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Examining the Effect of Daylight in Residential Buildings on Resting-State and Task-Positive Brain Waves through Quantitative Electroencephalography; A Proof of Concept

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Abstract

The optimal design and construction of high-performance buildings to ensure the inhabitants' health, both physically and mentally, has attracted many designers. Maintaining appropriate daylight is one of the most important variables in designing of high-quality residential buildings. Indeed, it has a great impact on creating a sense of desirability, health and relaxation. The main question of this study was the relationship between the intensity of light and the activity of areas outside the brain's default mode network and its effects on the level of sustained attention. Based on the research question, the hypothesis was presented as follows: Low light inhibits sustained attention and regions outside the DMN are expected to be activated by increased light. The study results indicated that the measurable intensity of daylight, can meaningfully influence the examinees. In other words, ambient light at the intensity of 197 lux may activate some brain areas with a defining role in cognitive processes. This would help in activation of the default mode network and helping one to stay even more vigilant during the whole process. This could help better designing architectural spaces such as residential buildings, classrooms and meeting rooms, in which light is a key content of design where vigilance is concerned. It is suggested that researchers, in future studies, pay attention to the effect of other factors on the intensity of illumination, such as Dimensions and type of architectural space, type of materials, color, and absorption coefficient of walls and floors.

Keywords: Daylight; Brain waves; Electroencephalography; Residential building.

1. Introduction

Daylight combines sunlight and light reflected from the earth and surrounding objects(CIBSE, 1991). Daylight, as one of the most basic human physical and mental needs, is a crucial factors in designing residential buildings with an expected impact on the vitality, creativity, and mental health of the residents (Pourdeihami and Haji Seyyed Javadi, 2008; Sameni and Karimi, 2012). Recent discoveries in the field of neuroscience indicate that the environment directly affects the brain structure (Banasiak, 2012). In fact, changes in the luminous intensity source can change one's perceptions and mental states (Turner, 1994). Latitude and Longitude, building form, its location and orientation, shading, type of materials, and the location and type of windows all can affect the quality of indoor daylight (CIBSE, 1991).But the main factor is the amount of daylighting in the interior places.

Ambient light has many neurological and behavioral effects on humans in addition to the ability to see the scenery and surrounding environment; Light regulates the body's biological clock and as a result, controls many physiological aspects, metabolism and behavior and leads to the release of some hormones, temperature regulation, sleep cycle, and changes in performance patterns. Light at night suppresses melatonin production and increases heart rate and temperature (Anderson, 2013).Changing physiological and psychophysiological variables such as heart rate can overshadow the level of motivation, excitement or other mental aspects of people (Vahdattalab, et al;2019). Exposure to daylight activates many parts of the brain involved in consciousness and memory (Anderson, 2013).Based on this, it seems necessary to investigate the effects of ambient light in the research of health, treatment and care fields in modern researche. In this regard, this research has investigated this issue by utilizing the tools and methods of neuroscience studies.

The amount of daylight in the interior spaces can be measured by methods calculating the luminous intensity in space (based on lux and foot-candle), as well as the Daylight Factor (DF) (British Standard 8026-2, 2008). Quantitative Electroencephalography (QEEG) is a clinical and research tool to record electrical activity of the brain using surface electrodes placed on the scalp. The present research examines the impact of lux-metered daylight on brain waves using QEEG in an apartment complex located in Shiraz. - Moreover, the t-test was used to study the significance level of luminous intensity

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impact on brain waves. The results also will be compared by the standard luminous intensity table presented by the Iranian *National Standard Lighting Group* (Kalhor, 2009).

2. Research Background

The existing research works on daylight are not scant. In this regard, international associations including the International Commission on Illumination(CIE), The European Lighting Association , the *illuminating engineering society of north America* (IESNA), *China Illuminating Engineering Society* (CIES), The *Indian* Society of *Lighting* Engineers (*ISLE*) and other scientific associations in Australia and Canada have carried out well-designed experiments to define ambience lighting standards, including natural and artificial lights. Some studies show how an optimization methodology and genetic algorithm can be applied to achieve the optimum fenestration pattern based on the most qualified daylight level and the minimum annual thermal discomfort in the early stages of design(Ahmadnejad, et al;2022). The recent research Results show that lighting essentially affects people both directly and indirectly. It directly affects visual performance through stimulating visual system. It also can directly affect our mood, behavior and even hormonal balance. In fact, lighting can exert physiological responses of the human body as well as its visual perceptions (Pourdeihami and Haji Seyyed Javadi, 2008: 69).

Extensive and valuable studies have also been conducted on the indirect effects of daylight on people in architectural context. A group of researchers examined the direct effect of light on the vital chemical reactions within the human body. There exists a considerable body of the elegant research(Lewy, et al. 1985; Veitch and McColl, 1993; Joseph, et al. 2001; Kellert, et al. 2008).

Other than the above, some researchers have the psychological impact of natural light on quality of life measures as well as human moral addressed behaviors (Lewy, et al. 1985; Kaufman and Christensen,1987; Tiller, 1994; Flagge, 1994; J. Turner, 1994; Veitch and Newsham, 1995; Nadeen, 2005; Nayebi et al. 2007; Pourdeihami and Haji Seyyed Javadi, 2008; Farzi, 2009; Ahadi, 2014, Tomassoni, et al:2015). Along these lines, Veitch and Newsham (1996) showed that the quality of lighting is measurable.

In addition to the above studies, a number of studies have investigated the effect of daylight on sensory perception in indoor spaces of residential environments(Nikzad, 2013; Dashti Shafee, et al. 2014; Pormohammad, et al. 2015; Soltani Zarandi, 2014; Alhoee Nazari and Ziya bakhsh, 2014; Alikhani and Torabi, 2015; Alinezhad and Talarposhti, 2015; Zargar Daghigh, 2015; Soleymani and Safari, 2015; Safari and Gharagozlo, 2015; Safari and Pour panah, 2016; Ahadi et al. 2016).

In the same vein, an interesting research on the impact of color and light conditions on man's emotional and physical health was done by Nadeen (2006), where he considered the impact of light and color on the Heart Rate variability (HRV), Skin Conductance (SC) and Self-Assessment Manikin (SAM). According to his findings, one's emotional responses could be altered with color and lighting conditions.

With the advent of neuroscience, the development of medical equipment, and the advancement of medicine to engineering in the 1950s and 1960s, the concept of biomedical engineering emerged in the field of neuroscience (Saraee, et al., 2013: 57). Over the past three decades, the evolution of our knowledge on the brain and its cognitive capacity has affected various scientific fields. Since the end of the 1980s, the research has grown rapidly in the field of neuro aesthetics and then architecture with the extensive development of imaging tools (Mallgrave, 2010). Semir Zeki (1999), a microneurologist from London, investigated the brain-art interaction with the introduction of "neuroaesthetics". John Onians (2007) introduced "neuroarthistory". Accompanied by an architect, Hugo Spiers, another researcher from London, hosted workshops at the London Architectural Society. Later, Olafur Eliasson, et al.(2008) Initiated the Neuroaesthetics community in 2008. Nami, et al. (2011) Reviewed the relationship between art, aesthetic and neuroscience.

Meanwhile, a group of architects and scientists led by John P. Eberhard founded the Academy of Neuroscience for Architecture (ANFA) in San Diego in 2003 (Mallgrave, 2010). This academy was established by the American Institute of Architects (AIA) as the international center for interdisciplinary activities to link the research related to the brain and those who design places for human use (Karipour and Shahroudi, 2014). The focus of scientific workshops and scientific conferences of the Academy of Neurology for Architecture is summarized in Table 1.

Table 1
The topics of scientific workshops and scientific conferences of ANFA

Title	**Date and Place**	**Description**
Workshop on Neuroscience and Health Care Architecture	2004 Erik Jonson Center of the National Academy of Sciences, Woods Hole MA	Measuring the effect of the environment on patients' comfort and recovery and the hospital staff's wellbeing through discussion on routing, the effect of windows and lighting, relaxation environments and hospital interior architecture.
Neuroscience and the architecture of spiritual spaces	2004 Columbus Area Visitors Center,Columbus, Indiana	Investigating the effect of spaces and elements of spiritual architecture on users' perceptions and emotions and their role in the experiencing relaxation

Elementary Schools Neurosciences Workshop	2005 ANFA and HMC Architects,San Diego	Examining the effect of learning in the brain; the effect of sound and light on the students' brain; the study of concentration and attention; spatial cognition
Workshop on Neuroscience and Health Care Architecture	2005 Erik Jonsson Center of the National Academy of Sciences, Woods Hole MA	Investigating the brain function in spatial orientation and representation of space in hospital settings, communication and spatial orientation, environmental stress situation, the effect of natural light on patient recovery and hospital staff performance
Neuroscience Laboratory Design Workshop	2006 Dana center ,Washington DC	The exchange of information between neuroscientists about the laboratory environment and the office space required by the researchers; issues such as the impact of the environment on creativity, the impact of the environment on stress, the impact of the environment on memory
Workshop on Aging and Alzheimer's Facilities	2006 The Dana Center, Washington DC	Transforming theoretical research into practice on memory, psychological and physical abilities, sensory perception, cognitive map
Senses, Brain, and Spaces Workshop	2007 University of Salford , Greater Manchester United Kingdom	Examining the specific aspects of consumer needs such as: age, identity and personality, orientation and learning
ANFA Conference	2012 Salk Institute for Biological Studies, La Jolla, San Diego	The interaction of space with the human nervous system and its effect on human psychology, the relationship between brain, mind and architecture, neuroscience and the golden ratios, the nervous mechanisms of sense of place.
ANFA Conference	2014 Salk Institute for Biological Studies, La Jolla, San Diego	Ideas and new collaborations that will ignite change and unlock the potential of Neuroscience in Architecture.
ANFA Conference	2016 Salk Institute for Biological Studies, La Jolla, San Diego	The experience of architecture and design of the built environment, as well as the use of insights from neuroscience to develop new approaches in designing intelligent buildings.

(Source: Shahroudi, 2014)

New applied researches have been done on the relationship between the sciences of the brain and the quality of architecture and sensory perception. For instance, Shahroudi (2014) explored the use of neuroscience in upgrading the quality of architectural space (Shahroudi, 2014). Kavandi (2010) discussed sensory perception and new theories of neuroscience (Kavandi, 2010). Nanda, et al. (2013) also referred to the influence of the form of space on the users' senses (Nanda, et al;2013). In another research, Caroline Paradise (2014) showed how daylight and e architectural materials can affect the users' health and comfort (Caroline Paradise, 2014).

As outlined in diagram 1, there has been a growing body of research on the effects of daylight upon quality and mental state of space users. However, it seems that research evaluating the quality of light quantitatively and examining it in the field of neurobiology is yet to gain momentum. To this end, this study attempted to determine the effect of daylight on brain waves in an apartment complex located in Shiraz. The article aims to quantify the intensity of light with regard to the related effects on brain activity to reach an appropriate approach in even more appropriate architectural designs.

3. Research Methodology

Iran is one of the world's most heavily exposed areas to sun radiation. The radiation varies from 2.8 kWh / m^2 in the southeast to 4.5 kWh / m^2 in the central area. Figure 1 shows that the proper solar radiation time in Iran is more than 2800 hours per year (Fadaee, 2007: 177).

Shiraz located in 29°33'N and 52°36'E is at an altitude of 1491 meters above sea level (Climate Charts). According to Koeppen, the city is located in a warm and dry climate (B) and in the semi-desert region (BSK) (Koeppen-Ggeiger). Calculation of solar radiation in Shiraz by Jafarpour, et al. (1989: 77) suggests that the area has a high frequency of solar radiation. They reported the total annual solar radiation was 7250 MJ/m^2; the mean daily radiation was 19.9 MJ/m2; and the percentage of sunny day was 59%. The possible role of solar radiation in psychological health and neurocognitive performance of individuals living in architectural space in Shiraz, appealed to this research's interests.

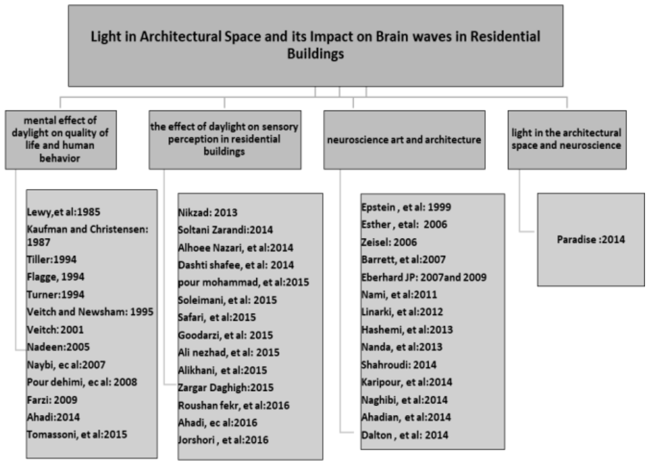
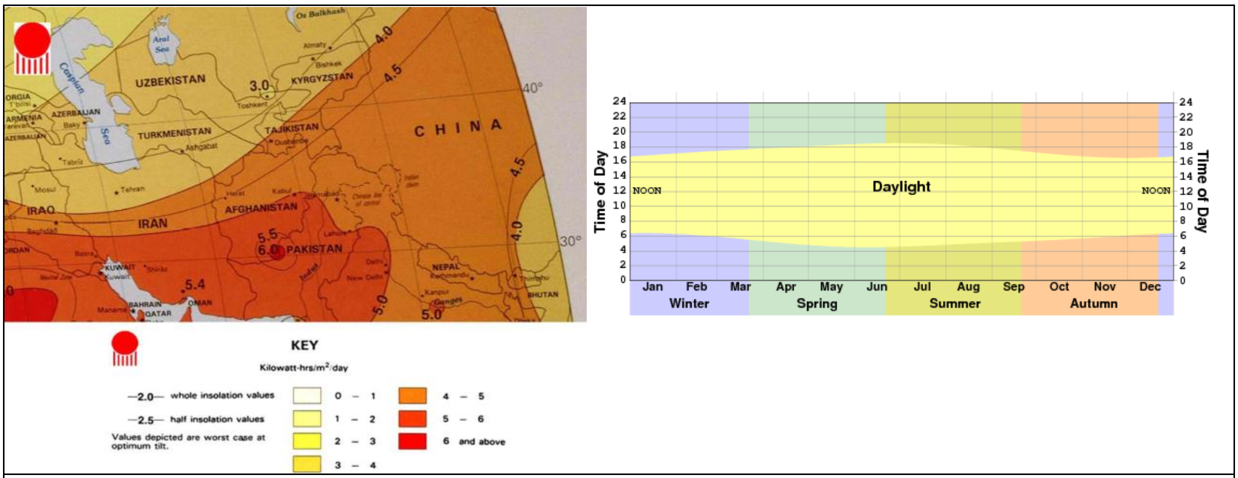


Diagram 1: A growing body of evidence addressing the impact of light in architectural space on brain waves in residential building. See references section for details.



A B

Fig. 1.A- The amount of radiation received in different regions of Iran (Fadaee, 2007: 179), B- Daylight Diagram (Climate-Charts)

For choosing case study, the climatic, economic and urbanization and architectural parameters was considered. Based on the important of daylight role in residential building and the abundance of apartment complexes compared to houses, a case study was selected among modern apartment complexes in Shiraz. In order to achieve more practical and precise results, the chosen apartment required direct sunlight without shading or any other barriers such as high-rise buildings. In fact, the apartment should have been located in a place where there was no radiation barrier. Therefore, a building near the boundary of historical district of the city was deemed appropriate. Among the ancient sites registered by UNESCO, the Eram Garden was selected as the study area. According to the criteria of Table 2 (Building age , Lack of high-rise buildings or other barriers around it, SW-NE orientation, The possibility of watching TV, Having more than two windows to control the light, Having suitable curtains, possibility artificial lighting, Living room with an area of 50-70 m2), the Case study was selected. The characteristics which was the reason of choosing the apartment building have been summarized in Table 2.

Table 2
Study context, Sample Selection Criteria

Characteristics	Acceptable	Non-Acceptable	Description
Building age (modern)	*		
Lack of high rise buildings or other barriers around it	*		
SW-NE orientation, the best orientation in the arid climate to absorb sun radiation (Kasmai, 2015)	*		
The possibility of watching TV	*		
Having more than two windows to control the light	*		Eight windows on the Northern, Eastern, Western and southern front of the living room
Having suitable curtains	*		Five windows out of eight have a dark curtain with a light transmission control rate of up to 95%.
possibility artificial lighting	*		Two 60-lux chandeliers
Living room with an area of 50-70 m^2	*		64 m^2

Given the fact that daylight is considered as a key issue in designing high-performance buildings, it is hypothesized that proper lighting leaves a significant impact on inhabitants' sense of desirability, health, and peace of mind. For this purpose, the present study aimed at examining The hypothesis, i.e. the effect of daylight on brain waves of residents, recorded brain activities by EEG, under the influence of different intensity of daylight, in a controlled area of one unit apartment. Figure 1-A represents the plan of living room (the most common area in house), number and the place of windows.

The present quantitative study employed electroencephalography (QEEG) to monitor electrical activity of the brain in different architectural spaces and various optical qualities. The setup was used to address how changes the amount of daylight effects an individual's brainwaves in an indoor space. To this end, A14-channel EMOTIV EPOC EEG amplifier that made in United States was used to register brain waves. The selected samples were watching TV in natural daylight at 10:00 am in summer. Besides, the EEG-Lab platform in MATLAB and Neuroguide (ver.NG-2.8.7, Applied Neuroscience Inc, Florida) were employed to preprocess and analyze the obtained brain signals throughout the research. Finally, SPSS software ver20 and t-test, was be used to study the significance level of luminous intensity impact on brain waves. The results in the form of quantitative data have also been presented as possible design solutions in residential complexes.

The investigation was done in a living room with the area of 45 m2 in the fifth floor of an apartment complex. The room contained six windows in the Eastern and Northern sides with the total area of 16.45 m2 (figure 2-A).

the brain activities of ten males (mean age 35 +_ 3), with academic education (B.A or higher degrees), who had complete mental health and had no illness or drug use, were recorded by a 14-channel EMOTIV EPOC (figure 2-C), in three consecutive days in summer (September 2-4). It was a sky without cloud; the average temperature was 19.90 °C, and the humidity was 30 percent. They were sked to simulate watching TV at 10:00 am.

Among six windows as the light sources, at first only the curtains of W1, W3 and W6 were open; while others were covered with dark curtains with a 95% coverage. Then, the lumination intensity was measured by the X101lux Meter(Figure 2-B) while the examinee was asked to spend 6 minutes on the desired activity (watching TV). The lumination intensity measured was compared to the standard luminous intensity laid down by the Iranian National Standard Lighting Group (Kalhor, 2009). Since this intensity was below the standard level, W2 light source, with an area of 6.40 m², was added to the living space. The luminatin intensity, therefore, reached the upper limit of the recommended standard. Later, The examinee was again asked to continue simulating watching TV for 3 minutes. QEEG signals were obtained in task positive state(Figure 3).

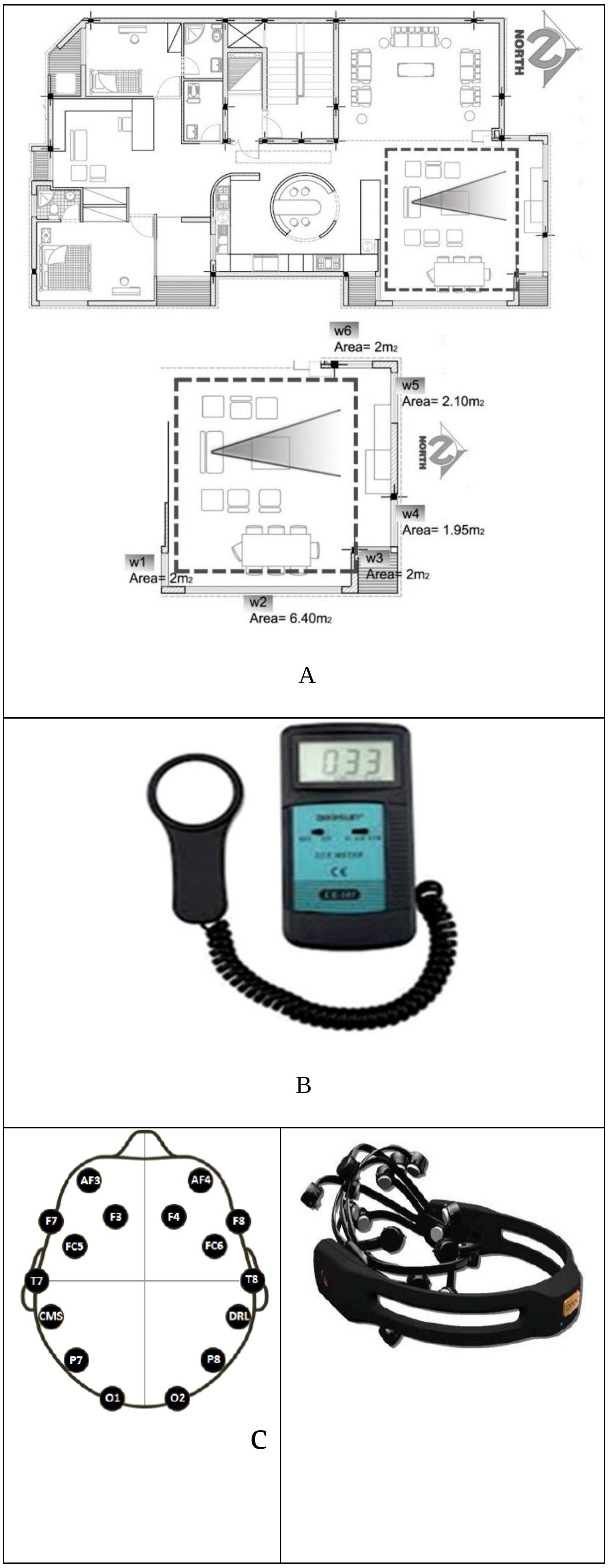


Fig. 2. A- The plan of living room and the place of windows in Mehraz apartment building, B- The Lux meter, X101, C- The 14-channel Emotiv Epoc +14 brain wave recorder.

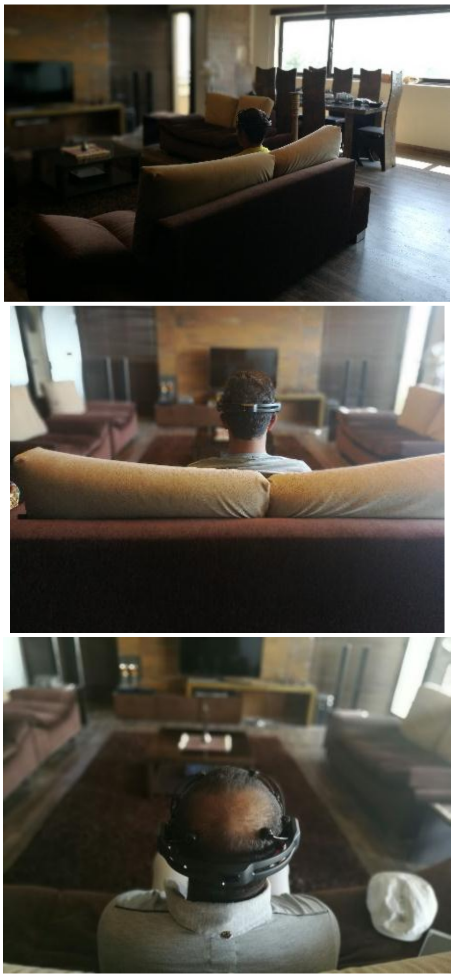


Fig. 3. Recording the brain activities during simulating watching TV

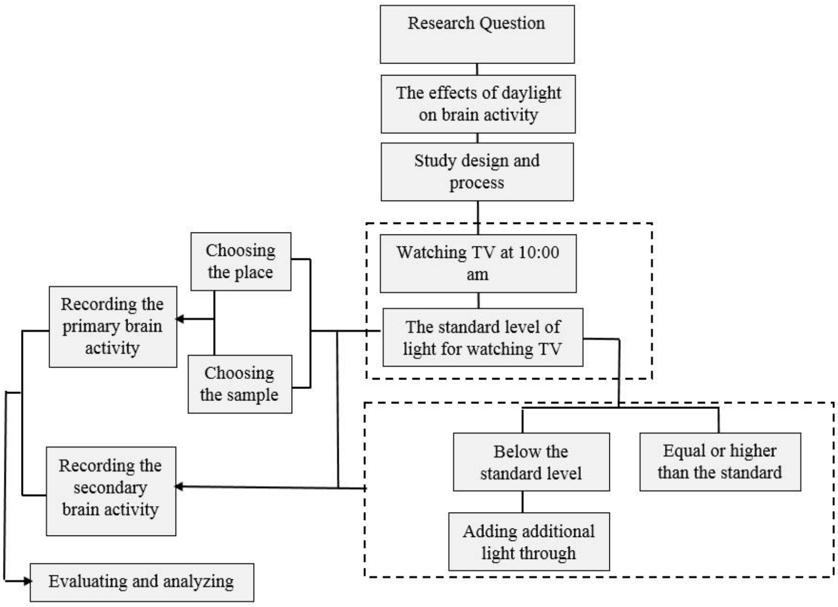


Diagram 2. Study design and executive process

The obtained results were then evaluated and analyzed. Diagram 2 represents the research design and executive process.

Table 3 shows the primary luminous intensity measured in watching TV activity, the standard luminous intensity (Iran National Lighting Committee) and the secondary luminous intensity in terms of lux.

Table 4 Demonstrates some meanings in neuroscience and the expected assumptions in architecture.

Table 3
The primary and secondary luminous intensity measured in watching TV activity and, the standard luminous intensity (Iran national lighting committee)

activity	**primary luminous intensity (low light)**	**window**		**standard luminous intensity**	
		Position	**area**	Min	max
watching TV	58	W1, W3 & W6	6 m^2	70	200
	secondary luminous intensity (high light)	W1, W2, W3 & W6	12.40 m^2		
	197				

Table 4
Some terminology and meanings in neuroscience and the expected assumptions in architecture

Title	**Architecture Assumption**	**Meaning in Neuroscience**
DMN (Default mode network)	Low light appears to hinder sustained attention and It is expected that areas which are outside of the DMN will be activated when the light increases	The default mode network (DMN) is known to be active when a person is not focused on the outside world and the brain is at wakeful resting state, such as during daydreaming and mind-wandering (Buckner,et all ,2008)
Brainwave	Fast brain activity in beta range in sustain attention & high light appears to increase beta activity	Neural oscillation, or brainwave, is rhythmic or repetitive neural activity in the central nervous system. The frequencies of the brain are the following: Delta 1-4 HZ,Theta 4-8 HZ, Alpha 8-12 HZ, Beta 13-30HZ(Evans et al.,1999).
Color-coded brain maps	Once light intensity in architectural space is optimized, this would be expected to enhance sustained attention performance predominantly reflected in an increased beta wave amplitude in prefrontal cortical brain areas.	Color coded brain maps as demonstrated in figure 5 and 6. represent the absolute power of distinct frequency bandwitch pertaining to neural activity. The high amplitude of a given frequency band, the hot colors represent highest amplitude while dark blue show the lowest power of a given frequency band(Maurer& Dierks,1991).
Coherence	We expect the coherence waves reduce in the DMN and coherence of fast-waves outside of DMN specifically increased in prefrontal cortex . Based on the lumination intensity, sustained attention could be optimized once the subject is getting involved in a routine activity.	Coherence measures, the degree of association between two brain regions, indicating functional relationship between different regions of the brain. The thin blue line represents one standard deviation (SD) below the norm and gets thickest up to three SD below the norm. The thin red represents one SD above the norm and gets thickest at three SD above the norm. No lines mean within normal range(Decker et al.,2017).(Figure 6)
Theta/ Alpha Ratio	We expect the theta-alpha ratio decrease in the prefrontal cortex once the light is increased. Such a reduction may represent an enhanced sustained attention.	The relationships between various brain frequencies are compared to a normative database. Ratios lower or higher than normal may represent variation, in either the brain's ability to process incoming information, or attending to executing specific tasks(Evans et al.,1999).
Amplitude asymmetry	We expect that by optimizing the ambient light , the amplitude of asymmetry changed in favor of the dominant hemisphere. It is expected, when we increase ambient light and get involved in a cognitive function, we have an asymmetry in the dominant hemisphere, and the waves that have a fast oscillation like beta and high alpha, amplitude increase in the dominant hemisphere	Asymmetry or the brain's balancing act, scores reveal to us whether the brain waves between the various parts of the brain are balanced. Excessive activity may indicate an over-firing of brain cells. Insufficient activity may suggest brain cells are not firing sufficiently to maintain proper brain function. Both will lead to inefficient brain function (Budzynski et al.,2008).

4. Results and Discussion

The results from the QEEG analyses on 10 subjects suggested that some differences between alpha and theta power at various regions on the brain upon low light and high light states. Across all the areas (figure 1-C) which were found to show high amplitude for alpha and theta in low and high light states, some areas demonstrated predominantly increased theta and alpha amplitude. Such regions of interest are summarized in Table 5.

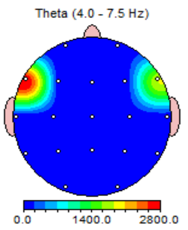
Table 5
Theta and alpha absolute power in regions of interest upon low and high-light states.

Absolute power			
Theta		Alpha	
Low light	High Light	Low light	High
FP1, FP2 F8	FP1, FP2 F7, F8 F3, F4	FP1, FP2	FP1, FP2 F7, F8

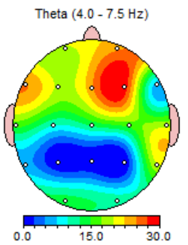
In low-light state, high theta amplitude was documented in right inferior frontal lobule (F8), As well as bihemispheric frontopolar brain regions (FP1, FP2). On the other hand, frontopolar brain regions (FP1, FP2) demonstrated high theta amplitude. Moreover, bihemishpheric fronto central brain regions were also found to have high theta absolute power as compared to other brain regions. In high-light state, frontopolar regions and bihemispheric inferior frontal areas with high theta power partly rested within the well-descripted DMN. While regions with high alpha amplitude were outside DMN.

The topographical color-coded brain maps of the 10 examined subjects based on the theta power and alpha power are illustrated in figures 4 and 5. With regard to theta absolute power unlike low light state , theta absolute power was increase in F7, F3 and F4 regions which are considered to be outside DMN.

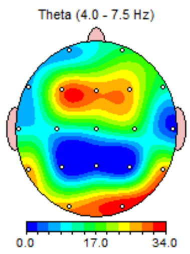
Case 2



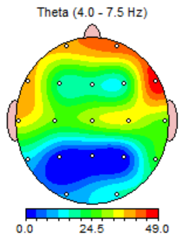
Case 3



Case 5



Case 8



Case 10

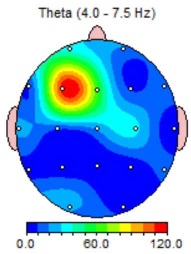
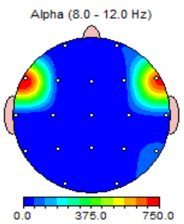


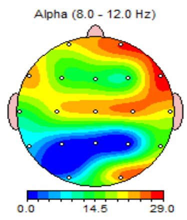
Fig. 4. Increased theta absolute power in F7, F3 and F4 regions in exemplary brain map accross our subject groups

In addition, alpha absolute power was specifically increased in F7, F8, which are similarly considered to be outside DMN. As such, high-light alpha and theta absolute power were increased in areas other than the key components of DMN.

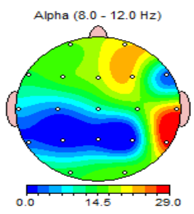
Case 3



Case 6



Case 8



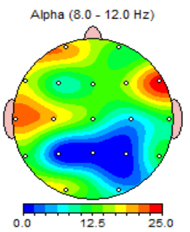
Case 9	

Fig. 5..Increase alpha absolute power in F7, F8 regions in exemplary brain map accross our subject groups.

Based on the result of Table 6, it seems that Fp1, Fp2 theta /alpha ratios are creased, hence the default mode network is less involved when the subject is submitted to high rather than low-light state.

Table 6
Theta / Alpha Ratio in low-light and high-light states.

T/A RATIO	
Low light	High Light
FP1- FP2 F7 -F8 T3	F7 T3

It appeared that high-light state exclusively exited the F7, T3 in terms of theta/alpha ratio which suggest less involvement of less activity of default mode network DMN in high-light state.

Table 7 shows the relative power of theta and alpha in low and high-ligh states. In low-light state, theta relative power was increased in C3, C4, FP1, FP2 which are known to rest within DMN plus F3,F4 which are considered to be outside DMN. In high-light state, theta relative power was increased in FP1,FP2, C3,C4 within DMN plus F3,F4, T3,T4 outside DMN. In low and high-light states, alpha relative power was increased in T6, O2, as well as right temporo occipital area which are known to be outside default mode network DMN.

Table 7
The relative power of theta and alpha frequency bands in low and high-light states.

Relative Power of Alpha and Tetha			
Theta		Alpha	
Low light	Hight Light	Low light	Hight Light
FP1, FP2 F3, F4 C3, C4	FP1, FP2 F3, F4 C3, C4 T3, T4	T6 ,O2	T6 ,O2

With regard to the amplitude asymmetry, research findings demonstrated significance, for theta and alpha frequency at low light and high light states in O1 and O2. Descriptive analysis and quantitative values for theta and alpha coherence in areas showing most predominant coherence level are summarized in Figure 6.

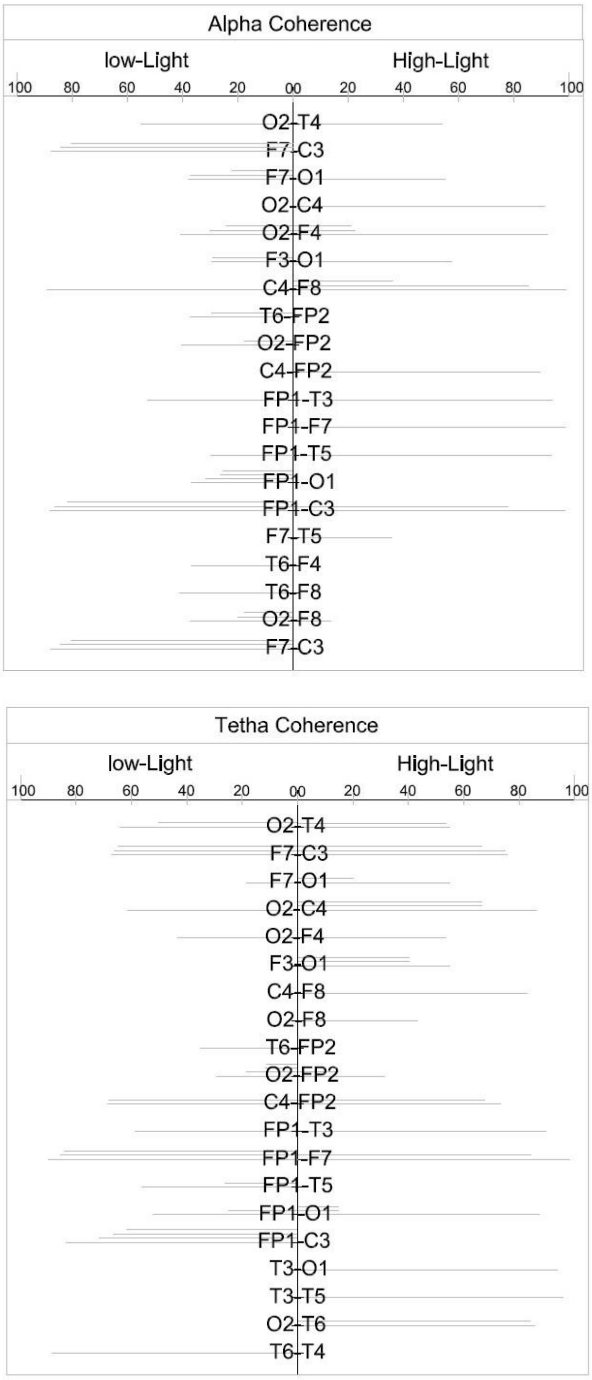


Fig. 6. Quantitative values for theta and alpha coherence.

As demonstrated in figure 6, it appears that high-light state correspond to an increased theta coherence between O2-C4. Moreover, an increased alpha coherence in O2-F4 dipole suggested that high-light state potentially result in fronto occipital networks involvement which play a role in visual attention. Figure 7 illustrates an increased theta and alpha coherence in some regions of interest.

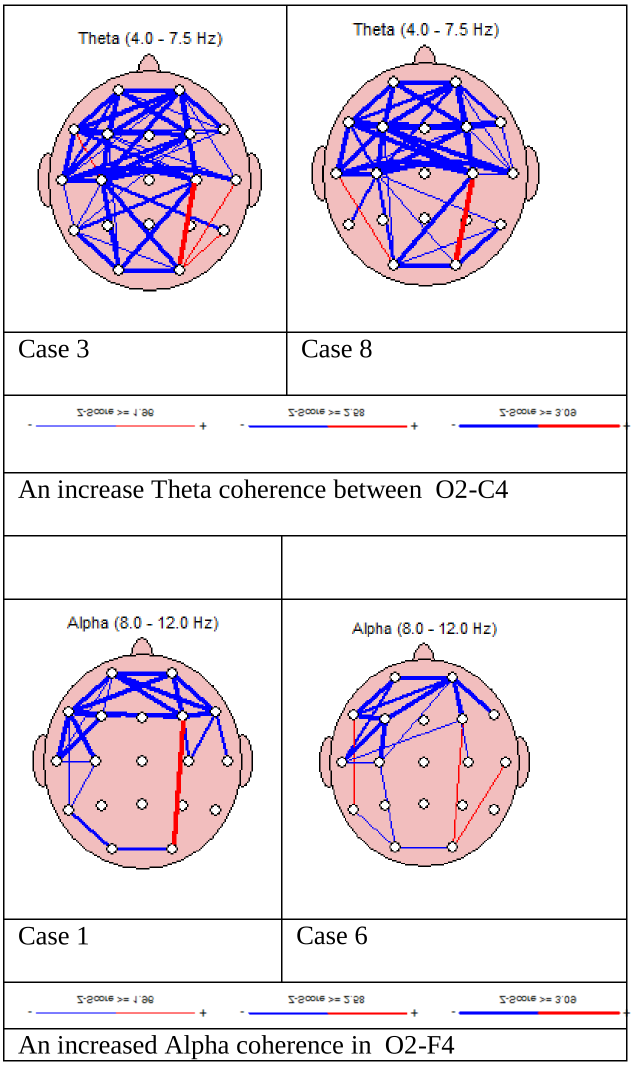


Fig 7. An increased theta and alpha coherence in some regions of interest. An increased alpha coherence in O2-C4 dipole suggested that high- light state potentially result in fronto occipital networks involvement which play a role in visual attention.

An independent-sample t-test was conducted to compare alpha coherence in low and high- light conditions. There was not a significant difference in the scores for low light (M=42.04, SD=25.59) and high light (M=55.13, SD=39.20) conditions; $t(52)= -1.48$, $p=0.14$.
An independent-sample t-test was conducted to compare Theta coherence in low and high- light conditions. There was not a significant difference in the scores for low light (M=52.70, SD=25.76) and high light (M=61.14, SD=26.72) conditions; $t(57)= -1.23$, $p=0.22$.

Despite an overall increase in alpha coherence in fronto-occipital brain regions upon high light state, the overall t-test comparison of means showed no significant difference in terms of mean Alpha and Theta coherence values between high and low-light states across subjects.

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5. Conclusion

The main question of this study was the relationship between the intensity of light and the activity of areas outside the brain's default mode network and its effects on the level of sustained attention. Based on the research question, the hypothesis was presented as follows:Low light inhibits sustained attention and regions outside the DMN are expected to be activated by increased light. This article proposes the impact of high- light state on the activity of key cortical regions outside the default mode network. In other words, high light state may in some ways provide substrates of sustained attention and vigilance. Such domains are mainly involved when default mode network is not playing the main role in our cognitive state. Based on our findings, when light intensity in architectural space is optimized, sustained attention performance predominantly reflected in an increased beta wave amplitude in prefrontal cortical brain areas would be expected to gain. Moreover, in such an optimized illumination, the coherence score would be reduced in the DMN and coherence of fast-waves outside of DMN would specifically in prefrontal cortex . Based on the lumination intensity, sustained attention could be optimized once the subject is getting involved in a routine activity. The theta-alpha ratio decreases in the prefrontal cortex once the lumination intensity increases. Such a reduction means that sustain attention is potentially increased. Based on the finding from the present investigation, the light intensity of 197 lux could probably be optimal when designing in living room. In other words, ambient light at the intensity of 197 lux may activate some brain areas with defining role in cognitive processes. This would help in activation of the default mode network and helping one to stay even more vigilant during the whole process. This could help better designing architectural spaces such as class rooms, meeting rooms, in which light is a key content of design where vigilance is concerned. Accordingly, designers could pay special attention to the type of activity that takes place in a space. For example, in a living room, activities such as watching TV, reading, and relaxation occurs; it is necessary to justify luminous intensity for each activity. In other words, all parts of the space should be within the standard luminous intensity range according to the type of activity. Otherwise, this might negatively impact the focus and cognitive processes of the individuals. This study examined the standard range of natural light intensity for a particular activity and its effect on brain waves. It seems that higher levels of luminous intensity may exert positive effects on the individual's performance in space. In fact, ambient light has an important effect on achieving maximum comfort in the living or working environment and preventing fatigue, which is necessary to increase the productivity and efficiency of humans, especially in the work environment. It should also be noted that many public tasks such as eating and resting are also possible in low light, but people are unaware of its negative and long-term results. Until a few decades ago, the only problem in designing architectural spaces was measuring and knowing the standard level of lighting intensity, which ultimately led to the standard table of lighting intensity for each space being presented by the National Lighting Committee of each country. But as a result of the advancement of science and the help of other sciences such as neuroscience, cognitive science, lighting engineering, architecture and psychology, it became possible to be examined in more details, the effect of lighting intensity on human health, behavior and efficiency in architectural spaces.

In this regard, this article was compiled with the same purpose. In fact, this article linked the lighting intensity presented in Iran's standard lighting table taken from the previous generation of research, with the help of a set of new sciences and techniques, to human cognitive and psychological issues and the new generation of research.It is suggested that researchers consider the effect of other factors on the intensity of lighting in future studies. These include: The distance between the light source and the surface, airborne particles or pollution, humidity, dimensions and type of space, type of materials, their color, the level of gloss or darkness of their surface, absorption coefficient of walls and floors, ergonomics and details of human behavior in space, etc. Extending this relatively young field of research with future multidisciplinary approaches can be the subject of future investigations.

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