Short-term effects of audio-visual stimulation on EEG

M. Teplan, A. Krakovská, S. Štolc

Institute of Measurement Science, Slovak Academy of Sciences,
Dúbravská cesta 9, 841 01 Bratislava, Slovakia
Email: michal.teplan@savba.sk

Abstract. *In order to identify direct and transient changes in human cortex under influence of the training with audio-visual stimulation (AVS) various EEG measures were estimated. In the course of 2 months, 25 repetitions of a 20 min AVS program with stimulation frequencies in the range 2-18 Hz were applied to 6 healthy volunteers. EEG data were recorded from 6 head locations during relaxed wakefulness prior, during and after AVS. Entrainment as a direct reaction to AVS was well developed in majority of cases, being strongest in backward regions and spreading also to other cortex locations. Transient effects displayed significant decreases in beta and gamma bands across head locations, and increase of theta-1 and alpha-1 coherence in central cortex regions.*

Keywords: electroencephalography (EEG), audio-visual stimulation (AVS), spectral power

1. Introduction

Audio-visual stimulation (AVS) is a simple method for external influence on the brain. The source of rhythmic stimulation such as light and sound synthesizers delivers the AVS signal to the brain through peripheral nerves. Headphones and glasses with light-emitting diodes are usually utilized.

During AVS adaptation of dominant EEG frequency to external stimuli may be observed [1]. This kind of resonant phenomena is known as entrainment of the brain waves.

Audio-visual stimulation has been reported to influence sleep and learning disorders, neurological disorders, addictions, tension, anxiety, premenstrual syndrome, migraine headaches, etc. AVS has become popular mainly for assumed induction of relaxing effects and altered states of consciousness. The main purpose of this study was to investigate the effects of AVS on the EEG on the short-term basis.

Brain electrical activity resulting from sensory stimulation is referred to as an evoked potential (EP) or event-related potential (ERP). ERP are usually modelled as signals superimposed, without interaction, on background of ongoing EEG. A rapid change in a sensory stimulus evokes a transient evoked potential. If this stimulus occurs repetitively at a rate high enough to prevent the EPR from returning to a baseline state, the elicited response is called a steady-state evoked potential [2]. A distinctive feature of the visual steady-state evoked potential (SSVEP) is that it comprises sinusoidal components at stimulus frequency and its harmonics. The latency of the response with the SSVEP, elicited by an unstructured flicker (low spatial frequency) in the range 7 to 15 Hz is approximately 200 to 275 milliseconds. In this case the signal comprises a frequency spectrum with several peaks, while stimulus in the form of an alternating checkerboard (high spatial frequency) consists of only one frequency maximum.

In the situation with SSEP one may observe under certain conditions, in addition to mechanisms mentioned above, adaptation of the brain waves to external stimuli. The simplest expectation may be that EEG components caused by repetitive stimulation would be superimposed to a spontaneous EEG pattern. But typical ERP amplitude is about 2 μV, while typical amplitude of spontaneous ongoing EEG is about 25 μV (in alpha regime). One may assume that there isn't present just a simple additional effect but that mechanisms governing neuronal activity are sensitive enough to be entrained by repetitive low amplitude ERPs. Under "entrainment" of the brain waves this kind of resonant effect is understood. As the ensembles of neurons are able to synchronize their activity without external stimulus, small repetitive input may after a certain adaptation period synchronize their firing thresholds.

Salansky et al. [3] studied entrainment due to visual stimulation in the range of 1-20 Hz with frequency increment 0.4 Hz. They found resonance activation only for 20% of stimulation frequency values. Several studies have suggested that photic driving response has a more diffuse character on cortical EEG, not only in the occipital regions. In visual stimulation experiments conducted by Rosenfeld one group of subjects did not produce a photic driving response within the alpha band while low-baseline alpha participants showed transient AVS effects [4]. Timmermann found that the overall effects of AVS in the alpha range on the cortical EEG did not have a significant effect on the corresponding alpha activity of the cortex [5]. Preservation of alpha rhythm shortly after photic driving was reported by Sakamoto et al. [6]. The aim of this study was to identify effects of commercially available AVS device in immediate and transient frame as a complement to our previous study concerning long-term effects [7, 8].

2. Subject and Methods

Subjects and EEG recording

Six right-handed healthy subjects (2 females and 4 males) volunteered for the AVS training. Overall training of each subject from the test group consisted of 25 AVS program sessions (Fig. 1), each of 20-minute length. AVS was provided by commercially available light and sound synthesizer. We chose a program described as suitable for AVS beginners to make acquaintance with different "mind states" according to their frequency profile performed. The program stimulated the brain at following frequencies: 18 Hz during first 3 minutes, then 18-10-8 Hz at min. 4-8, 8-5 Hz at min. 8-9, 5-4 Hz at min. 9-12, 4-2 Hz at min. 13, 2 Hz at min. 14-17, 5,9, and 15 Hz at min. 18-19. EEG data from 3-minute period before, 20-minute during and 3-minute period after each AVS session were recorded.

Fig.1.: Subject during audio-visual stimulation session.

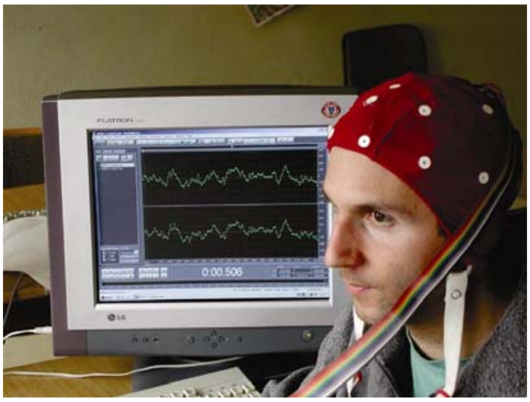

Fig.2.: EEG montage realized by EEG cap with electrodes placed according to International 10-20 system.

Monopolar EEG montage was realized by EEG cap (Fig.2) and comprised eight channels with electrodes placed on F3, F4, C3, C4, P3, P4, O1, and O2 locations according the International 10-20 system. The reference electrode was located at Cz and the ground electrode at Fpz point (Fig. 3).

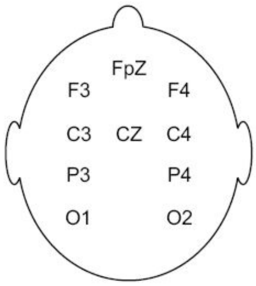

Fig.3.: Placement of active electrodes. Reference and ground electrodes placed at Cz and Fpz points, respectively.

Measures

To uncover objective changes from obtained EEG data, we computed the following characteristics: total power, absolute and relative frequency band powers, and coherences. Volunteer's subjective perception of the training process was also monitored.

Frequency spectrum was divided into 9 bands: delta-1 (0.5-2 Hz), delta-2 (2-4 Hz), theta-1 (4-6 Hz), theta-2 (6-8 Hz), alpha-1 (8-10 Hz), alpha-2 (10-12 Hz), beta-1 (12-16 Hz), beta-2 (16-30 Hz), and gamma (30-45 Hz).

3. Results and discussion

Direct AVS effects

During time period within stable stimulation at 18, 4, and 2 Hz relative powers for corresponding bands of 0.13 Hz width were computed and compared to those derived from referential period prior to stimulation.

Direct reaction to AVS was well developed in majority of stimulation sessions. In Fig. 5 averaged entrainment values for all artifact-free data (across persons and sessions) are displayed. Relative powers around 17 Hz, 4 Hz, and 2 Hz increased in all cortex location. The highest increase was observed in occipital parts as visual cortex is located just there. It is apparent that from these regions the specific rhythm spread as far as to frontal areas of the cortex. Without focusing on mechanism of spreading (generally synaptic or volume conductance), its attenuation is notable in the figure. In frontal region average reaction was attenuated from 4 to 7-times.

The highest increase of average relative band power, 30 times, occurred in the right occipital location during 17 Hz stimulation. Single session maximum occurred in left backward region during 17 Hz stimulation as well, reaching 217-times higher relative power compared to prestimulation period.

Also Lazarev [9] found that driving response varied with frequency and was demonstrable in majority of cases (70-100%) of children and adolescents; according to criterion peak amplitudes 20% larger than neighbouring frequencies. They observed the strongest response in alpha and theta ranges. In our case 17 and 4 Hz entrainments were stronger than 2 Hz entrainment.

This is in agreement with general knowledge on SSVEP. SSVEP evoked by lower stimulation frequencies have longer time gaps to return to baseline state and thus interfering more with spontaneous EEG activity.

The extend of entrainment is dependant on baseline (prestimulation) EEG. In addition to Rosenfeld et al. [4], who found that low prestimulation alpha power implies higher alpha entrainment, we found that increasing theta-1 and theta-2 coincided, at least in central cortex region, with rising entrainment.

Regarding subjective experiences, quite often participants reported different pleasant and colourful visions during certain stages of the stimulation session. Sometimes personal reminiscences surfaced.

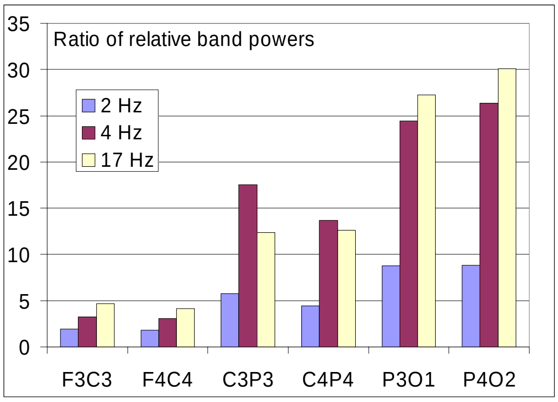

Fig.5.: Comparison of relative band powers in narrow frequency bands. Ratio of powers: from data during stimulation to powers obtained from data prior to stimulation. Displayed are results for different head regions and for averages through all persons and their sessions.

Transient AVS effects

For exploring transient AVS effects data recorded after AVS were compared to those recorded before AVS. Differences in individual measures during post stimulation period in respect to prestimulation period were examined by Wilcoxon matched-paired test [10]. In each group there were 25 values obtained as inter-person averages with the respect to the number of the session. For significant change at personal level Wilcoxon test appeared to be too strong criterion, thus the following weaker criterion was used:

Majority of increases or decreases from 25 pairs of values had to correlate with the group direction (increase or decrease).

The strongest changes in spectral domain occurred in higher frequency bands 12 - 45 Hz (beta and gamma) across all cortex regions. Absolute power from this interval decreased after stimulation in comparison with period prior to stimulation.

Positive shifts were obtained for interdependencies evaluated synchronization between left and right hemisphere in both lower and higher frequency ranges. The strongest increase was revealed for coherence in theta-1 band in central and parieto-occipital ($p<0.0005$, $p < 0.012$) areas, alpha-1 coherence increase in central ($p<0.0005$) and beta-2 coherence increase in frontal regions ($p<0.039$).

Results from transient AVS effects might be interpreted in the following way: Power attenuation in beta range may be understood through the fact that during post AVS resting session subjects were already laying for 25 minutes in darkened room with eyes closed. Their resting state differed from their normal conscious brain state more than that during resting session prior to AVS. Thus their conscious was altered from wake one connected with activity in beta domain.

After half of an hour of resting participants felt significantly better, that was reflected in a rise of subjective evaluation of general release during the second relaxation period compared to the first relaxation period.

We detected several significant changes in cortex functioning during regular application of AVS. However, further research is needed to support extensive clinical applications of AVS technology. For future studies we suggest investigation of long-term AVS with simultaneous recording of other relevant physiological parameters (e.g. electrodermal resistance, respiratory rate) for determination purposes, and post measurements after longer time-period from completion of long-term AVS experiment.

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References

[1] Walter V.J. and Walter W. G.: The central effects of rhythmic sensory stimulation. Electroenceph. Clin. Neurophysiol., 1949, 1:57-86.

[2] Regan D.: Human brain electrophysiology: Evoked potentials and evoked magnetic fields in science and medicine. Elsevier, New York, 1989.

[3] Salansky N. et al.: Response of the Nervous System to Low Frequency Stimulation and EEG Rhythms: Clinical implications. Neuroscience and Biobehavioral Reviews, 1998, Vol. 22, 395-409.

[4] Rosenfeld J.P. et al.: The effects of alpha (10 Hz) and Beta (22 Hz) "entrainment" stimulation on the alpha and beta EEG bands. Applied Psychophysiol. & Biofeedback, 1997, Vol. 1, 3-20.

[5] Timmermann D.L. et al.: Effects of 20-minute audio-visual stimulation (AVS) at dominant alpha frequency and twice dominant alpha frequency on the cortical EEG. Int. J. Psychophysiol., 1999, Vol. 32, 55-61.

[6] Sakamoto H. et al.: Preservation of alpha rhythm shortly after photic driving. International Journal of Neuroscience, 1993, Vol. 73, 227-233.

[7] Teplan M. et al.: EEG responses to long-term audio-visual stimulation. International Journal of Psychophysiology, 2006, Vol. 59/2, 81-90.

[8] Teplan M. et al.: EEG in the context of audiovisual stimulation. Measurement Science Review, 2003, Vol. 3, 17-20. http://www.measurement.sk

[9] Lazarev V.V. et al.: Photic driving in the electroencephalogram of children and adolescents: harmonic structure and relation to the resting state. Brazilian Journal of Medical and Biological Research, 2001, 34: 1573-1584

[10] Andel J.: Matematická štatistika, SNTL, 1985.