Power spectral analysis of very slow brain potential oscillations in primary visual cortex of freely moving rats during darkness and light

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Abstract

Previous reports demonstrated the presence of very slow oscillations (frequencies less than 1 Hz) in primary visual cortex (V1) neurons. In this work the hypothesis was tested that very slow brain potential (VSBP) oscillations in V1 accompany illumination changes. In darkness (0 lux), the results revealed the presence of oscillations in the range of seconds, multisecond and minute fluctuations. Continuous light exposure (2000-2500 lux) induced statistically significant ($P<0.001$) dramatic changes only in the frequency domain of seconds. These observations permit the conclusion that in V1 VSBP reproducible changes in the range of seconds occur in response to light and darkness.

Key words: Slow oscillatory activity, very slow brain potential oscillations, primary visual cortex.

Introduction.

Very slow oscillatory phenomena (with frequencies less than 1 Hz) were described in cortical neurons in a different current research articles [15]. Investigations of

electroencephalographic (EEG) recordings also revealed existence of similar rhythms in this type of CNS activity [3,11,15]. The accumulating evidence demonstrates a wide range of frequencies of brain activity, including very slow spontaneous extracellular potential fluctuations (oscillations) ranging from several seconds to more than several minutes [4]. Formerly such signals were referred to as “DC-shifts” or “slow” potentials, and there are many reports dedicated to this topic [1,8,10,12,14, etc.]. These processes, also known as very slow brain potential oscillations, are categorized into different frequency bands. These are “minute (60 s)” oscillations or fluctuations (less than 0.0167 Hz), “multisecond” oscillations or fluctuations (0.1-0.0167 Hz), and the frequency band (0.1-0.5 Hz) whose period is ca. 1 second, known as “second” oscillations or fluctuations [3,9].

Albeit several recent reports have shown the presence of very slow oscillatory activity at the different levels of the visual system [2,15,16], the extracellular dynamics of very slow brain potential (VSBP) oscillations in visual system is mainly undocumented, and the functional significance of this activity remains poorly known. In this work the hypothesis was tested that VSBP oscillations changes in the primary visual cortex should accompany changes in illumination.

Methods

The experimental part of this research was carried out in accordance with the "Principles of laboratory animal care" (NIH publication No. 86-23, revised 1985).

Animal surgery and general experimental design. Experiments were performed on 10 adult freely moving male albino rats. Under general anesthesia (sodium pentobarbital, 40 mg/kg i.p.) and according to the rat brain atlas [13] two electrodes were stereotaxically implanted across the primary visual cortex (V1) for long-term chronic extracellular recordings. Experimental studies were initiated after 14 days from the implantation. During experiments, animals were placed in a

large Faraday cage and isolated in special individual compartments with a light source on the top and light reflecting non-transparent walls. Freely moving within this cage the animal was then exposed to different background illumination levels: darkness (0 lux) or continuous ambient light (2000-2500 lux). Electrophysiological recordings of the VSBP from the primary visual cortex were performed in both darkness (n=70) and light (n=70) conditions in each experimental animal daily. After the end of an experimental series, the rats were devitalized using an injection of sodium pentobarbital (100 mg/kg i.p.). The brain was prepared in order with the methods described in detail in handbook [5], so that classical light microscopy could be used to determine the electrode tracks in the aforementioned brain area together with visual inspection of electrode positions using the topographical cytoarchitectural maps of the rat cortex [13].

Electrophysiological technique, special test procedures and measurements. Extracellular bipolar recordings were obtained with the implanted trans-cortical gold electrode pair (horizontal inter-electrode distance, 2 mm). Electrodes were manufactured from 98% gold wire and had the diameter, 0.35 mm, with the active area length, 2 mm. High input impedance (2×10^8 ohms) differential multi-channel low-noise (internal noise in 0-0.5 Hz bandpass, less than 3 μV) low bias current (less than 10^{-12} A), and high-stable (zero line drift not more than 15 μV per hour after setting the temperature mode) universal AC/DC-amplifier with DC-offset compensation (model UU-93, EPM IEM RAMN, St.-Petersburg, Russia) was used for the electrophysiological measurements. Amplified signals were continuously digitized on-line at a sampling frequency of 1 Hz by analog-to-digital converter board (model KPCI-3101, Keithley Instruments, Inc., Cleveland, Ohio, USA) and subjected to the personal computer for storing, pre-processing, and further off-line analysis.

Some authors [6,8,9] have shown previously that gold metal electrodes in conjunction with high input impedance amplifiers are an adequate tools for chronic very slow brain potential oscillation recordings (up to the frequencies of 0.008 Hz). However, since this type of metal electrode was used for very slow potential recordings, the special attention was paid to measures

aimed to eliminate possible artifacts because, apparently, very slow potential fluctuations and shifts may have an artifactual origin. These special measures were: (1) all electrodes were absolutely identical. (2) Before the implantation procedure, careful individual selection of electrodes for the pairs was used: all electrodes were tested in physiological saline (recordings were made with the same electrophysiological research equipment settings and in the absolutely same conditions as were used for experimental animal studies) and only those electrodes were used for the pairs that had the stable standing inter-electrode potential without any transient shifts, fluctuations, noise, etc. (3) Another tests (n=20) with the same paradigm were aimed to exclude the possible artifact effect(s) of metal electrode illumination on the inter-electrode potentials in the very slow frequency domain. For these purposes the bath with physiological saline solution was placed into experimental cage (where the animals were tested) and recordings were performed in darkness and during illumination in the same conditions as during animal tests with illumination changes. As a result, it has been found no statistically significant differences between inter-electrode potentials in the very slow frequency domain in darkness and during illumination in these control experimental series. (4) Only those time fragments of electrograms were analyzed when animal moving activity was minimal or absent.

Statistical analysis. For analysis, it was selected the following length of acquired data. For the ca. 1 Hz oscillation band - 256 data points (= 256 seconds) and for the multisecond band - 512 points (= 512 seconds). Each segment was subjected to the fast Fourier transformation (FFT) and power spectral analysis. Obtained data were analyzed by two-way ANOVA. Statistical difference with $P<0.05$ was considered significant.

Results

In general, all recordings (both in darkness and during light exposure) typically displayed the presence of spontaneous VSBP oscillations (Fig.1A, B) in the primary visual cortex with the

following properties: regular quasi-sinusoidal ca. 1 Hz oscillations with peak-to-peak amplitude up to 0.3 mV, relatively regular quasi-sinusoidal multisecond oscillations with peak-to-peak amplitude up to 1 mV, and seldom irregular spontaneous sinusoidal minute (60 s) fluctuations with peak-to-peak amplitude up to 3 mV.

In darkness, results of the power spectra analysis (Fig.1C, D) demonstrated that: (1) The main ca. 1 Hz or second range oscillations were within 0.1-0.21 Hz frequency domain, with several peaks in this band and three significant peaks around 0.11Hz, 0.12 and 0.15 Hz; the middle one was the most prominent. (2) In the multisecond oscillations range prevailed waves in the band of 0.0167 - 0.03 Hz without particular peaks. But it is necessary to note that the relative power was higher in the slowest types of this activity.

During illumination, there were observed statistically significant ($P<0.001$) dramatic changes only in the ca. 1 Hz or second frequency domain (Fig.1C). It can be seen that, in contrast to the darkness, light exposure induced a remarkable decrease in the power of oscillations in the frequency domain of 0.1-0.21 Hz. During illumination, it was found no statistically significant differences ($P=0.3187$) in the multisecond frequency domain of the primary visual cortex in comparison to darkness (Fig.1D).

Discussion

Aforementioned findings are consistent with the modern data regarding the very slow spontaneous oscillatory activity in the visual system. Albrecht and colleagues [2] have described the very slow oscillations in the dorsal and ventral lateral geniculate nucleus of the urethane anesthetized and awake freely moving rats during darkness and continuous illumination. It has been found that many lateral geniculate neurons display a strong very slow oscillatory behavior in the range of 0.025-0.01 Hz. It was also demonstrated that such activity could be significantly altered by the change from darkness to light in the direction that continuous illumination blocked

these very slow oscillations. There are some data (also agreeing with this work results) regarding the presence of very slow fluctuations in the neocortical extracellular recordings during wakefulness, i.e. oscillations of 0.02-0.068 Hz were determined in human cortical EEG at rest and were described as very slow EEG modulations [11]. Very slow fluctuations of visual threshold in the frequency domain of 0.02-0.068 were also shown in psychophysiological tests [16].

The results on the band whose period is ca. 1 second or second oscillations (0.1-0.5 Hz) demonstrate correlation between this activity in primary visual cortex and the level of illumination. Accordingly, it is logical to propose that this very slow frequency domain may possibly reflect some brain mechanisms implicated in the process of vision. However, it is possible to assume that the very slow oscillations of ca. 1 Hz range could be associated with the mechanisms of visual attention sustaining and switching during visual environment changes. Indirect support for this hypothesis is the report of spontaneous attentional fluctuations with frequencies of 0.083 - 0.33 Hz [3].

Basing on experimental data, it is possible to suggest that VSBP multisecond oscillations and minute (60 s) fluctuations are associated with spontaneous fluctuations of functional states in primary visual cortex neurons. These spontaneous fluctuations could reflect periodical influences from the brainstem nuclei (e.g. locus coeruleus, dorsal raphe nuclei, etc.), which form massive axonal projections within the primary visual cortex [13]. This is in agreement with the previously proposed hypothesis [11] that the very slow EEG modulations occur as a result of spontaneous fluctuations in the excitability of cortical neurons, controlled by brain stem structures. Previous studies made at our laboratory in which the presence of very slow oscillations in the locus coeruleus - frontal neocortex of corresponding frequencies was discovered [7] also provide strong support for the proposal above.

In conclusion, the obtained results show the presence of a variety of different forms of VSBP oscillations (ca. 1 Hz or second, multisecond oscillations, and minute fluctuations) in the

extracellular recordings from V1 of rats. It was determined different functional significance of the different frequency domains of this activity in response to sensory stimulation of the change to darkness or light. These data allow author to hypothesize the possible relations between oscillations in the band whose period is ca. 1 second and mechanisms of specific visual attention shifts, while the multisecond oscillations, minute (60 s) fluctuations, obviously, reflect processes of global excitability of cortical neuronal networks during different illumination levels.

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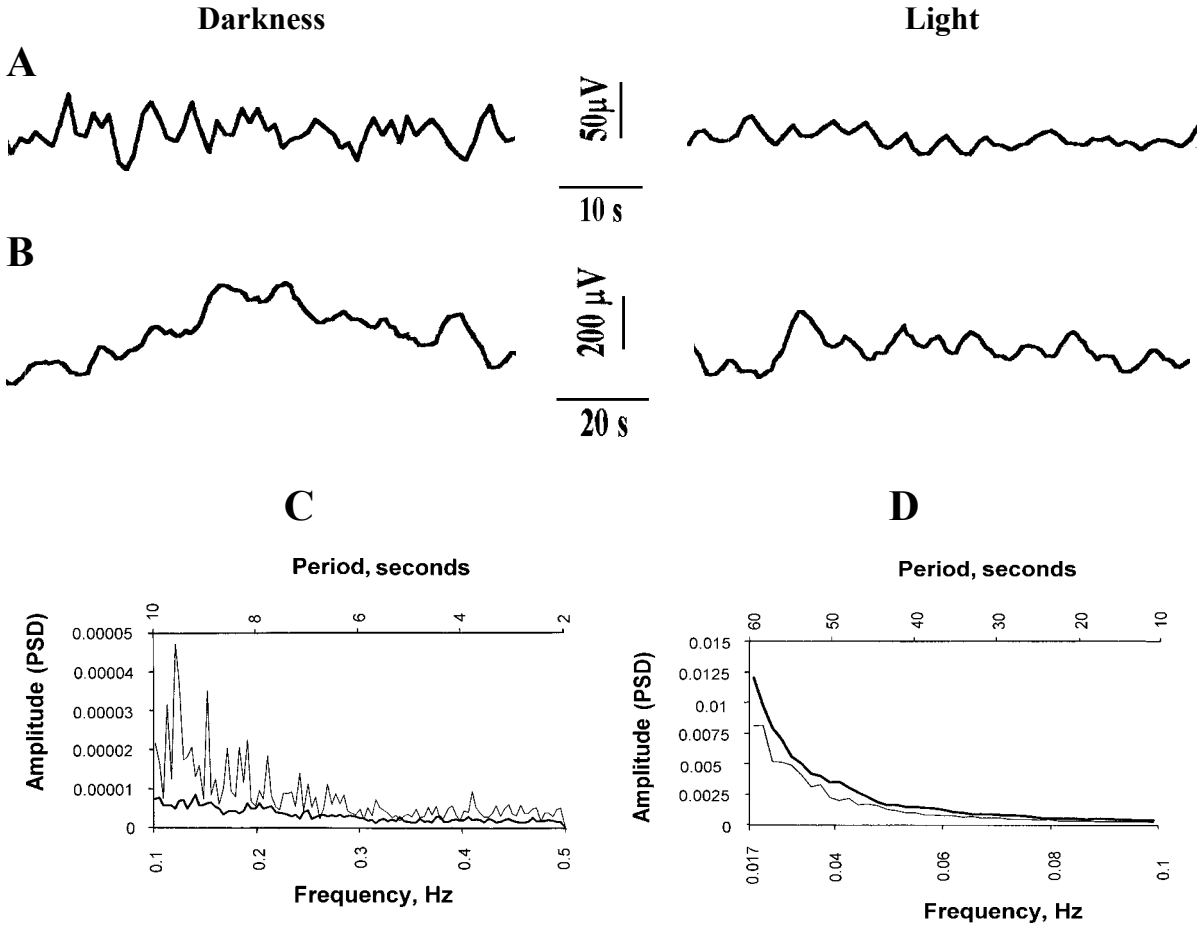
Fig. 1


Darkness
Light
A
50µV
10 s
B
200 µV
20 s
C
Period, seconds
Amplitude (PSD)
0.00005
0.00004
0.00003
0.00002
0.00001
0
10
8
6
4
2
0.1
0.2
0.3
0.4
0.5
Frequency, Hz
D
Period, seconds
Amplitude (PSD)
0.015
0.0125
0.01
0.0075
0.005
0.0025
0
60
50
40
30
20
10
0.017
0.04
0.06
0.08
0.1
Frequency, Hz

Legend to the Fig. 1 for the article Igor V. Filippov “Power spectral analysis of very slow brain potential oscillations in primary visual cortex of freely moving rats during darkness and light”.

Fig. 1. Examples of typical very slow oscillation recordings from primary visual cortex of the rat in darkness and during illumination in two frequency domains: (*A*) – second oscillations, (*B*) – multisecond oscillations. On this figure are also presented graphical results of power spectral analysis for the different frequency domains during darkness (thin line) and light exposure (thick line): (*C*) – second oscillations, averaged over n=70 graphs; (*D*) – multisecond oscillations, averaged over n=50 graphs.

Note: Abbreviation (*PSD)* on *C* and *D* means power spectral density; amplutude on these graphs is expressed using absolute scale units (mV per Hz). The resolution of the power spectra on *C* and *D* is not proportional in the three scales (e.g. number of points per octave).