PHYSIOLOGICAL MARKERS OF ECO-FRIENDLY URBAN VISUAL ENVIRONMENT

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ABSTRACT

Some parameters of human physiological responses serve as markers of eco-friendly and comfortable living. Given that 50% of the world's population lives in cities, the study of the impact of the urban environment on humans is of high relevance. The urban visual environment, which can be comfortable or uncomfortable, is an important environmental factor. We studied features of eye-tracking, brain activity and responses of the autonomic nervous system during perception of urban environment images of different comfort. Participants included 50 healthy people of both sexes aged 21. It was revealed that while viewing modern monochrome minimalistic and homogeneous urban space, the number of saccades increased, the duration of saccades and fixations decreased. This eye-tracking corresponds to the work of the human visual system in search mode. At the same time, the intense work of the visual system is accompanied by the flow of absolutely identical information to the brain. This changes the scenario of evolutionarily conserved brain mechanisms of visual stimuli processing. Bioelectric activity of the cerebral cortex is reduced even in areas that are specialized for this activity. The activity of subcortical structures of the brain responsible for the formation of the emotional component increases. Furthermore, we recorded activation of the ergotropic system of the brain, that favors the mobilization of the body reserves. Such physiological changes are also typical for stress response of the body. Spending a long time in a visually uncomfortable environment leads to chronic stress and the development of pathologies.

Keywords: *bioelectric activity of the brain, video-ecology, visual environment of different comfort, eye-tracking, autonomic nervous system.*

INTRODUCTION

Eco-friendliness of the environment depends on many factors: water and air pollution, noise and radiation levels, etc. An important component of eco-friendliness is the visual environment [1], [2]. It is well known that we receive up to 90% of all information about the surrounding world through vision [3]. Our eyes detect and see best of all the moving objects. The retina does not perceive stationary images. Their statics is compensated by eye movements. Thus, our eyes are in constant motion [4], [5], [6], [7]. There are dynamic (saccades) and static (fixations) parameters of eye movement. We scan the environment during a saccade, while processing of information occurs during fixation [8]. The duration of fixations and saccades, their number per unit of time, the correlation of saccades and fixations are optimal during visual perception of the natural environment. Such an environment is full of elements and color combinations and is regarded as comfortable [9].

More often a resident of any modern city sees an artificial urbanized visual environment, which is made up of different building designs created at different times. While viewing the surrounding space, a city dweller can experience aesthetic pleasure or discomfort, depending on the presence of details in the visual field, dynamics and variety of lines, relation of planes, the variety of colors and tones, the diverse texture and structure of the building material. [10]. Let us consider two opposing variants of urban visual space concerning the physiological impact and architectural style. Most modern districts of urban agglomerations, administrative and business centers are represented by multi-storey buildings, whose facades are made of large panels, mirror or glass. This creates a specific featureless (homogeneous) visual environment, which provides poor information. In terms of video ecology such space is regarded as uncomfortable. In the context of global urbanization historic city centers coexist with modern minimalist buildings. Flowing lines, multiple moldings and colors are seamlessly intertwined in the architecture of the historic buildings. In terms of video ecology, such a visual environment is regarded as comfortable. It brings satisfaction and a sense of harmony. Most of his life a city dweller is plunged into the visual space of the modern part of the city with offices, banks, shopping centers, creating homogeneous visual field by architecture.

The level of any comfort and eco-friendliness is determined by the deviation of physiological responses of the body and its systems from the norm or by the change of evolutionarily conserved physiological mechanisms. In the case of visual perception, the markers of comfortable visual environment are the parameters of eye movement. Oculo-motor activity is an essential component in mental processes, related to obtaining, transformating and use of visual information. The brain activity and the parameters of its bioelectric activity (BEA) will naturally change during perception of images of different comfort [11]. In addition, the process of visual perception as any other function requires participation and support from other systems of the body. The autonomic nervous system (ANS) is of paramount importance in the activation and coordination of these systems. One of the characteristics of the autonomic nervous system is its sufficient plasticity. It easily changes the parameters of its functioning at the first presentation of any significant sensory stimulus [12]. It is obvious that under the influence of visual environments of different comfort, the tension of the divisions of the autonomic nervous system will be different.

In connection with the above, it would be interesting to study the features of eye-tracking measures, bioelectric activity of the brain and the ANS reactivity during perception of images of modern and historic urban architecture.

Participants included 50 healthy people of both sexes aged 21. The experiment was conducted in accordance with the ethical standards represented in the Declaration of Helsinki and European Community directives (8/609 EC). Visual-motor reactions based on saccadic movements tracking (eye-tracking) were recorded via iView X ™ RED (Remote Eyetracking Device). The electroencephalogram (EEG) and caused skin vegetative potential (CSVP) were simultaneously recorded to assess the state and activity of the brain and the autonomic nervous system. EEG was recorded using Neuron-Spectrum hardware and software solution. EEG recordings were monopolar from 16 symmetrical leads installed according to the international 10–20 system. CSVP was monitored by use of ANS-spectrum apparatus, which is compatible with a computer. The studied parameters were continuously recorded in a state of relative calm with eyes open (background) and while viewing the images of the urban environment of different comfort. Visual stimuli were photos of modern high-tech buildings, creating a specific type of architecture of business centers in large cities (1 series of stimuli) and images of barocco and gothic buildings built from the early 17th to the late 19th century and giving a special flavor to the historic centers of the largest cities in the world (2 series of stimuli). In addition, images of nature selected in accordance with the classification were used as a standard of comfortable visual environment [1], [9]. The duration of recording for each series of visual stimuli was 90 seconds. Each series included 3 images. SMI BeGaze program analyzed eye-tracking recordings. The curves of CSVP were processed using the VNS-Spectrum Copyright programs. EEG analysis was performed using Neuron-Spectrum.NET software v. 1.4.1.0. The maximum power of coherence (COH) was analyzed in 120 pairs of leads by the main bands of bioelectric activity (BEA): theta-4-8 Hz, alpha-8-14 Hz, beta-LF (low frequencies)-14-20 Hz, beta – HF (high frequencies) - 20-35 Hz. The statistical analysis of the studied parameters was assayed using Statistical Package for the Social Sciences (SPSS) for Windows v. 22.0. Statistical processing of the results included Analysis of Variance Test for Normality (Shapiro-Wilk's test) and Levene Test for Equality of Variances. Based on the results, all further statistical analysis was conducted using parametric processing methods. The data were presented as mean value and mean error ($X \pm m$). One-way Analysis of variation (ANOVA) was used to determine significant differences in parameters of visual-motor activity during perception of visual environments of different comfort. Post Hoc Multiple Comparisons were based on Bonferroni test. Differences were considered to be statistically significant at $p<0,05$. To determine statistical correlations between different measures of caused skin vegetative potential, BEA and eye-tracking during visual stimuli perception Spearman's rank correlation coefficient was calculated. In the subsequent discussion, the statistically significant coefficients with the correlation value $r \geq 0.75$ were taken into account [13]. Since the studied parameters in persons of different gender did not have significant differences, the results are presented without regard to gender. It should be noted that according to the results of statistical processing, during perception of nature images (3 series of stimuli) and historic buildings (2 series of stimuli) the parameters of EEG, eye-tracking and CSVP showed no significant differences and were almost identical. In this connection, we will further present the results of the study on the 1 and 2 series of visual stimuli.

Oculo-motor reactions during perception of modern and historic buildings also have their own characteristics. In analyzing eye-tracking parameters, it should be noted that when viewing images of modern minimalist buildings (stimuli I), number (99.4 $\pm$3.9 count), frequency (3.6 $\pm$0.1 count/s) and amplitude (5.9 $\pm$0.2^{o}) of saccades are significantly higher than similar parameters during perception of historic building images (stimuli II) (Table 1). Number of fixations (66.3 ±2.4 count) and their frequency (2.2 ±0.1 count/s) are significantly lower, while fixation duration (340.3 ±13.4 ms) is significantly higher. The presented images of modern buildings were characterized by a small number or lack of visual details, because their facades are made of large monochrome or mirror panels. In such conditions the scanning work of the eye dramatically increases. Due to the lack of fixation points, the eye stops in the "empty space" where there is no information for analysis. As a result, the physiological and evolutionarily conserved scenario of visual perception mechanisms is disturbed. There is an active scanning of the visual field in search of new visual information, but due to its absence in 30% of cases the saccade is followed by another saccade instead of fixation. Under these conditions the eyes operate in search mode: the number of saccades increases, the number of fixations decreases. Spending long time in such an empty homogeneous space leads to overstrain of visual system, its fast fatigue and psychological discomfort.

Table 1. *Eye-tracking measures during presentation of visual stimuli*

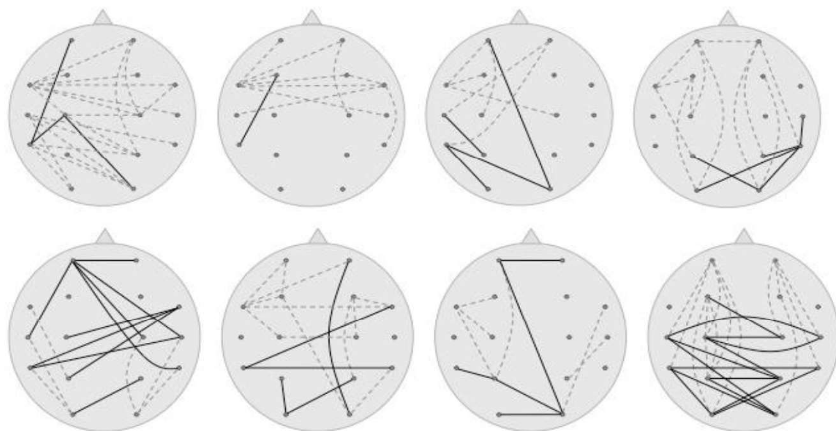
Values	Experiments	
	I, M±m	II, M±m
Fixation count (fix)	66,3±2,4	82.0±4,2**
Fixation frequency (fix/s)	2,2±0,1	2,6±0,2**
Average fixation duration (ms)	340,3±13,4	294±11,1*
Saccade count (sac)	99,4±3,9	84.12±3,8*
Saccade frequency (sac/s)	3,6±0,1	3,2±0,1
Average saccade duration (ms)	48,2±2,4	45,2±3,1
Average saccade amplitude (^{0})	5,9±0,2	5,1±0,2*

1 – I series visual environment; column II - II series visual environment; * or** - differences reliable ($p \leq 0{,}05$ or 0,005).

The situation is different during perception of images of historic buildings. In this case, oculomotor reactions are characterized by an increase in the number and duration of fixations, a decrease in the number of saccades. Almost every saccade is followed by a fixation. This alternation of saccades and fixations is the most natural and evolutionarily conserved. The abundance of information in such a visual environment stimulates brain activity, as we can see in the increased synchronization of bioelectric activity in almost all areas of the cerebral cortex (Fig.1, second row).

The solid lines in the brain mapping between the EEG registration points show the synchronized activity of brain structures. During perception of images of historic buildings rich in details and color combinations, a significantly high level of synchronization of bioelectric activity was revealed in large areas of the cerebral cortex. Facades of such buildings attract attention and are scanned in detail. During the fixation period, the information received by the brain is actively analyzed. This brain activity is supported by the development of extensive constellations of working neurons in the cerebral cortex. The development of statistically significant long and short intra - and inter-hemispheric correlations in the high beta frequency band in visual and association cortices testifies that the cortical neurons specialized for visual perception and analysis of this information are involved in the activity.

The increase in synchronization and neural activity in the theta band is undoubtedly due to the positive emotional component of the perceived image. Such brain activity during perception and processing of visual information is natural and evolutionarily conserved. While viewing images of modern homogeneous buildings, spatial synchronization of brain bioelectric activity is limited and localized only in occipital cortex specialized for visual activity. At the same time, there is a dissociation of statistical correlations in the remaining EEG bands within and between hemispheres (Fig. 1, first-row), which testifies to the lack of information for analysis.



Teta Alpha Beta low Beta high

***Figure 1**. Significant changes of coherence during the perception of urban architecture images compared to the background (solid line - statistically significant increase, dotted lines -statistically significant decrease)*

First-row - changes of coherence at visual perception of modern buildings; the second row-historical buildings.

The comfort of the visual environment causes changes in oculomotor responses and brain activity and can undoubtedly affect the emotional state of a person and the overall state of the body. These changes are controlled by the autonomic nervous system (ANS). Any emotional response, experience, stress, tension are justified by changes in the parameters of the ANS functioning. These changes can be identified by the level of the caused skin vegetative potential (CSVP) [14], [15]. Following are the results of studying the parameters of the ANS functioning during visual perception of images of modern and historic urban environment (Fig. 2).

There was a significant increase in the amplitude of the first and second phase (A1 and A2) during the presentation of modern buildings images (0.12 mV, 0.39 mV, respectively), compared with historic buildings images (0.06 mV, 0.09 mV, respectively) ($p<0.05$). A1 and A2 measures show the activity levels of trophotropic and ergotrophic centers [14]. A significant increase in the amplitude of CSVP during perception of modern buildings images confirms the active role of the sympathetic nervous system in the perception of homogeneous images. In this case the height of the waves (amplitude) depends on the strength of the emotions experienced. Accordingly, images of modern minimalist buildings can be considered as the most negative ones. Analysis of wave duration (S) of CSVP revealed that S1 significantly increases during the perception of historic buildings images (1.15 seconds, at $p<0.05$). Apparently, there is a temporary delay in activation of nerve centers at the level of hypothalamus. The delay activates trophotropic systems, increases parasympathetic tone and provides an optimal mode of visual perception.

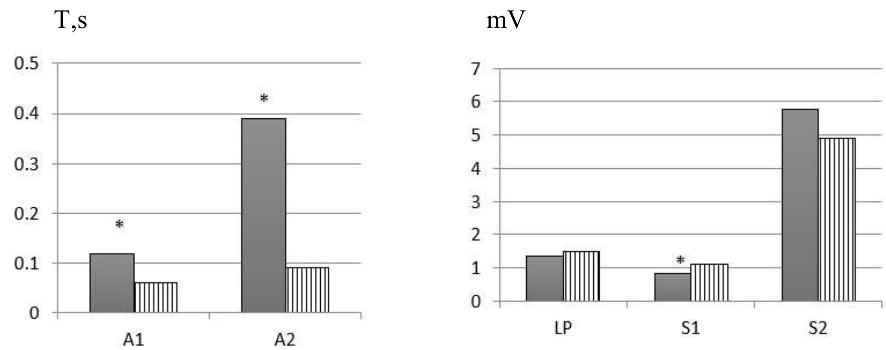


Figure. 2. *CSVP a measures during presentation of images of urban architecture.*

Column 1 – visual perception of modern buildings; column 2 - historical buildings. * - differences reliable ($p\leq0,05$) ; LP - latent period; A1- amplitude of the first phase; A2 - amplitude of the second phase; S1 – duration of the first phase; S2 – duration of the second phase.

The correlation analysis of the studied parameters revealed that various kinds of significant statistical correlations are developed between static (fixations) and dynamic (saccades) parameters of eye-tracking, the total brain bioelectric activity (BEA) and the parameters of CSVP during perception of historic buildings images. In other words, a stable relationship is formed between the processes of visual field scanning, the processes of visual information processing and the structures of the ANS, which also participate in this activity. Thus, an effective functional system develops during perception of historic architectural sites. It includes the ANS, visual and brain structures, thereby providing an optimal visual perception (Fig.3, II).

The analysis of statistical correlations between eye-tracking measures, EEG and CSVP parameters during perception of modern buildings images revealed a decrease in the number of significant correlations. During perception of a homogeneous visual field, after a series of saccades the brain receives poor information, i.e. an action has taken place - saccade, but there is no confirmation to this action. As a result, insufficiency of sensory signal reduces the connections between structures of visual system, which normally function seamlessly. Long-term stay and perception of homogeneous visual environment leads to securing given disbalance, rapid eye fatigue and psychophysiological discomfort.

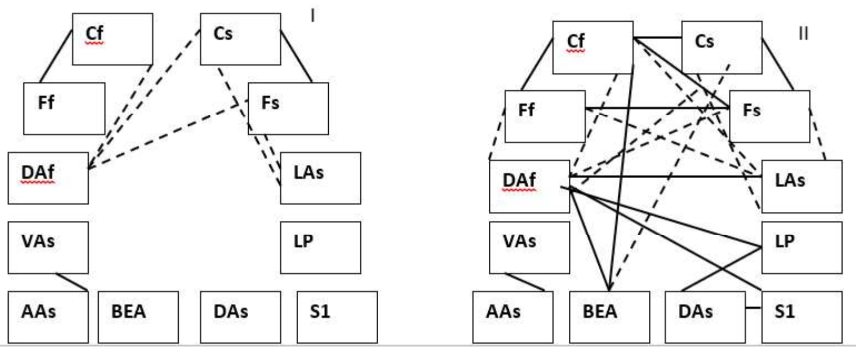


***Figure 3**. Statistical interaction of the parameters of eye-tracking, BEA and CSVP during presentation of images of urban architecture compared ($r \geq 0,75$).*

I - at visual perception of modern buildings; II - historical buildings.

Solid line - direct correlations, dotted lines - inverse correlations.

Parameters of eye-tracking: Cf - fixation count, Ff - fixation frequency, DAf - fixation duration average, Cs - saccade count, Fs - saccade frequency, LAs - saccade latency average, DAs - saccade duration average, AAs - saccade amplitude average, VAs - saccade velocity average;

Parameters of CSVP: LP - latent period; S1 – duration of the first phase;

Parameters of BEA - total bioelectrical activity.

CONCLUSION

The urban visual environment filled with man creations is not always comfortable. Modern technologies make possible the construction of high-rise buildings, which is an ideal solution in the context of global urbanization. Minimalistic and monotonous buildings with monochrome facades made of glass and concrete form a homogeneous visual field, which is uncomfortable. The results of our study have shown that physiological characteristics of uncomfortable urban visual environment are higher number of saccades compared to fixations (by 25-30%), the decrease in spatial synchronization of brain bioelectrical activity and its localization in the occipital cortex, activation of the sympathetic division of the autonomic nervous system. Moreover, statistical interaction of oculo-motor reaction parameters is less diverse and has no significant correlations with the parameters of brain bioelectrical activity and the measures of the ANS functioning . This proves that in these conditions visual system is out-of-balance. Constant or long term influence of an uncomfortable visual environment may lead to chronic stress. Consequently, when designing and creating a truly eco-friendly urban space it is necessary to take into account among other things the physiological characteristics of visual perception.

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