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The effects of interior design on wellness – Eye tracking analysis in determining emotional experience of architectural space. A survey on a group of volunteers from the Lublin Region, Eastern Poland

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Abstract

Introduction and objective. Using the concepts of Ulrich's theory of supportive design and Malkin's healing environment, an eye tracking experiment was designed in order to measure respondents' reactions while looking at visualisations of various interiors, with the aim of verifying whether certain parameters of an interior are related to emotional reactions in terms of positive stimulation, and the sense of security and comfort.

Materials and method. 12 boards were designed, incorporating standard features of an interior, i.e. (1) proportions, (2) lighting, (3) colour scheme of a room, as well as (4) the colours and spatial arrangement of furnishings. Respondents' reactions were recorded with an eye tracker Tobii TX300 and supplemented by self-descriptions of emotional reactions.

Results. The results showed that the varying spatial and colour arrangements presented in the interior visualisations provoked different emotional responses, confirmed by pupil reaction parameters, as measured by the eye tracking device.

Conclusions. Architectural space can have a diverse emotional significance and impact on an individual's emotional state. This is an important conclusion from the point of view of optimising and creating the so-called supportive and healing environment. The results have implications for the interpretation of the pupil diameter as an index of emotional reactions to different architectural space visualisations. Testing the eye tracker as a method helpful in diagnosing the emotional reactions to features of the interior is justified, and can provide an effective tool for early diagnosis of the impact of architectural space on the well-being of individuals. It can also be a good form of testing the emotional significance of architectural designs before they are implemented.

Key words

supportive design, healing environment, emotional significance of space, optimisation of treatment conditions, eye tracking in medical research

INTRODUCTION

The art of design significantly affects the natural environment as well as human habitats and functioning. Today, in order to enhance the living conditions and usability of architectural space, in addition to environmental and technological considerations, architects need to take into account psychological aspects, as their focus is the end user of the space, or, more precisely, his/her feelings, needs, preferences and expectations. Architectural space can teach, educate, inspire, produce emotions, or even have therapeutic effects on people. This is why interior architecture is expected, among other things, to develop that space and fill it with the elements that will positively contribute to people's well-being [1] and, consequently, to their health. Nowadays, an increasing value is being attached to the significance of the space in which people live, in terms of their general mental and physical state. In order to ensure the maximum effectiveness of education and work conditions, medical care and hospitalisation, one seeks to employ such architectural and technical solutions which are the most supportive of students, workers and patients, and give them the highest level of comfort [2, 3, 4, 5].

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Today, the majority of studies stress the role of the functional criterion of architectural space – regarding medical care and educational facilities – primarily in relation to its proxemic significance [6]. Numerous theories have been proposed to explain the effect of architectural space characteristics on human well-being. Examples of the effects of joint interdisciplinary activities include the principles of supportive design [2] and a healing environment [3]. Clearly, one can observe that certain elements of architectural space, such as colours, lighting and the size of rooms, can have either a negative or a positive influence on mood, well-being and efficiency [7]. However, although this fact is hardly questionable, the character of the course of emotional evaluation is not fully known. We only have limited data based on empirical research referring to the relationship between the character of space and the emotions it evokes, measured by means of an objective method, which is a necessary condition for the effective application of knowledge in designing a supportive and healing environment [8].

To sum up, it can be stated that treatment under institutional conditions should make use of all possible ways of alleviating the patient's negative somatic and psychic states. For that reason, the need to pay attention to future architectural solutions, so that they are perceived as attractive, safe and comforting, seems to have major practical implications [5].

Eyesight is the sense that triggers most emotions experienced by people (ca. 80%). This is why it seems appropriate to include the monitoring of eye activity in the measurement of emotions. People are oriented towards sight, and what is seen appears to have a considerable impact on them in terms of psychology. This relates to the conditions in which people live, i.e. various kinds of spaces, including architectural space, and various life situations.

Application of neuroscience methods to analyse and understand human behaviour in controlled environments or laboratories has recently gained research attention. Eye tracking technologies are being utilized at increasing rates within industry and research due to the very recent availability of low cost systems [9]. In the fields of medicine and psychology, eye tracking is used to study the effects of various diseases, and the behaviour and decision making process of individuals in various health-related cases. It has become a tool for visual examination of attention and cognition, and the diagnosis of both mental disorders and neurodegenerative diseases. It is also used in the description of functioning of people with autism, ADHD or diagnosis and description of mild impairments [10, 11, 12, 13, 14], and even the risk assessment of suicide tendencies [15]. There are also papers in which eye tracking was used for other purposes, such as a therapy or improvement of medical education [16, 17, 18], it is also increasingly used to test the usefulness of medical devices [19]. It seems that it can be used more widely in environmental medicine, mainly for the optimisation of operating conditions of individuals, which clearly suggests implications for urban planning and environmental design [20, 21]. Eye tracking has thus become a platform that brings together researchers in an interdisciplinary team, integrating expertise in medicine, psychology and urban planning. This applies to the design of architectural spaces, including hospitals, schools and other public buildings, i.e. spaces that play a huge role in shaping a friendly environment for life and daily functioning.

This method provides a large amount of data on visuomotor activity, i.e. information on saccades, fixations, areas of interest. However, from the point of view of this study, the authors focus on changes in the pupil size, as this parameter was most often associated in the literature with emotional reactions. Recent research has shown that tracking changes in pupil size in high resolution can be used to predict the perception of certain stimuli [22].

Changes in pupil size (dilation and constriction) correspond to brain activity in several domains, including emotional arousal. Although historically speaking, it was proved that pupil dilation is typical of negative emotional evaluation of a presented picture [23], nowadays most research does not confirm that standpoint, suggesting that the pupil diameter changes when people process stimuli which are emotionally triggering, irrespective of their hedonic valence [24, 25, 26, 27]. Partala *et al.* [28], in their research reported pupil dilatation even in the case of participants who were listening to affectively absorbing, compared to neutral, sounds, suggesting that emotional affection contributed to pupil dilation even if the perceptive concept was not visual. The relationship between pupil size and emotional reactions is confirmed by the fact that pupil dilation is linked to the activation of the sympathetic or parasympathetic nervous systems [26, 29], and adrenergic and cholinergic neuromodulation [30]. Joshi *et al.* [31] found that changes in pupil diameter can reflect neural activity in the locus coeruleus (LC) and, less reliably, several other interconnected structures. Visual perception patterns were related to emotional reactions [28, 32, 33, 34, 35]. Hence, such a device was selected as a measuring method, confirming the occurrence of an emotional reaction in which the widening of pupils is modulated by the locus coeruleus-norepinephrine (LC-NE) system [26, 36, 37]. Changes in pupil size can also be a measure of stress experienced in reaction to presented visual materials [38]. It should be remembered, however, that this relationship is complex, since the pupil size can be also related to the load of cognitive processing [26, 39, 40, 41], the quantity of light[1] or the colour in the sight stimuli and luminance-contrast [42, 43].

To sum up, the results of the past and the current study confirm the relationship between changes in pupil diameter and emotional reactions of subjects, which justifies the use of eye tracking in simulation studies. This could assist in the future assessment of architectural designs, in terms of their impact on the well-being and health of residents and users, which is particularly important not only from the point of view of the construction of hospital facilities, but also educational and residential buildings.

OBJECTIVES

The aim of the study is conduct an experimental emotional assessment of the significance of architectural space and its components, such as proportions, lighting, colour scheme and the spatial arrangement of furnishings in positive stimulation, as well as the sense of comfort and mental security, by means of an eye tracking method. The study additionally indicates possible applications of eye tracking in

[1] Hence the lighting conditions of the experiment were controlled and standardised.

environmental medicine that have not yet been exhaustively investigated, and will be a prospective, long-term direction of research. The study received ethical approval from Ethics Committee at Lublin University of Technology.

MATERIALS AND METHOD

Nowadays, eye trackers, which so far have been used to examine cognitive processes, evoke interest as far as examining emotional processes is concerned. The very latest research results indicate the possibility that eye movement features and their distributional properties can be used to classify mental states, both within and across individuals [44]. Results of the study by Oliva and Anikin [45] have shown that the pupil reactions to emotionally stimulating input converge in time with the decision making process, and that the process of emotion recognition is in itself enough to generate a pupil response. The pupil's response mirrors the subject's engagement involving the decoding of emotional signals. Therefore, this study is based on the premise that the objectification of interior evaluations by means of tools which allow the recording of psycho-physiological reactions occurring in the human body. To this end, for the first time this perspective has been used in assessing the emotional significance of architectural space by means of an eye tracking method.

Study group. The study was carried out on a group of 202 volunteers, 103 women and 99 men, aged between 18–49 (M=23.5, SD=6.11), from rural areas of the Lublin Region in eastern Poland. All volunteers declared that there were no contra-indications for eye tracking measurements, which was verified by a written statement[2].

Apparatus. Pupil diameter parameters were obtained using a remote eye tracker (Tobii TX300) [47], which allowed free head movement. The Tobii TX300 is a binocular video-based eye tracking system that utilises near-infrared technology, and uses a dark pupil and corneal reflection method to calculate the gaze position. The pupil diameter was continuously sampled at 300 Hz. All stimuli were presented on a laptop computer (Asus G750JX-T4191H with Intel Core i7–4700HQ and 8GB of RAM), running a custom application for stimuli presentation and Tobii Studio 3.3.2. for experiment control. Stimuli were displayed on a 23-in. TFT monitor, equipped with Tobii TX300. Distance between the screen and the participants ranged from 50–75 cm.

Procedure. Upon arrival at the laboratory, each participant signed a consent form and was asked to sit in an upright chair, in a quiet testing room with artificial lighting. Natural light was blocked to ensure stable conditions for the duration of the experiments. Light intensity in the room was measured and reached approximately 350 lux. Participants were instructed to minimise body movements and to keep their gaze directed toward the screen during experimental tasks. A calibration procedure was conducted using 9-point calibration process. The stimuli were displayed at random within one Visualisation group. Time of exposure to a stimulus was determined by the participant (he or she switched the subsequent screens with Visualisation boards and made a self-description of the experienced emotions).

Data extraction and analysis. Aspects such as insolation, colour scheme, architectural solutions, interior microclimate and the quality of space, are all essential for an improved outcome, in performance at school or work, or in the course of treatment and rehabilitation. Lighting is an inseparable part of the colour. Both colour and lighting are inter-dependent as they occur in a single spectrum of radiation. The intensity of light and the type of source are factors which, when modified appropriately, can positively or negatively influence a person's general mental and physical state by creating the sense of comfort or discomfort [7]. The stimulus material was constructed by taking into account both research data and the rules of designing architectural space. The stimulous material included 12 schematic boards (monochrome and colour visualisations) of hypothetical interiors which incorporated standard features of architectural space (essential aesthetic design elements due to its high impact on human emotional responses), i.e. (1) proportions, (2) lighting (angle and scope of incidence of the light), (3) colour scheme of a room, and (4) colours of furnishings, with their spatial (symmetrical or asymmetrical) arrangement presented in standardised light conditions. Tables for Groups 1 and 2 served as the control material, used to determine whether the lack of colour also generated different pupillary responses and emotional assessments of the presented interiors. The primary material included Tables for Groups 3 and 4, differing in terms of colour and fitting arrangements. This approach to stimulus arrangement was based on research findings which suggest that pupillary responses are colour-sensitive, and therefore, to some extent are manageable. Parameters of the stimulus material are presented in Table 1.

Pupil diameter was measured separately for the left and the right eye as the exact pupil size in millimetres (mm). The algorithms for pupil size estimation took into account the magnification effect given by the spherical cornea, as well as the distance to the eye [47]. Linear interpolation was used to estimate pupil size for samples in which the pupil was corrupted due to blinking or artifacts [48]. A sudden pupil size increase or decrease of 0.1 mm, within a 3 ms time span, was assessed as an artifact [28]. Moreover, the pupil size data were smoothed by using the Savitzky-Golay filter [49], with window length=51 and 2nd order polynomial. Interpolation and smoothing were separately applied for the left and the right eyes data. The initial light reflex during stimulus exposition was investigated on the basis of pupil constriction after stimulus onset [27]. Using the average waveform during stimulus exposition, the initial light reflex was estimated at 1,500 ms (Fig. 1)[3] and was not included in the analysis of pupil size changes. In order to obtain more reliable results, recordings with stimuli presentation shorter than 2s were excluded from further statistical analysis. The data from the left and the right eye were then averaged (arithmetic mean). The effect of architectural space characteristics on emotional and pupillary responses was analysed by means of the Kruskal-Wallis test.

[2] The preliminary part of the results was presented in a conference presentation on the use of eye tracking for designing of learning spaces [46].

[3] An initial decrease in pupil diameter following picture onset was strongly related to luminance, as expected.

Table 1. Parameters of the stimulus material

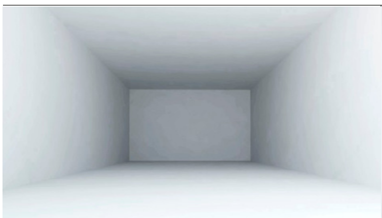
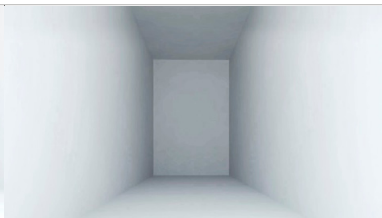
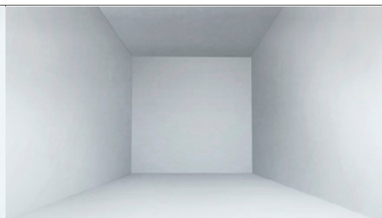
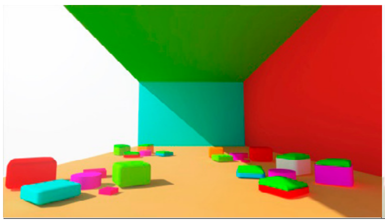
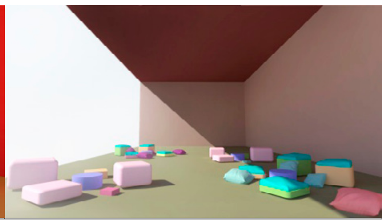
1st Interior Group – basic interiors (control material)			Design parameters
1	2	3	Room No.
			Visualisation view
Symmetrical, centripetal, horizontal, open, static.			Composition
Orthogonal interior in the shape of a cuboid standing on its shorter edge; proportions between the edges of the room's side walls based on the harmonious ratio (golden ratio) ~1.618.	Orthogonal interior in the shape of a cuboid standing on its longer edge; proportions between the edges of the room's side walls opposed to the harmonious ratio (golden ratio) ~1.618.	Orthogonal cubic interior in the shape of a cuboid; 1/1 proportions between the edges of the room's side walls.	Architectural proportions of the interior
None			Lighting
In a scale of grey.			Colour scheme
No layout / No defined function of the room.			Interior layout/ function
2nd Interior Group – basic interiors with lighting (control material)			
4	5	6	Room No.
			Visualisation view
Symmetrical, centripetal, horizontal, open, dynamic.			Composition
Orthogonal interior in the shape of a cuboid standing on its longer edge; proportions between the edges of the room's side walls based on the harmonious ratio (golden ratio) ~1.618.			Architectural proportions of the interior
Defined, access of light from the left.	Defined, access of light from the right.	Defined, access of light from the top.	Lighting
In a scale of grey.			Colour scheme
No layout / No defined function of the room.			Interior layout/ function
3rd Interior Group – interiors with varied colours, lighting from the left and a relaxation-suited room layout			
7	8	9	Room No.
			Visualisation view
Symmetrical, centripetal, horizontal, open, dynamic.			Composition
Orthogonal interior in the shape of a cuboid standing on its longer edge; proportions between the edges of the room's side walls based on the harmonious ratio (golden ratio) ~1.618.			Architectural proportions of the interior
Defined, access of light from the left.			Lighting
The tone of the bright colours, range of primary colours and their derivatives; primary colours: magenta – purple pink, cyan – blue, yellow. Other colours obtained through subtractive mixing.	Colour scheme with subdued colours, range of primary colours with much use of white.	Colours in grey scale with an accentuated tone.	Colour scheme
Interior design arranged as a room with a function suited for rest and relaxation/recreation.			Interior layout/ function

Table 1. Parameters of the stimulus material – continuation

1st Interior Group – basic interiors (control material)			Design parameters
4th Interior Group – interiors with varied colours, lighting from the left and a studying/work-suited room layout			
10	11	12	Room No.
			Visualisation view
Asymmetrical, centripetal, horizontal, open, dynamic.			Composition
Orthogonal interior in the shape of a cuboid standing on its longer edge; proportions between the edges of the room's side walls based on the harmonious ratio (golden ratio) ~1.618.			Architectural proportions of the interior
Defined, access of light from the left through accentuated window shapes.			Lighting
Colours in grey scale with an accentuated tone.	The tone of bright colours, range of primary colours and their derivatives; primary colours: magenta – purple pink, cyan – blue, yellow. Other colours obtained through subtractive mixing.	Colour scheme with subdued colours, range of primary colours with much use of white.	Colour scheme
Interior layout designed as a room for studying/work. Chairs and benches defined; arrangement in two rows evenly spaced from each other. Defined row of lamps.	Interior layout designed as a room for studying/work. Every second row of benches and chairs moved relative to each other. Variable row of lamps.	Interior layout designed as a room for studying/work. A free arrangement of chairs and benches. Variable row of lamps.	Interior layout/ function

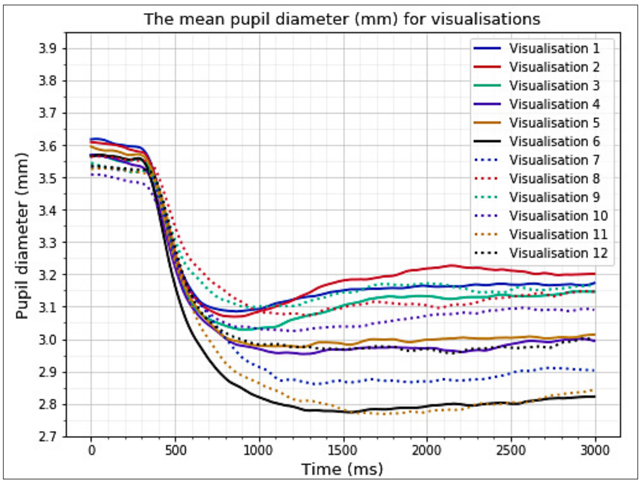


Figure 1. Initial light reflex

It needs to be borne in mind that eye trackers provide information only about the eye movement activity (saccades, fixations, or areas of interest – AOI), but they do not indicate what emotions the respondents experience during the experiment. To examine the effects of stimuli on the selected emotional responses, the participants were asked to evaluate the computer-generated scenes of the simulated spaces, using the simplified semantic differential method, and indicate whether the interior shown to them was: (1) attractive – unattractive, (2) friendly – unfriendly, or (3) relaxing – stressful. For a positive evaluation of visualization in each of the above-mentioned categories, one point was awarded, for a negative one to zero points. The results were summed-up to obtain the overall emotional significance assessment (the higher the sum, the higher the emotional assessment).

The Task-Evoked Pupil Response (TEPR) is a useful tool for analysis of the pupil signal in time, which is confirmed by the previously mentioned research results. The use of this method is justified by the fact that it uses a similar principle as event-related potential (ERP) in electroencephalographic monitoring (EEG) [50]. Although the magnitude of the psychologically-induced change in the diameter of the pupil's response can be in the order of tenths, or even hundredths of a millimetre, the time correlation between the examined phenomena confirms their relationship [38].

RESULTS

EMOTIONAL SIGNIFICANCE ASSESSMENT ANALYSIS

Interiors – Group 1 (control). Analysis of the results revealed statistically significant differences in the evaluation of three visualisations from Group 1. The highest emotional assessment was obtained for Visualisation 1 (an orthogonal interior in the shape of a cuboid standing on its longer edge; proportions between the edges of the room's side walls, based on the harmonious ratio (golden ratio[4] ~1.618), and the lowest for Visualisation 2 (an orthogonal interior in the shape of a

[4] The golden ratio refers to the Fibonacci sequence and is considered a model ratio [51]. This proportion is approx. 1.618 (the section is divided into two parts so that the ratio of the whole section to the longer section corresponds to that of the longer one to the shorter one), and has been employed in many physical, biological, economic, technical and other sciences. The golden ratio was used, for example, by the famous architect Le Corbusier in his canonical proportion known as The Modulor. He believed that any form developed on its basis would be perfect [52]. The reference to one of the most popular and widely-known golden ratios is crucial for the experiment. This background knowledge provides rationale to support the conclusion that the proportions in the rooms arranged for the purposes of this experiment are correct, and aligned with the world of nature. If the study of this characteristic of the (control) material produces findings to support the hypothesis that this interior shape is preferable (assessed positively), it will give credence to further results.

cuboid standing on its shorter edge; proportions between the edges of the room's side walls, opposed to the harmonious ratio ~1.618). The statistically significant differences related to the evaluation of Visualisations 1 and 3, which were valued significantly higher than Visualisation 2. This means that, according to the respondents, room 3 (in the shape of a square) and room 1 (a rectangle) were evaluated higher than interior 2 (in the shape of a standing rectangle), in terms of attractiveness, security and comfort. The results showed that the proportions based on the harmonious ratio ~1.618 evoked the highest emotional assessment.

Interiors – Group 2 (control). The highest emotional assessment concerned Visualisation 5 (light from the right) and the lowest – Visualisation 6 (light from the top). However, the analysis showed no statistically significant differences between visualisations in Group 2. This means that lighting (the angle of incidence of light) did not affect the emotional significance assessment of the presented space.

Interiors – Group 3 (rest and relaxation/recreation). This analysis demonstrated that the colour scheme also differentiated the emotional assessment of space. There were statistically significant differences between Visualisations 7 and 8. Table 2 shows their statistically higher grade in comparison to Visualisation 7 which was graded the lowest. This means that in the space arranged as a room with a function suited for rest and relaxation/recreation, colours which were either vivid and diverse, or subdued, were connected with a lower positive emotional grade when compared to a monochrome interior with some elements of bright colour.

Interiors – Group 4 (studying/work). There were statistically significant differences between the emotional assessments of all visualisations in this group. Visualisation 12 was graded statistically higher than the other two (although there were also differences between Visualisations 10 and 11). This means that space designed as a room for studying/work, with subdued colours and a freely-defined arrangement of chairs, benches and lamps, had the highest positive emotional grade, compared to the interior designed with a pre-defined arrangement of chairs, desks and lamps in vivid colours, and compared with a monochrome interior with some elements of bright colour, with a pre-defined arrangement of chairs, desks and lamps.

Pupillary response analysis. Pupillary responses to individual visualisations varied significantly. In Group 2, the largest average pupil dilation was produced by Visualisation 4, and the smallest by Visualisation 6. In Group 3, the smallest average pupil dilation was produced by Visualisation 7, and the largest by Visualisation 8. Finally, in Group 4, the largest average pupil dilation was recorded for Visualisation 10, while the smallest for Visualisation 11. Only in Group 1, there were no statistically significant differences between the average pupil diameters (the diameter was the smallest for Visualisation 1). Only in one case, the significantly highest (positive) emotional assessment of the presented architectural space was not accompanied by the largest pupil diameter in respondents (Visualisation 12). In all cases, visualisations with the lowest emotional assessment evoked the lowest pupil dilation (although not all differences were significant).

Table 2. Means, SDs and differential analysis of the emotional significance assessment of visualisations

Emotional significance assessment	Value of 'z' for multiple comparison Kruskal-Wallis test	
1st Interior Group – basic interiors	H (df: 2; N = 606) = 21.3498; s = 0.00001	
	Visualisation 1 M = 0.876; SD = 1.131	Visualisation 2
Visualisation 2 M = 0.455; SD = 0.846	3.556	-
Visualisation 3 M = 0.841; SD = 1.048	0.084	3.472
	s	
	Visualisation 1	Visualisation 2
Visualisation 2	0.0011	-
Visualisation 3	n.s.	0.0015
2nd Interior Group – basic interiors with lighting	H (df: 2; N = 606) = 0.6452; s = 0.7242	
Visualisation 4 M = 1.846; SD = 1.189		
Visualisation 5 M = 1.920; SD = 1.143		
Visualisation 6 M = 1.821; SD = 1.187		
3rd Interior Group – interiors with varied colours. lighting from the left and a relaxation-suited room layout	H (df: 2; N = 606) = 35.5011; s = 0.00001	
	Visualisation 7 M = 1.905; SD = 1.157	Visualisation 8
Visualisation 8 M = 2.336; SD = 0.959	3.536	-
Visualisation 9 M = 2.524; SD = 0.805	5.216	1.679
	s	
	Visualisation 7	Visualisation 8
Visualisation 8	0.0012	-
Visualisation 9	0.000001	n.s.
4th Interior Group – interiors with varied colours. lighting from the left and a studying/work-suited room layout	H (df: 2; N = 606) = 106.0434; s = 0.0001	
	Visualisation 10 M = 1. 272; SD = 1.119	Visualisation 11
Visualisation 11 M = 0.920; SD = 0.916	2.944	-
Visualisation 12 M = 2.074; SD = 1.055	6.767	9.712
	s	
	Visualisation 10	Visualisation 11
Visualisation 11	0.009	-
Visualisation 12	0.0000001	0.0000001

Data shown in Table 3 illustrate the average pupil size as a function of the emotional character of the picture shown. The procedure for extracting data was in line with methodical suggestions [53], and the obtained results were consistent with source reports, suggesting the occurrence of an emotional reaction. Nevertheless, it needs to be borne in mind that the brightness of the presented stimuli could differ slightly. In order to address the question whether

Table 3. Means, SDs and differential analysis of the pupil diameter

Pupil diameter data	Value of 'z' for multiple comparison Kruskal-Wallis test	
1st Interior Group – basic interiors	H (df: 2; N = 575) = 1.767461 s = 0.4132	
Visualisation 1 M = 3.216; SD = 0.397		
Visualisation 2 M = 3.160; SD = 0.372		
Visualisation 3 M = 3.179; SD = 0.376		
2nd Interior Group –lighting	H (df: 2; N = 557) = 29.17038; s = 0.00001	
	Visualisation 4 M = 3.002; SD = 0.358	Visualisation 5
Visualisation 5 M = 3.020; SD = 0.350	0.644223	-
Visualisation 6 M = 2.849; SD = 0.320	4.316587	4.957488
	s	
	Visualisation 4	Visualisation 5
Visualisation 5	-	
Visualisation 6	0.000048	0.000002
3rd Interior Group – interiors with varied colours. lighting from the left and a relaxation-suited room layout	H (df: 2; N = 527) =39.04693; s = 0.00001	
	Visualisation 7 M = 2.928; SD = 0.320	Visualisation 8
Visualisation 8 M = 3.127; SD = 0.351	5.079849	-
Visualisation 9 M = 3.158; SD = 0.364	5.714026	0.676900
	s	
	Visualisation 7	Visualisation 8
Visualisation 8	0.000001	n.s.
Visualisation 9	0.0000001	-
4th Interior Group – interiors with varied colours. lighting from the left and a studying/work-suited room layout	H (df: 2; N = 518) =51.28221; s = 0.00001	
	Visualisation 10 M = 3.143; SD = 0.384	Visualisation 11
Visualisation 11 M = 2.865; SD = 0.294	7.084712	
Visualisation 12 M =3.033; SD = 0.350	2.646477	4.594251
	s	
	Visualisation 10	Visualisation 11
Visualisation 11	0.0000001	
Visualisation 12	0.024400	0.000013

the physical characteristics of the visualisations were solely responsible for pupil responses, the relationship was also examined between visualisation brightness and the pupil diameter during the visualisation assessment by respondents (Fig. 2). It seems that pupil response is not a reaction solely to the physical characteristics of the stimulus; while pupil response, for instance, to Visualisation 6 could be treated as a manifestation of not only emotional response, but also image brightness (the greater the brightness, the smaller the pupil diameter), such a simple explanation seems insufficient to account for responses to Group 4 visualisations. This is aptly illustrated by pupillary responses to Visualisation 11, where rapid contractions of the pupil were observed and could not be linked to increased image brightness. In addition, Visualisation 11 produced rapid emotional responses in respondents, which were significantly lower than those for other Group 4 visualisations (Tab. 2).

The results confirmed the relationship between pupil size and emotional reactions, which suggest that including pupil dilation indices in emotionally characterized contexts might help to distinguish the positive and negative emotional significance of the presented interiors. The differences between the experimental conditions were reflected in pupil dilation indices, and confirmed by the level of sensitivity and specificity of these indices in distinguishing certain emotional events.

DISCUSSION

This study has shown that architectural space can have various emotional meanings (positive or negative), thus increasing or decreasing positive emotional stimulation and the sense of security and comfort for the individual concerned. In relation to monochromatic basic interiors (control material), the highest emotional assessment was recorded for the interior, designed in line with the golden ratio principle, while the lowest assessments were recorded for the interior that violated that principle, and was accompanied by the smallest pupil dilation (although the differences were not significant). Light (access of light) proved not to play any significant role in the emotional assessment of the rooms, but there were significant differences between pupil diameters, with the greatest dilation being produced by the visualisation of a room lit from the right (which was accompanied by the highest average emotional assessment). The emotional assessments also differed depending on the purpose of the room; the highest assessments were recorded for leisure space in shades of grey. For learning/work, respondents preferred interiors with subdued colours and flexible furniture arrangement. These findings were partially confirmed by pupillary responses.

The above data provide support for the hypothesis that the respondents' reactions while looking at the pictures, reflected their emotional stimulation connected with increased activity in the nervous system. Although the data do not state explicitly whether a positive reaction increased or decreased the pupil diameter, the obtained results suggest that changes in pupil diameter are connected with emotional assessment of the presented materials – decrease was typical of the negative emotional assessment of a presented picture. By means of an additional self-description method, it could be stated that the examples of architectural space evoked various emotional reactions.

Therefore, in designing supportive treatment facilities (as well as schools and offices), it is important to consider room proportions, colour preferences and spatial arrangement of equipment and fittings, which affect the emotional assessment of the room in terms of its attractiveness, sense of security and comfort. It turns out that, apart from eliminating exterior stress-inducing elements, as postulated by Malkin [3], ensuring contact with nature, privacy or socialisation, along with the possibility to control the surrounding environment,

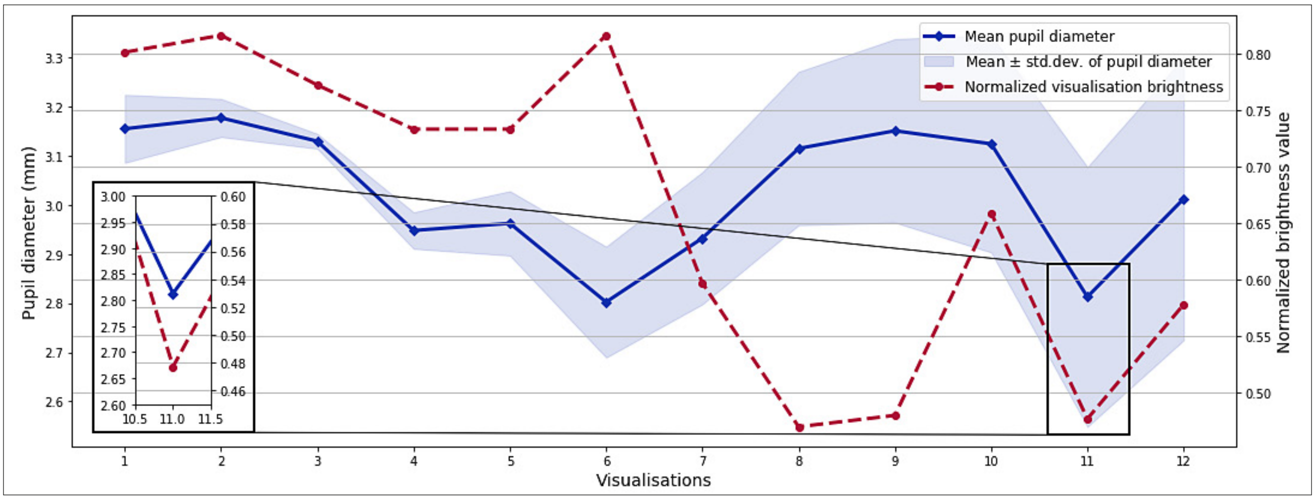


Figure 2. Analysis of pupil diameter and visualisations brightness

as well as ensuring contacts with the closest relatives, access to cultural assets, contact with the world, fun and rest, emotions evoked by the objective features of architectural space, as demonstrated in this research, are also important.

It seems that the results of this study have created a new quality for evaluating the emotional significance of architectural space, important from the point of view of an individual's well-being and general mental and physical state. The interior characteristics actively affect an individual's general mental and physical state, altering the state of comfort and security. This conclusion is important from the point of view of optimising, among other things, the stay in hospital facilities, waiting rooms, operating rooms, hospital schools, etc. It is worth ensuring that such places are compliant with contemporary psychological and architectural practice, including basic emotional reactions to stimuli. The element of physical space is one of its essential components [2, 3, 8, 54, 55, 56, 57, 58, 59], in addition to interpersonal, behavioural and exterior environments. Although today much effort is put into designing educational and medical establishments by ensuring, among other things, that hospitals built nowadays in Europe are low, specialist, ecological and commercially viable buildings [8], it is worth ensuring that they are also compliant with contemporary psychological and medical knowledge, including basic emotional reactions to stimuli.

Emotional affection contributes to pupil dilation, which was empirically confirmed by this experiment which supported the results obtained in some previous studies [24, 25, 27, 28, 32, 34, 45, 60, 61, 62, 63, 64, 65, 66]. The results obtained confirmed the relationship between pupil size and emotional reactions, and suggest that pupil dilation was typical of the positive emotional assessment of a presented picture.

The value of this study stems from the innovative use of the eye tracking method in emotional assessment of architectural space, which may have practical meaning. Despite the fact that the obtained findings agree with other studies showing a significant influence of the presented pictures on emotions, no studies were located that were suitable for direct comparison with the presented study.

Limitations of the study. Beside its positive aspects and value, the conducted study had some limitations. The disadvantage was the lack of analysis of gender and cultural differences, which may have some significance for assessing architectural space. Although these variables were not been included, they have been controlled and will be discussed in subsequent articles. Other data from eye tracking studies (times, saccades and fixations) will also be analysed and described in further papers. However, one needs to remember that pupil-related changes occur through parasympathetic or sympathetic activation, as a result of which it is postulated to incorporate the organism's autonomous activity in future research covering, among other things, the frequency of heartbeat and skin conductance [27, 67, 68].

The brightness of visualisations influences the mean pupil diameter value because the pupil is adapted to light. Therefore, to eliminate that impact, further analysis based on normalised pupil size change should be conducted (e.g. normalisation can be based on subtraction of the initial pupil diameter from successive samples).

Visualisations of future designs should separate their individual characteristics, such as colours and interior fitting arrangement, to provide more accurate data on the dimensions of architectural space connected with specific responses, both emotional and pupillary. In addition, the adopted methodology (allowing respondents to look at visualisations as long as they needed to) appears to somewhat hamper material sampling, as a result of which it is necessary to test a method with a specified time for decision making.

CONCLUSIONS

The obtained results have shown that architectural space can have a diverse emotional significance and impact on an individual's emotional state. This is an important conclusion from the point of view of optimising the patients' stay in hospital units (hospitals, waiting rooms, hospital schools, etc.) and creating a so-called supportive and healing environment. The results also have implications for the interpretation of the pupil diameter as an index of emotional reactions evoked by different architectural space visualisations. Testing the eye tracker as a method helpful in diagnosing the significance of the emotional space is justified, and can also be an effective tool for early diagnosis of the impact of architectural space on the well-being of individuals. It can be a good method for testing the emotional significance of architectural designs before they are implemented. New research models, such as the one presented here, appear to be promising practical diagnostic solutions. Such results can also be used in automatic recognition of human emotional states, and their utilisation in a computer system (affective computing)[5].

Can physical environment be designed to improve man's emotional state? Today, most architects commonly agree that architectonical spaces (including medical spaces) should offer a more user-friendly environment. There are many ways to achieve this goal, but typically they include the use of soothing colours, attractive spatial arrangement, pleasant lighting, etc. Using an empirically verified and clearly defined set of emotional comfort, safety and attractiveness design principles and process recommendations will ensure that all participants of the design process share a common goal and focus on the end-users wellness. More research in this area seems worthwhile.

Conflict of interest disclaimer

The authors declare that the research was conducted in the absence of any commercial or financial relationships which could be construed as creating a potential conflict of interest.

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