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PHYSIOLOGY

Comparative Analysis of the Effect of Stimulation with a Binaural Beat and Similar Kinds of Sounds on the Falling Asleep Process: A Brief Note

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Abstract—Beats are the physical phenomenon appearing when two oscillation processes of close frequencies are superimposed. In acoustics, there is also the concept of binaural beats, a subjective feeling of the listener when acoustic tones of slightly different frequencies are applied separately to each ear. Commercial products based on the effect of binaural beats enjoy steady popularity in the market of the modern technological tools for psycho- and physiotherapy. In particular, they are applied to improve sleep. But it is the objective evaluation of the physiologic effect of binaural beats on the sleep onset process that has very little evidence for support. This paper provides comparative analysis of the time to fall asleep determined by the onset of the second daytime sleep stage (sleep spindle appearance). The subjects listened to a monotonous sound of three similar kinds: a combination of binaural beats with pink noise, a similar sound with a combination of monaural beats, and a similar sound without any beat. Stimulation by the combination of binaural beats is shown to produce the least sleep onset time as compared to the similar sound containing monaural beats and to the similar sound without beats. Further investigation is required to obtain results that are more consistent.

Keywords: binaural beats, falling asleep, insomnia, acoustic stimulation, daytime sleep, electroencephalogram.

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INTRODUCTION

One of the promising methods of noninvasive physical therapy is acoustic stimulation, the effectiveness of which is associated, according to one hypothesis [1], with the ability of the subliminal auditory stimuli to synchronize the cortical activity of large neuronal populations. Sound effects are employed in various devices of light-and-sound stimulation [2], some software products, as well as in applications of biofeedback and audio recordings of psychotherapeutic orientation. One of the types of sound effects they employ is low-frequency beats, that is, periodic decrease and increase in sound intensity. Despite the presence of certain encouraging publications [3, 4], the impact of sound beats on sleep is still poorly understood in scientific terms.

Psychoacoustics distinguishes sound binaural and monaural beats (BBs and MBs). MBs are the easiest to hear when electric signals of slightly different frequencies (such as 440 and 434 Hz) from outputs of two generators are mixed and applied to the source (speaker), resulting in acoustic beats with a difference frequency, in this case, of 6 Hz. These signals can be simultaneously applied to two different dynamics, so one would again hear the beats. Here, the approach to signal mixing, at the stage of electric or acoustic oscillations, does not affect the final result. It is quite another phenomenon that is observed in the case of feeding the same signals separately to each ear (using the stereo headphones). In this case, if one ear receives the tone with the frequency of 440 Hz and the other the tone with the frequency of 434 Hz, one is able to hear the beats with the same frequency of 6Hz, which have, however, a different, partly subjective nature. These beats are called binaural.

A number of applied studies demonstrate the positive impact of listening to BBs on behavior and cognitive processes [5, 6], but there is also evidence to the contrary [7, 8]. Most authors believe that the observed therapeutic effects are associated with the relaxing effect of BBs.

Most attention in the development of new methods of sleep therapy is given to the stage of deep (slow-wave) sleep [9], because of its decisive role in the implementation of recovery functions of the body. However, an equally important task is to develop the means of affecting the sleep onset stage, since the problems of falling asleep prevent any attempts to influence the deeper sleep stages. Most authors agree that the sleep spindle appearance can be considered as the criterion for sleep onset, which corresponds to the onset of the second sleep stage [10]. Therefore, the latency of the sleep spindle appearance can be used as an indicator of the sleep onset time.

The purpose of this study was to investigate effects of the sound of BBs on the falling asleep process and to compare it with effects of two similar kinds of sound: monaural beats and monotonous sound without beats (imitations, IM). The latency of the second sleep stage, measured by the time of the first sleep spindles, was chosen as a criterion for the stimulation effectiveness.

MATERIALS AND METHODS

The study involved 14 healthy subjects (12 males and two females) aged from 20 to 32 years who did not have sleep disorders and hearing impairments. Each of them participated in three experiments in the afternoon (from 3:00 to 6:00 pm). During the experiment, a subject was lying on a comfortable bed in the experimental chamber with the connected equipment for distant registration of electroencephalogram (EEG) and eye movements (electrooculograms, EOG). Polysomnograms were recorded using a miniature 8-channel wireless biopotentials amplifier (as designed by A.G. Troshchenko). EEG and EOG were recorded in a monopolar fashion using gilt cup electrodes fixed by glue gel produced by Natus (United States). EEGs were recorded in leads T3, T4, Cz, and Oz (according to the international 10–20 system); EOGs were recorded from electrodes located at the outer corners of eye slits, with a sampling frequency of 200 Hz. The sound fed to each ear through Sennheiser CX-200 vacuum stereo headphones (sampling frequency 1000 Hz) was recorded in two channels. The sound volume was adjusted individually to provide comfortable listening with the ability to fall sleep and was in the range of 50–53 dB (db SPL). The experiment lasted for 32 min: (1) the first minute, the background; (2) 15.5 min of stimulation, when one of the three soundtracks was reproduced (chosen at random); (3) subsequent 15.5 min, the background, the aftereffect.

Each of the three soundtracks was a 10-s looped fragment of a monotonous sound with pink noise, which was perceived as a four-resonant chord. The sequence of presenting these three soundtracks to each subject was chosen randomly.

The soundtrack type 1 employed BBs, for which tones of the used chord were slightly desynchronized for the channels: left ear (L)—(1) 47.89 Hz, (2) 95.74 Hz, (3) 191.48 Hz, (4) 239.87 Hz; right ear (R)—(1) 48.39 Hz, (2) 97.74 Hz, (3) 195.48 Hz, (4) 243.87 Hz, which resulted in the range of the sound chord of 4 BBs: 0.5 Hz, 2Hz, 4 Hz, and 4 Hz (Fig. 1a).

This combination of carrier frequencies and beats was chosen because it is close to the one implemented in audio recordings of the company's Monroe Products, which certain authors [5, 8] use in their studies as a means of improving sleep and cognitive functions.

The soundtrack type 2 employed MBs obtained by combining the sounds of the two stereo channels into a single mono channel, including pink noise. The beat frequencies were the same as in Soundtrack 1, that is, 0.5 Hz, 2 Hz, 4 Hz, and 4 Hz (Fig. 1b): left ear (L)—(1) 47.89 Hz + 48.39 Hz, (2) 95.74 Hz + 97.74 Hz, (3) 191.48 Hz + 195.48 Hz, (4) 239.87 Hz + 243.87 Hz; right ear (R)—(1) 47.89 Hz + 48.39 Hz, (2) 95.74 Hz + 97.74 Hz, (3) 191.48 Hz + 195.48 Hz, (4) 239.87 Hz + 243.87 Hz.

In case of the soundtrack type 3, both ears were receiving a monaural sound that did not contain beats but consisted of pink noise identical to the noise of the soundtrack type 2 and pure tones with the following frequencies: (1) 48.39 Hz, (2) 96.77 Hz, (3) 193.55 Hz, and (4) 241.93 Hz (Fig. 1b). Experiments with this type of sound served as a control series or IM.

The soundtracks of all the three types were subjectively very similar, especially when reproduced at the low volume used in the experiments, although a trained person could tell them apart. Therefore, some of the subjects reported differences of sound in different experiments, while others did not.

RESULTS AND DISCUSSION

Sleep stages in 42 entries of polysomnograms obtained for 14 subjects were detected according to standard criteria [10] with the epoch of the analysis of 20 s. Visual analysis of sleep stages was carried out with the bandpass filters software: 0.5–30 Hz for EEG and 0.2–3 Hz for EOG. As the criterion to determine the moment of falling asleep, we selected the first 20-s epoch with the presence of at least one sleep spindle (Fig. 1d), which is the main criterion for the onset of the second sleep stage [10]. This figure was further used to compare the time of falling asleep at the presentation of the three different soundtracks.

The data obtained for each subject are displayed in Fig. 2, where they are ranked by the descending difference in the falling asleep time between experiments with BBs and IM. In cases where the second stage did not occur during the experiment, its latency (time to fall asleep) was equal to the time of registration, that is, 1860 s. One can see that, when stimulated with BBs, the time of falling asleep was less than when stimulated with IM in ten subjects out of 14 and less in five subjects out of 14 when stimulated with MBs. Sleep spindles were not observed (the second sleep stage did not come): in experiments with BBs in one subject, in experiments with MBs in four subjects, and in experiments with IM in three subjects (those are marked with a cross in Fig. 2).

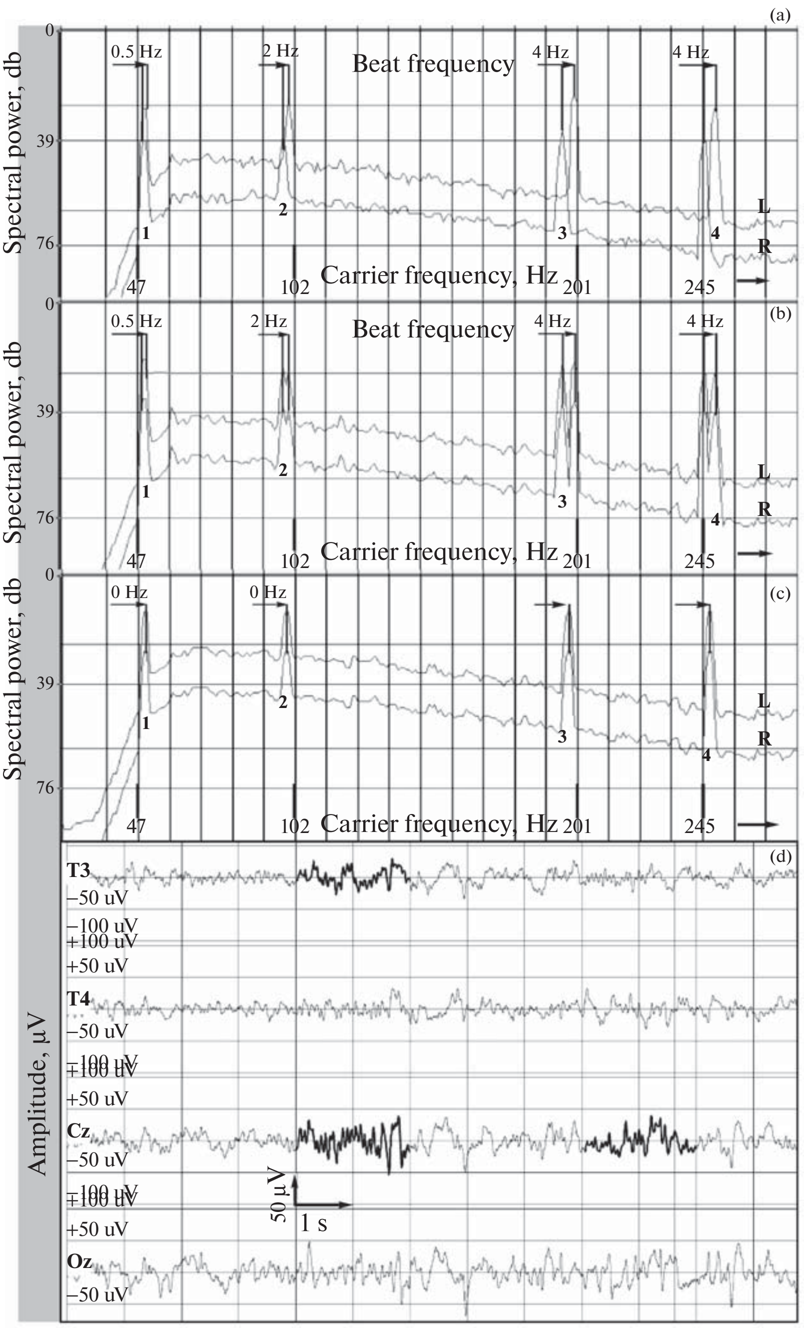

Fig. 1. (a–c) Spectrograms of sound stimuli used in the experiments; (L) at the top, left channel; (R) at the bottom, right channel. (a) Soundtrack with binaural beats; (b) soundtrack with monaural beats; (c) soundtrack without beats (imitation); (d) example of a 20-s epoch of the EEG in the second sleep stage with highlighted sleep spindles.

The probability of acceptance of the null hypothesis (no differences in the falling asleep times) when stimulated with BBs and IM for the entire group of 14 people was $p = 0.043$ according to the Wilcoxon signed-rank test, $p = 0.13$ (no significant differences) when stimulated with BBs and MBs, and $p = 0.96$ (no significant differences) when stimulated with MBs and IM.

For the ten "successful" subjects in which the time to fall asleep when stimulated with BBs was less than when stimulated with IM (circled in Fig. 2), the average values were as follows: time to fall asleep with BBs—429 s; time to fall asleep with IM—809 s; time to fall asleep with MBs—926 s. Differences for the Wilcoxon signed-rank test both between BBs and IM ($p =$ 0.005) and between BBs and MBs ($p = 0.047$) were significant.

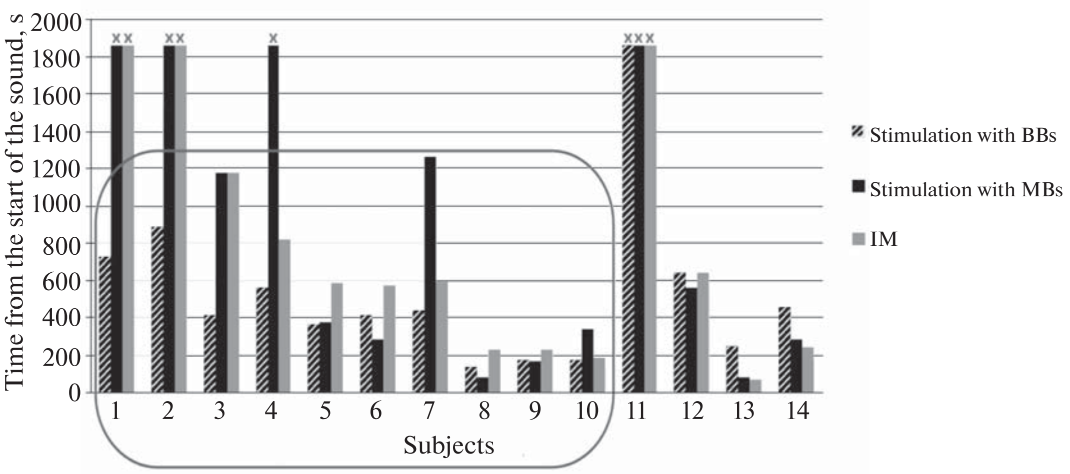

Fig. 2. Histogram of the falling asleep time for 14 subjects when listening to the soundtracks of three types: (1) hatch, binaural beats; (2) black bars, monaural beats; (3) gray bars, without beats, imitation. Ten "successful" subjects are circled (see the text).

Thus, this study has shown that listening to the sound with slow (0.5–4 Hz) BBs significantly reduces the time to fall asleep compared to this indicator when listening to the IM-sound that contains no beats but has a similar structure and volume. In ten out of the 14 subjects, the average time to fall asleep when listening to the soundtrack with BBs was less than when listening to the soundtrack with MBs or IM. Further studies are required to obtain results that are more consistent.

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