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Neural Oscillatory Responses to Binaural Beats: Differences Between Musicians and Non-musicians

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ABSTRACT

In the present study, multivariate Electroencephalography (EEG) signals were recorded from thirty-two adult human participants while they listened to binaural beats (BBs) varying systematically in frequency from 1 to 48 Hz. Participants were classified as musicians or non-musicians, with sixteen in each group. Our results revealed that BB stimulation modulated the strength of large-scale neuronal oscillations, and steady state responses (SSRs) were larger in musicians than in non-musicians for BB stimulations in the gamma frequency band with a more frontal distribution. Musicians also showed higher spectral power in the delta and the gamma frequency bands at all BB stimulation frequencies. However, musicians showed less alpha band power for BB stimulations in the gamma band. Our results suggest that BBs at different frequencies (ranging from very low frequency delta to high frequency gamma) elicit SSRs recorded from the scalp. Musicians exhibited higher cortical excitations than non-musicians when stimulated by BB stimulation in the gamma band, which was reflected by lower alpha, and higher gamma band EEG power. The current study provides the first neurophysiological account of cortical responses to a range of BB stimulation frequencies and suggests that musical training could modulate such responses.

Background

When two sinusoidal tones with a slight frequency mismatch are separately presented to each ear, listeners perceive an illusion of a beating frequency equal to the frequency mismatch between the two tones; this is termed a 'binaural beat' (BB) (Oster, 1973). This subjectively perceived beat, which has its origin in the brainstem (Smith et al., 1975), may also evoke cortical activity.

Karino and colleagues (2006) studied BBs at 4 Hz and 6.66 Hz with base frequencies of 240 Hz and 480 Hz. They reported auditory steady state responses (ASSRs) to the two chosen BBs with neural sources in the parietal, frontal and temporal cortices. Further, they found that the phases of ASSR showed large variability, suggesting top-down modulation.

Cortical evoked responses of brain activity were shown by Draganova et al. (2008) in ASSR to 40 Hz BB with a base frequency of 500 Hz. The ASSR magnetic field distribution indicated a bilateral representation but with a right hemispheric dominance.

Another study investigated 40 Hz BB with a base frequency of 380 Hz (Schwarz & Taylor, 2005), and revealed that such auditory stimulation evoked a SSR in the EEG signal; further, the response was evident across frontal and central areas of the scalp suggesting that the effect of BB stimulation might not necessarily be strictly localised. More recently, Pratt and colleagues (2009) studied event-related potentials (ERPs) in response to BBs with two base frequencies (250 Hz and 1000 Hz) and two BBs (3 Hz and 6 Hz). All stimuli elicited distinct ERP components such as P50, N100, and P200 following tone-onsets, with larger brain responses to the lower base frequency and to the lower binaural beat frequency. Beat-evoked oscillations were largely located in the left lateral and inferior temporal lobe areas.

Though these studies suggest that BB stimuli could elicit cortical activity recorded from the scalp, they covered only a handful of BB frequencies. Therefore it remains unclear whether there is a systematic relationship between BB frequency and cortical SSRs or if there are some preferred BB frequencies which evoke stronger SSRs. In the visual domain, Hermann (2001) presented flickering stimuli with flickering frequency varying from 1 to 100 Hz, and found visual SSRs at all these stimulation frequencies but with the strongest resonance effect at 10, 20, 40 and 80 Hz. Herrmann's study suggests that the visual cortex can be synchronized and driven by external stimulation over a wide range of frequencies, and it would be interesting to establish whether there is an auditory analogue to these findings. Further, there is no data available on the role of musical training in modulating cortical responses against BB stimulation.

Aims

The current study has two principal aims: firstly, to investigate the interrelationships between strengths of neuronal oscillations recorded from the scalp when stimulated by binaural beats, and secondly, to study the differences in brain responses to binaural beats between musicians and non-musicians.

Method

Thirty-two healthy participants were divided into two equally-sized groups: musicians (mean age: 25.5 years, age range: 19 to 32 years, 6 males, all right-handed) and non-musicians (mean age: 26.1 years, age range: 21 to 33 years, 7 males, 15 right-handed). Musical expertise was measured using a pre-test questionnaire with musicians reporting an average of 18.56 years (*SD* 4.08 years) of engagement with an instrument and of 14 years (*SD* 3.40 years) of formal training on a solo instrument. The group of non-musicians had no formal training beyond the standard musical practice during their preteenage school years.

Auditory stimuli were divided into 34 blocks. Each block, which lasted for 140 seconds, consisted of two conditions: the *non-binaural beat* (non-BB, duration 60s) and the *binaural beat* (BB, duration 60s) plus a gap of 20s of silence at the end.

In the BB conditions a tone with a mismatched frequency (*f*) was produced with *f* varying from 1 to 48 Hz. In the range of 1 Hz to 20 Hz, *f* was varied using a step size of 1 Hz and from 20 Hz to 48 Hz, *f* was varied using a step size of 2 Hz. This approach was taken as frequency resolution is less important for higher frequencies (> 20 Hz). For both conditions, the base frequency was 200 Hz. For example, in order to produce BB at 6 Hz, tones of 200 Hz and 206 Hz were separately presented to each ear.

EEG signals were recorded and amplified by a 64-channel BioSemi Active-II(R) system. EEG spectral power was estimated by the method of multitapers (Mitra & Pesaran, 1999). The SSRs were estimated according to BB frequency: SSRs for BB at f_b Hz were calculated by averaging the spectral power over $f_b \pm 0.5$ Hz.

During auditory stimulation, participants watched a muted film with subtitles in order to ensure that any effect elicited by BBs would largely be due to implicit brain responses (i.e. not requiring overt attention).

The experimental protocol was approved by the local Ethics Committee, Department of Psychology, Goldsmiths.

Results

Higher spectral power was observed for SSRs in the beta and gamma BB frequency bands (> 15 Hz) across musicians than across non-musicians . By comparing the SSR at each BB across both groups, significant differences were found at higher BB stimulation frequencies (gamma BB frequency band) [BB = 30 Hz ($t(29) = 2.38$, $p = .024$), 36 Hz ($t(29) = 2.3$, $p = .029$), 38 Hz ($p = .001$), 40 Hz ($t(29) = 2.09$, $p = .045$), 42 Hz ($t(29) = 4.133$, $p < .001$), 44 Hz ($t(29) = 4.463$, $p < .001$), 46 Hz ($t(29) = 3.41$, $p = .001$) and 48 Hz ($t(29) = 2.40$, $p = .022$), *p*-values below .05 are considered significant]. A comparison across all BB stimuli indicated that the profiles of SSR-BB were significantly different across the two groups (Wilcoxon, $Z = 3.43$, $p < .01$, a = 5%).

The topographic analysis indicates that SSRs, averaged across BB stimuli from 15 Hz to 48 Hz BB, were mainly localized over frontal regions in musicians, with slightly larger responses from the left hemisphere. In non-musicians, weaker but similar activation was observed in the temporal region with a reverse lateralization effect (i.e. larger responses from the right hemisphere). SSRs in the delta, theta and alpha bands seemed to be distributed for both groups over a wide range of brain regions. Finally, musicians showed higher spectral power in the delta and gamma frequency bands across all BB stimuli, whereas non-musicians showed higher alpha band EEG power across BB stimulation in the gamma band.

Conclusions

The present study revealed that BB stimulation can indeed modulate the strength of neuronal oscillations recorded noninvasively from the scalp. Further, musicians showed higher cortical excitations than non-musicians when stimulated by BBs at beta and gamma frequency bands. The finding of bilateral activation, which seems to be more efficiently localised in musicians, is also consistent with previous findings (Schwarz & Taylor, 2005; Draganova et al., 2008). Meaningful differences in the total power of individual frequency bands (delta, theta, alpha, beta and gamma) were also observed between the two groups across all BB stimuli. Results revealed a significantly higher resonance effect in the delta and the beta-gamma frequency bands across all BB stimuli for musicians.

The evidence presented above supports our hypothesis that musicians' brains behave differently to those of non-musicians when stimulated by BBs. It seems that greater sensitivity to the auditory stimuli, resulting from a long interaction with music, may lead to a stronger resonance effect. Neural synchronisation as well as neuroplasticity, which are yet to be fully understood, can be investigated further by comparing musicians and non-musicians. Further research could also investigate the possible impact of BB on cognitive and affective states, and how these are modulated by musical training.

Keywords

Electroencephalography, Binaural Beat, Musicians vs. Non-Musicians, Neural Responses

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