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Methods of indication of low intensity pupil reaction on the subjectively-important stimuli

Marina Petrovna Boronenko, Pavel Yurievich Gulyaev, Vladimir Ivanovich Zelenskiy

Yugra State University, Chekhova St. 16, Khanty-Mansiysk, Khanty-Mansi Autonomous Okrug, Yugra, 628012, Russia.

Correspondence to: Laboratory of Complex Engineering, Yugra State University, Chekhova St. 16, Khanty-Mansiysk, Khanty-Mansi Autonomous Okrug, Yugra, 628012, Russia. Email: boronenko.ysu@bk.ru

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Abstract

It is becoming impossible to do without high-tech security systems in the modern world. Pupilography systems carry out timely detection of individuals under the influence of drugs or alcohol. Our research allows widening the application scope of systems for recognition of such states to include the state of stress or aggression. The combination of marketing method of eye tracking and pupilography using specific test objects will make it possible. We synchronized the pupillograms and oculograms, which clarified the interpretation of the pupillograms. Presumably, part of the pupillograms are waves of attention, and can be explained by focusing the gaze on a specific element of the test object. However, part of the pupillogram does not explain the movement of the gaze. Spectral analysis of the pupillograms showed a gradual formation of peaks at 7 and 14 Hz, which implies a link between the diameter of the pupils and the rhythms of the brain. The possibility of registering a pupillary response to a low intensity stimulus that is significant for an individual is shown. Binding waves of attention to a specific element of the test object and the link of the pupil diameter and the brain potentials will improve existing security systems.

Introduction

Scientific and technological progress allows the widespread use of high-tech electronic devises in security systems. Now, almost all foreign companies not only use biometrics in cell phones, but also create special devices that track, recognize and collect data on human emotions through the day. The mobile application makes suggestions that aid the development of good habits and positive emotions basing on the data accumulated. Sensors successfully monitor several physiological parameters: pulse, galvanic skin reactions (GSR), and skin temperature, while the system algorithms interpret biological signals in terms of emotions. Despite the widespread use of biometrics, many problems remain unresolved. To develop objective indicators of individual's emotions' polarity and analysis of emotional processes requires a multilateral approach. As we know, the indication and diagnosis of emotions through the analysis of the subjects' self-report, record of expressive movements, and changes in the performance is rather subjective. Quantitative methods traditionally used to diagnose emotions (GSR, electrocardiogram (ECG), plethysmogram) also have their drawbacks (Cacioppo & Gardner 1999; Arakelov & Shott 1998). The remote methods allowing continuous monitoring of person's psychophysical state parameters are preferred. Thanks to the simplicity of implementation and cost-effectiveness, pupillograms and indicators of ocular-motor activity are of particular interest (Cacioppo 2004; Arakelov & Shott 1998; Stern *et al* 2000; Kucalo 2004). Oculography is used not only in marketing research, but also to study the cognitive processes of the brain, decision-making mechanisms, etc. (Meyberg *et al* 2015; Costela *et al* 2017; Borisyuk *et al* 2002; Pritchard 1981; Lowet *et al* 2018). Oculography is based on determining the position of the pupil and derivation of the position of the pupil center from time with the subsequent spectral analysis of the time dependencies. The trajectory of eye is video-recorded with no contact (usually the Eyegaze Analyzing System), capturing infrared light is reflected from the cornea. Pupilography is also widely used. The pupillograph records a change in the size of the pupil during speech (Stern *et al* 2000). If a person is deceiving, he/she experiences stress, the size of the pupils changes. Pupillometry in study of the autonomic nervous system allows us to investigate various neurological abnormalities, recognize Alzheimer's disease, neuropsychiatric disorders, sleep disorders, migraines, Parkinson's disease. Early stage diabetes, amyloid and rheumatic disorders, and Chagas disease (one of the most common parasitic diseases in Latin America) manifest themself through changes in the normal pupillary response. Pupilograms are actively used for diagnostics in ophthalmology, neuropathology, narcology (Kucalo 2004), and in general medical practice. Pupil diameter monitoring is non-invasive and correlates with brain theta rhythm (Perotti *et al* 2019). It is also known that the potentials of the brain can be reliable markers of stress (Pashkov *et al* 2017) and are used as an indicator of the recognition of objects by an individual (Jordanova & Kolev 1998). Thus, if one synchronizes the pupil tracking and recording of pupillograms in responce to a specific test object, it allows to specify the test object element to which the emotional reaction occurred.

LITERATURE REVIEW

Electrooculography, contact photooptical and electromagnetic methods, as well as contactless photoelectric and video-recording (which acquired wide use recently) methods are used for eye movement registration. Eye micromovements (microsaccades) are one of the most important indicators of oculomotor functions. These are rapid eye movements of 10–20 ms, ranging in amplitude between 2' and 50'. Previously it was thought that microsaccades only complicate the analysis of the oculograms, and are a source of artifacts in electroencephalograms (EEG). However, recent studies (Meyberg *et al* 2015) have demonstrated the relation of microsaccades to cognitively modulated brain potentials, and their potential as non-intrusive attention probes. Later (Costela *et al* 2017) it was found that microsaccades restore the visibility of a stationary target in a wide range of spatial frequencies (SF), with larger microsaccades increasing the visibility of the target more efficiently than smaller ones. When studying the relationship of microsaccades to brain potentials, regulating the flow and processing of visual information in macaques (Lowet *et al* 2018), a narrowband spatial-specific response to a stimulus in the gamma range (25–80 Hz) was found, as well as microsaccades associated with visual fixation (3–4 Hz). This suggests that the way the information is transmitted and integrated between early-stage visual cortical layers depends on the timing of microsaccades. Thus, further study of microsaccades is important not only from a clinical point of view (Ying *et al* 2018), but also for the study of visual information processing.

The pupillometry method, which is widely used in toxicological and ophthalmic practice, reflects both quantitative and qualitative changes in the body. The study of pupillograms as an indicator of emotional response (Partala & Surakka 2003) demonstrated that the pupil size was significantly larger by emotionally negative and positive stimuli than by neutral stimuli. Later (Nishiyama *et al* 2007), an increase in the amplitude of low-frequency oscillations of the pupil diameter was linked to the state of drowsiness. The depressive state was proven to influence the pupillary reaction (Steidtmann *et al* 2010). Premises for use of pupillary reactions as correlates (Beatty & Lucero-Wagoner 2000; Lanata *et al* 2011; Onorati *et al* 2013) and the characteristics of the main emotional stimuli were found. The descriptive statistics of pupil dilation during emotional stress are identified and the correlation with respiration (RESP) and heart rate (HRV) (Onorati *et al* 2013) was established. A number of studies (de Gee *et al* 2014) showed that pupil dilation occurs during, and not at the end of a prolonged decision, specifically different pupillary reactions on equal brightness stimuli with different image structures and dominant colours were recorded (Brambilla *et al* 2018). Finally, two potential biomarkers were demonstrated as an indicator of tonic noradrenergic activity: pupil diameter and P3 potential, recorded using electroencephalography (Murphy *et al* 2011). In the most recent studies on the P300 potential (Sorokina *et al* 2018), the event-related potential of P300 in the gamma range (40 Hz) was found to probably reflect the specific characteristics of cognitive processes in the normal and epileptic brain. The role of beta and gamma rhythms in the implementation of the working memory functions and at the time of presentation of the stimulus to be memorized was identified, as well as during retention of the stimulus in the working memory (Karakas *et al* 2001).

Thus, at this stage of research, the relation of microsaccades and attention to the cognitively modulated potentials of the brain, the diameter of the pupils, and the psychophysical state of a person is established.

MATERIALS AND METHODS

The algorithm of optoelectronic biometric security systems operation, whose designation is assessment of the person's emotional response to a specific test object, should include a marker by which the system identifies a predetermined emotional response of a person. Biometric systems aimed at searching for certain signs of the psychophysical state in the pupillograms should be able to interpret them correctly. The discerning is very complicated, as numerous factors affect pupil size. Thus, one of the most important tasks, whose solution determines if the developed biometric system works, is the interpretation of each plot of the pupillogram.

We investigated the reaction of the pupil to stimuli (test objects) with a certain theme and, therefore, causing proportional emotional effect to the degree of the individual's internal attitude to the topic. The images shown on the laptop monitor were used as emotionally colored test objects in the first stage of the experiment. The theme comes from a pool of topical problems of society, relevant psychological problems, etc. The average value of the emotion intensity level was considered normal, basing on the hypothesis that most people are mentally balanced and tolerant. In general, the intensity of the evoked emotions on a scale from 1 to 10 did not exceed 4, where 10 is the strongest emotion possible.

Pupilograms were recorded from age groups (16–25 years old and 45–50 years old) of 10 and 5 people respectively, with representatives of both genders, having no eye diseases, with vision normal or corrected to normal. The stand for recording of the pupillograms is demonstrated in Figure 1. The video filming was performed minimizing the effect of light from the test object (taking into account its color) on the size of the pupils. Additional illumination control was adjusted basing on the subject's skin tint (in the gray scale, normalized by the mean value). For this test, a participant with sensitivity to family scandals was selected.

Hardware includes:

- Galvanic Skin Response Sensor (GSR – Sweating), measuring the resistance between two points;
- T7 Astro Camera Astronomical Astronomy Planetary High Speed Electronic Eyepice Telescope Digital Lens for Guiding Astrophotograp, 30 fps video mode, 1X–100X optical zoom microscope lens;
- helmet, which creates a rigid coordinate connection between the video camera and the head;
- Hardware platform Arduino UNO R3;
- The images were analyzed in shareware application FiJi — an enhanced and modified ImageJ distribution that combines many plug-ins allowing a complete scientific image analysis.

Pupilograms and oculograms were obtained in the OriginPro 2019. To ensure the correctness of the interpretation of the pupilograms obtained, direction of gaze was traced in each frame. For this purposethe monitor reflected in the pupil was captured on the frames. Then, the center of mass of the selection was tracked in each frame and its coordinates were determined. The coordinates of the monitor reflection center of mass in the pupil and the pupil diameter measured in each frame were used to construct the pupillograms and oculograms. When studying the effect of light on the pupil, the parameters of a single pupillogram, as well as its beginning and end, depend on the magnitude and duration of the light pulse. In our case, complex images were used to provoke the response of the pupil. Its details can also be considered independent stimuli under certain conditions. To simplify the task, we considered that the pupillary reaction is regulated by the most significant parts of the image. In the example, we will assume that the pulse affecting the pupil from one slide is made up of the pulses received from the components of the image that are most significant for the participant. In our case, the slide contained two separate components, these are images of a man and a woman. The part of the pupilogram captured by looking at one component was considered its unit structural element. When analyzing the attention centre track, we took into account that in the FiJi program, the smaller is the absolute value of the Y coordinate, the higher it is located.

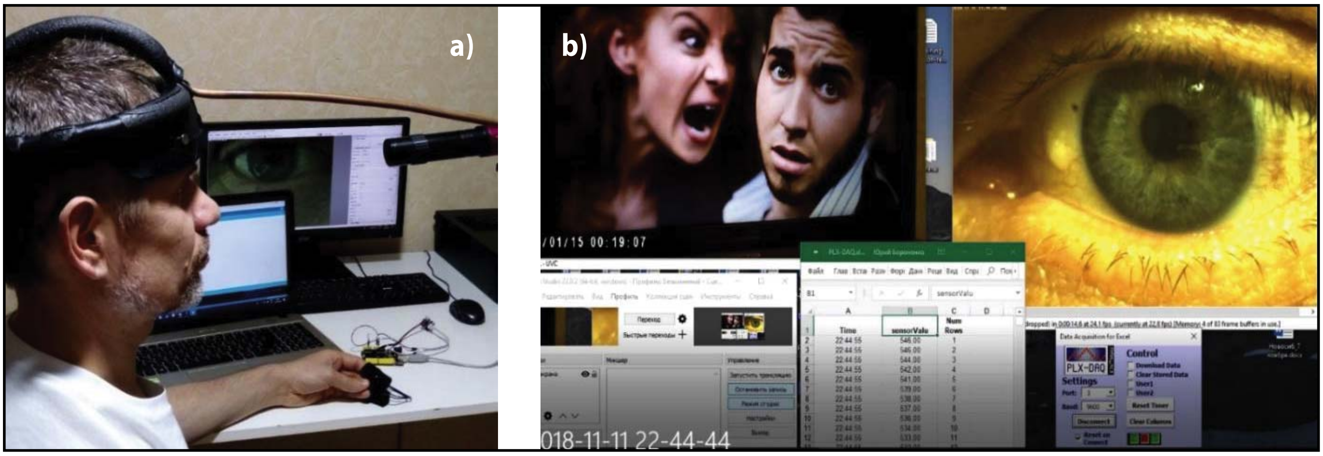

Fig. 1. a) Experiment stand; **b)** Synchronisation (test object 2 is being viewed) in OBS Studio application.

RESULTS

The tracking of attention centre in each frame was basing on the coordinates of the monitor reflection center of mass on the image of the pupil (Figure 2). Synchronization of the attention centre and pupillograms' hodographs is shown in Figure 4.

Therefore, it becomes obvious that most of the time the subject paid attention to examining a screaming woman. It was confirmed by a questionnaire. The combination of pupillograms and oculograms allowed to split the graphs into areas of focus on a woman and a man. Microsaccades-aided focusing on the details of the image under consideration after moving the gaze (saccades are observed) explains the change in the diameter of the pupils on the pupillogram in the first three zones M, W, M. However, in the latter area of the W most likely, one needs to look for the answer in emotions. The participant confirmed that most of the time his attention was devoted to the woman, and he experienced unpleasant feelings, the intensity of which was rated "2" on a 10-point scale. Visual information captured by the eye must first be analyzed by the brain before it causes any conscious memories or emotions. Then it turns out that if we draw an analogy with the reaction of the pupil on a light stimulus, each segment of the pupilogram after the saccade (when a person focuses on the analysis of the next element of the object) should be considered the beginning of the pupilogram. The beginning of the next saccade will be the end of the pupillogram. According to modern data, the minimum viewing time required for visual perception ranges from 13 to 80 ms per image, without an interval in between (Potter *et al* 2014). On our graph it is clear that the duration of the very first perception of a woman's image is about 400 ms and that of a man is 300 ms. No instruction was given to complete the task as fast as possible, which might explain such a long time. According to one of the existing neural models of information processing in the brain, perception takes place in two stages. One can assumed that in this case it was up to 0.72 seconds that the evaluation selection and recognition of the considered stimuli's features happened. This was followed by the rescanning step, which turned out to be longer. On the graph one can observe that at each moment the attention focuses on some element of the stimulus. Presumably, a thorough detailing of the attention focus picture takes place at this very time. The search for the most significant element of the stimulus is most likely carried out when the focus is shifted from one part of the object to another. At this stage, implemented with conscious attention, a general idea of the object is formed. As we can see, a plot segment of 1.64–2.18s is noticeably different from the rest, because it is the only one that holds two full-length pupillograms. In addition, due to the almost unchanged coordinate of the attention center in the last segment of the W graph, an increase in the diameter of the pupils is observed in the pupilogram. This may indicate some degree of importance of the individual's emotional response. In this case, as already mentioned, the second of the pupillograms of this area can be explained by the selectivity of attention, indicating that this part of the test object is more significant.

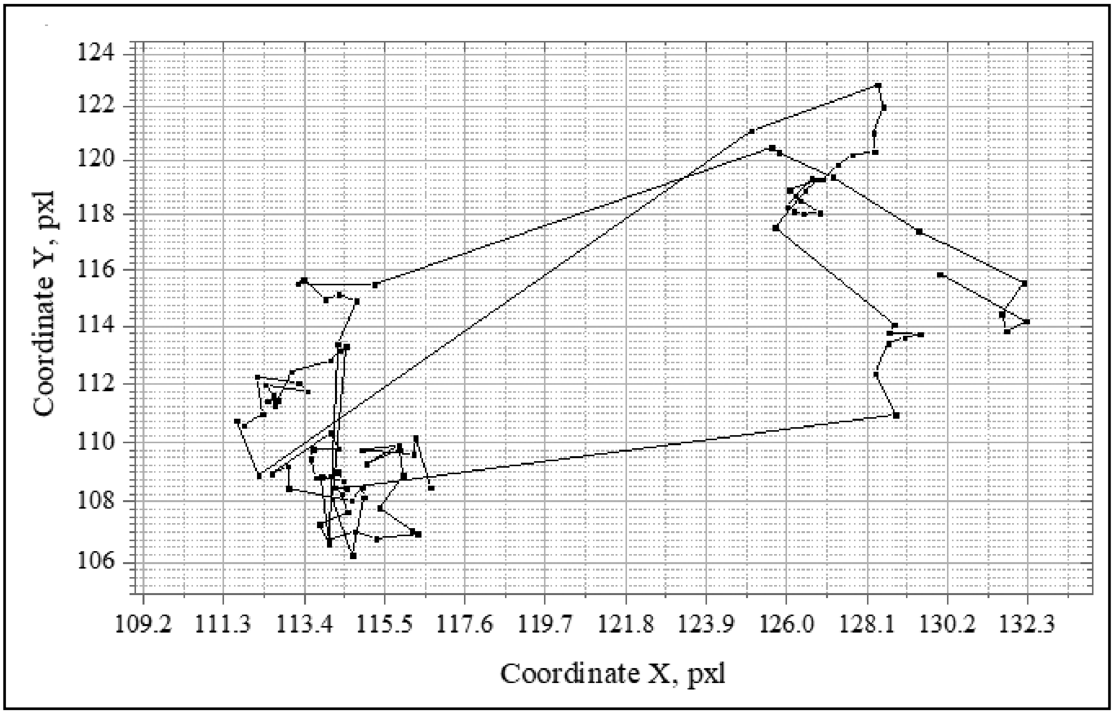

Fig. 2. Track of the pupil monitor reflection centre of mass (attention centre).

In all the experiments performed, the pupillograms of the participants made it possible to track the focus of the gaze on the participant's object of interest. So, the structure of the attention waves in the pupillograms includes saccades by eye movement, microsaccades by concentrating on individual elements of the objects inspected, and the emotional component, provided that the test object is significant for the individual.

The mathematical model of the pupillogram using the peak analysis method was found with Origin. Peaks are well approximated by the Gaussian function, which has the form:

$$y = y_0 + \frac{A}{w}\sqrt{\frac{4\ln(2)}{\pi}}\,exp\left(\frac{-4\ln(2)\,(x-xc)^2}{w^2}\right)$$

We see that the approximating function contains the exponent, just as the formula of ratio of the integrative-threshold neuron dynamics, which takes into account the problems of integrating features, attention, recognition and storage of new information.

The observed changes in pupil sizes are the result of all factors (both emotional and any other). All changes taking place are controlled by brain potentials. The final noisy signal can be represented as a sum of sinusoids and cosine waves of different frequencies. Then, for the spectral analysis of the pupillograms in Origin, a periodogram can be used to detect and estimate the amplitude of the sinusoidal component hidden by noise. The periodogram allows estimating the power from the amplitude of the data converted by Fourier transform. In the general, the spectrum of the periodic signal x (t) from the Fourier complex series is two-sided, i.e. is determined at positive and negative frequencies. The power spectrum can be either one-sided or two-sided. To calculate one-side power density, one must first calculate the two-side power density. Only the real part has physical interpretation. The power density estimation was performed using the MSA method:

$$PowerDensity(two - sided) = \frac{Re^2 + Im^2}{n^2}$$

Re and *Im* are the real and imaginary parts of the transformation data; n is the length of the input sequence; *Δt* is the sampling interval. We used the Blackman window function to have the lowest possible

Table 1. The values of the mathematical model parameters.

		Value	Shared	Standard Error	t-Value	Prob>|t|	Dependency
Peak1(Gaussian)	y0	0	0	0	––	––	0
Peak1(Gaussian)	xc	0.50834	0	0.0074	68.6652	1.61E–71	0.6891
Peak1(Gaussian)	A	0.00535	0	0.00336	1.59155	0.11553	0.98495
Peak1(Gaussian)	w	0.08917	0	0.02257	3.95112	1.70E–04	0.87623
Peak2(Gaussian)	y0	0	0	0	––	––	0
Peak2(Gaussian)	xc	0.61801	0	0.03141	19.6738	5.65E–32	0.95839
Peak2(Gaussian)	A	0.00985	0	0.00485	2.03177	0.04558	0.98541
Peak2(Gaussian)	w	0.17945	0	0.06334	2.83308	0.00587	0.96216
Peak3(Gaussian)	y0	0	0	0	––	––	0
Peak3(Gaussian)	xc	0.98483	0	0.01371	71.8127	5.14E–73	0.78469
Peak3(Gaussian)	A	0.05751	0	0.00313	18.3937	4.29E–30	0.88686
Peak3(Gaussian)	w	0.57918	0	0.03467	16.7059	1.74E–27	0.87518
Peak4(Gaussian)	y0	0	0	0	––	––	0
Peak4(Gaussian)	xc	1.71418	0	0.05683	30.1653	9.31E–45	0.91466
Peak4(Gaussian)	A	–0.0074	0	0.00352	–2.105	0.03851	0.9568
Peak4(Gaussian)	w	0.27994	0	0.10754	2.60306	0.01106	0.91192
Peak5(Gaussian)	y0	0	0	0	––	––	0
Peak5(Gaussian)	xc	1.98185	0	0.01743	113.679	2.00E–88	0.9043
Peak5(Gaussian)	A	–0.0179	0	0.0033	–5.4389	5.96E–07	0.9581
Peak5(Gaussian)	w	0.23862	0	0.02776	8.59698	6.54E–13	0.86043
Peak6(Gaussian)	y0	0	0	0	––	––	0
Peak6(Gaussian)	xc	2.57665	0	0.00437	589.804	#######	0.00745
Peak6(Gaussian)	A	–0.0374	0	9.92E–04	–37.735	7.38E–52	0.34456
Peak6(Gaussian)	w	0.33779	0	0.01043	32.3847	5.49E–47	0.35634

leakage. The high resolution Blackman window is a cone formed using the first three terms of the cosines sum:

$$w(n) = 0.42 - 0.5cos\left(\frac{2\pi n}{N-1}\right) + 0.08cos\left(\frac{4\pi n}{N-1}\right)$$

Spectral analysis (Figure 4) of the last two segments of the pupillogram made it possible to establish the presence of gradual peaks of emotionality. Segment M corresponding to the focusing on the man contains the same peaks as in the next segment W, but weakly pronounced.

Thus, the spectrum of the waves of attention has clearly pronounced peaks of 7 and 14 Hz, which have the greatest amplitude. If we compare the frequencies of the attention waves obtained by the method described above with the frequencies of the potentials of the brain, the potential of the subject's attention to the stimulus belongs to the slow β-rhythm observed by mental activity in adults. Theta rhythm from 5 to 7, characteristic of the search behavior or troubled state, is also known. In the absence of a significant stimulus, there is no emotional peak in the wave of attention.

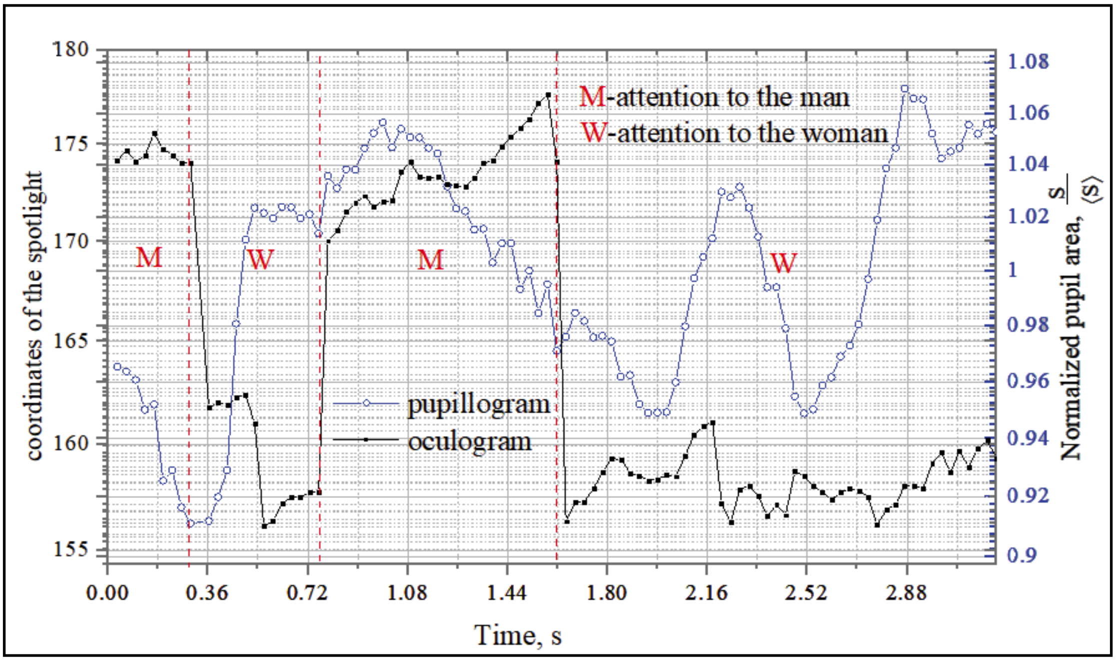

Fig. 3. Oculogram-synchronized pupillogram.

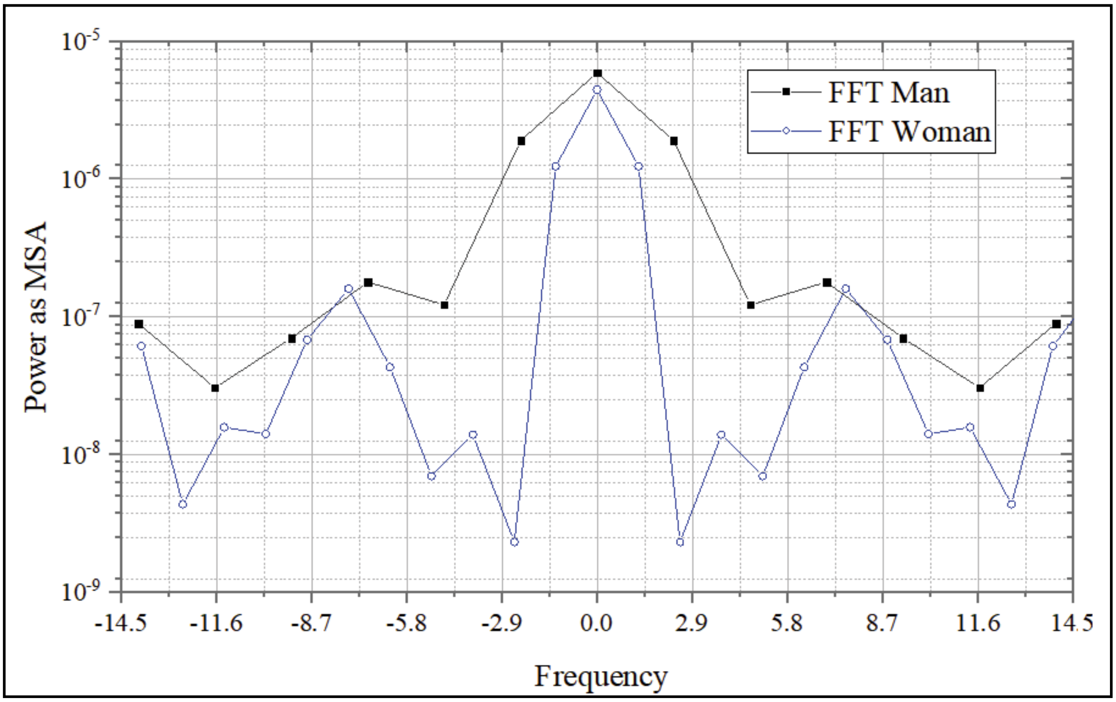

Fig. 4. Power spectral density of the attention waves.

DISCUSSION

Recently, development of methods for determining the focusing of a subject on a stimulus received much attention. It is impossible to form a clear picture without a clear understanding of how the brain works in the process by focusing. Invasive electrophysiological studies in primates and humans allowed significant advances in understanding the neurophysiological mechanisms of attention. Scherberger *et al* (2005) studied the potentials of the local cortex field (LFP) of the brain, which is the sum of excitatory and inhibitory dendritic potentials, and reveled planning and decision making, which made it possible to predict animal behavior. Later (Sapountzis & Gregoriou 2018), neural activity was noted in almost all areas of the brain with visually sensitive neurons. It was found that frequencies below 60 Hz carry information about the location of the stimulus and the direction of the saccade, but do not provide any information related to attention. The wave activity of the brain in the range of 60–80 Hz and in the low gamma range (30–60 Hz) carries significant information about the functional relationship of attention and signals obtained with maximum accuracy from the epidural ECoG electrodes located above the visual cortex. Frequencies lower than the gamma, theta range (4–8 Hz), also hold a somewhat less information. It has been reported that the behavioral state can also be optimally decoded from LFP frequencies in the range of 0–20 Hz.

More recently (Perotti *et al* 2019) presented the results of applying a new, more accurate, discrete Padet transform (DPT) method to LFP rhythms recorded in the hippocampus of mice. Frequency modulated oscillations were observed in the physiologically important areas of theta (θ) (4.3 ± 0.45 Hz; 7.0 ± 1.5 Hz) and low gamma (γ) (7.0 ± 1.5 Hz; 10.1 ± 1.7 Hz) rhythms. The oscillatory parts of the spectral waves were characterized by a stable set of frequencies and amplitudes. The highest amplitudes appear in theta region, that is, in the frequency range from 4 to 12 Hz. The superposition of oscillations reproduces the original LFP signal with high accuracy, which means that these waves provide a surprisingly rare representation of the LFP oscillations. All results were based on empirical data analysis, therefore, represent the real physical structure of synchronized neuronal oscillations, previously described as “brain waves”.

In near past, the task of determining the subject’s focus on the stimulus was solved by measuring the microsaccadic movement dynamics (Otero-Millan *et al* 2018). It was also shown that the dilation of the pupil reliably reflects the decision-making process and there is a noticeable reaction of the pupil by target detection, even in the presence of a distraction (Strauch *et al* 2018).

In our studies, we expanded the scope of synchronized puppilography and oculography (without discarding microsaccades) as selective indicators for determining the response to specific test objects. It is assumed that neuromuscular synapses are the generators of saccades (Belov *et al* 2016). When studying the role of beta and gamma rhythms (Novikov & Gutkin 2018) in implementing the functions of working memory, the role of these rhythms at the moments of stimulus demonstration to be memorized and retention of the stimulus in the working memory was revealed.

Although our results need an additional set of statistics, they suggest that a link between pupil sizes, brain potentials, and oculograms is possible. Thus, further research should be directed to verifying the existence of a relationship between the potentials of the brain and the attention waves frequency spectrum.

CONCLUSION

The method of registering attention waves is based on the synchronous recording of pupillograms and oculograms (without discarding microsaccades). The method can be used as a selective indicator of a low-intensity reaction to specific test objects, provided that the stimulus is significant for the individual. The possibility of specifying an element of the test object to which an emotional reaction occurred has been established. Synchronization of the pupillogram and oculogram allowed to interpret the microsaccades of the pupillogram as attention waves, the physical nature of which is focusing on the details of the image inspected after moving the gaze (saccade). Spectral analysis of the pupillograms showed peaks of 7 and 14 Hz, which suggests that there is a relationship between pupil diameters and brain potentials.

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REFERENCES

1 Arakelov GG & Shott EK (1998). GSR by emotional-oriented and movement reactions. *Psychological Journal*. **19**(4): 70–79.

2 Beatty J & Lucero-Wagoner B (2000). The pupillary system. In: Cacioppo JT, Tassinary LG, Berntson GC (Eds.). *Handbook of Psychophysiology*. Cambridge: Cambridge University Press.

3 Belov DR, Milyutina EA, Kolodyazhniy SF (2016). Saccades and presaccadic potentials by playing Tetris. *Russian Physiological Journal named after Sechenov*. **102**(10): 1233–1245.

4 Borisyuk GN, Borisyuk RM, Kazanovich IB (2002). Models of neuronal activity dynamics by processing of information in the brain – outlines of the decade’s work. *Achievements in Physics*. **172**(10): 1189–1214.

5 Brambilla R, Onorati F, Russo V, Mauri M, Magrassi L, Mainardi LT, *et al* (2018). A Stimulus-Response Processing Framework for Pupil Dynamics Assessment during Iso-Luminant Stimuli. *Conf Proc IEEE Eng Med Biol Soc*. **2018**: 400–403.

6 Cacioppo JT (2004). Feelings and emotions: role for electrophysiological markers. *Biological Psychology*. **67**: 235–243.

7 Cacioppo JT & Gardner WL (1999). Emotions. *Ann Rev Psychol*. **50**: 191–214.

8 Costela FM, McCamy MB, Coffelt M, Otero-Millan J, Macknik SL, Martinez-Conde S (2017). Changes in visibility as a function of spatial frequency and microsaccade occurrence. *Eur J Neurosci.* **45**(3): 433–439.

9 de Gee JW, Knapen T, Donner TH (2014). Decision-related pupil dilation reflects upcoming choice and individual bias. *Proc Nat Acad Sci.* **111**(5): E618–E625.

10 Jordanova Zh & Kolev V (1998). Event-related Alpha-oscillilations are functionally related to the P300 by information processing. *Neuroreport.* **9**(14): 3159–3164.

11 Karakas S, Basar-Ergolu S, Ozesmi S, Kafaday H, Erzengin OU (2001). Gamma-response of the brain: multifunctional oscillation, representing a bottom-up and top-down process. *Int J Psychophysiol.* **39**(2–3): 137–150.

12 Kucalo AL (2004). Pupillometry as a method of express diagnosis of drug intoxication. Saint Petersburg: Intitute of toxicology by the Ministry of Health of the Russian Federation.

13 Lanata A, Armato A, Valenza G, Scilingo EP (2011). Eye tracking and pupil size variation as response to affective stimuli: a preliminary study. *Proceedings of the 5th International Conference on Pervasive Computing Technologies for Healthcare (Pervasive-Health)*, Dublin: IEEE, p. 78–84.

14 Lowet E, Gips B, Roberts MJ, De Weerd P, Jensen O, van der Eerden J (2018). Microsaccade-rhythmic modulation of neural synchronization and coding within and across cortical areas V1 and V2. *PLoS Biology.* **16**(5): e2004132.

15 Meyberg S, Werkle-Bergner M, Sommer W, Dimigen O (2015). Microsaccade-related brain potentials signal the focus of visuospatial attention. *NeuroImage.* **104**: 79–88.

16 Murphy PR, Robertson IH, Balsters JH, O'connell RG (2011). Pupillometry and P3 index the locus coeruleus–noradrenergic arousal function in humans. *Psychophysiology.* **48**(11): 1532–1543.

17 Nishiyama J, Tanida K, Kusumi M, Hirata Y (2007). The pupil as a possible premonitor of drowsiness. *Conf Proc IEEE Eng Med Biol Soc*. **2007**: 1586–1589.

18 Novikov NA & Gutkin BS (2018). Role of beta- and gamma-rhytms in the realization of functions of working memory. *Psychology. Journal of Higher School of Economics.* **15**(1): 174–182.

19 Onorati F, Barbieri R, Mauri M, Russo V, Mainardi L (2013). Characterization of affective states by pupillary dynamics and autonomic correlates. *Front Neuroeng.* **6**: 9.

20 Otero-Millan J, Macknik SL, Martinez-Conde S (2018). System and method for using microsaccade dynamics to measure attentional response to a stimulus. U.S. Patent No. 9,854,966. 2 Jan. 2018.

21 Partala T & Surakka V (2003). Pupil size variation as an indication of affective processing. *International Journal of Human-Computer Studies.* **59**(1–2): 185–198.

22 Pashkov AA, Dakhtin IS, Kharisova NS (2017). Electroencephalographic biomarkers of experimentally-induced stress. *South Ural State University Herald. Series: Psychology.* **10**(4): 68–79.

23 Perotti L, DeVito J, Bessis D, Dabaghian Y (2019). Discrete structure of the brain rhythms. *Sci Rep.* **9**(1): 1105.

24 Potter MC, Wyble B, Hagmann CE, McCourt ES (2014). Detecting meaning in RSVP at 13 ms per picture. *Attent Percept Psychophys.* **76**(2): 270–279.

25 Pritchard WS (1981). Psychophysiology of P300. *Psychol Bull.* **89**(3): 506–540.

26 Sapountzis P & Gregoriou GG (2018). Neural signatures of attention: insights from decoding population activity patterns. *Front Biosci.* **23**: 221–246.

27 Scherberger H, Murray JR, Andersen RA (2005). Cortical local field potential encodes movement intentions in the posterior parietal cortex. *Neuron.* **46**(2): 347–354.

28 Sorokina ND, Percov SS, Selickiy GV (2018). Role of bioelectric activity of the brain in gamma range in the psycho processes. *Russian Physiological Journal named after Sechenov*. **104**(10): 1163–1175.

29 Steidtmann D, Ingram RE, Siegle GJ (2010). Pupil response to negative emotional information in individuals at risk for depression. *Cognition and Emotion.* **24**(3): 480–496.

30 Stern RM, Ray WJ, Quigley KS (2000). Psychophysiological recording. USA: Oxford University Press, ISBN 978-0195113594. 296 p.

31 Strauch Ch, Greiter L, Huckauf A (2018). Pupil dilation but not microsaccade rate robustly reveals decision formation. *Sci Rep.* **8**(1): 13165.

32 Ying G, Huber C, Sabel BA (2018). Stable Microsaccades and Microsaccade-Induced Global Alpha Band Phase Reset across the Life Span. *Invest Ophthalmol Vis Sci.* **59**(5): 2032–2041.