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Physiological markers of visual environment comfort in the North

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Abstract. The effectiveness of visual perception is influenced by many factors, including the number and variety of visual elements, rich color palette, etc. The comfortable visual environment may be represented by nature (mountains, forests, fields, rivers), because in these conditions the mechanisms of visual perception are optimally balanced. The visual environment of the North is associated with endless expanse of snow with no visible elements and a limited color palette (from white to blue). It is classified as homogeneous. Northern cities make a difference in the natural visual environment, as they break monotonous visual field. However the urban visual environment is not always evaluated as comfortable. We studied features of eye tracking and the response of the autonomic nervous system during image perception of the urban environment of different comfort. We revealed a significant discrepancy between the dynamic parameters of eye tracking and indicators of static characteristics of eye movements, when viewing the uncomfortable visual space. We also recorded activation of the ergotropic brain system providing body mobilization. This corresponds to the stress response of the body.

1. Introduction

Global urbanization results in rapid growth in the size of the urban population [1]. Requirements for the city life organization, its comfort and convenience are constantly increasing. They focus on cost savings, convenience, environment-friendly building materials, faster construction, often neglecting the aesthetic component. However, the appearance of cities has been an environmental factor, which acts as a stress agent as long as it is visually uncomfortable. Thus, to solve housing related issues of the increasing urban population, they create uptown neighborhood comprising many standardized multi-storey blocks. A resident of the area is immersed in visually poor environment that surrounds him most of his life. Visual deprivation leads to violation of mechanisms of visual perception. The urban space undoubtedly includes parks, historic centers and art installations, where the visual perception occurs through evolutionarily conserved mechanisms. Thus, modern urban space is multifaceted and as any habitat has multiple implications on humans. In terms of the impact on the human body and visual system, a homogeneous, aggressive and comfortable visual environments are distinguished [2, 3]. Visual elements are absent in homogeneous visual environment or their number is dramatically reduced. In nature, such an environment is represented by endless expanse of snow in the Arctic and the Antarctic regions [2, 3]. In cities this visual space is formed with concrete and glass large panel constructions, large asphalt-surfaced areas, gable facades without windows and doors. The color scheme of such a space is usually monochromatic, consisting in various shades of grey. This all creates empty visual space, which dramatically increases the scanning work of the eye. Due to the lack of fixation points, the eye stops in "the empty space", and the brain does not receive information for

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analysis. Natural physiological mechanisms of visual perception, i.e. scanning of the visual field and the subsequent analysis of information, are violated. An individual turns his gaze in search of details, which results in using additional resources of the visual analyzer and visual perception systems. If the visual environment is created with a set of similar elements evenly disposed on the surface, for example, multi-storey buildings with a large number of identical windows, in this case there is a constant visual drifting on the repetitive elements of the visual field. Under these conditions, the brain receives identical information and is overloaded with repetitions. This is typical for the visual perception of an aggressive visual field. In evolutionary terms, active ocular motility should be accompanied by a flow of new visual information, which is typical for perceiving comfortable visual environment. Optimal conditions for vision mechanisms are created in presence of curves having different widths and contrasts, a variety of colors, different distances between visible elements [2, 3, 4]. For sure, nature in all its diversity - forests, mountains, rivers, seas, clouds - can be referred to comfortable visual environment. In cities, comfortable visual environment is created of park areas, historic centers, buildings with curved lines of different widths and contrast and acute angles forming shapes. Like most cities, those located in the Arctic and subarctic regions are characterized by the presence of a homogeneous, aggressive and comfortable visual environments. A distinctive feature is the long off-season period with a predominance of grey shades and a long winter with white monochrome in the natural environment. In such conditions homogeneous natural visual space is overlaid with city monotony of high-rise buildings in uptown neighborhood and administrative areas. Looking at such a space, an individual receives negative emotions, which are accompanied by functional disturbance of visual perception mechanisms. Oculo-motor reactions serve as an indicator of visual environment comfort, as the parameters of saccades and fixations can vary under the influence of different factors [5, 6]. Oculo-motor reactions have a complex functional organization at their core. During image perception, there are constant jerk-like movements of varied amplitude and duration, known as saccades, which alternate with fixations (short eye gaze pauses). During saccades the image is scanned, while during fixations an individual processes visual information [7]. It is also well-known that the tension of autonomic nervous system (ANS) will change under the influence of visual environments of different comfort [8]. ANS easily changes the parameters of its functioning during the first presentation of any significant sensory stimulus. That can be recorded by the value of the caused skin vegetative potential (CSVP) [9].

Considering the information above, it would be interesting to identify physiological markers of visual environment comfort of modern cities located in the polar and pre-polar regions of Russia.

2. Main Text

The study involved 50 people aged 20 years without any visual and nervous systems pathology. The experiment was conducted in accordance with the ethical standards represented in Declaration of Helsinki and European Community directives (8/609 EC). Oculo-motor reactions based on saccadic movement tracking (eye-tracking) were registered using infrared recording of eye movement. Eye-tracking was recorded via iView X™ RED (Remote Eyetracking Device) used for non-contact measurement of eye-tracking parameters. In parallel the caused skin vegetative potential was recorded to assess the state of the autonomic nervous system. CSVP was monitored by use of ANS-spectrum apparatus, which is compatible with a computer. The studied parameters were continuously recorded during the perception of urban environment images. Pictures of typical northern city buildings erected in the second half of the last century and pictures of modern architectural sites were used as visual stimuli. The stimuli were presented in series. The first series of stimuli consisted of images of constructions erected in 18-19 centuries and giving a special character to the historic centers of the Northern cities: low-rise buildings with many carved details, such as cornices, architraves, openwork brackets, bay windows, small balconies with balusters. The architectural style of these buildings is designed in the Baroque, classical or Gothic style. The second series of stimuli consisted of images of modern buildings erected in the last decade of the 21st century, in high-tech, deconstructivism or postmodernism styles. Such buildings are made of monochrome slabs, mirror panels and respond to the challenges of efficiency and rationality. They are characterized by minimalism or unusual forms. In addition, pictures selected in accordance with the Filin‘s classification [2, 3] were used as a standard of comfortable urban visual environment: comfortable - images of nature (3rd series of stimuli), homogeneous - gable facades without windows or other elements (4th series of stimuli), aggressive – the facade of standardized multi-storey buildings with a large number of identical windows (5th series of stimuli). Each visual stimulus in the series was presented for 30 seconds. The obtained CSVP curves were processed via ANS-spectrum Copyright programs. SMI BeGaze program analyzed eye tracking recordings. The statistical analysis of the studied parameters was assayed using a package of computer programs, Statistical Package for the Social Sciences (SPSS) for Windows v. 23.0. 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+m). We used One-way Analysis of variation (ANOVA) to identify significant differences between the indicators of caused skin vegetative potential (CSVP) and oculo-motor activity during the perception of images 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 indicators of caused skin vegetative potential 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 [10]. Since the studied parameters in persons of different gender did not have significant differences, the results are presented without regard to gender.

The data obtained during the study and statistical processing are shown in table 1 and figures 1, 2. No significant differences were found between the parameters of the latent period of CSVP (LP), the duration of the second phase of CSVP (S2) independently from presented stimuli (Fig. 1).

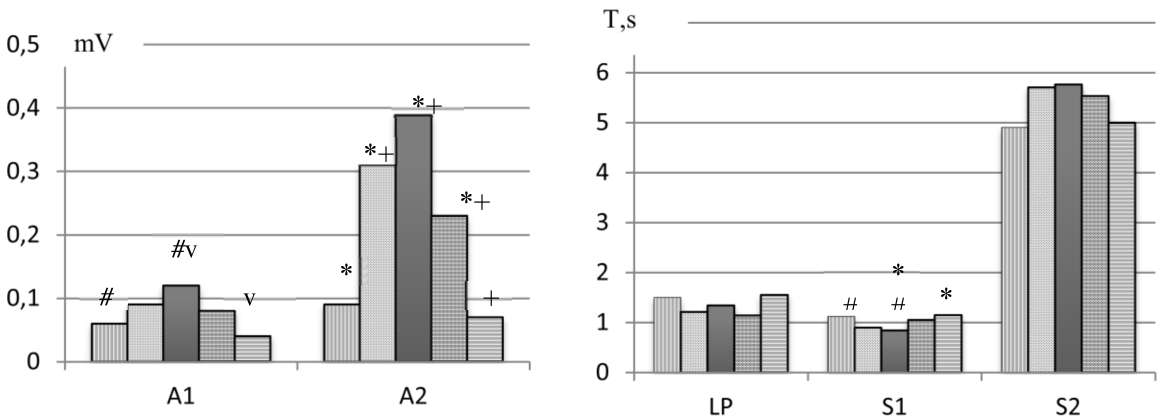

Figure 1. CSVP measures during presentation of stimuli of different comfort.
Column 1 – I series visual environment; column 2 - II series visual environment; column 3 - homogeneous visual environment; column 4 - aggressive visual environment; column 5 - comfortable visual environment; *, #,v, + - differences 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.

Significantly higher A1 parameter during homogeneous image presentation (0.12 мV) was observed in contrast to the comfortable one (0.04 мV) and a series of stimuli depicting historic buildings (0.06 mV) ($p<0.05$). A2 parameter during the I and V series presentation was significantly lower (0,07 mV и 0,09 mV, at $p<0,05$) than during others stimuli presentations. A1 and A2 parameters reflect activity levels of trophotropic and ergotrophic centers [9]. Significant increase of CSVP amplitude during perception of homogeneous, aggressive stimuli and images of modern buildings from the II series of

stimuli confirm an active role of the sympathetic nervous system in uncomfortable image perception. The wave height in this case depends on strength of emotion but unrelated to its valence. Consequently, this might indicate comfortable visual environment as the most neutral in the study. Analysis of CSVP wave length revealed that S1 significantly increased during perception of images of nature and historic buildings from the I series of stimuli (1.15 s, at $p<0.05$) compared to the homogeneous ones (0.84 s). Apparently, there is a temporary delay in activation of nerve centers at the level of hypothalamus. The delay activates trophotropic centers, increases parasympathetic tone and provides an optimal mode of visual perception.
Oculo-motor reactions during perception of images of different comfort also have their own specifics. Analyzing eye tracking parameters, it should be noted that, when viewing a homogeneous image (stimuli III), number (99.4 +3.9 count), frequency (3.6 +0.1 count/s), latency (349.1 +16.8 s) and amplitude (5.9 +0.2) of saccades are significantly higher than similar parameters during perception of historic building images (stimuli I) (Table 1).

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

Values	Experiments				
	I	II	III	IV	V
Fixation count (fix)	82.0+4,2**	79.34+2,9*	66,3+2,4	79,3+3,2	83,1+3,6*
Fixation frequency (fix/s)	2,6+0,2**	2,2+0,2*	2,2+0,1	2,1+0,1	2.6+0,2*
Average fixation duration (ms)	294+11,1*	298+10,1*	340,3+13,4	298+12,8	291+13,2
Saccade count (sac)	84.12+3,80	92.71+3,2	99,4+3,9	101,1+3,5	98,2+3,7
Saccade frequency (sac/s)	3,2+0,1	3,4+0,1	3,6+0,1	3,9+0,1	2,7+0,2
Average saccade latency (s)	295+12,1*	298+13,1	349,1+16,8	293+12,6	301+13,2
Average saccade duration (ms)	45,2+3,1	49+3,70	48,2+2,4	44,7+0,7	47,2+1,2
Average saccade amplitude (0)	5,1+0,2*	5,8+0,20	5,9+0,2	4,1+0,2	5,1+0,2
Average saccade velocity (0/s)	100+3,2	105+4,2	103,1+4,9	92,5+4,2	95+3,9

1 – I series visual environment; column II - II series visual environment; III - homogeneous visual environment; IV - aggressive visual environment; V - comfortable visual environment;
* or** - differences reliable with a homogeneous stimulus (p≤0,05 or 0,005); o - differences reliable with an aggressive stimulus (p≤0,05).

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. It is well- known that visual elements are limited in homogeneous environment [2, 3, 4]. The eye scans the visible field in search of details to be caught, but since they are not available, there is an increase in saccade number and amplitude. In these conditions, the reduced number and frequency of fixations seem logical. During them an individual processes visual information. Duration of fixations in such circumstances is used for new saccade programming, as their saccadic automation in homogenous visual field is disturbed. Similar parameters were recorded when viewing the buildings of modern architecture (stimuli II), which is quite understandable. Such buildings are made of large monochrome panels. Homogeneity is violated only by an unusual form of these constructions, which results in an increase of fixation number and frequency.

Buildings with "a chessboard effect" also form an uncomfortable visual environment. This is an aggressive visual environment of no visual interest [2, 3]. According to the results of our study, higher values of saccade number (101.1 +3.5 count), frequency (3.9 +0.1 count/s), as well as their short duration (44.7 +0.7 ms) and amplitude (4.1 +0, 2o) were recorded during visual perception of such images (Tab.1, stimuli IV). Difference in number of saccades and fixations during perception of uncomfortable images (homogeneous and aggressive) stands out particularly: not every saccade is ended by a fixation, because visual information is either missing or identical, and requires no thinking. There has been an intensive scanning of visual field with short low-amplitude saccades and a small number of fixations, which causes overstrain of visual system, its fast fatigue and psychological discomfort. Similar parameters of eye movements were recorded when viewing images of modern buildings, which formed the II series of stimuli (Tab.1). These were buildings with many repetitive elements evenly disposed on the facade. Such buildings are typical for uptown neighborhood and business centers. The similarity of oculo-motor reactions and changes in CSVP parameters during perception of these architectural sites allows to consider them as an aggressive visual field, which is also confirmed by the results of correlation analysis (figure 2).

Correlation matrices of stimuli II, III and IV show strong inverse statistical correlations for average fixation duration parameter with number of saccades and their frequency during uncomfortable visual field perception. This is a result of intensive eye work to scan an image that does not carry any information to the brain.

Eye tracking parameters during visual perception of the standard comfortable environment (stimuli V) do not have statistical differences with similar parameters during perception of stimuli 1 (images of historic buildings in Northern cities) (Tab. 1). The correlation analysis confirms the similarity of the mechanisms in visual perception of these stimuli (fig.2, stimuli I, V). The variety of direct and inverse statistical correlations between static (fixations) and dynamic (saccades) eye tracking parameters stands out particularly. A stable interrelation is formed between visual field scanning processes and mental processing of visual information received by brain: number and frequency of fixations increase with an increase in number and frequency of saccades. Thus, almost every saccade ends with a fixation, because the visual urban field contains a variety of details. In addition, the results of correlation analysis show reliable statistical correlations between the time indicators of CSVP (LP, S1) and the duration of saccades and fixations. The natural visual environment is in line with the physiological mechanisms of vision. During its perception an effective functional system, combining visual structures and ANS, is formed, which provides an optimal mode of visual perception [11]. Images depicting wooden architecture monuments and historic monuments of Arkhangelsk were selected as the first series of stimuli. These are low-rise buildings in the Baroque style, classical style or carpenter Gothic. The facades of the buildings are decorated with a bright color, white carved cornices, architraves, openwork brackets, bay windows on twisted brackets, small balconies with balusters. Such architecture catches eye for a long time and is always of great interest. A variety of details, original colors, repetitions of natural lines in the Northern architecture create a comfortable visual field.

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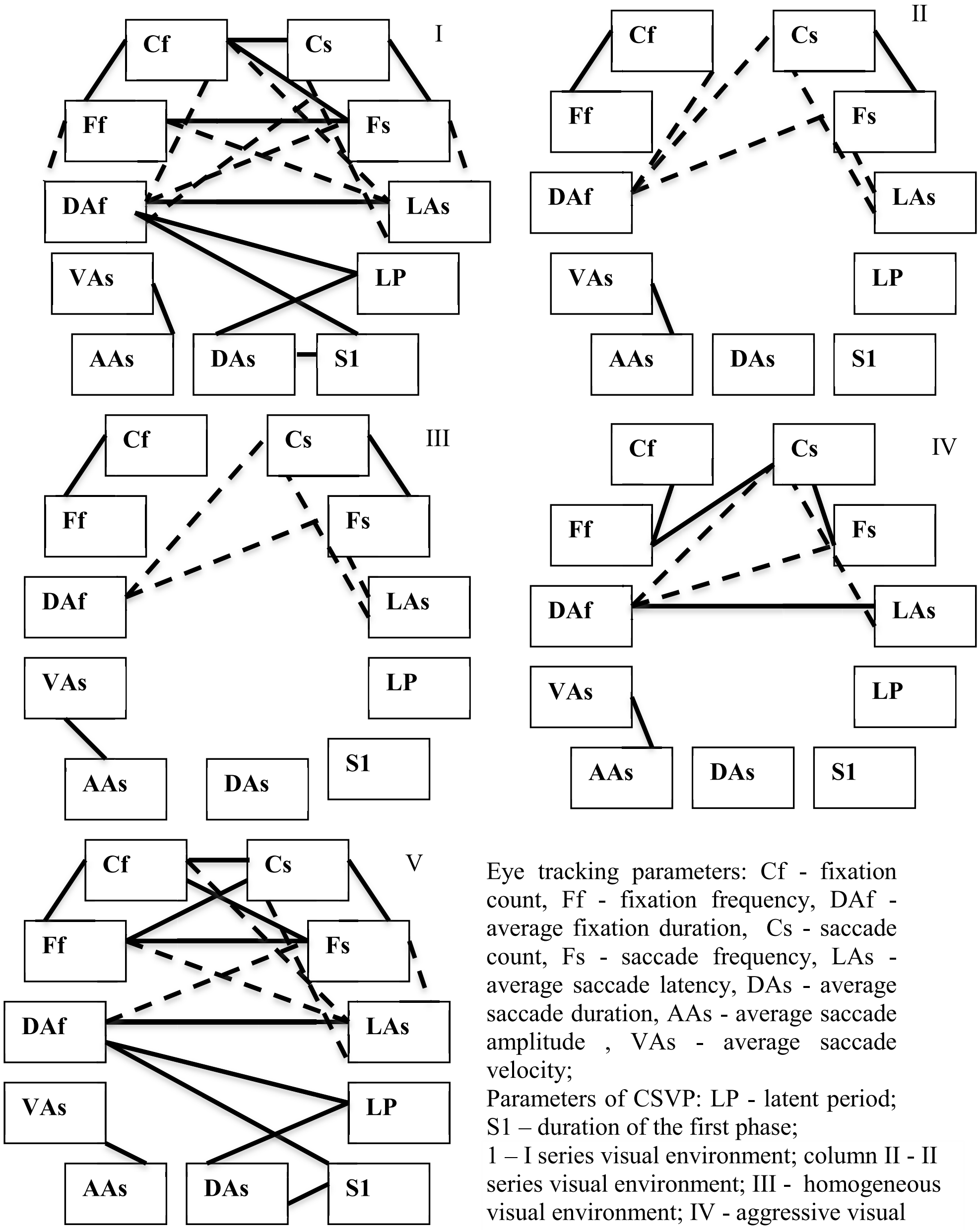

Eye tracking parameters: Cf - fixation count, Ff - fixation frequency, DAf - average fixation duration, Cs - saccade count, Fs - saccade frequency, LAs - average saccade latency, DAs - average saccade duration, AAs - average saccade amplitude , VAs - average saccade velocity;
Parameters of CSVP: LP - latent period;
S1 – duration of the first phase;
1 – I series visual environment; column II - II series visual environment; III - homogeneous visual environment; IV - aggressive visual environment; V - comfortable visual environment; ━━- direct correlations, ‒ ‒ - inverse correlations.

Figure 2. Statistical interaction of the parameters of eye tracking and CSVP during presentation of stimuli of different comfort (r ≥ 0,75).

3. Conclusion

The visual system is known to be the most important source of information for humans [12]. We see everything that surrounds us and the visual space is not always comfortable. In the North, even nature creates a homogeneous visual field, especially in the autumn-winter period, which lasts most of the year. The combination of monotonous natural environment and man-made artificial one (homogeneous and aggressive) aggravates uncomfortable effects on the body. The results of our study have shown that physiological markers of discomfort in urban visual environment are: the predominance of the number of dynamic parameters of eye tracking over static (by 25-30%); activation of the sympathetic part of the autonomic nervous system. Moreover, statistical interaction of oculo-motor reaction parameters is less diverse and has no reliable correlations with the parameters of the ANS functioning as during perception of comfortable visual environment. This proves that in these conditions visual system is out-of-balance. Spending long time in visually uncomfortable conditions leads to chronic stress and the development of pathologies. Thus, when creating urban visual environment, it is important to take into account the physiological characteristics of visual perception. To redress the uncomfortable visual space, it is recommended to use wall painting, increase the number of park areas with art installations, use a variety of color palette when finishing with siding or painting the facades of buildings.

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