International Journal of Humanities and Social Science Invention (IJHSSI)
ISSN (Online): 2319 – 7722, ISSN (Print): 2319 – 7714
www.ijhssi.org ||Volume 6 Issue 12||December. 2017 || PP.12-16

Hemoencephalography (HEG) Biofeedback As A Method Of Stress Control Among Healthy Subjects

Andrzej Bartosinski[1],Pawel Bodera[1],Wanda Stankiewicz[1]
[1]*Department of Microwave Safety, Military Institute of Hygiene and Epidemiology,*
[4]*Kozielska Str., Warszawa, Poland*
Corresponding Author: Andrzej Bartosinski

ABSTRACT: *Hemoencephalography (HEG), noninvasive brain imaging which is used to measure local changes in hemoglobin concentrations and spatial image reconstruction. The resolution of HEG, may be complementary to other imaging methods based on the hemodynamic response such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET).This method can be used for imaging activation and functional connectivity in the prefrontal cortex of healthy subjects during the demonstration of colorful words (in the proper meaning) in the Stroop test. A form of neurofeedback named hemoencephalography (HEG), using HEG, may improve the brain function by training the subject to increase blood flow in the prefrontal cortex (PFC). Neurofeedback is an effective tool for self-regulation, useful for achieving better self-knowledge and enhanced cognitive skills. Visual evoked potentials (VEP) are the brain's responses to visual stimuli displayed on a computer screen, such as a reversing checkerboard pattern, color pictures or words. Analysis were prepared using LORETA software for EEG. Oxygenated and deoxygenated arterial blood levels before (BEF) and after (AFT) HEG session were presented.*

Keywords: *hemoencephalograph (HEG), neurofeedback, visual evoked potentials (VEP).*

Date of Submission: 05-12-2017 Date of acceptance: 26-12-2017

I. Introduction

Hemoencephalography (HEG), which is used to measure local changes in hemoglobin concentrations and spatial image reconstruction (diffuse optical tomography), is a developing technology for noninvasive brain imaging with a growing use in research and clinical practice. HEG is a novel imaging technique to measure changes in regional blood oxygenation and flow caused by neuronal activity. This method detects hemodynamic modulation as an indirect measure of neuronal activity with several unique features whose capabilities have not yet been fully explored. An excellent temporal resolution of HEG, may be complementary to other imaging methods based on the hemodynamic response such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET). In the present study, we have explored the feasibility of using HEG technology (hemoencephalography) for image activation and functional connectivity in the prefrontal cortex of healthy subjects during the demonstration of colorful words (in the proper meaning) in the Stroop test. We tested HEG as a quick and simple device placement on head and demanding short recording time to evaluate the level of stress. We were interested in the macro consequences of the stress response [1].

Stroop test

The Stroop Color Word Test was established to assess psychological processes and functions that effect cognition in normal, neuropsychological, and psychiatric populations. The interference of word reading with color naming is the immediately distinctive facet of the Stroop effect. Neuropsychological parameters such as cognitive flexibility, creativity, defense structures, cognitive style and complexity, attention deployment and resistance to interference from outside stimuli are associated with Stroop scores. The Stroop test can be utilized as a battery for making a differential diagnosis such as an assessment of responsiveness to psychotropic medication [2]. The Stroop test possesses numerous advantages: it can be translated into foreign languages without difficulty, it requires only elementary education, and requires only 5 minutes to perform a reliable test.

Hemoencephalography (HEG)

We use the term *neurofeedback* to refer to the use of the electroencephalogram (EEG) to produce biofeedback, although the use of other measurements, such as cerebral blood oxygenation, are also possible [3, 4]. A form of neurofeedback named hemoencephalography (HEG), may improve brain function by training the subject to increase blood flow to the prefrontal cortex (PFC). The cortical region, localised directly behind the

forehead, controls higher-level executive functions such as planning, judgment, organization, inhibition, and emotional regulation.
Case studies have shown HEG training increases brain activity by increasing blood and is beneficial in reducing symptoms associated with migraines, ADHD, and autism. An increase in cognitive performance, alleviating depression, stress and chronic anxiety after HEG training was also demonstrated. During HEG treatment clients were pre-tested and post-tested using the GO/No-GO Stroop test to monitor and measure improvements.

Studies of the mechanisms of selective attention commonly use such tasks as these. They play an important role in goal-directed behavior. A response was required from subjects when a target (color name disagreed with the description) was detected (the "Go" condition) and a response was otherwise withheld (the "NoGo" condition). We use the term *neurofeedback* to refer to the use of the electroencephalogram (EEG) to produce biofeedback, although the use of other measurements, such as cerebral blood oxygenation, are also possible [3, 4]. Hemoencephalography biofeedback (HEG) which is a different form of biofeedback to brainwave neurofeedback may improve brain function by training the subject to increase blood flow to the prefrontal cortex (PFC).

There are two types of mainstream HEG sensors, either a sophisticated infrared thermometer known as a passive infrared HEG (pirHEG) or, a near infrared HEG (nirHEG) sensor that shines light through the skin and skull to assess the colour of brain tissue. Oxygenated arterial blood is red, deoxygenated venous blood is blue. Increased demand for nutrition results in faster blood flow and redder blood in the tissues leads to more effective function. The cortical region, localised directly behind the forehead, controls higher-level executive functions such as planning, judgment, organization, inhibition, and emotional regulation. Case studies have shown HEG training increases brain activity by increasing blood and is beneficial in reducing symptoms associated with migraines, ADHD, and autism. An increase in cognitive performance, alleviating depression, stress and chronic anxiety after HEG training was also demonstrated [3, 4]. During HEG treatment clients are pre-tested and post-tested using the GO/No-GO Stroop test to monitor and measure improvements.

II. Methods Participants

Thirty right-handed young adults (men, aged 20-32) participated in the study.
All participants signed a consent form approved by the Bioethical Comittee and were reported as being in good health and without medications. All subjects had normal (or corrected-to-normal) vision and undertook a battery of behavioral tests that included measures of IQ (Weschler Abbreviated Scale of Intelligence; the average IQ score 121.7±SD) and handedness before one experimental session lasting 2 h, during which they performed a target-detection task with simultaneous optical and EEG recording of brain activity.
All subjects were compensated for their participation in these experiments.

Optical Data Collection

Optical signals were recorded using a continuous-wave imaging system (HEG) that measures the amplitude of light traveling through the brain and surrounding tissue. The HEG system has a source emitting light at two wavelengths, 690 and 830 nm (i.e., 16 lasers at each wavelength), and 2 detector channels.After the detected signals have been digitized and saved to disk, they are demodulated in software to determine the contribution at the detector from each source.

EEG data collection

EEG recordings were obtained in a dimmed room with each participant sitting upright on a comfortable chair with a footrest.The actual recording lasted approximately 10 min before and after the biofeedback procedure. The standard 10-20 International placement, referenced to linked ears was used to he EEG data collection.The EEG was sampled with 21 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, O2, A1, A2).Data were collected at the sampling rate – 512 Hz and band passed 0.5-200 Hz. Data were band-pass filtered (fast Fourier transform filter) to 2-60 Hz and subsequently transposed into BioTrace software (MindMedia, Holland) plotted and carefully inspected for manual artifact-rejection. The stream of the EEG was cleaned from such artifacts as eye blinks, eye movements, teeth clenching and body movement.

LORETA imaging

LORETA, which computes inverse solutions that approximate the cortical sources, is a brain imaging method using a three-shell spherical model registered to the Talairach human brain atlas [5] from EEG recordings (http://www.uzh.ch/keyinst/NewLORETA/LORETA01.htm. [6].The theoretical basis of LORETA is that the inverse solution corresponds to the 3D distribution of electrical neuronal activity of adjacent voxels of neighboring neuronal populations. The final LORETA solution is independent of the used electrical reference, due to the scalp electric potentials which are determined up to an arbitrary additive constant.The activation of concurrent neuronal populations are restricted by The Laplacian penalty term, which limits the

detection of very circumscribed and small generators with a low localization error of 7 mm [7].The coherent firing of neighboring cortical neurons during stimulus processing is the fundamental assumption of LORETA [6, 8, 9] which can be seen as a physiologically based constraint.
The cortical columns, where this coherent firing is observed, have a much smaller diameter than the voxels used in the LORETA software, therefore the characteristic feature of the final results is its relatively low spatial resolution, which directly relies on the smoothness constraint.

LORETA analysis

The LORETA solution produces a point source, "blurred-localized" image, which is advised to counteract anatomical and localization errors due to inter-individual differences in eg. head geometry and electrodes placement. The confounding variables such as the inter-individual variability in skull thickness and electrode impedance were eliminated by spatial normalization by the square root of the sum of squared current density values for each subject at all voxels. Such manipulation conserves the location of maximal activity, but with a certain degree of dispersion.Statistical analysis was performed based on the current density amplitude estimates which were computed and pre-processed.We used the permutation multiple comparison *t*-sum approach to compare voxel-by-voxel the current density amplitudes of the tinnitus distress, which accounts for multiple comparison.

Brain microstate

The difference between target- and nontarget-related ERPs - so-called differential ERP activity- has negative polarity over temporal-occipital cortices and a positive polarity over the frontal cortex. This is to be measured with a brain microstate technique.A brain microstate presents a functional/physiological state of the brain during which specific neural computations are performed.A time sequence of non-overlapping microstates with variable duration, which are composed for modelling brain electrical activity, is uniquely characterized by a fixed spatial distribution of active neuronal generators with time varying intensity.The microstates are represented as normalized vectors constituted by scalp electric potentials due to the underlying generators in a precise mathematical formulation of the model for evoked potential recordings.Each multichannel evoked potential measurement is classified as belonging to some microstate, which is based on a modified version of the classical k-means clustering method, in which cluster orientations are estimated. The corresponding measurements were estimated by projecting time varying intensities, using statistical image segmentation techniques for obtaining smooth continuous segments.

Visual Evoked Potentials (VEP) procedure

Visual evoked potentials (VEP) are the brain's responses to visual stimuli displayed on a computer screen, such as a reversing checkerboard pattern, color pictures or words. They refer to electrical potentials, whose appearance are related with stimuli presented to the subject. Responses are recorded from electrodes which are placed on a special cap which is connected to the electroencephalogram (EEG), and the waveforms are extracted from the signal through a process of averaging. These responses usually originate from the area of the brain involved in receiving and interpreting visual signals - the occipital cortex. First, a cap with electrodes (international 10-20 system) was placed on the subject's head to detect the brain waves. During the VEP test the subject is sitting in front of a screen with various visual patterns. The subject received the necessary instruction before training session.

A very important thing is cooperation between researcher, who conducts the test and check if the participant fix vision in a certain spot (checkerboard) or understands task with other stimuli.Measured signal will be recorded through the electrodes from cap on head.After the procedure, the cap is removed from participant's head. In this research visual evoked potentials were recorded during the Stroop task. Each of the stimuli from the list displayed on the screen were tagged as Go (the meaning of displayed word was in the corresponding color) or NoGo – (color of the word was different than it's meaning). The subjects received instruction to mark the appropriate button when it matched the color of word displayed on the screen (condition "Go"). The time between displayed events was randomized from between 600 to 1200 miliseconds, and the dominant stimuli were "NoGo" (about 3 times more stimuli than "Go"). Each task lasted for 10 minutes. In the second part of VEP measurement, the participant had to watch a checkboard which was reversing every 100 ms. This part of measurement lasted for 5 minutes.

Presenting stimuli

During the biofeedback procedures (trans-cranial oximetry - hemoencephalography, HEG) the computer games DRIVE was presented in order to maintain an appropriate level of emotion.
Zukor's Drive is an advanced feedback game which offers gameplay from very relaxed to extremely intense, or any point in between. It is designed for clinical neurofeedback or biofeedback training and, with an upgrade, for

peak performance training.

Zukor's Drive also includes all the standard features of Zukor feedback games, such as profiles, scores, auditory feedback, period/session length presets and more. It is Zukor Interactive's most ambitious feedback game and is certain to focus your clinical patients and engage those undergoing peak performance training.

Fig. 1. The shrinking screen was presented during neurofeedback (alfa/theta coherence) session as a confounding factor . http://zukor.com/interactive/

The size of the screen (after reduction) was 40 percent lower than the initial screen.

Visual Evoked Potentials (VEP) procedure

During the VEP test the subject was sitting in front of a screen with various visual patterns at a distance of 1 meter wearing a cap with electrodes (located in International 10-20 system) to detect the brain waves patterns. The subject was sitting on a chair in comfortable position – with legs on footstool and outstretched arms. The subject received instructions on what to do during the test. The test procedure was conducted and checked if the participant could fix vision in a certain spot or understands task with other stimuli. Visual evoked potentials (VEPs) were recorded during the Stroop task and checkerboard reversal pattern.

Stroop task

In this task stimuli were images displayed as a presentation built from slides with presented words – the Oddball paradigm with "Go" and "NoGo" events. Each of the stimuli from the list were displayed on the screen sequentially, and were tagged as Go (the meaning of displayed word was in the corresponding color: black, blue, red, green and yellow) or NoGo – (color of the word was different than it's meaning, for example the word "Red" was written with blue font). The subjects received instruction to mark the appropriate button when it matches the color of word was displayed on the screen (situation "Go"). Time between displayed events was randomized from 600 to 1200 milisceconds, and the dominant stimuli were "NoGo" (150 stimuli) in comparison to 50 "Go" stimuli. The task lasted about 8 minutes.

Checkerboard pattern reversal

In second part of VEP measurement participant was sitting in front of a screen with checkerboard pattern with red fixation point. The checkerboard pattern reversal was presented at the 1024x768 dpi screen, where the pattern was reversing every 100 ms. Visual stimuli were based on checkerboard with 1.0 Hz frequency. This part of measurement contained 400 stimuli and lasted about 7 minutes.

The Stroop Color Word Test was established to assess psychological processes and functions that effect cognition in normal, neuropsychological, and psychiatric populations. The interference of word reading with color naming is the immediately distinctive facet of the Stroop effect. Neuropsychological parameters such as cognitive flexibility, creativity, defense structures, cognitive style and complexity, attention deployment and resistance to interference from outside stimuli are associated with Stroop scores.

The Stroop test can be utilized as a battery for making a differential diagnosis such as an assessment of responsiveness to psychotropic medication [2]. The Stroop test possesses numerous advantages: it can be translated into foreign languages without difficulty, it requires only elementary education, and requires only 5 minutes to perform a reliable test.

III. Results

In the present study, we used the Stroop paradigm to investigate the relationship between skill and automatic reading and reaction time – before and after the neurofeedback procedure and biofeedback hemodynamic response (hemoencephalography, HEG).

The following parameters (match and mismatch) were analyzed for the following colors: blue, green, red. The colors' names were presented in Polish in order to avoid a language interference.

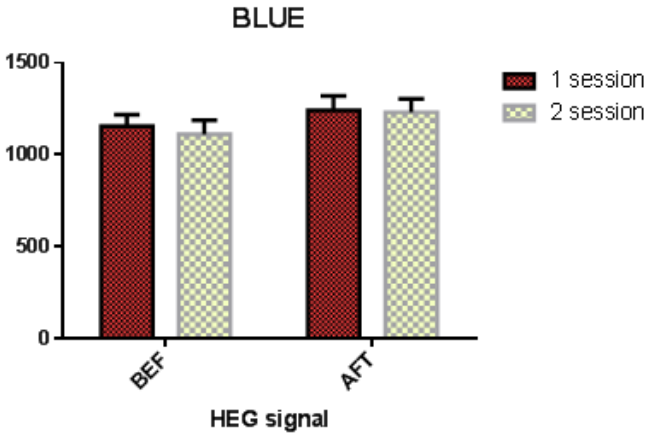

Fig. 2. Deoxygenated arterial blood level before (BEF) and after (AFT) HEG session – 'BLUE' sensor

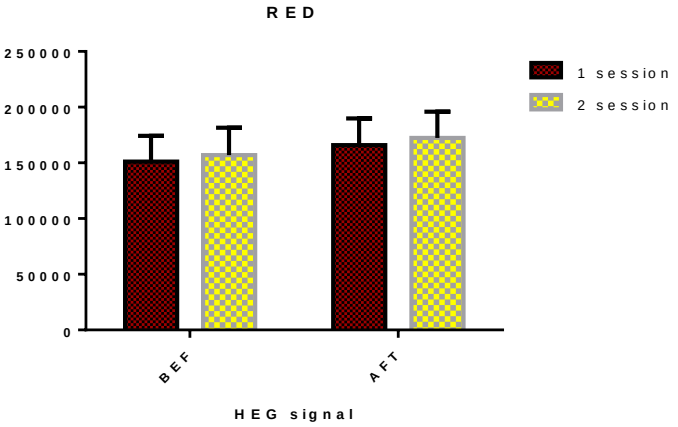

Fig. 3. Oxygenated arterial blood level before (BEF) and after (AFT) HEG session – 'RED' sensor

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Andrzej Bartosinski. "Hemoencephalography (HEG) Biofeedback As A Method Of Stress Control Among Healthy Subjects." International Journal of Humanities and Social Science Invention (IJHSSI), vol. 06, no. 12, 2017, pp. 12-16.