening were firstly recorded (baseline). After that, participants listened for 20 minutes via standard headphones to one of the three same audios described in the first experiment. All were instructed to relax and listen with closed eyes in a comfortable position. After that, headphones were removed and participants were questioned about any unusual feeling during the course of the listening.

2.4 Instrumentation

2.4.1 Stimulation

20 min stimulation with sampling frequency of 44100 and 16 bits. The commercial audio consist on 2 binaural beats on theta (4 Hz) and beta (16 Hz) with 13dB dynamic range, self- made audio consist on

4 layers in theta (4Hz) and four layers in beta (16 Hz) with 18dB dynamic range, both have pink noise because it is more comfortable to listen binaural beats, the placebo signal consist in the pink noise with 15 dBs All developed with MATLAB.
For the application of sound we use Philips SHH9567 headphones.

2.4.2 EEG

EEG was recorded by a Brainvision Braimnamp EEG at 29 scalp points (International 10/20 system) with simultaneous registration of ECG during 20 min. Sampling rate was 1000 Hz. Mid-forehead electrode was the ground and Nuprep cream was placed on each electrode.

Spectral analysis of the EEG was calculated offline. A 30-second time interval free of artifacts was extracted from the baseline resting state and at 5, 10, 15 and 20 minutes of listening. The extracted intervals were notch-filtered at 50 Hz and band pass filtered between 1 and 70 Hz. EEG power was computed by FFT for the following frequency bands: delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz), gamma (30-40 Hz), and for two narrow bands (0.2 Hz width) centered in 4 Hz and 16 Hz. Entrainment was defined for every band and electrode as the ratio of power between stimulation and pre stimulation (baseline).
Therefore, we calculated four matrixes of 29x7 entrainment values for every subject in the experiment.

As the number of entrainment values was very high (29 electrodes x 7 bands x 4 moments), we considered significant a $P<0.01$, in order to minimize type I errors. A non-parametric Kruskal-Wallis analysis of variance was performed

2.4.3 Perception test of differences

The perception test of differences developed to assess the speed and hits in partially ordered stimulation patterns similarities and differences. It is a discrimination test based on the similarities and differences principles. This type of testing have been shown positive correlations with general intelligence[14].

Consist on 60 graphic elements, in blocks of three elements; the task is to determining which of the three faces is different from the other two.

2.4.4 EMAV test

The EMAV test assesses the attention capacity and effectiveness in children and adults. With this test provides evidence on the sustained attention in simple tasks of visual analysis and synthesis. Provides two levels of focus: Sustained Attention (AS) and Quality of Attention (CA)[15].

2.4.5 Five digits test

The Five Digit Test is a tool to evaluate, cognitive processing speed, the ability to focus and refocus attention and ability to cope with interference. Based on the known Stroop effect, but instead of using words and colors as stimulus, figures or digits are used, allowing a greater variety of tests and is used with less educated people, even people who do not know the language or cannot read [16].

3 Results

Experiment A: There was no significant difference in scores between groups for any of the three tests. A non-parametric Kruskal-Wallis analysis of variance was performed. Data are presented in Table 1 as mean ± s.d. P<0.05 was considered significant.

table 1: Statistic Analysis Results

Test	*Placebo*	*Binaural commercial group*	*Binaural experimental group*	*P*
Perception of differences				
Score	51.5 ± 6.9	49.6 ± 6.6	49.1 ± 7.9	0.52
5 digit				
Reading time	19.6 ± 3.5	21.5 ± 5.0	19.4 ± 3.6	0.36
Counting time	20.9 ± 2.7	21.9 ± 3.3	20.9 ± 3.4	0.38
Election time	31.9 ± 7.0	31.3 ± 4.5	29.0 ± 4.9	0.43
Alternation time	37.2 ± 9.1	38.6 ± 5.0	37.2 ± 7.3	0.23
EMAV-2				
Inhibition	12.3 ± 6.7	9.8 ± 5.5	9.5 ± 4.3	0.54
Flexibility	17.5 ± 8.3	17.1 ± 5.5	17.7 ± 7.1	0.77

Experiment B: As the number of entrainment values was very high (29 electrodes x 7 bands x 4 moments), we considered significant p<0.01, in order to minimize type I errors. A non-parametric Kruskal-Wallis analysis of variance was performed but we could not find any significant differences between the three groups for any electrode, band or moment of stimulation. In Fig.2 are depicted box plot of the entrainment values for the narrow bands at temporal lobes.

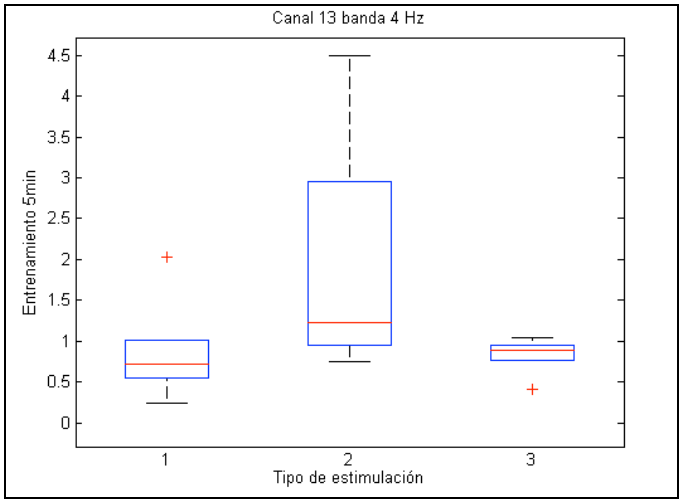

Fig 1: left temporal entrainment at 4 Hz

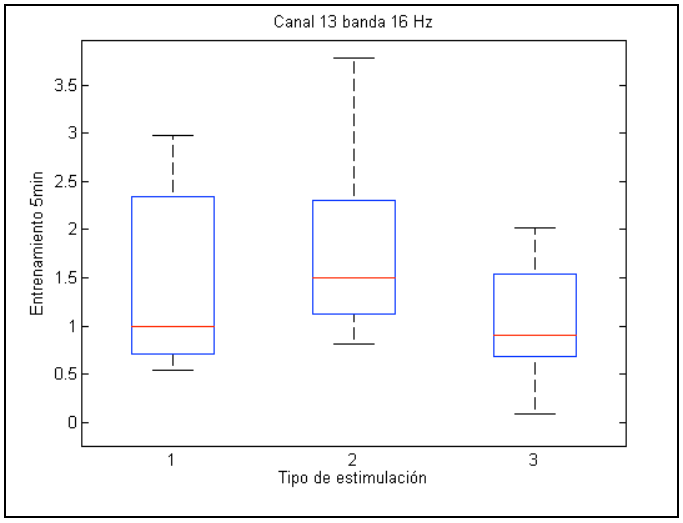

Fig 2: left temporal entrainment at 16 Hz

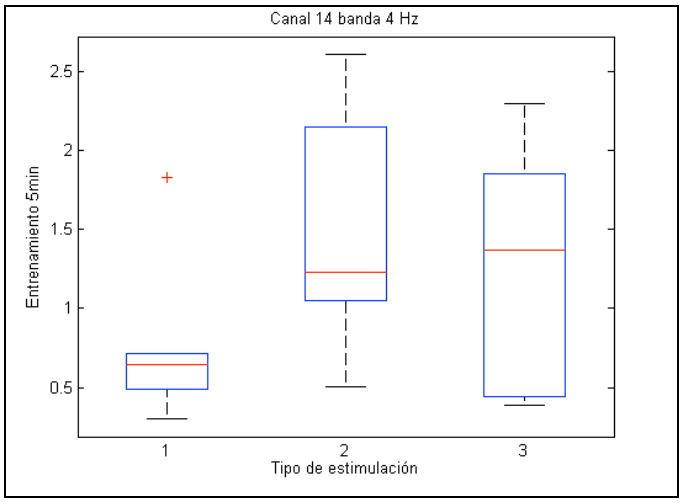

Fig 3: right temporal entrainment at 4 Hz

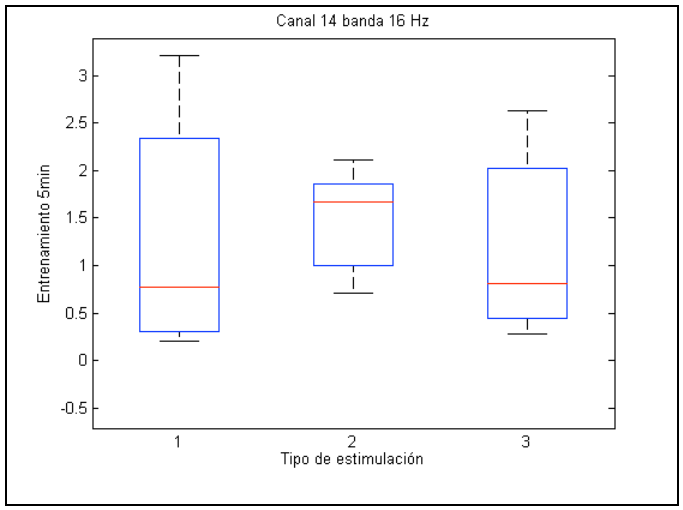

Fig 4: right temporal entrainment at 16 Hz

4 Discussion

In this paper effects of commercially available BB's and a self-made stimulation were examined. We could not found any significant difference in the cognitive tests. This may be due to several factors: because the wrong types of cognitive task were used, may also be due to the short duration of stimulation. It is true that the tests used in this study did not cover the whole spectrum of cognitive tasks (for instance planning and problem solving were not analyzed), but the commercial stimulation is advertised as "perfect for any mental task requiring focus and concentration", and the tests did require those capabilities.

We could not find either any significant difference in brain activity by means of EEG recording. It is possible that the size of the sample (6 per stimulation) was too small to examine group differences, also the stimulation time and the last possibility is the embedded noise with the stimulation, Kasparz reported significant changes using only BB's with no background sound. There were no side effects or adverse events noted by participants.

These results provide no evidence for improvements in cognitive function or changes in brain activity following binaural beat listening in a small sample of healthy adults after 20 min. It is important to consider the possibility that one session is insufficient to produce a measurable effect, and further studies including several sessions of listening should be considered.

Because BBAS is a safe non invasive, and potentially useful modality to entrain brainwaves [4] and to improve attention[13] this modality should be investigate farther using a larger sample.

Since subjects response can depend on baseline condition [17] population characteristic including mental health, psychological profile, QEEG, age, gender and other baseline variables should be specific clearly. Measurement of QEEG and relevant hormones pre and post stimulation would help clinical outcomes and improve our understanding of mechanism. Hormones such as glucocorticoids and melatonin fluctuate during the day and affect arousal and thus EEG.

Finally, future studies should follow participants for an extended period of time to determine the effectiveness of this therapy over the time.

In further experiments it is necessary also use simple stimulation with only one layer of BBs trying to observe the fast following response. The EEG analysis for this signal is a difficult election, future studies will have to calculate trends in order to know what happens along time. Also it is important to evaluate new parameters like hemispheric lateralization and evoked potentials.

References

[1] G. Oster, "Auditory beats in the brain," *Scientific American*, vol. 229, no. 4, pp. 94–102, 1973.

[2] J. D. Lane, S. J. Kasian, J. E. Owens, and G. R. Marsh, "Binaural Auditory Beats Affect Vigilance Performance and Mood," *Physiology & Behavior*, vol. 63, no. 2, pp. 249–252, 1998.

[3] E. Ozimek, J. Konieczny, and T. Sone, "Binaural perception of the modulation depth of AM signals.," *Hearing research*, vol. 235, no. 1–2, pp. 125–33, Jan. 2008.

[4] C. Kasprzak, “Influence of Binaural Beats on EEG Signal,” *Acta Fhysica Polonica*, vol. 119, pp. 986–990, 2011.

[5] D. W. F. Schwarz and P. Taylor, “Human auditory steady state responses to binaural and monaural beats,” *Clinical Neurophysiology*, vol. 116, no. 3, pp. 658–668, 2005.

[6] R. Padmanabhan, a J. Hildreth, and D. Laws, “A prospective, randomised, controlled study examining binaural beat audio and pre-operative anxiety in patients undergoing general anaesthesia for day case surgery.,” *Anaesthesia*, vol. 60, no. 9, pp. 874–877, 2005.

[7] J. C. Smith, J. T. Marsh, and W. S. Brown, “Far-field recorded frequency-following responses" evidence for the locus of brainstem sources,” *Brain Research*, pp. 465–472, 1975.

[8] H. Wahbeh, C. Calabrese, and H. Zwickey, “Binaural Beat Technology in Humans: A Pilot Study To Assess Psychologic and Physiologic Effects,” *The Journal of Alternative and Complementary Medicine*, vol. 13, no. 1, pp. 25–32, 2007.

[9] D. S. Foster, “EEG and Subjective Correlates of Alpha-Frequency Binaural-Beat Stimulation Combined with Alpha Biofeedback,” pp. 1–34, 1990.

[10] Imants Baruss, “The Art of Science : Science of the Future in Light of,” vol. 15, no. 1, pp. 57–68, 2001.

[11] L. I. Aftanas and S. a Golocheikine, “Non-linear dynamic complexity of the human EEG during meditation.,” *Neuroscience letters*, vol. 330, no. 2, pp. 143–6, Sep. 2002.

[12] C. F. Lavallee, S. A. Koren, and M. A. Persinger, “A Quantitative Electroencephalographic Study of Meditation and Binaural Beat Entrainment,” *The Journal of Alternative and Complementary Medicine*, vol. 17, no. 4, pp. 351–355, 2011.

[13] S. Kennel, A. G. Taylor, D. Lyon, and C. Bourguignon, “Pilot Feasibility Study of Binaural Auditory Beats for Reducing Symptoms of Inattention in Children and Adolescents with Attention-Deficit/Hyperactivity Disorder,” *Journal of pediatric nursing*, vol. 25, no. 1, pp. 3–11, 2010.

[14] C. REPARAZ, F. PERALTA, and J. NARBONA, “El test de percepcíon de diferencias (caras) como instrumento de medida de la atencíon sostenida,” *Revista de ciencias de la educación*, no. 166, pp. 265–280.

[15] M. Pérez and A. Lago, “Escalas Magallanes de Atención Visual,” *Escalas Magallanes de Atención Visual*, p. 30092, 2000.

[16] M. A. Sedó, “Test de las cinco cifras : una alternativa multilingüe y no lectora al test de Stroop,” vol. 38, no. 9, pp. 824–828, 2004.

[17] J. P. Rosenfeld, a M. Reinhart, and S. Srivastava, “The effects of alpha (10-Hz) and beta (22-Hz) ‘entrainment’ stimulation on the alpha and beta EEG bands: individual differences are critical to prediction of effects.,” *Applied psychophysiology and biofeedback*, vol. 22, no. 1, pp. 3–20, Mar. 1997.