博士論文

Neuroarchitecture: A Study on the Relationship Between Architecture and Neuroscience

（ニューロアーキテクチャー：建築学と脳科学の関係に関する研究）

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ABSTRACT

Neuroarchitecture portrays a new frontier in architecture that lies between the interrelation of neuroscience and architecture. This discipline aims to combine human experience in architecture on one hand and brain research on the other in order to accumulate factual knowledge on the impact of architectural design in the human brain. Efforts to understand the relationship between neuroscience and architecture, in particular from a neuroscientific point of view have provided a groundwork for further investigation. Several neuroscientists have given stimulating arguments on the relationship between these two disciplines. However, research in this area from an architectural point of view leaves much to be desired. The general aim of this research is to examine the relationship between architecture and neuroscience from an architectural point of view as well as to present the potential of interrelation between these two fields of study. The goal is to analyze the possibilities that architects could have in the use of tools provided by the field of neuroscience - wearable devices - the interpretation of results, and the potential of implementing those results in the design processes.

The intention is not to provide scientific details from the field of neuroscience, but rather to analyze from an architectural point of view this given possibility. Therefore, this research will try to focus on architectural factors by trying to break down the complex system of environments so that we can understand more closely which factors tend to have the most notable impact on our brains. This will be achieved through the analysis of existing researches as well as from the original experiments designed for this research. Neuroscience is a complex field of study, and architects alone could have substantial obstacles in understanding or using it without the professional assistance of neuroscientists. However, through this study, we aim to investigate whether architects could independently achieve efficient use of neuroscientific devices as a means to set

the stage for an evidence-based approach in design. This research will analyze effective strategies for increasing the potential of the use of neuroscientific tools, particularly non-invasive brain monitoring wearable devices, in assisting the process of architectural design. Therefore, this research's main question is: ***How can the use of neuroscientific tools aid the decision-making process in architectural design?*** To answer the main research question, we conducted theoretical research as well as designed original research through which we aim to verify the limits and possibilities that architects may have to achieve this goal. To complement this search, we will concurrently find answers so several subsidiary questions:

1. What is the past experience in the use of wearable neuroscientific devices in the field of architecture?
2. What is the most effective way to select, analyze, and evaluate architectural parameters?
3. What are the possibilities and limitations of the independent use of neuroscientific tools for architects?
4. Are algorithms of neuroscientific devices reliable to offer sufficient freedom and accuracy of use?

Consequently, this study introduces a new methodology of research that combines analysis of the built environment and measures of the brain's responses towards uncovering feelings and preferences of the living environments. With the latest technological advances, this study will focus on offerings from non-intrusive and wearable devices for the evaluation of psychological responses. These technological advances provide a wide variety of biometric research scenarios and paradigms for a more well-rounded view of human behavior. Due to the novelty of the topic regarding empirical evidence, this research will start by collecting initial information from the first test studies in order to achieve an understanding of the relationship between brain responses and subjective declarations.

In conclusion, neuroscience displays excellent potential to provide new applied science tools for 21st-century engineering. As a result, just as a joint effort of architects, mechanical engineers, electrical engineers, construction engineers, is needed to complete an architectural project, the need to introduce the contribution of neuroscientists in this process is equally important. This synergy would add to the understanding of human experience in the architectural environment.

Acknowledgment

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I dedicate this work to my late father, Nahil, an extraordinary man of courage and vision. We miss you. Të dua.

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Abbreviations

3D	3-Dimesnional
AFA	American Architectural Foundation
AIA	American Institute of Architects
ANFA	Academy of Neuroscience for Architecture
ANOVA	Analysis of Variance
BCI	Brain Computer Interface
CAVE	Cave Automatic Virtual Environment
CIB	International Council for Building Research
CO2	Carbon Dioxide
ECG	Electro-Cardiography
EEG	Electroencephalography
EMG	Electro-Myograph
EOG	Electro-Oculography
ESD	Extreme Studentized Deviant
FDA	Food and Drug Administration
fMRI	Functional Magnetic Resonance Imaging
HCI	Human Computer Interface
MS	Millisecond
RP	Relative power
SNR	Signal-to-Noise Ratio
VE	Virtual Environment
VEP	Visual Evoked Potential
VR	Virtual Reality
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

CHAPTER 1:

INTRODUCTION

1.1. CONTEXT OF THE ISSUE

The impact that architecture has on our brain, respectively, on our behavior has shown a rise in the concern over the last two decades. Several studies (Harrison & Hester, 2019; Hellenbeck, 2018; Medicine, Practice, & Health, 2011; Rippe, 2013) confirm that people, in general, spend 80-90% of their time indoors be it in schools, homes, offices or other environments. (Bluyssen, 2009, p. 95) counts the average time spent indoors, which results in 16 hours on weekdays and 17 on weekends. These values have higher ranges for older and younger generations, approximately 19-20 hours per day. However, empirical evidence on how the built environment affects our brain and behavior, as well as our perception of architecture, is currently insufficient.

Over the years, most studies have attempted to find solutions for separate issues such as air quality, thermal comfort, and other physical conditions, which could only be addressed as one measure at a time. This was stated by (Bluyssen, Oostra, & Meertins, 2013), who also recognize that the earliest undertakings on epidemiological studies related to this issue were raised only in the last decades of the 20^{th} century.

However, with the development of neuroscience and advances in the understanding of the brain, an expansion in the body of knowledge leads us to the argument that environments affect adult brains effectually. An increasing number of studies are validating the relationship between Architecture and Neuroscience and its contribution to health-related issues in a built environment. Thus, "neuro-architecture" portrays a new frontier in architecture that lies between the interrelation of neuroscience and architecture. This discipline aims to combine human experience in architecture on one hand and brain research on the other to accumulate factual knowledge on the impact of architectural design in the human brain, respectively, in the human behavior.

Decision-making processes in architecture have had its historical course of development based on various factors depending on the trend of architectural developmental stages - albeit not always prioritizing the occupants' well-being. One of the buildings' crucial roles is to meet occupants' needs and interests, which commonly differ from one person to another. For people to be able to adapt a setting to their unique needs, to begin with, we need to understand how spaces make people feel, which brings them stress or relaxation.

Consequently, this study intends to analyze the possibilities that architects could have in the use of tools provided by the field of neuroscience to deepen the understanding of the relationship between occupants and the built environment. This study introduces a methodology of research that combines analysis of the built environment and measures of the brain's responses towards uncovering feelings and preferences of the living situations.

1.2. PROBLEM STATEMENT

The past decade has seen a growth in the concern of occupants' health and comfort in indoor environments. Despite this, over the years, architects have continued to design without having empirical evidence on how those environments affect us. Studies already show a rise in the interest in the use of neuroscientific tools as a way to gather evidence towards understanding the human body and behavior in architecture (Eberhard, 2009; Edelstein & Macagno, 2011; Mallgrave, 2010; Pallasmaa, Mallgrave, & Arbib, 2009). Thus, recent neuroscientific records (Albright, 2015; Gage, 2003) suggest that the environment can change our brain's structure, respectively, our behavior.

Therefore, we stand at an intersection of a situation as favorable as it is challenging. An indisputable advantage is that a new window of opportunities is opening for architects, providing us a possibility to aid design-processes through neuroscientific means. On the other hand, the difficulty lies in the demands for a multidisciplinary approach that would intertwine the contributions of neuroscientists on the one side and architects on the other.

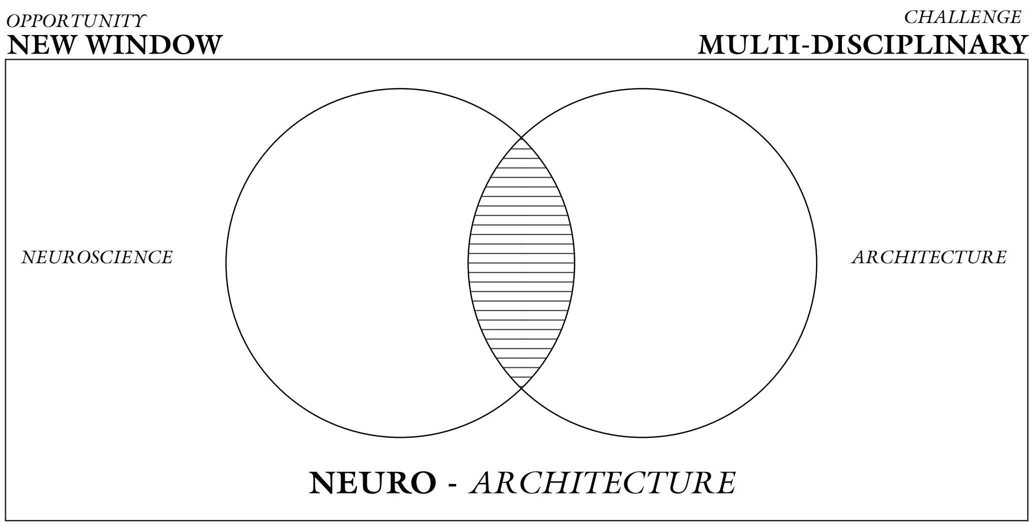

Figure 1. Neuroarchitecture intersection: possibilities and challenges

The main benefit of this crossroad is that neuroscientific devices are available on the market, and have been validated for their accuracy and simplicity of use. Therefore, if neuroscience has proven that environments affect our brains, while architects have not yet developed methods and frameworks to design considering these findings, it is essential to research how we can connect bridges between these two areas to be able to use neuroscientific tools effectively. Therefore, this research aims to investigate the possibilities of using neuroscientific tools to help the decision-making process of architectural design.

1.3. Aims and Scope

The general aim of this research is to examine the relationship between architecture and neuroscience from an architectural point of view as well as to present the potential of interrelation between these two fields of study. The goal is to analyze the possibilities that architects could have in using tools provided by the field of neuroscience, the interpretation of results, and the potential of implementing those results in the design processes. Since the term 'architecture' includes a wide range of considerations, it is significant noting that the target in this research is the interior design. The reason for this is related to the purpose of this paper, which focuses on the well-being of users of architecture who spend most of their time indoors.

The intention is not to provide scientific details from the field of neuroscience, but rather to analyze from an architectural point of view this given possibility. Therefore, this research will focus on architectural factors by trying to break down the complex system of environments so that we can understand more closely which factors tend to have the most notable impact on our brains. This will be achieved through the analysis of existing researches as well as from the original experiments designed for this research. Nonetheless, a considerable part of this paper will present the neuroscientists' point of view on this collaboration to create a clearer picture of the two sides' current situation.

To get to this point, we must first understand the beginning of the theoretical connection between these two fields, the strengthening of the connection as a result of technological development, and the examples of neuroscience-based experiments in the field of architecture. Thereon, we will analyze the methodologies and alternatives of earlier research paths focusing on the selection of architectural elements. This way, we will gather evidence in order to understand the gap in knowledge. Finally, an original design research attempt will be presented using neurological tools to understand possibilities and the capabilities that architects need to reach this task. From this attempt, we will try to understand the impact of architecture on the human brain and gather information on the relationship between the subjective declaration and brain measurements.

Through these steps, we aim that in combination with the facts from the experience of testing others and from the experience of our testing, we come to understand whether it is feasible to create a system of guidelines that could be adapted by architects so that it could contribute to the architectural design processes. Therefore, the main investigation will focus on the potentials and limits of cooperation of these two fields to contribute to the practical aspect of the process of architectural design. Collecting factual knowledge and applying it to architectural design could be beneficial to the users as this study's objective is primarily focused on occupants' well-being.

1.4. Research Question

Neuroscience is a complex field of study, and architects alone could have substantial obstacles in understanding or using it without the professional assistance of neuroscientists. However, through this study, we aim to investigate whether architects could independently achieve efficient use of neuroscientific devices as a means to set the stage for an evidence-based approach in design. This research will analyze effective strategies in the use of neuroscience wearable devices for brain monitoring in assisting the process of architectural design. Therefore, this research's main question is: ***How can the use of neuroscience wearable devices aid the decision-making process in architectural design?*** To answer the main research question, we conducted theoretical research as well as designed original research through which we aim to verify the limits and possibilities that architects may have to achieve this goal. To complement this search, we will concurrently find answers so several subsidiary questions:

1. What is the past experience in the use of wearable neuroscientific devices in the field of architecture?
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To answer the questions mentioned before, we have divided this research into two phases:

Phase 1: Theoretical research
Phase 2: Research design

Detailed elaboration of the methodology of study and experimental design are presented in Chapter 3.

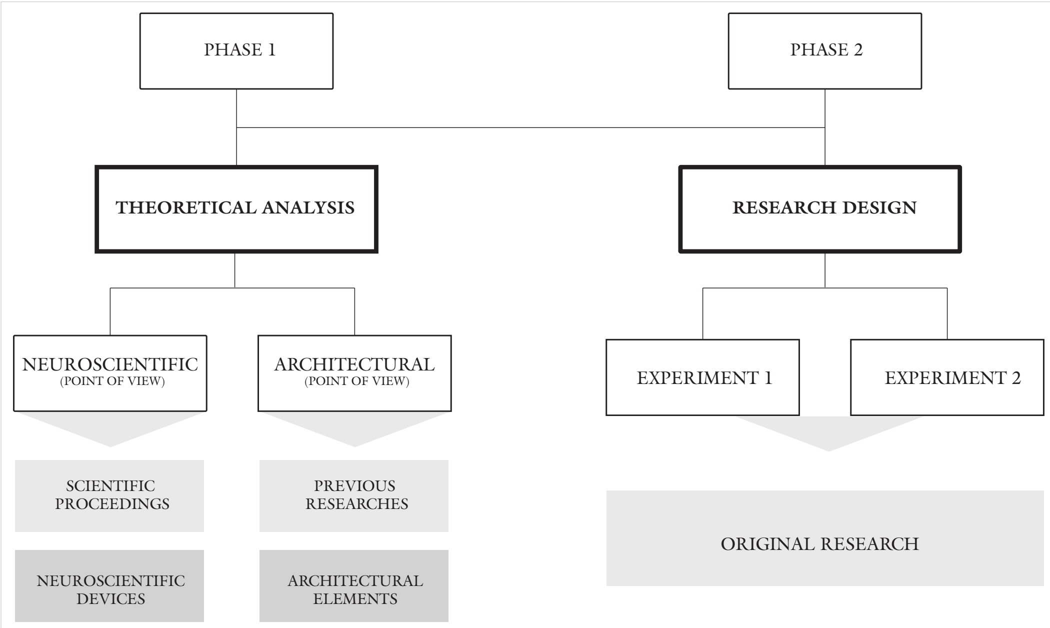


Figure 2. Overview of the research steps

1.5. CONTRIBUTION AND SIGNIFICANCE OF THE STUDY

One intended outcome of the study is the identification of potentialities in understanding the use of neuroscientific tools towards helping to understand the architectural effect on the human brain as well as understanding its potential to guide design decisions. Secondly, this study will offer an original trial of tastings to extend the understanding of the limitations that this experience would bring.

Understanding the functioning of the body and examining its relation to the architecture through neuroscientific means is a developing topic. The findings of this study will redound to the benefit of the society considering that architecture plays an essential role in human health as it is the host of our daily indoor activities where people spend more than 90% of the time. World Health Organization (WHO) reports that the aging (aged over 60), which was 600 million in the year 2000, by 2025 will be 1.2 billion (World Health Organization, 2002). In Japan's rapidly aging population, followed by the continually increasing medical costs, the indoor environment's quality has become a vital factor in facilitating the current situation, and maintaining stable health condition. A significant house-related issue will become the care for social inclusion and the elderly. Institutions are introduced to new demands for the specific group of people that are working with as well as architects will have a different view on differences in design based on the end-users. In the long term, this research intends to bring closer together neuroscientists and architects to determine long-term effects on human health while in indoor environments with a commitment to advance the design methodologies based firmly on the medical evaluation of occupants. This research aims to develop architectural design methodologies that could turn our living and working environment into a healthy environment, resulting in a healthier user. Hence, the focus of this research is the indoor environment considerations in design.

1.6. LIMITATIONS

It is plausible that several limitations might influence the course and results of this research. First, we need to consider the limits due to the limitations of the wearable devices. By the time of this thesis's writing, current devices in the market, particularly the device that we have work with, are constantly evolving. Thus, there is still considerable uncertainty concerning the device's scope, the collected data, and their accuracy and reliability.

Second, neuroarchitecture is a new frontier in architecture, so there is an insufficient research background for the field. Hence, the significant lack of literature that represents similar types of researches in the field of architecture is a fundamental issue. With limited information and material, the need for observation and understanding the pattern to create a hypothesis is necessary. The literature at our disposal extends as far as the last two decades only. Moreover, this study has been done by a researcher who does not have a

Japanese cultural background, so the lack of knowledge of the Japanese language has led to the limitation in accessing local/national scientific findings, which could make a valuable contribution to the literature review of this paper.

Another limitation is the experimental design method, which in this research is based on visual stimulation and does not take into account the reactions of participants in real environments. This limitation could affect the interpretations of the results, so this condition deserves particular importance too.

1.7. OVERVIEW OF THE STUDY

This study is structured into six chapters. Chapter 1 introduces the context of the issue, problem statement, the aim, and the scope of the research, the central and subsidiary research questions, and the limitations and possibilities of it.

Chapter 2 gives a brief overview of the background of the study. The first section includes a sequential increase of consideration of occupants' well-being in architectural design, from the rise of the concern to the implications of the regulations and advocacy of the human needs in architecture. The second section introduces the beginnings of the collaborative means between architecture and neuroscience, by presenting the pioneering actors of this interdisciplinary approach and the possibilities that this joint effort could bring. Moreover, a short introduction of the advances of the brain study, wearable devices, and brain-computer interfaces is presented, by concluding the section with the scientific proceedings – architectural and urban analysis of this approach.

The methodology of this research and design is described in Chapter 3, where also more details about the neuroscientific devices available are presented. Further, we introduce the experimental design technique, the market research for the study, the final choice of the device, the description of the apparatus, and the validity of the device. Moreover, this chapter gives details in the evaluation methodology.

Chapter 4 and Chapter 5 present two research studies of the thesis, which are the same in terms of the methodology of the research but differ in the premises and factors analyzed. Chapter 4 represents the beginnings of an understanding of this new approach towards empirical-building evidence in architecture and therefore stands as the basis on which the second research study is built in Chapter 5. Chapter 4 begins with the description of the research methodology, selection, and consideration of factors and the research results. Furthermore, from the discussions, we have extracted some critical questions from which we have compiled the premises for the second experiment presented in Chapter 5. This subsequent chapter also begins with the introduction and methodology of the research, elaborating on the considerations of factors and results obtained from the research. A section with subsequent discussions encloses Chapter 5.

General discussions, limitations, conclusions, and future recommendations are drawn in Chapter 6, representing the final chapter of this study. This chapter summarizes the findings, answers research questions, and then presents two possible ideas of how future recommendations towards this approach in architectural design could lead to a successful venture.

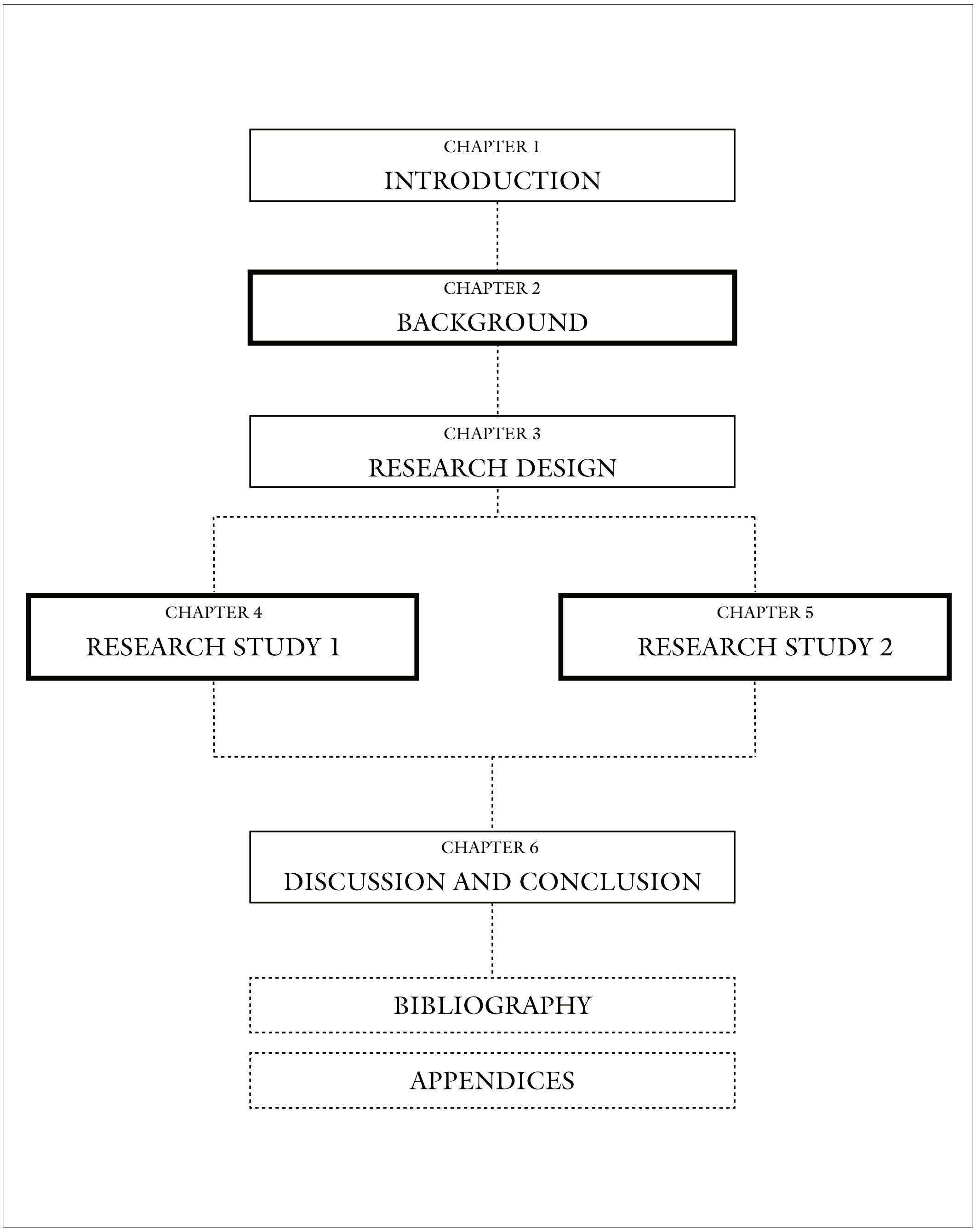


Figure 3. Thesis structure

CHAPTER 2

BACKGROUND

CHAPTER 2:

BACKGROUND

2.1. PART 1: THE RAISE OF CONCERN IN OCCUPANTS' WELL-BEING IN ARCHITECTURE

> "Architect's work is intended to live on into a distant future. He sets the stage for a long, slow-moving performance which must be adaptable enough to accommodate unforeseen improvisations. His building should preferably be ahead of its time when planned so that it will be in keeping with the time as long as it stands."

Steen Eiler Rasmussen

Quality of indoor environment and occupants' well-being has traditionally been a concern for a considerable number of disciplines. "The well-being of the population is largely affected by health, comfort and safety conditions during the main activities of living, working, and transportation in an enclosed space in which people spend more than 90% of their time (Jenkins et. al, 1990)" (Bluyssen, 2009, p. 95). As mentioned earlier, Bluyssen (2009) counts the average time spent indoors, which results in 16 hours on weekdays and 17 on weekends, whereas these values have higher ranges for older and younger generations, approximately 19-20 hours per day. As a result of the long times that occupants spend indoors, this connection between architecture and occupant implies the influence of the surrounding environment on the physical and mental health of the users (Mao, Qi, Tan, & Li, 2017, p. 1271)

2.2. Engineering Considerations

Although the concern on occupants' well-being has traditionally been raised as an issue, the capacity of measures needed to be taken has been conditioned by the time's engineering developments. The interest dates back when fire used to occupy the center of the abode, thus, the need to open the roofs to let the smoke out to control combustion developed the first idea of an indoor ventilated space (Janssen, 1999). Bluyssen (2009) adds that only from the Middle ages, people started to realize that if the air in the building is not good, it can result in "diseases or at least extreme discomfort."

The first published estimate of the minimum quantity of ventilation needed for a person came from mining engineer T. Tredgold in 1836, while mechanical implications were introduced only after Billings, a physician has set the standards of the amount of the ventilation air per person needed to necessary keep a room's CO2 level satisfactory for occupants' metabolic needs. Moreover, ventilation was also necessary for preventing the spread of disease, especially tuberculosis. Overheating of buildings was recognized as the single most critical problem (Janssen, 1999).

To achieve ventilation air for metabolic needs, it was possible only by the development of the electric power industry, which became generally available early in the 20th century (Janssen, 1999; Linden, 1999). The following developments of the 1930s of air conditioning made natural ventilation obsolete (Janssen, 1999, p. 52). Air quality in commercial buildings, as well as industrial buildings, started to have strict environmental and health regulations (Linden, 1999). Moreover, in modern days, Linden (1999) states that "the designs often created unusual conditions for ventilation: tall, open-plan spaces with large solar gains. Poorly designed, naturally ventilated buildings are uncomfortable to live and work in and lead to reduced quality of life and loss of productivity." Ghanoon of Ibn-e-Sina (1978: 198-199) argue that occupant satisfaction in an indoor environment is altered by indoor pollutions (toxins) which they divide into three groups: "1) The pollutants which come from outside to the inside of the house; 2) The pollutants which include activities and the metabolism of residents in the houses; 3) The pollutants which are produced by indoor materials" (Mahdavinejad & Mansoori, 2012, p. 477). Thus, the following years of research in the 19th century were mostly concentrated on the flow of CO_2, temperature, and moisture (Janssen, 1999).

2.3. Regulations

An increase in basic knowledge concerning human reactions to the indoor climate has been noted before the International Council for Building Research (CIB) conference in Stockholm 1988 called Healthy Building 88' Conference, organized by Swedish Council of Building Research, which carried out researches to give recommendations to architects, real-estate owners, manufacturers, and other stakeholders. Many questions were raised regarding healthy buildings, and various approaches have been put forward. The issues tackled were mostly those related to the Outdoor Air Pollution and Climate; Building physics including Building Envelope, Building Tightness and Moisture; Thermal Climate Technology including topics of Heating, Air Movement, Cooling, and Daylight; Indoor Air Quality Technology including System Performance, Indoor Air Pollution, and Noise; Choice of Materials; Quality Assurance; including Design recommendations; and Policy and Regulatory Science (Berglung, Thomas, & Mansoon, 1988).

The need for a global framework to provide direction on indoor air quality - as a significant role in determining health - and give guidance to local levels has been recognized by the World Health Organization (WHO). This concern was raised due to the fact that there might be cases where the indoor environment can violate human rights.

Bluyssen et al., (2013) introduces the concept of the "healthy building" as originated from World Health Organization during the 1990s: "A healthy building is free of hazardous material (e.g., lead and asbestos) and capable of fostering health and comfort of the occupants during its entire life cycle, supporting social needs and enhancing productivity."

In May 2000, WHO European Centre for Environment and Health (World Health Organization, 2000) based on the principles of human rights, biomedical ethics, and ecological sustainability, had formulated statements on "The right to healthy indoor air." These principles mainly apply to the European region and aim to reach policymakers and regulators for the benefit of the general public. WHO (2000) counts several factors that influence indoor air quality, including design, construction, operation, maintenance of the building, and other significant phases of planning and design.

Article 25 of the Universal Declaration of Human Rights states that: "Everyone has the right to a standard of living adequate for the health and wellbeing of himself and of his family, including food, clothing, housing, and medical care and necessary social services [...]" (Nations, 2015, p. 52). However, WHO draws the focus to the fact that exposure to indoor air results in more contact with many environmental contaminants than exposure to food, water, and outdoor air, but, regulations concerning indoor air, food quality or drinking water are more developed than the laws protecting people from harmful exposures indoors even though, in comparison to food, water, and outdoor air, exposure to those indoor situations prevails (World Health Organization, 2000, p. 3).

The European Health Report 2002 by the World Health Organization has determined three major determinants of health: socioeconomic determinants, lifestyle, and physical environment (2002). The physical environment incorporates issues related to air quality, food safety, water, housing, work, transport, ionizing radiation, and global environmental change. WHO further argues that "the housing environment is one of the main settings that affect human health"(Health & Regional, 2002, p. 98).

2.4. ARCHITECTURAL CONSIDERATIONS

Despite the before-mentioned endeavors of the engineering developments concerning considerations on occupants' well-being, architecture has had its course of development, not always in line with these considerations. Decision-making processes in architecture have been based on various factors depending on the trend of architectural developmental stages. Several authors have written about the factors that have influenced decision-making processes in architecture from a historical perspective.

One of the essential considerations in world architectural cultures has been an aesthetic experience. A growing body of literature has particularly examined the dominance of the sense of vision over other senses in the decision-making processes of architectural design.

Over two thousand years ago, the Roman architect Vitruvius stated in his book "*De Architectura*" that buildings should possess strength, utility, and beauty – beauty being a production of the "pleasing appearance and good taste of the while, and by the dimensions of all parts being duly proportioned to each other" (Pollio, 1874, p. 13). Up to date, theorists and architects still discuss the concept of beauty and visual sense, as well as the role it plays in the decision-making processes of architecture. In his book "*The eyes of the skin,*" Juhani Pallasmaa, Finish architect, attempts to investigate design regarding the senses - in particular, the dominance of the sense of vision. He argues that "architectural theorizing, education, and practices have primarily been concerned with form, yet, the capacity of humans to perceive and grasp unconsciously and peripherally complex environments is astonishing." (Pallasmaa, 2012)

Pallasmaa (2012) further outlines that in Western culture, back from classical Greek thought, "sight has historically been regarded as the noblest of the senses."Moreover, he adds that "Greek architecture, with its elaborate systems of optical corrections, was ultimately refined for the pleasure of the eye" (Pallasmaa, 2012, p. 18-28). The constructions of temples, The Doric column, Ionic columns, and highly ornamented Corinthian columns, were constructed according to precise rules and mathematical principles delicately for the same intentions.

Chronologically, the importance of the sense of vision has continued throughout the subsequent stages of architecture – invariably to the developments of the time: elaborate mosaics of classical forms, innovations such as pointed arches and ribbed vaulting, stained glass and high ceilings, sculpting and decorative functions, as well as extravagant ornaments (Craven, 2020).

Subsequently, the Modern movement which followed the phrase "form follows function," aimed to eradicate all the decorative elements of architecture reaching to the "less is more" conceived once as central in the history of western architectural style by avoiding symmetry and frontality, and putting attention to harmony with the natural landscape (Ashihara & Riggs, 1992, p. 109).

> "Working by calculation, engineers employ geometrical forms, satisfying our eyes by their geometry and our understanding by their mathematics; their work is on the direct line of good art"(Corbusier, 1986, p. 25).

However, even the purity of excessive decorative elements presented an attempt to please the eye. Following the Modernist movement, Postmodern architecture combined modernist ideas with traditional forms as resistance to purity following the slogan "less is a bore". Finally, computer-driven designs are a final tendency to push forward and challenge any form known to history, to triumph over the possibilities that parametricism offers.

2.5. ADVOCACY OF HUMAN NEEDS IN ARCHITECTURE

The over-simplified historical chronology of architecture presented above was an attempt to highlight the dominance and importance of forms and perceptions of beauty in architecture. However, these historical currents, as in any cause, have had objections. Indeed, as Bluyssen confirms (Bluyssen, 2009, p. 106), "vision is the primary sense through which we experience architecture, whereas light is the medium that reveals space, form, texture, and color to our eyes." However, the awareness of embracing the various sensory modalities in architecture and focusing on occupants' needs and well-being, rather than 'what eyes can see' has had its advocates in the architectural world as well.

Elieen Gray, an Irish architect and a pioneer of Modern Movement in architecture as well as an advocate of the importance of human need in an indoor environment, tried to influence the modern architecture through the critical process by challenging the totalitarian claims of the misleading examples of contemporary theory as well as prioritizing spiritual, physical, psychological needs (Caroline Constant, 2015, p. 152).

> "External architecture seems to have absorbed avant-garde architects at the expense of the interior, as if a house should be conceived for the pleasure of the eye more than for the

> well-being of its inhabitants" – Elieen Gray (as cited: Caroline Constant, 2015, p.152).

Pallasma on the other hand (Pallasmaa, 2012), argues that alongside the sense of sight, there is a "haptic architecture of the muscle and the skin":

> "An architectural work is not experienced as a series of isolated retinal pictures, but in its full and integrated material, embodied and spiritual essence. It offers pleasurable shapes and surfaces molded for the touch of the eye and the other senses, but it also incorporates and integrates physical and mental structures, giving our existential experience a strengthened coherence and significance" (Pallasmaa, 2012, p. 13)

Edward Hall (Hall, 1969) makes an extraordinary anthropological-based description of all the elements that affect our perception of architecture and the role of the senses. Through his book "*The hidden dimension*" Hall tends to emphasize that all of the man encounters are closely related to experience of space. He argues that "man's sense of space is as a synthesis of visual, auditory, kinesthetic, olfactory and thermal." Moreover, Hall highlights the cultural background as a dimension that affects different experiences through different sensory worlds. In particular, Hall compares European architecture with Japanese architecture. Hall describes the Japanese gardens as an understanding of the "interrelationship between the kinesthetic experience of space and visual experience," which are designed to be "viewed with the eyes but more than the usual number of muscular sensations are built into the experience of walking through a Japanese garden."

Similarly, by emphasizing the importance of the content, rather than form in architecture, Ashihara and Riggs (1992), argue that: "the survival of a city or of individual buildings within it, requires a shift from 'form' to 'content' and from 'the whole' to 'the parts'." Further, authors draw a point of view on Western culture:

> "Paris is splendid, beautiful city, indeed, but may be encountering difficulty when it comes to adjusting to the needs of the twenty firsts century. Its masonry architecture makes it, in a way, a static and inorganic monument of the past" (Ashihara & Riggs, 1992, p. 42).

Moreover, they compare cities from the time of Renaissance with "stage settings," emphasizing the superficiality of two-dimensional drawings to create an "architecture of frontality" and attractive townscapes (1992, p. 119).

Back in 1954, Richard Neutra wrote the book "*Survival through design*" which is one of the books that open our eyes but also finds relevance in the issues raised in our times. At the time, the author emphasized the importance of design in order to prove that the environment is "livable," composed with more "solid physiological foundations" than that of sales and speculations (Neutra, 1954, p. 4).

> "Architecture is the masterly, correct and magnificent play of volumes brought together in light" – Le Corbusier

Elien Gray responded to the Le Corbusier's allegation that "Architecture is the masterly, correct and magnificent play of masses brought together in light," by saying that: "If lyricism can be dedicated to the play of masses brought together in daylight, the interior should respond to human needs and the exigencies of individual life, and it should ensure calm and intimacy" (Caroline Constant, 2015, p. 152).

Pallasmaa argues that architectural theorizing, education, and practices have primarily been concerned with form, highlighting the fact that the "inhumanity of contemporary architecture and cities can be understood as the consequence of the neglect of the body and the senses, and an imbalance in our sensory system"(Pallasmaa, 2012, p. 21).

In an philosophical discourse, Alain de Botton in his book "*Architecture of Happiness*" discusses the inevitably of being vulnerable to architecture, for which he argues that: "our sensitivity to our surroundings may be traced back to troubling human psychology" (De Botton, 2008, p. 106). Moreover, De Botton describes architecture as puzzling, too, in how unpredictably it generates happiness. He argues that there are occasions where unattractive buildings may elevate our moods, but other times, not even our very favorite locations can change our sadness (2008, p. 18). While, on a more scientific view, the studies of Li et al. (2007, 2008a, 208b) already reported that human immune system is affected by the surroundings and that the same can promote its recovery as determined from the perspective of the NK (natural killer) activity (Li, 2013, p. 62).

As can be observed, architecture is perplexing in how within its systematic framework, it is necessary to have a multifold intersection of disciplines including building engineering, building structure, architectural design, mechanical implication, health, etc. As argued in Volume II of the Sustainable Built Environment (Haghighat & Kim, 2009): "no single profession or authority has full responsibility for healthy indoor air," so can be the case for the general situation when we focus on the user's well-being in architecture.

Finally, as De Dear (2004) traces, the philosophy of the Gestalt school of psychologists who claim that "the whole environment being more than just the sum of its constituent stimuli" has reinforced the idea that the interrelations between stimuli in the environment are just as important as the individual stimuli themselves, therefore, the environment-behavior relationships must be studied as integral units. Moreover, as Pallasma (2012) points out, "an architectural work is not experienced as a series of isolated retinal pictures, but in its full and integrated material, embodied and spiritual essence." Therefore, the next part of this research will present another methodology to understand more closely the relationship between the environment and the user expressed through the connection of architecture and neuroscience.

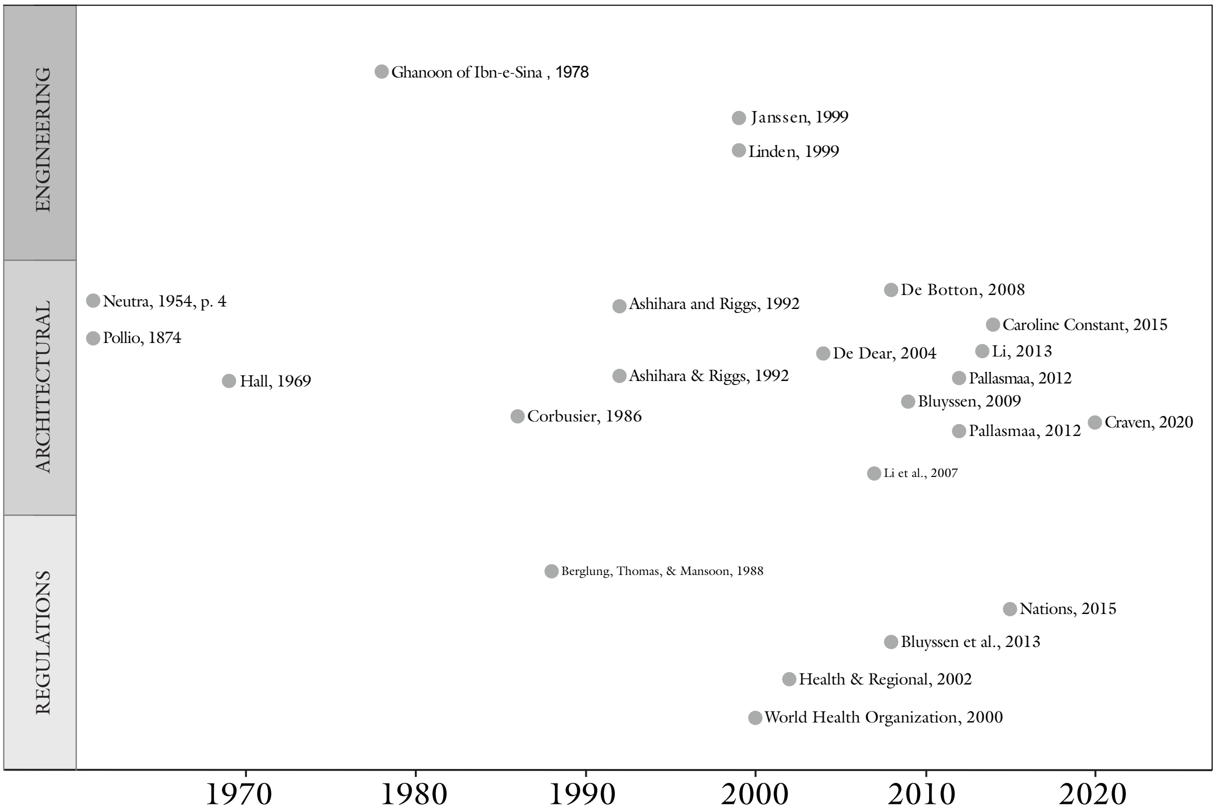


Figure 4. Timeline of the literature review - architectural point of view

2.6. PART 2: BETWEEN ARCHITECTURE AND NEUROSCIENCE

> "Hope lies in dreams, in imagination and in the courage of those who dare to make dreams into reality."
>
> *Jonas Salk*

In 1952 Dr. Jonas Salk developed the first safe and effective polio vaccine. Following the discovery of the vaccine, Dr. Salk shared his personal experience during his attempt to find the cure for polio in the 1950s. He said he had reached a point where he was intellectually blocked and, as a result, was forced to take a rest period. So, he decided to spend a few weeks in Abbey, Assisi, Italy (Eberhard, 2009, p. 21).

> "The spirituality of the architecture there was so inspiring that I was able to do intuitive thinking far beyond any I had done in the past. Under the influence of that historic place I intuitively designed the research that I felt would result in a vaccine for polio. I returned to my laboratory in Pittsburgh to validate my concepts and found that they were correct." – Jonas Salk (Coleman, 2005, p. 185)

Picture 1. Basilica of Saint Francis of Assisi, Italy. Source: Borghi Italia Tour Network

Resultantly, the spiritual nature of architecture became the cause of the inspiration for the creation of the vaccine concept. Impelled by the fact that architecture stimulated his intuitive thinking, Dr. Salk believed that the human brain constantly reacts to architectural environments. Following his experience, he proposed to the American Architectural Foundation (AAF) that "someone in the architectural world should be looking at human experiences with architecture from a scientific point of view" (Eberhard, 2009).

Figure 5. Jonas Salk (left), architect Louis Kahn (middle), viewing the architectural model of Salk Institute (circa 1960). Source: UC San Diego News Center

In 1960 Dr. Salk sought the collaboration of renowned architect Louis Kahn to design a research institute that would similarly inspire the intellectual, creative and collaborative aspect of the scientists. As a result, in close collaboration with Dr. Salk, Louis Kahn created one of the architectural masterpieces of our time - Salk Institute. At the time, the two represented a pioneering effective collaboration between an architect and a scientist.

Dr. Salk's call is the starting point for today's scientific research on the impact of architecture on the human brain, while Salk Institute's neuroscientists are in the frontline of the collaborative work between Architecture and Neuroscience.

This call has gradually influenced architects in placing attention on this research opportunity, albeit slowly and in very limited numbers. This particularly intrigued John Eberhard, architect and director of discovery of the American Architectural Foundation, to spend many years of study of neuroscience research, consequently becoming the only architectural member of the Society for Neuroscience.

Picture 2. Salk Institute, La Jolla, San Diego, California. Source: Salk Institute for Biological Studies

In 2003 San Diego chapter of the American Institute of Architects (AIA), with the help of John Eberhard, founded the innovative Academy of Neuroscience for Architecture (ANFA) while Eberhard became its first president. The academy was formally announced in June 2003.

2.7. NEUROARCHITECTURE

> "I believe it is time for us as architects to introduce another variable into the design process—a consideration of the human beings for whom we construct our built environments."
>
> *Harry Francis Mallgrave*

Architecture, in addition to the meaning of art or the practice of designing and constructing buildings, as a word it also defines the structure of something carefully designed, such as for example: the chemical architecture of the human brain (New American Oxford Dictionary). Brain architecture is comprised of billions of neuron connections, so neuro-architecture has historically been used to define those connections across the brain.

Simultaneously, "neuro-architecture" portrays a new frontier in architecture that lies between the interrelation of neuroscience and architecture. This discipline aims to combine human experience in architecture on one hand and brain research on the other, in order to accumulate factual knowledge on the impact of architectural design in human brain, respectively in human behavior.

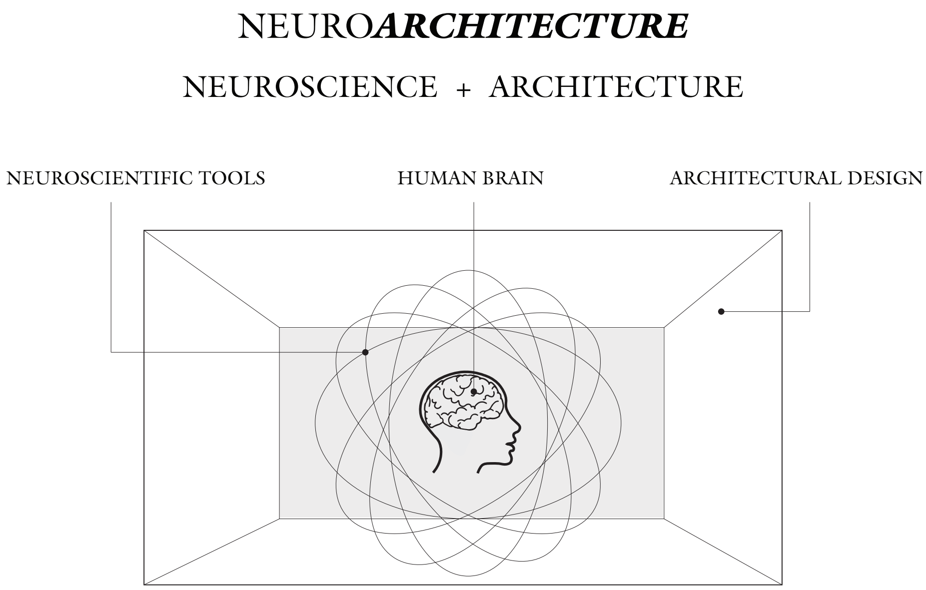


Figure 6. Neuroarchitecture - diagrammatic illustration

Several authors have expressed the meaning, potential, and the importance of this approach. Edelstein (Edelstein, 2013) describes Neauroarchitecture as the approach that informs design by measuring the built environment, with brain and body measurements as well as sociological, behavioral, and economic outcome. Meanwhile, (Banaei, Hatami, Yazdanfar, & Gramann, 2017) claims that "neuroarchitecture uses neuroscientific tools to better understand architectural design and its impact on human perception and subjective experience." Similarly, in his book "*Neuroarchitecture*" Metzger defines the notion as a combination of aspects of neuroscientific research with features of the buildings designed to "provide people with essential sensory stimulation." Further, Metzger recognizes its fundamental potential although he argues that is still mostly presented as a collection of ideas rather than as a tenable theory (Metzger, 2018), while Edelstein highlights the challenges that the 'inherent complexity of the brain and mind brings to the researchers. (Edelstein, 2008, p. 54)

2.8. HOW CAN NEUROSCIENCE HELP ARCHITECTURE?

With the development of neuroscience and the advances in the understanding of the brain, we have come to expand the body of knowledge that leads us to the argument that environments affect adult brains effectually. This has been pointed out by Dr. Fred Gage, a senior neuroscientist at the Salk Institute, in the National Convention and Expo of *Architecture and Neuroscience* in San Diego, California, back in 2003. In his keynote theme presentation (Gage, 2003), Dr. Gage calls on architects by addressing the impact of architecture on the brain:

> "The environment - the structures that we live in, the areas that we play in, the buildings that we work in - affect our brain and our brain affects our behavior. You (architects) are designing the structures that we live in. You are

> affecting our brains. You are changing our brain structures and you are changing our behaviors, and you have been doing so for a long time. And I think it's time that we work together to understand how those brain structures are affected by the designs that you are constructing." – Fred Gage

Efforts to understand the relationship between neuroscience and architecture in particular from a neuroscientific point of view have provided a groundwork for further investigation. Several authors have given stimulating arguments on the potential of the relationship between these two disciplines.

Eberhard emphasizes the connection between architecture and the brain, saying that it is impossible not to have an impact. According to this, we understand this from the sensory system response to the impact after visiting a particular building (e.g. Abbey Church) – which, according to him, is "less dramatic form in 90 % of our waking hours—the amount of time most of us spend inside of buildings" (Eberhard, 2009, p. 2).

Edelstein and Macagno argue that any attempt to use a hypothesis in relation to "neuro-architecture" can be used to understand how a specific design feature can affect psychological and physiological aspects. Furthermore, they see the potential in the measurements of these changes in order to understand the impact that the environment has on human health. (Edelstein & Macagno, 2011, p. 3)

Dr. Thomas Albright, a chair at Salk Institute for Biological Studies, suggests that there is a practical value for architecture and design to know how neurons are wired up in the brain. He argues that the value stands in analogy to the fact that "knowing how the machine works can offer insights into its performance and limitations, insights into what it does best, and how we might be able to tune it up for the task at hand." Moreover, Dr. Albright recognizes the importance of sciences in architecture from a historical point of view. He argues that despite the limits that arise in architectural design processes such as site constraints, materials, budget, architecture it must have always taken into account the biological aspect as well: "[...] architecture has always bowed to biology: the countertop heights in kitchens, the rise/run ratio of stairs, lighting, water sources, heat and airflow through a building, are all patent solutions to salient biological needs and constraints" (Albright, 2015, p. 199).

Sarah Robinson, a practicing architect, in the book '*Mind in architecture*" discusses the fact that several disciplines such as cognitive neuroscience, biology, psychology, and phenomenology have provided sufficient evidence to prove that mental properties depend on the functioning of the human nervous system. These disciplines together have confirmed the fact that the brain, as an organic member of our bodies, is actively engaged in ecological, architectural, social, and cultural environments through which we live. This means that the types of environments we create have an impact on our ability to think, on our emotions, and on our behavior (Robinson & Pallasmaa, 2015, p. 3).

Harry Francis Mallgrave, another pioneer in the theory of interrelation between architecture and the brain, highlights the importance of neuroscience, if not in suggesting a theory, in the possibility of offering something which would be a "theoretical route or the ability to reformulate a few basic questions about the person for whom the architect designs." Additionally, Mallgrave brings the attention back to the 1950's "precious plea" of the architect Richard Neutra for the designers to have a stronger consideration towards biology – "in the sense that the architect should center his or her concern not on formal abstractions but on the flesh-and-blood and psychological needs of those who inhabit the built world" (Mallgrave, 2010, p. 5). Likewise, Mallgrave believes that it is fair to say that the past quarter-century has provided more information in the understanding of the biological workings of human organisms than throughout all of human history. "And this new understanding of our neurological mapping, our chemical and synaptic systems, our DNA molecules and their sequencing has transcended the strict sciences, and their implications have begun to be translated into the humanistic sciences" (Pallasmaa et al., 2009, p. 24).

Dr. Arbib, a pioneer in the interdisciplinary study of computers and brains (Pallasmaa et al., 2009, p. 52), outlines several goals that Neuoroscience could reach towards aiding architecture. Of those, it is important to understand, in particular, the function of different parts of the brain during various tasks, their interaction, and the function of circuits. Dr. Arbib argues that all this rests on the "design of repeatable experiments" and the development of reasoned explanations that address a growing range of empirical data.

In his book "*The eyes of the skin*", Juhani Pallasmaa (Pallasmaa, 2012) argues that form has been the primary concern for architectural theory, education, and practices. Yet, he draws attention to the fact of the "capacity of humans to perceive and grasp unconsciously, and peripherally complex environmental entities and atmospheres (characteristics of spaces, places, and settings) before any conscious observation of details is made." In addition to the importance of atmospheric perception, Pallasmaa outlines that neurological investigation as well as our processes of "perception and cognition, advance from the instantaneous grasp of entities towards the identification of details, rather than the other way around."

In his book "*Brain landscape*" John Eberhard affirms that the link between design and scientific research is inevitable to get a more profound understanding of the human response in an environment. "The promise is that architects and scientists will collaborate more to determine what we build and why it will enhance the human experience"(Eberhard, 2009).

> "Brain controls our behavior, and genes control the blueprint for the design and structure of the brain, but the environment can modulate the function of genes and, ultimately, the structure of our brain. Changes in the environment change the brain and therefore can change our behavior." – John Eberhard

Present-day brain-studies have opened up many limitations in knowledge so far in terms of understanding the functioning of the brain. In the course of these developments, the dogma that the brain is static has seen a change as well. Several authors have pointed out the advantage of the new understandings that the existing neurons of the brain are more "plastic" than they previously believed. Dr. Albright affirms that information-processing features of our brains are not rigid over, but on the contrary, they are plastic and tunable by experience. From the new shreds of evidence, he outlines that sensory system sensitivities tend to accommodate the environment's statistics and that the "recalibration" of these sensitivities are coherent with the change of the world properties (Albright, 2015, pp. 214–215). On the plasticity of the brain, Eberhard, too, confirms that recent findings have challenged the idea of static brain and that the connection between neurons, their increase or decrease, is based on the experience. Moreover, Eberhard argues that changes in the experience and the interaction with the environment can change the total number of neurons in particular parts of the brain. Besides, this change can not only be seen during development but throughout adult life (Eberhard, 2009, p. xiv).

2.9. THE QUEST FOR EMPIRICAL ARCHITECTURE

Several of the above-mentioned authors (Albright, 2015; Gage, 2016; Pallasmaa et al., 2009; Arbib (2009) have noted that the importance of the joint efforts of architecture and neuroscience land towards empirical evidence, as an important part of the research process.

Since the brain controls our behavior the environment can modulate the structure of our brain, in planning the environments in which we live, Gage (Gage, 2016) introduces the suggestion of developing an "empirical architecture - an experimental architecture based on some of the premises that are used in science. This way, just as scientists start their experiments - with the first and most important step being the development of a hypothesis, so could the way we design our environments today represent the architectural hypothesis. One possible hypothesis that Gage introduces is, for example: "large windows in a school are effective for enhancing the academic performance of children." Eberhard (2009) introduces another example hypothesis: "how might design help keep the elderly alert as they move about the environment?"

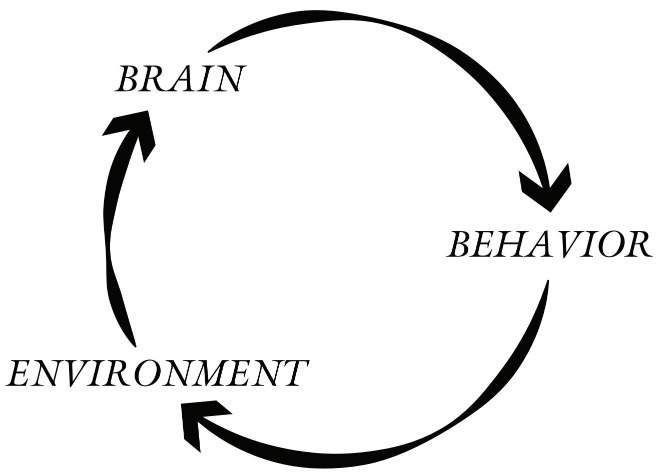


Figure 7. Interrelation between Brain - Environment - Behaviour

Dr. Tomas Albright has also introduced experimental approaches to developing an empirical understanding of how the "acquisition, organization, and the use of information present in the built environment" are influenced by design features. He seeks to understand how visual perception is affected by attention, behavioral goals, and memories of previous experiences. Albright defines Neuroscience as a new research discipline that joins the many previous attempts to understand how built environments impact human mental function and behavior. Therefore, he adds that experimental approaches towards an empirical understanding of how the design influences occupants would help the efforts to understand the capacities of the brain's information-processing (Albright, 2015, p. 215).

> "A fuller understanding of these relationships between organizational properties of the brain and visual environmental statistics may lead to novel design principles." - Tomas Albright (Albright, 2015, p. 215)

Regarding the joint efforts of neuroscience and architecture and the importance of its landing towards empirical data, Arbib (Pallasmaa et al., 2009, p. 52) outlines several goals too that Neuroscience could reach towards aiding architecture. He points out the importance of understanding the function and interaction of different parts of the brain during various tasks. Arbib prioritizes the idea of "repeatable experiments" as a means to develop an empirical database to get to arguable explanations of this interrelation.

In his essay " *(Why) Should Architects Care about Neuroscience*" Arbib, who has studied brain mechanisms underlying the visual control of action, emphasizes, in particular, one of the ways which might explore the linkage between architecture and neuroscience which is the "neuroscience of the design process," by asking "what can we understand about the brain of the architect as he or she designs a building?" Focusing on the architect's brain rather than the user's brain pushed the boundaries of understanding what influences the decision-making process and how much the architect's biography has an impact on that. In this regard, Arbib highlights the engagement of different sensory modalities in architecture by taking the example of Thermal Vals - a building designed by the renowned architect Peter Zumthor – as a representative example where the environment encourages combinations of sensual modalities. Arbib starts this discussion by taking as study case Zumthor's book "*Thinking Architecture*" and extracting parts from it, but with an analytical eye emphasizing the key points of interest concerning neuroscience like "image, half-forgotten memories, developing a whole out of innumerable details" in order to shift the understanding of the psychological processes that Zumthor may have gone through during the design process.

Another interesting insight comes from Dr. Gage, who reports that such collaborative means have called into question the reduction of the artistic flow by "overly scientificizing architecture." However, he suggests that goal is for creativity to be part of it, but that adding science would make decisions more affective (Gage, 2003).

Indeed, the collection of evidence is now more than ever possible due to the technological advances such as functional magnetic resonance imaging (fMRI) and other computer capabilities of neuroscience. However, in this situation, Eberhard (Eberhard, 2009, p. xi) argues that the important thing is that neuroscientists are quick in their actions and warnings that this knowledge still requires an increase in knowledge to achieve their effect in essentially informing design decisions as evidence-based.

In conclusion, neuroscience displays excellent potential to provide new applied science tools for 21st-century engineering. As a result, just as a joint effort of architects, mechanical engineers, electrical engineers, construction engineers, is needed to complete an architectural project, the need to introduce the contribution of neuroscientists in this process is equally important. This synergy would add to the understanding of human experience in the architectural environment.

2.10. Understanding the brainwaves

The last century is considered to have made the most significant contribution regarding brain research. Back in 1875, Caton was the first to observe the spontaneous electrical activity of the brain. Since then, continuous efforts were made to investigate further this finding (Başar, 1998, p. 31).

However, it was not until 1924 that Hans Berger, a German Professor of Psychiatry, discovered that the human brain's electrical signals could be recorded from the scalp. The first publication of Berger included 14 articles through which established Electroencephalography (EEG) as a fundamental tool for clinical diagnosis and brain research (Wolpaw & Wolpaw, 2012, p. 3).

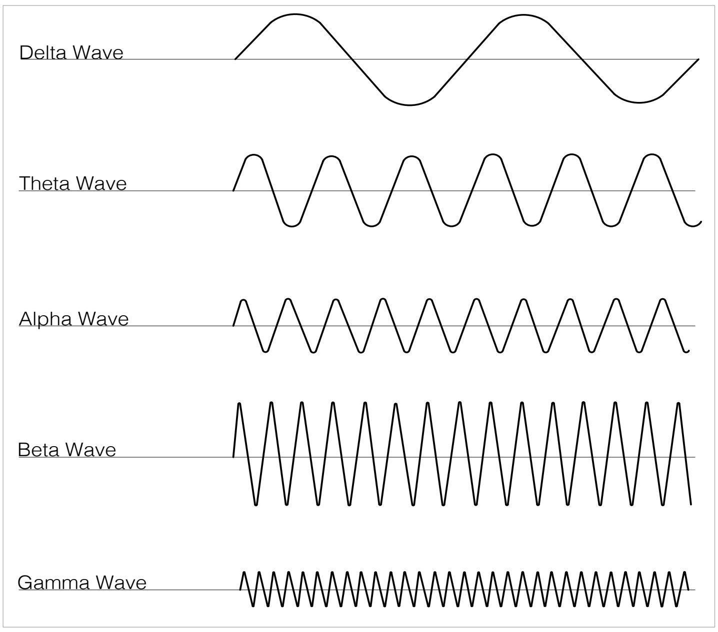


Figure 8. Figure 1. An illustration of brain waves (Ramadan et al. 2015)

Tatum et al., (2008, pp. 1–3) endorse the value of Electroencephalogram (EEG) in reading the electrical signals which are created in the central nervous system and generated by the brain, by displaying graphically the differences of voltages from different parts of the brain, recorded over time. Mountcastle describes (cited in Başar, 1998, p. 31) we experience different states of awareness due to the different frequencies and amplitudes in electrical potential. These frequency are categorized in five bands: Delta, Theta, Alpha, Beta, and Gamma (Tab. 1). Hence, states such as excitement, drowsiness, sleep, coma anesthesia as well as epileptic attacks – make these potential wavelike changes measurable indices of brain activity. Basar (Başar, 1998, p. 31) outlines that the frequency range of these potential waves recorded varies from 0.5 Hz to over 100Hz. The table below is a simplified version of the original table referred to the study of Lindley and Wicke (1974) (cited in Başar, 1998, p. 34) with additional illustration which outlines the conditiones present sue to the a types of waves and rhythms in the human brain:

Type of wave rhythm	Frequency per second	Condition when pres-ent	Amplitude or voltage	Prominence or Maxi-mim
Gamma	30-50	Awake	2-10	Precentral and Frontal
Beta	18-30	Awake, no movement	2-20	Precentral and Frontal
Alpha	8-12	Awake, relaxed eyes closed	5-100	Ocipital and Parietal
Theta	5-7	Awake, affective or stress	5-100	Frontal and Temporal
Delta	0.5-4	Asleep	20-200 20-400	Variable

Table 1. Types of waves and rhythms in human electroencephalogram and their approximate and relative specification and distribution (from Lindsley and Wicke 1974 cited in Basar 1998, p. 34

Advancements in the discipline of Neuroscience have made it possible to extend our understanding of architecture and its perception. Traditionally, investigation of the human responses to design was either philosophical or based on the analysis of behavior patterns (Edelstein & Macagno, 2011, p. 3). For example, in the visual system, one might test a neuron to determine what type of visual feature best stimulates it and wherein the visual field that features elicits the most significant response. The position where stimuli cause the neuron to fire is called its receptive field. Neighboring neurons in the visual areas usually respond to similar regions of the image. Hence these areas are roughly retinotopic in that their spatial organization is similar to that of the image at the retina. This retinotopic structure is the strongest in the primary visual cortex and gets weaker, and receptive fields get larger, as we ascend the visual hierarchy (Arbib, 2016, p. 2). Regarding the understanding of emotions, Mallgrave (Pallasmaa et al., 2009, p. 27) suggests that in order to move from our timeworn thinking concepts of it, the best way to start would be a simple biological definition. Mallgrave states that emotion, in the words of the neuroscientist Joseph LeDoux, "is the process by which the brain determines or computes the value of a stimulus." Arbib (Pallasmaa et al., 2009, p. 54), on the other hand, has raised the question of what is the job of neuroscience in architecture? He further underlines that among other goals is understanding the interrelation of the different parts of the brain during different tasks. On another note, Arbib discussed the matter of image as its understanding, and how different parts of the brain collaborate to create images. He further presents another study done by Ishai et al. (2000), who found that "visual perception of houses, faces, and chairs evoke differential responses in the ventral temporal cortex."

Neuroimaging is a new field in medicine that illustrates the architecture and function of nervous system, also known as brain imaging. In their study, (Fouad, Amin, El-Bendary, & Hassanien, 2015, p. 5) categorize neuroimaging into two main categories: Structural Neuroimaging and Fuctional Engineering. The first one is focused on imaging of the anatomical structure of the brain including blood vessels and tissues, while the second one focused on the metabolic activity of the brain such as electrical impuls, vessel blood flow, and other changes based on the responses.

2.11. ADVANCES ON BRAIN COMPUTER INTERFACES (BCI)

With the technological developments, the interests on the readings of brain electrical signals known as impulses has grown. Ramadan, et al., (2015, p. 31) endorse Brain Computer Interface (BCI) as the latest development of Human Computer Interface (HCI) as the direct connection between computer and the human brain. As brain produces the waves as electrical potentials from different parts of the human head, BCI reads and "translates these signals into actions, and commands that can control computers." Wolpaw & Wolpaw (2012, p. 5) suggest that the term "brain-computer interface" was first used by Jacques Vidal in 1970s who used the term to describe any computer-based system that produces detailed information on brain function. Vidal developed a system which could determine the eye gaze through recordings of the sculp using Visual Evoked Potential (VEP). Ramadan et al., (2015, p. 36) classify BCI into three main groups: "Invasive BCI Acquisition Techniques; Partially Invasive BCI Acquisition Techniques; and Non-Invasive BCI Acquisition Techniques." The latter falls into our study interest and is considered one of the safest techniques while maintaining low-cost devices. Current solutions in the market include a wide range of wearable wireless and non-intrusive devices that vary depending on the numbers of the electrodes, which detect electrical signals from their placement in the scalp, in order to process these signals as a part of the BCI System. Same study (Ramadan et al., 2015, p. 42) further lists the steps that are required for forming a BCI System forming:

1. The strength of the signal recorded from the brain's electrical potential is usually low, so, in order to be used by a computer application, it needs amplification, and then digitalization.
2. The signal processing: this step includes three parts: *Processing* - which means preparing the electric signal for processing; *Feature extraction* - which means extracting specific signal features - EEG recordings contain both electrical signals from the brain as well as unwanted

signals which need future extraction procedures in order to prevent the lead from wringing direction; *Signal Classification* or the translation algorithm in which the feature extraction is translated into device commands orders and are classified on both frequency and their shape;

3. The data manipulation is the output from signal classification employed to suite the output devices (e.g., computer screen).

This way, BCI system has opened a new window to the architects in their design process so that they can base their decision making on the evidence on brain recordings, leading to a better understanding of how architecture affects brain.

2.12. WEARABLE DEVICES

As presented above, technological advances in contemporary neuroscience have enabled measurement and visualization of neural activity. In the course of these advancements, non-intrusive wearable devices for brain measurements have had an increased development. Moreover, the commercialization and affordability of wearable technologies for the measurement of brain electrical activity have increased the scope of use by different fields of study.

Before expanding the meaning and functionality of these wearable devices, we will briefly explain the key definitions. Wearable devices are electronic mobile devices, usually light in weight, that can be worn in the form of accessories on the human body to serve as tools for biometric measurements. The mode of operation is done through sensors, which are an integral part of these devices. (Byrom et al., 2018) define sensors as a component of the device that detects and measures physical and chemical information from the surrounding environment and translates those data into an electrical output signal. These electrical signals are further transmitted and displayed, through wireless network or Bluetooth, to a hardware or device. Byrom et al. (2018) suggest that in a regulatory context, wearable devices may classify as medical devices, which, based on Food and Drug Administration (FDA) are classified depending on the risk of use: Class 1 (e.g., elastic bandages), Class 2 (e.g., acupuncture needles), Class 3 (e.g., implantable pacemakers).

Traditionally, devices for the measurement of brain functioning have given vast and complex amounts of data, which required an expert for their interpretation. However, during the 70s, attempts were made to simplify the EEG readings with new techniques that would use quantitative analysis of EEG frequency and amplitude in real-time display (Ebersole & Pedley, 2003, p. 762). Moreover, due to practical inadequacy, their use was limited to only necessary medical examinations.

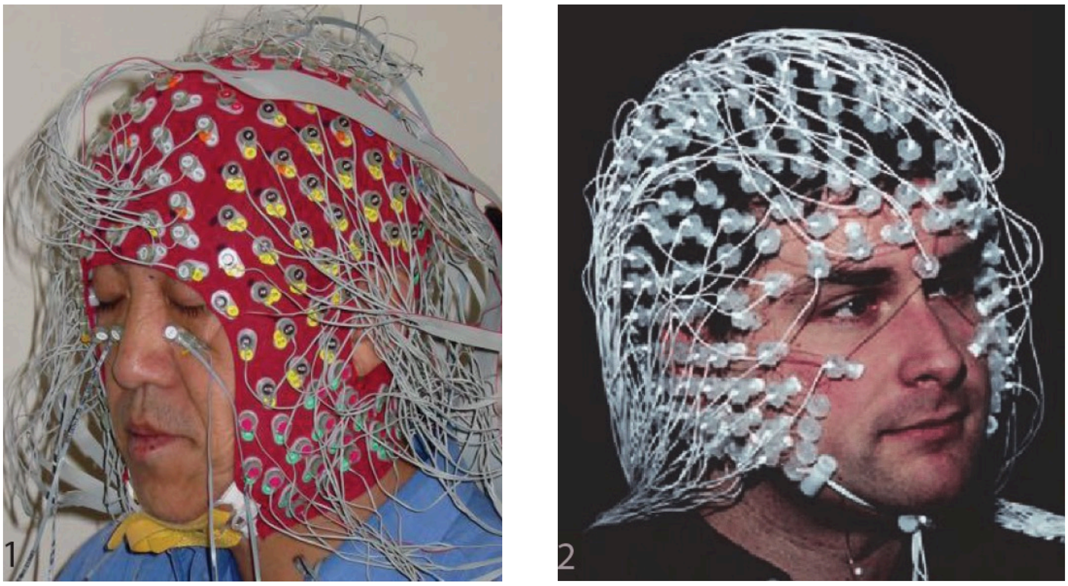


Figure 9. Traditional method of brain electrical measurements. Left picture source: Scott Makeig (2016); Right picture source: Mark D. Holmes (2017)

With the advancement of the brain-computer interface (BCI) and the simplification of the devices for measuring brain electrical activity, wearables' use has expanded its opportunities and opened a new possibility for use by non-experts. Up to date, these devices have also been used in combination with other biometric devices such as heart rate measurements, eye tracking, virtual reality, or other considerations depending on measurement needs.

Many fields are actively interested in the use of this equipment since it attracts greater information in the respective fields. So far, fields of study include those in art: drawing, performance, singing; in architecture: analyzing architectural elements to understand the impact of architecture on the human brain; in urbanism: used to understand the connection between the city and its impact on perception and security.

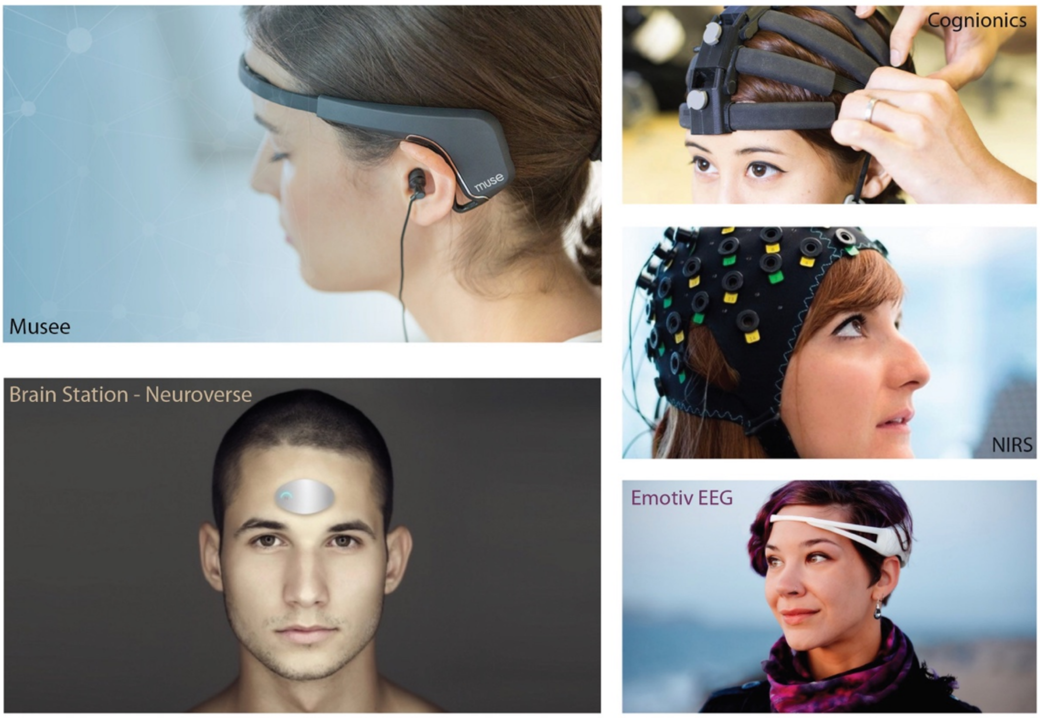


Figure 10. Simplified contemporary non-intrusive wearable devices for the measurement of brain electrical activity / Sources of pictures listed in the bibliography.

The technological innovations of these devices are substantially based on the management of big data and algorithms that developed alongside them. The sensors in the wearable devices can monitor several times in second (high sampling frequency, SF) to every few minutes (low SF) for many days and weeks. Consequently, these sensors generate electrical signals when detecting physiological responses, which are then stored as raw time series data. Principally, algorithms, such as structured computer-based protocols, analyze and process these electronic signals or data, and give meaningful outcomes. Nowadays, most wearable devices have installed algorithms that extract the applicable features of these data or access raw data for a more insightful research purpose (Godfrey et al., 2018). Other trends include *open-source* options of brain-computer interfaces that allow anyone interested in brain-computer interfacing and neurofeedback devices to create custom made devices and analyze data based on their needs.

2.13. Scientific Proceedings

2.13.1. Architectural analysis

An increasing number of studies are validating the relationship between Architecture and Neuroscience and its contribution to health-related issues in a built environment. Advancements of the technology related to neuroscience are also the arguments of Edelstein and Macagno (2011) in their study on the contribution that neuroscience can give to architecture. Alongside the advantages that wearable devices offer, such as the opportunity to study multiple functions of the brain, a highlighted advancement is also the freedom and practicality of use that these wearable devices offer due to their wireless connection which grant free movements around the space. Recent developments in this regard have been focused on advancing in particular wearable devices that measure brain waves. The readings of brainwaves have multiple applications, but our interest lays in understanding how the brain reacts to different indoor environments.

As a result, Edelstein and Macagno (2011) provide insights on the wireless, sensor-based tools towards understanding how science could inform design. They introduce their investigation in close collaboration professionals from different field of study other than neuroscientists such as biologists, engineers, designers, visualization and sonification specialists as well as architects which was focused on testing "how features within the scope of *light, sound, and location* may enhance human and environmental health." They introduce CAVE (Cave Automatic Virtual Environment) - a virtual space in which subjects would be immersed in different visual scenarios (e.g., indoor built environments), which simultaneously serves to measure their physiological and behavioral means. Subjects use a 3D joystick for interactive purposes within the virtual environment. In order to measure the neurological responses to design, simultaneous monitoring of subjects responses are available through the immersive and interactive capabilities of VR as well as collecting EEG brain waves, in addition to other electrical measurements such as those of the eye movement (EOG), cardiovascular measures (ECG), and muscular potentials (EMG).

Another methodology of the interrelation of the two disciplines from a scientific point of view is presented by the study of Papale et al. (2016) who introduce novel insights from cognitive neuroscience in the fields of architecture and planning. This study offers an understanding of another concept of "*hapticity as tactile perception*" and "*haptic imaginary,*" which are suggested to have a pivotal role in the architectural appraisal. They argue that texture, shapes, or other visual cues or elements of form in architectural environments can pass tactile information, and be processed independently in the sensory modality of specialized brain regions.

In their study, Edelstein et al., (2008) experimented with an empirical approach to investigate the psychological and physiological responses of patients to "*controlled light*" conditioned at night and in the morning. Through this study, the authors aimed to assess the influence of lighting on cognitive responses measure via electroencephalography towards understanding the impact that light has on the heart rate variability – which presents an important indicator of health. As a result of the experiments, this study offers novel insights into the impact of light on the red range in decreasing the heart rate variability. Despite the lack of knowledge on the impact that red range lights have on health, this study confirms that "brief exposure to light during the day may influence cardiac responses." This finding of this research could assist in the change of lighting in healthcare environments since, as authors argue, "the influence of light on many human functions underpins the value of architectural and electrical lighting strategies that support both visual and circadian needs."

The same lead author (Edelstein, 2013) further on has tested the impact of acoustic design on human responses and function - in particular to the consequence of noise condition on work errors. This research resulted from the demonstrated issues in which speech intelligibility and error increased the rate of error in medications with similar-sounding names. A similar CAVE environment has been used to test the hypothesis. This issue is closely related to the sound levels of hospital conditions. The increase of the sound levels risks psychological and physiological changes. This study has adopted Maslow's "hierarchy of needs" to a "hierarchy of the design principles" through a neuro-architectural approach to inform the design process of the built environment

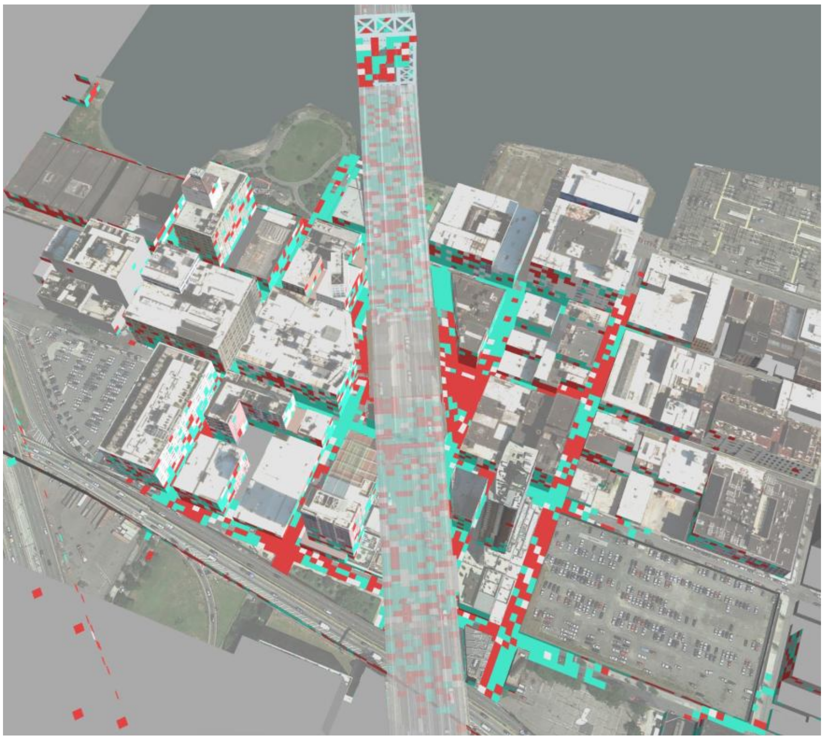
Another scientific study using neuroscientific tools in order to understand better architectural design and that sheds new light in the use of EEG and Virtual Reality (VR) is that of Banaei et al., (2017) which analyzes "the impact of interior forms on human brain dynamics." This study constructed 3D rooms from different indoor situations and computed those clusters. Subjects were tested using Virtual Reality (VR) goggles while they were asked to walk through different interior forms, whereas brain waves were measured during the action. This study revealed that curvature geometries in an indoor environment have a substantial impact on brain activity and processing of architectural features beyond their emotional impact.

Similarly, (Navarrete et al., 2013) studied how the variations in contour impact aesthetic judgment and approach-decision. This study used functional magnetic resonance imaging(fMRI) for examination. This study complements the previous hypothesis of some preliminary researches, which has shown a close relationship for the preference of curved lines in an indoor environment. Aside from contour, this study introduces factors such as the height of the ceiling and openness as two control variables of the design. Subjects were presented to several photographs of interior designs in the fMRI scanner. Results reveal that participants judged curvilinear contours as more beautiful than rectilinear contours.

Another study that combines modalities of neuroscientific tools for measurements through virtual reality in an architectural setting is that of Vecchiato et al. (2015). This research aimed to record subjects during the perception of three immersive virtual reality environments that represented three 3D modeled architectural environments: 1) an empty room; 2) a room furnished with modeled with modern furniture and; 3) a cutting-edge design. This study tended to test the hypothesis that different interiors would activate different cerebral circuits involved in the mechanism of embodiment. Each interior was designed to evoke different opinions regarding: "Pleasantness, Novelty, Familiarity, Comfort, and Arousal." Each dimension was compared to cerebral activity related to the visual cues. This study primarily provides new insights on the impact of architecture in the human brain; however, it also reveals that real-like Virtual Environments (VE) that are precepted as comfortable and familiar, activate cerebral circuits evoked by the sense of presence. Moreover, this study highlights the importance of the frontoparietal network when judging pleasantness, respectively, aesthetic.

2.13.2. URBAN ANALYSIS

Following similar methodologies of brainwave measurements, such research has also found application in terms of urban analysis. In 2014, Columbia University, in collaboration with Van Alen Institute, has mapped areas of DUMBO – a New York neighborhood while volunteers walked through wearing devices for brain wave measurements. One hundred volunteers have navigated their way through New York, while each of them carried a mobile device with a custom app to track the location while moving in the neighborhood. After a day of training, participants took their way passing by city blocks, underbridge spaces, intersections, and other urban infrastructure. Using EEG measurements, the research team overlapped the data of each participants retaining the spatial qualities.



Picture 3. Mapped areas of attention (red) and meditation (cyan) as volunteers walked through New York's DUMBO neighborhood. Source: https://www.architectmagazine.com/technology/columbia-university-and-the-van-alen-institute-map-how-our-brains-navigate-the-city_o

The recordings taken by Neurosky device collected data of frequencies related to waves of alpha, beta, and gamma, which, through complex algorithms, were simplified in indicators of attention and meditation. In this way, they displayed the findings in a map where cyan color would represent a meditative or relaxed state while red color would heighten awareness. This type of study would have great potential in architecture and planning as the advances of technology could help architects employ this technology in decision-making processes.

Another related urban study using similar methodology is that of (Karandinou & Turner, 2018) who study the relationship of the brainwave fluctuations during our walk-through of everyday spaces. Ten participants were asked to walk through four district routes chosen in Portsmouth city center but were asked to navigate the routes of their choice. Each participant was equipped with EEG device measurement (EmotivEpoc+). Moreover, each participant was also required to film along their road, which was later used for synchronizing the EEG and movements in the city. Researches studied, in particular, the brain responses through frequency bands widths of Beta, Alpha, Theta, and Delta. The recordings aimed to observe common patterns and understanding if wayfinding decisions are visible in brain activity recordings. Moreover, the scope of the aim includes whether familiarity of a place has a visible impact in the brain and how the brain reacts to intersections. In an attempt to confirm the association of beta brain wave frequency with active decision-making or the cognitive function, this study approves the emphasis of beta wave activity in critical points of the wall (wayfinding decisions). Moreover, it has been found that the beta wave is increased when encountering people. Meanwhile, the degree of familiarity in the areas that were more familiar to subjects shows lower rates of Beta in comparison with the cases where subjects did not have any information about the parts of the journey.

Through these studies, we have tried to present the knowledge that science has provided so far to understand carefully the existing state of studies that unite these two fields: architecture and neuroscience through measurements of brain waves. Moreover, these studies have enabled us to understand the gaps in knowledge, the possibilities, and the limits that this interdisciplinary research brings. As a result, we have compiled original research to reduce the knowledge gap by putting some more light in the understanding of this collaborative approach.

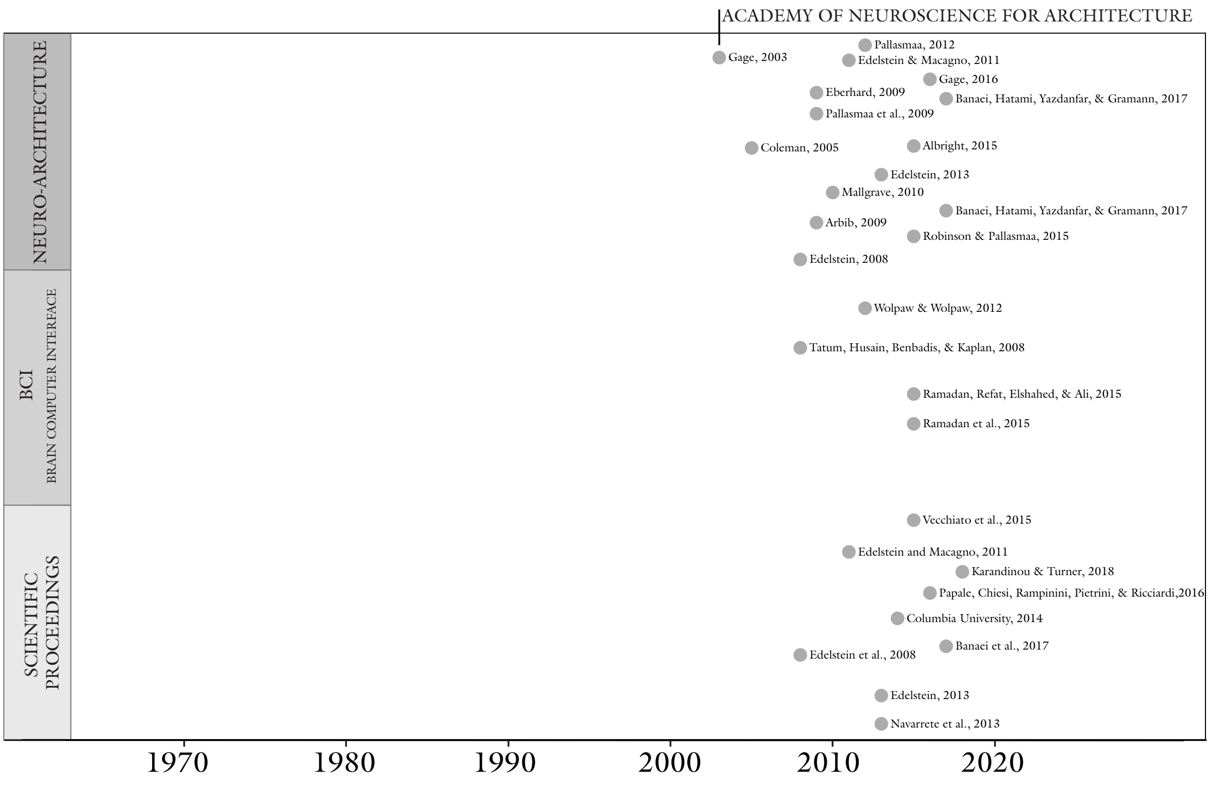


Figure 11. Literature review - Neuroscientific point of view

2.13.3. LIMITATIONS OF PREVIOUS RESEARCH AND ORIGINALITY OF THE STUDY

Occupants' well-being in the indoor environment has seen an increase in concern recently. Albeit, the significant lack in the body of knowledge, particularly regarding the impact that architecture has on the human brain, is one of the main limitations. This raises many questions regarding the best way to accumulate factual knowledge to increase the contribution that this field of study may have on decision-making processes in architecture design.

The goal from our literature review, which was mainly based on scientific journals and books, has been to find experiments that have used similar methodologies of research so that we can have a better understanding of the limits and possibilities. From the literature review presented above, we have observed two polarized architectural and urban research approaches, even though both use the same research methodology - the use of wearable devices for measuring brain waves. The first difference was in the experimental method. Experiments in architecture have mostly been tested through visual stimulation, using screens, projectors, or Virtual Reality (VR) by using 3D renderings as a base stimulus. Whereas, urban research has exposed participants to outdoor environments through free walking or wayfinding tasks in the city. Consequently, this essential difference leads us to the second observation, which pertains to the way of analyzing the targeted factors. In the case of the architectural studies, it is observed that the approach towards building analysis has been simplified by means of focusing on one factor at a time. For example, in all three studies by Navarrete et al. (2013), Vecchiato et al. (2015) and Banaei et al., (2017), targeted architectural elements (e.g., form, curvature, furniture) are analyzed in isolation, without other overlapping factors.

After analyzing both methodologies carefully, we have realized that there is a lack in the approach where the combination of both realms merges. Therefore, this research's significance and originality lie in the fact that we built our experimental design upon a combination of both of the approaches mentioned above. We designed two original research studies that include analysis of factors in isolation vs. combination & rendering vs. real pictures. We have attempted to bring out the advantages and disadvantages of each one of them. Additionally, we have used statistical analysis in order to manage to distinguish between the results of both approaches.

To the best of our knowledge and belief, this research holds the exclusivity in combining together the three factors of architecture: texture, colors, and proportions. We have made an original categorization of these factors by analyzing in detail the characteristics of texture based on usability and method of application; of colors based on the proportional distribution of colors in the physical aspect of the environment, color palette, and combinatorial variations in relation to the quantity and variety of colors; and of proportions by the height of the space and the ratio of openings in relation to the axes of the room, as well as taking into account some of the historical proportional applications such as Golden Ratio, Georgian, Modular, Contemporary, and traditional Japanese, including some of the images of buildings designed by the world-renowned architects such as Palladio and Le Corbusier.

Another benefit of our methodology lies in the aspect of the combination of the data extracted from the brain waves with those extracted from the questionnaire. This will emphasize and explore the possibility of the gap between how the brain reacts to stimuli as opposed to our subjective declarations.

Lastly, since the central question of this research is whether wearable devices for measuring the brain can aid the decision-making processes in architecture, another added significant value lays in our tendency to prove whether professional background, in this case, architects vs. not architects, will demonstrate consistency in perception of architecture, respectively, in brain wave analysis. A possible difference between these two groups is of interest in knowing because architects mainly design for non-architects; therefore, the interaction of these two groups is inevitable. Previous work has failed to address this issue; hence, we believe that through this study, we will draw innovative discoveries and solutions for future possibilities in design. With the limited information and material, the need for observation and understanding of the pattern to create a hypothesis is necessary.

CHAPTER 3

Research Design

CHAPTER 3:

RESEARCH DESIGN

3.1. RESEARCH METHODOLOGY

The premise of this research is to investigate the practice of neuroscience wearable devices to understand human response to design and create a database of evidence that can be used to aid decision-making processes in architecture. Recent developments of non-intrusive neuroscientific devices have led to a growth in the interests of the fields other than those related directly to neuroscience. As introduced in the first chapter, this research aims to study the relationship between architecture and neuroscience and its role in offering practical tools for architects to assist the decision-making processes of architectural design. These technological advances provide a wide variety of biometric research scenarios and paradigms for a more well-rounded view of human behavior. Due to the novelty of the topic regarding empirical evidence, this research will start by collecting initial information from the preliminary test studies to achieve an understanding of the relationship between brain responses and subjective declarations.

This study aims to investigate the effective strategies for increasing the potential of the use of neuroscientific tools in assisting the process of architectural design. Several steps are necessary to be taken in order to access the main question: ***How can the use of neuroscience wearable devices aid the decision-making process in architectural design?***

In the first chapter we have introduced the two main phases of the research: Phase 1 where we understood more about the neuroscientific point of view, findings presented so far, and analysis through the architectural point of view; while in Phase 2 – the following chapters, we will present two original research designs in an attempt to answer the main question by verifying the limits and possibilities that architects may have in achieving the efficient use of neuroscientific tools.

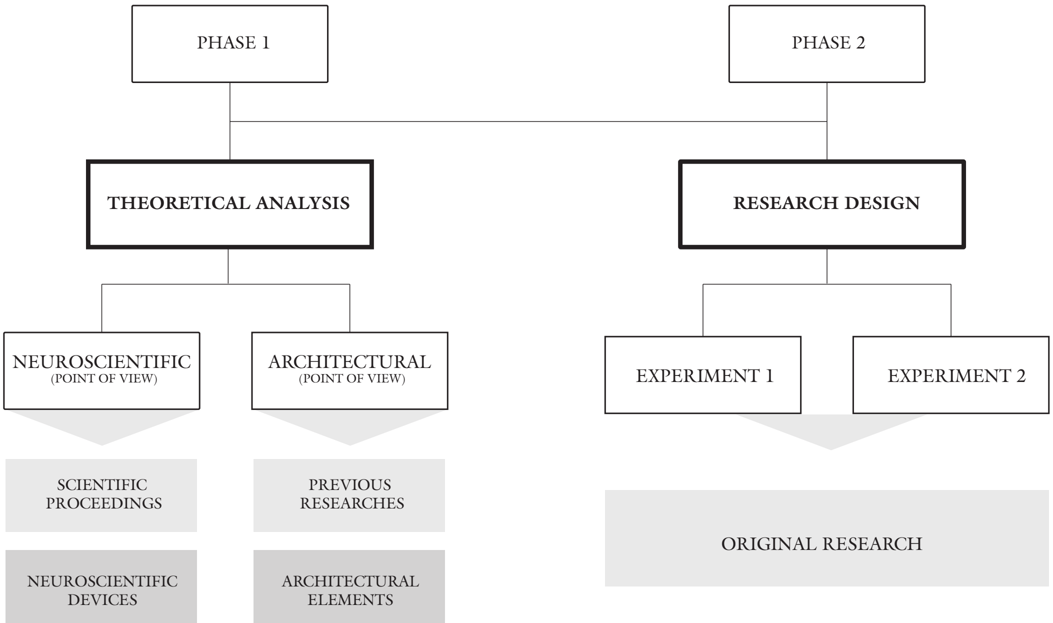


Figure 12. Research methodology

Two consecutive experiments will be conducted using the same methodology but with different content in principle. The second experiment is, to some extent, a continuation of the first experiment and tends to expand its scope of analysis from a single-stimulus analysis of the first phase, in a more complex approach with multiple-stimuli in the second one. Due to the complexity of this study, we have found a need for a progressive approach and elaboration of this research, by gradually increasing the number of target factors. Below an illustration of the flow of the work is presented:

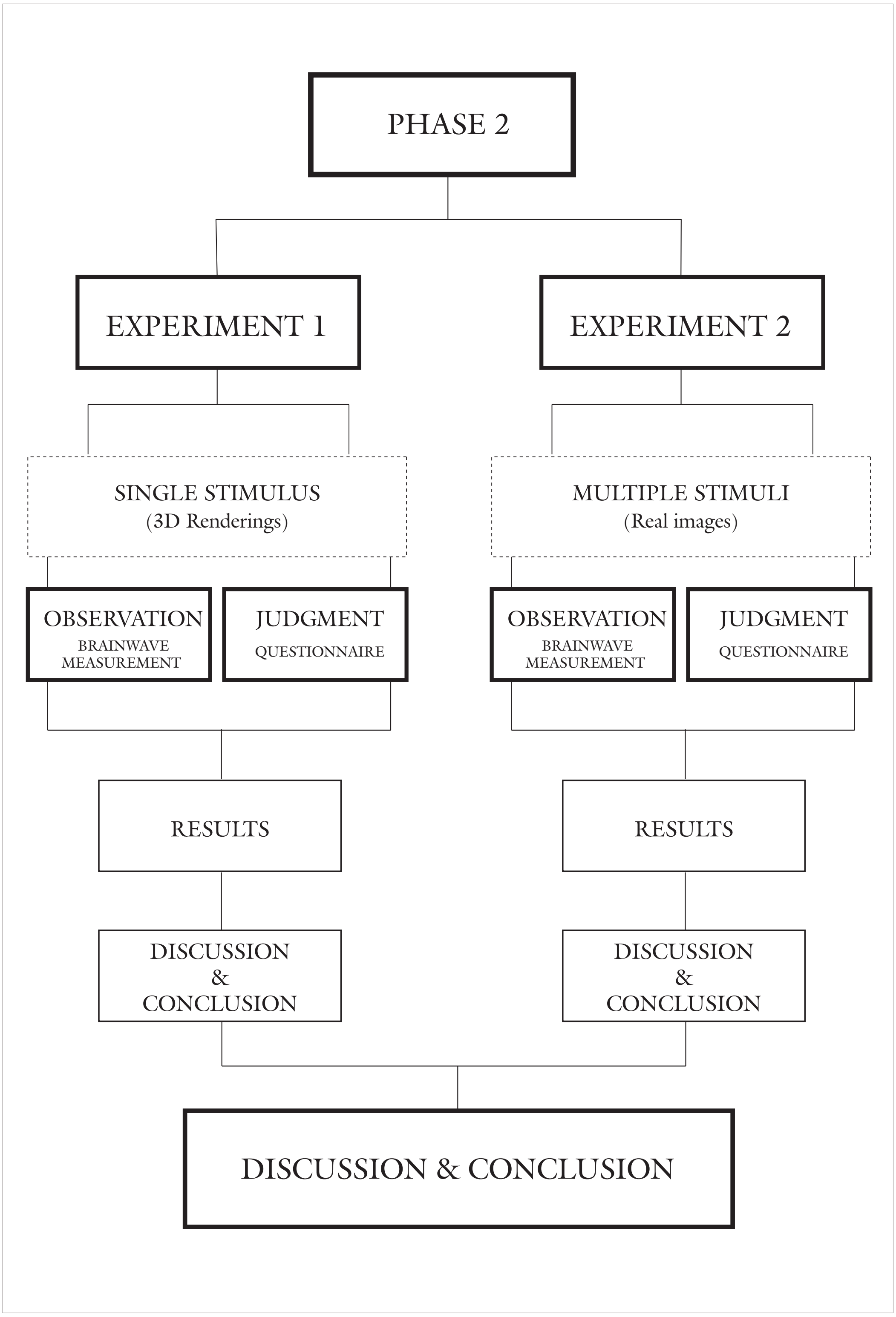


Figure 13. Overview of the Phase 2 of the research

The combination of the two dimensions of judgment and observation will give us a clearer understanding on how indoor built environment is observed by the users compared to their subjective declarations about it.

Both experiments are separated into these two parts:

Part 1: Observation
The first part starts with the visual stimulation of the pictures with the rooms selected for the targeted stimulus over a specific period of time. In the two experiments, visual stimuli have been presented through the projector and monitor screen. EEG brain recordings complement the observation part by using non-intrusive neuroscientific wearable devices available in the market, which will be broadly discussed in the proceeding chapter.

Part 2: Judgment
The second part of the experiment presents the judgment part, where participants are asked to fill a questionnaire and follow a judgment scale presented. The first experiment offers a manual questionnaire. In the second experiment, for interactive purposes, subjects have been given a tablet (Huawei Media Pad T3-7) in which they had a semantic differential bipolar slider designed in MAX Cycling 74 interactive language programming software.

3.2. EXPERIMENTAL DESIGN

One of the main methods to investigate an inquiry in research is through experiments. The experimental design is a technique in the field of statistics that informs us how to organize each sample to maximize statistical accuracy. In order to have a successful experimental design, it is essential to have a strong understanding of the system that we are examining by creating a research question and translating that question into an experimental hypothesis that follows a formal procedure of testing using statistics. It is essential to note that this research recognizes the importance of creating a strong understanding of this system; thus, it aims to identify the variables and see how they are related and create predictions that are specific and testable with the aim to reach to a hypothesis. Consequently, the research methodology of this study will focus on two main points:

1. Consider and define the variables and analyze their relation
2. Make predictions that are testable and specific.

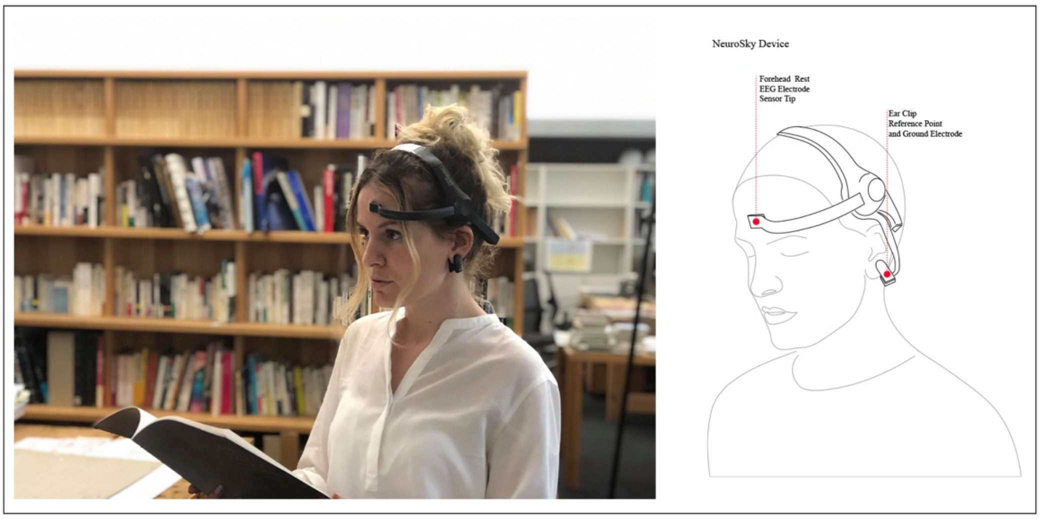
To reach this point, we designed two original experiments that follow the same research methodology but differ in the type of stimuli from single to multiple. In order to interpret the data in an architectural language, we will create charts for each of the groups indicating the tendencies for the relation between brain dynamics and architectural factors. Consequently, due to the novelty in understanding the relationship between variables, this study aims to set the stage for future experimental design through these procedures.

3.3. Research of the Devices in the Market

The recording systems for acquiring electroencephalographic recordings have traditionally been lab-based. However, (Gargiulo et al., 2010; Chi et al.,2010) argue that due to the reports of discomfort and lengthy procedures, in recent years, intending to improve the usability and portability of these devices – while maintaining the data quality - several wireless headset EEG devices have become commercially available (as cited: Rogers, Johnstone, Aminov, Donnelly, & Wilson, 2016). To identify and investigate the current trend of neuroscientific devices in the market, it was decided to do thorough market research of the current commercially available software and meet representative people from selected devices. After the market research, three final devices were considered for this study: Neurosky, Muse, and Emotiv.

Picture 4. Neurofeedback devices. Left: Emotiv; Middle: Muse; Right: Neurosky

Consequently, two meetings were carried, where the detailed introduction of devices has been completed. In conclusion, it was decided that for the reasons that we will provide below, the Neurosky device can be considered for further validation checks. Firstly, the simplicity of this apparatus's use is based on 'dry electrodes' as opposed to Emotiv, which requires wet electrodes and, as such, was considered less practical and comfortable. Secondary, the system comes completely equipped with auxiliary packages for analyzing algorithmic data, which helps define the meaning of the results. Finally, Neuosky presented one of the most feasible ways to reach economic support for this research.



Picture 5. Neurosky device

3.4. NEUROSKY TECHNOLOGY OVERVIEW

Neurosky is a mobile, gel-free device that measures the brain's electrical potentials from the scalp using a single contact sensor on the user's forehead. It is designed to give real-time feedback on brain activity. Neurosky device categorizes the Electroencephalographic (EEG) band frequencies in 7 categories: Delta, Theta, Alpha 1, Alpha 2, Beta 1, Beta 2, Gamma 1, and Gamma 2. Each category has its specific frequency band, which translates into mental states and conditions, from that of deep, dreamless sleep, relaxed state, relaxed and integrated, thinking and aware of the surrounding, and finally that of alertness and agitation (Table. 2).

Brainwave Type	Frequency range	Mental states and conditions
Delta	1Hz to 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz to 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha 1	8Hz to 9Hz	Relaxed, but not drowsy, tranquil, conscious
Alpha 2	10Hz to 12Hz	
Beta 1	13Hz to 17Hz	Formerly SMR, relaxed yet focused, integrated
Beta 2	18Hz to 30Hz	Thinking, aware of self & surroundings
Gamma 1	31Hz to 40Hz	Alertness, agitation
Gamma 2	41Hz to 50Hz	

Table 2. Neurosky EEG frequency band

Its brain-computer interface (BCI) technology works by monitoring brain electrical impulses for each second while the neural signals are inputted into the ThinkGear chip and interpreted with NeuroSky's patented algorithms (Neurosky, 2012).

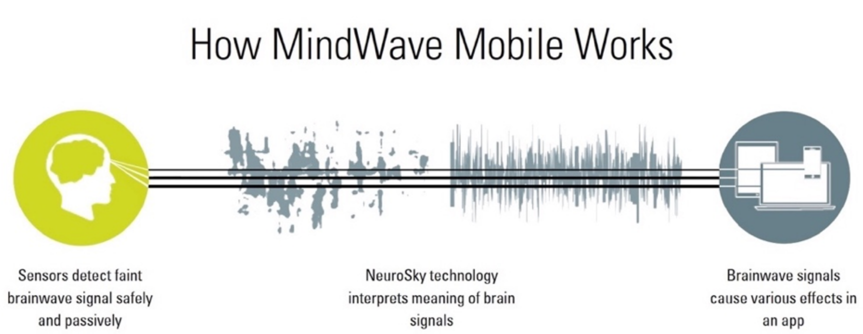


Figure 14. An illustration on how MindWave works. Source: www.neurosky.com

A complex data classification of combined artifacts is presented by the scale of measurement mentioned earlier which determines the cognitive mental state. Consequently, the raw EEG data in the form of neural signals and binary numbers are combined and outputted in two measures: "Attention" and "Meditation." This measurement scale refers to the eSense meters representing Neurosky's proprietary algorithm (Neurosky, 2009).

Based on the NeuroSky indications (Neurosky, 2012), "Attention" values range from 0-100 (eSense meter), and its intensity represents the mental "focus" or "attention". Meanwhile, "Meditation" values have the same range, 0-100, but they indicate the level of mental "calmness" or "relaxation." In addition to the Attention and Meditation, other algorithms offer information about Alertness, Familiarity, Mental effort, Blink detection, Appreciation, Emotional spectrum, Cognitive preparedness, Creativity, and Alertness. For this research, we will focus on the two main and characteristic results of this device: attention and meditation. However, to reach a deeper understanding of these two aspects and validate the usability of this device from past scientific experiences, we have analyzed previous examples through a literature review presented in the next section. The display portrays these measures in the form of waves in two colors, where the y-axis presents the sense scale/power, while the x-axis presents the time in seconds.

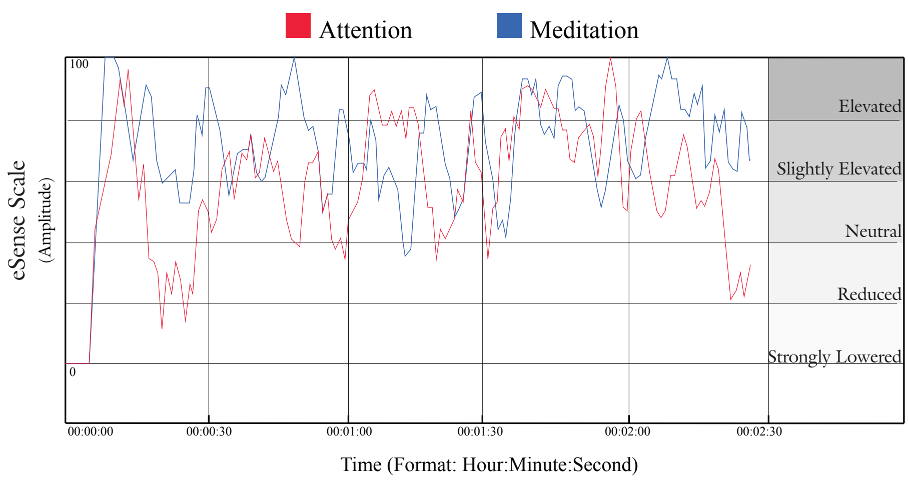


Figure 15. Details of brainwave evaluation using eSense meter scale

3.5. VALIDITY STUDIES

As we understood from the previous chapter, there are several types of devices for measuring brain waves that differ mainly in the number of electrodes and the type of electrodes. As a result, a general understanding makes it noticeable that the greater the number of electrodes, the more detailed the result. Therefore, regarding this point, some questions have been raised on the reliability of the devices which operate with a small number of electrodes. Consequently, in an attempt to investigate the possible shortcomings of the devices that fall into this category, including Neurosky, we have researched scientific evaluations to confirm their validity.

Rogers et. al. (2016) have done an in-depth validity study of NeuroSky ThinkGear Device – using test-retest and reliable channel analyses in order to reach a comparison with traditionally lab-based EEG recordings. Relative power (RP) of the brain-waves such as Alpha, Beta, Delta, Gamma, and Theta were derived from EEG devices from different age categories: healthy young (10-17 years old), healthy adults (18-28 years old), healthy older adults (55-79 years old). The study has been done in several conditions: eyes open, eyes closed, auditory oddball, and visual n-back conditions. The study data were recollected one-day, one-week, and one-month later. Results show that participants' mood was consistent across sessions of all ages. The lest good stability was shown in the open-eye paradigm; however, with the existing data, these findings encourage the use of the portable EEG system for the study of the brain function.

A shortcoming in the higher level of attention, as a trigger for interface changes, has been recognized by HaesenMieke et el. (2009). In their study on the effectiveness of Neurosky Mobile device, authors argue that initial differences in levels and patterns of attention is observed to change from user to user, since some of them have normally higher levels of attention even without being drawn to put more attention. Therefore, this has led authors to notice the need to "level-out" initial differences in attention levels. However, besides this, authors confirm that the readings corelate with self-reported attention levels and approve that the individual readings from the Neurosky MindBuilder are valid and constant.

Another study that validated the use of Neuosky for self-controlled experiments for researchers is Rieiro et. al., (2019). Authors conducted tests on 21 subjects using comparative methodology between medical-grade golden-cup electrode ambulatory device called SOMNOwatch + EEG-6 - versus NeuroSky Mindwave. As a result of several tests simultaneously conducted with both devices (eyes-open, eyes-closed, car-driving), it was concluded that results were "comparable to those obtained with medical-grade ambulatory device." The main limitation was recognized in that Mindwave has a lower signal-to-noise ratio (SNR) than the medical-grade ambulatory, which is an essential point on the Brain-Computer Interface (BCI) application since its performance depends on SNR. As a result, the authors suggest that researchers plan a more significant number of trials to counteract the low SNR. However, overall recordings show a stable state, and the device is confirmed to be valid for self-experiments.

3.6. Evaluation system and data analysis

The evaluation system for this research is based on preliminary research systems and acquiring the characteristics and algorithms provided by wearable devices for measurement. This research's primary system of stimulus has been through visual stimulation, which has been achieved through the projector and monitor screen. The visual stimulation is intended to present various photographs of architectural design, based on the categorization of the parameters mentioned above, which we will discuss in more detail in the following chapter.

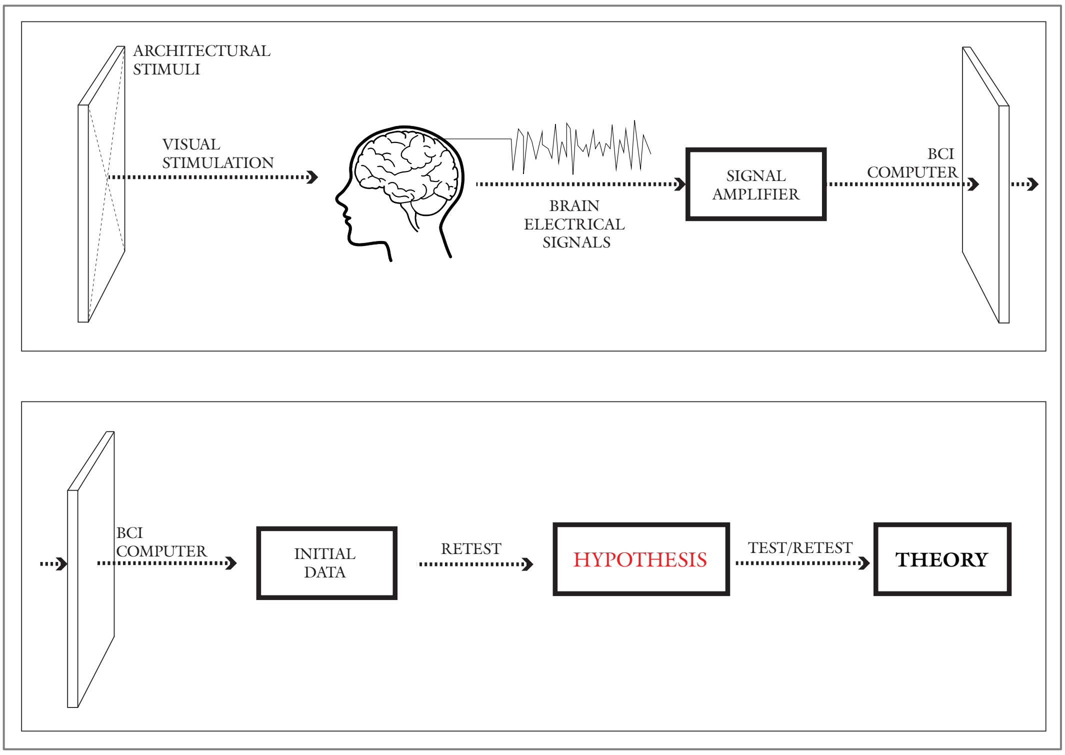


Figure 16. Evaluation system of the research

Participants were asked to observe the visual stimulation while they had the wearable neurological device attached to their body, which measured their brain electrical signals every second for 2-5 minutes. As described in the previous section, the neural signals are detected using a single contact sensor on the user's forehead, inputted into the chip, and interpreted with NeuroSky's patented algorithms (Neurosky, 2012). The two measures, Attention and Mediation, are combined and outputted in the computer display through the Bluetooth network. The installed algorithm allows us access to the raw data (Fig.12) for further evaluation. The raw data consists of binary numbers for each second of brain waves, represented independently (Gamma, beta, alpha, theta, and delta), and as a combined value for the two measures of interest in this study (attention and meditation).

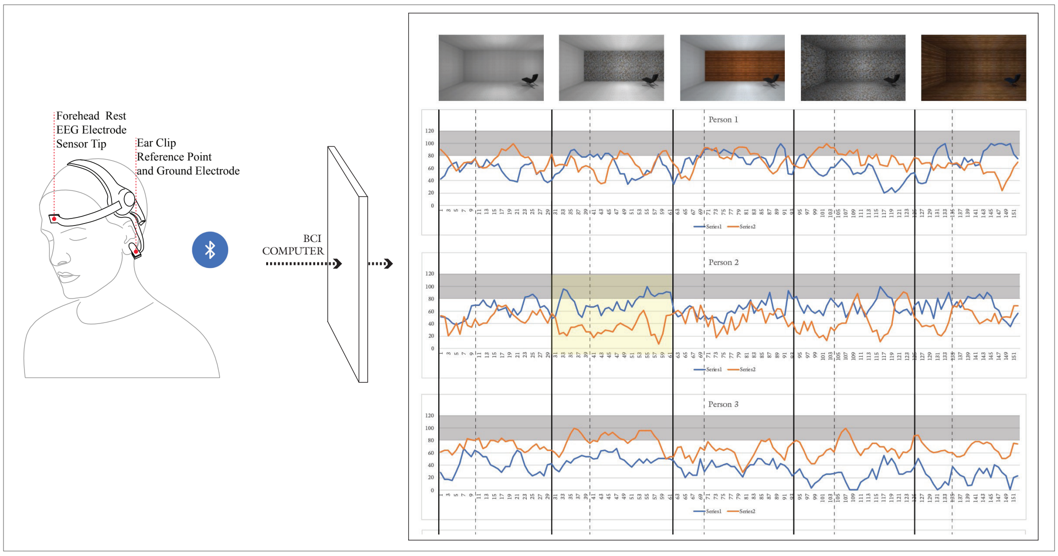


Figure 17. Illustration of the display of the data by Neurosky algorithm

Moreover, raw data presents other values such as the time, signal quality, GPS longitude, and GPS latitude. Moreover, an additional feature of the raw data is other biorhythmic algorithms that the device offers, such as Appreciation, Mental Effort, Familiarity, Creativity, Alertness, Cognitive preparedness, Yin-Yan, and eTensity. Finally, binary numbers for each stimulus are separated and investigated further through statistical analysis to understand their correlation or significant differences with maximized accuracy.

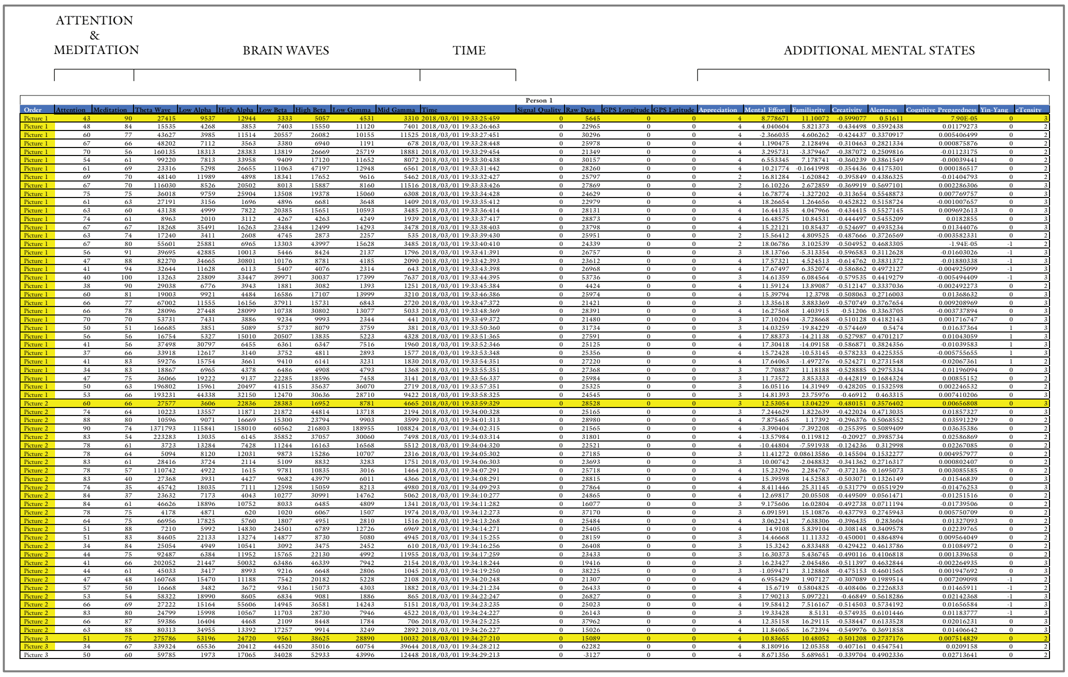


Figure 18. Raw data of the Neurosky Device

CHAPTER 4

RESEARCH STUDY 1

CHAPTER 4

RESEARCH STUDY 1

4.1. INTRODUCTION

This first experiment considered two aspects of analysis: psychological response (brain wave) and subjective declaration (questionnaire). To extract the data for the first part, brain waves were measured using the tool selected for this research – NeuroSky Mindwave. Based on the algorithms that this device offers – information on 'Meditation' and 'Attention', as previously explained, we have tried, through this first experiment, to understand more deeply the interconnection between these two psychological states in relation to the visual stimuli of the environment - which in this case would be the means for testing subjects. Whereas, for the second part of the research, a semantic differential type of questionnaire was used.

Consequently, the reason for combining these two methodologies, and this study has aimed to understand what stimulates these two states and whether there is a connection between subjective preference and brainwave analysis. Moreover, this research aims to understand if preferences and the state of the brain are related to how familiar the subjects are with those environments and their preferences.

4.2. EXPERIMENTAL METHOD

4.2.1. SUBJECTS

Ten volunteers have participated in this study (three females; mean ± SD 30.8 ± 5.79). The group has been mostly composed of the same cultural background (eight Japanese nationals), and two others. The subjects have gone through a visual experience of 5 interior designs same in the point of view, but each differentiated by the wall texture. Each picture has lasted 30 seconds with 3 seconds pause in between with a fixation cross. The subjects were recruited from the campus and lab environment. Of ten participants, nine were of architectural background (architects and graduate students).

4.2.2. STIMULI SET

4.2.2.1. TEXTURE

Visual stimuli of five room typologies differentiated by texture have been used as stimulus material. Before the set-up of the experiment, the initial stage of the process analyzed the previous tendencies of the use of materials and openings in an indoor environment. We analyzed interior design pictures, focusing primarily on texture features, from Books, Magazines, and Open sources on the Internet. The interior texture stimuli were selected based on two sub-categories:

- usability (common and uncommon)
- method of application / proportional balance of the texture in the physical structure (uniformly and in combination)

As a result, 3 final materials were selected: Wood, Concrete and Stone; two of them common (wood and concrete) and one uncommon (stone).

Picture 6. Materials used in test experiment

Despite the choice of the material, the study has also considered the proportional balance of the texture in the environment. As a result, applications as below have been extracted:

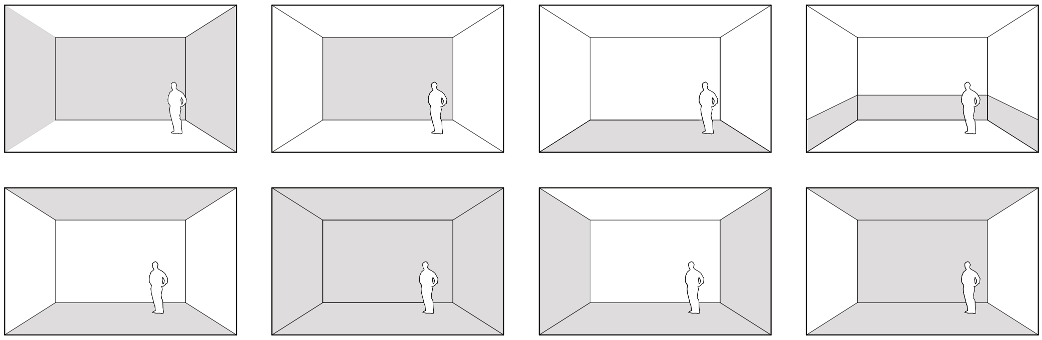


Figure 19. Proportional balance and application of texture in the indoor environment

These variations represent the different application of textures within one room, mainly defined as uniformly and alternatively. Contrasts in the room can alter the way we perceive it - they can enlarge, compact, stretch, narrow widen, shorten, or highlight any particular part of the room. Considering the importance of this selection as part of our experiment and within the framework of this criteria, eight main variations of texture in proportion to its use in the space have been proposed as a consideration: side and front wall, front wall, floor, the lower part of the walls, floor, and ceiling, inclusive, walls and floor as well as floor, front wall, and ceiling.

4.2.2.2. Openings

In the initial stages of compiling and preparing this experiment, in addition to the textures, the openings were also considered an additional feature. Different types of openings have been analyzed for this test experiment: No opening, small horizontal opening, thin vertical openings, and wide openings. An illustration of this study is presented below:

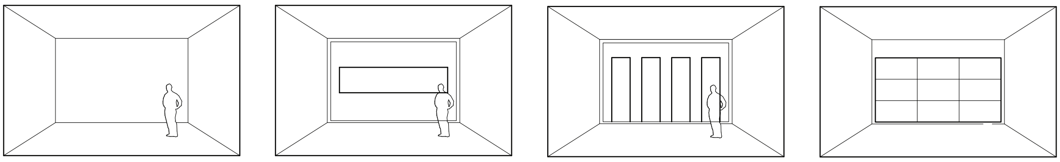


Figure 20. Types of openings analyzed for this study

In an attempt for further analysis for the combination of these two factors, a set of different parameters has been created: No openings, Wide Openings, Narrow Openings. Furthermore, this set of renderings has taken into consideration the proportional distribution of the texture.

No openings (Concrete, Wood, Stone):

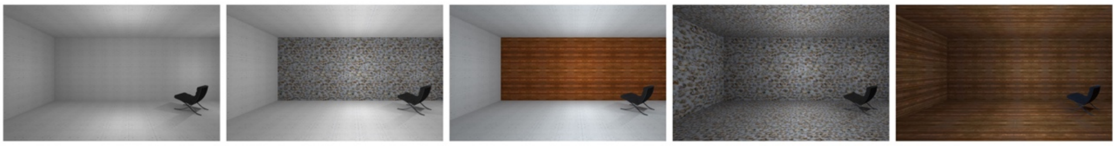


Figure 21. Rendering set representing No Openings

Wide opening (Concrete, Wood, Stone):

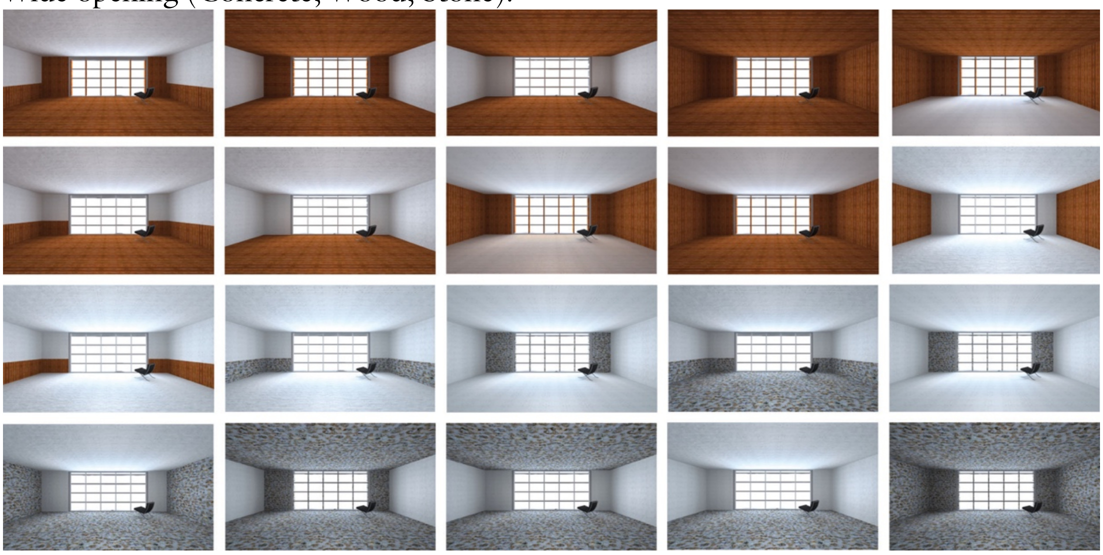


Figure 22. Rendering set representing Wide Openings

Narrow opening (Concrete, Wood):

Figure 23. Rendering set representing Narrow Openings

4.2.3. Finalizing Experimental Set

The analysis above has set the stage for continuation towards finalizing the experiment set up. It is plausible that several limitations may influence our final choice since a substantial issue is that architecture is a complex entity where many factors come together (design, function, colors, light, proportions, etc.). Thus, its complexity does not allow an easy understanding and solution to the issue. In this context, we have tried to simplify the building analysis by focusing on one factor at a time. In this regard, to achieve the goal of simplifying the analysis in as little factors as possible, it has been concluded that for the first test experiment it is favored to eliminate the effect of sunlight and additional furnishing, in order to leave a clean and empty space, without openings, so that people could only pay attention to the impact of the texture.

To achieve a situation that would respond to all the conditions set out above, it has been decided that the interiors will be created originally for this study by 3D rendering dedicated to this experimental set. Additionally, it is suggested that lightness and darkness be achieved as a reflection through the choice of the materials. As a result, a combination of the factors presented below has been chosen as a final set:

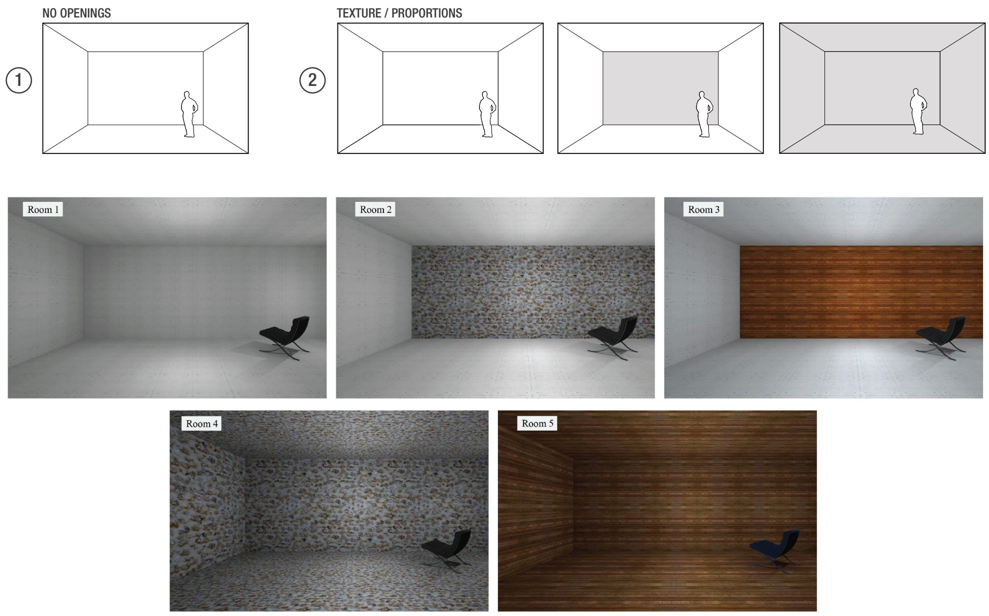


Figure 24. Final criteria choice

5 room typologies differentiated by texture (Wood - ratio100%, Concrete 100%, Stone 100%, Concrete and Wood 50%+50%, Concrete and Stone 50%+50%).

4.3. EXPERIMENTAL PARADIGM

The experimental procedure's event-related design aimed to investigate brain response of the subjects in addition to their subjective declaration through brain wave measurements and questionnaires as two main elements of the set. Five room typologies created have been presented in a planned order starting from the lightest to the darkest. Whereas, in terms of commonality, they are organized in random order. The experiment consisted of two parts: Part 1: Brainwave data acquisition and Part 2: Questionnaire.

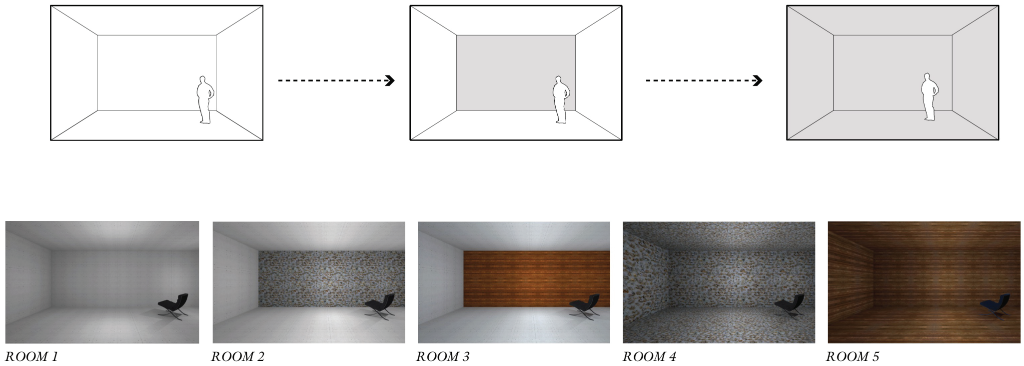


Figure 25.From lightness to darkness through the choice of the materials

4.3.1. PART 1: BRAINWAVE DATA ACQUISITION

The visual stimuli of the event-related design in which subjects' brainwaves were being measured presented one trial of the five pictures - each lasting 30 seconds, while before each picture, a fixation cross was presented for 3 seconds. The total screening time per subject in one session resulted in 2 min and 42 seconds.

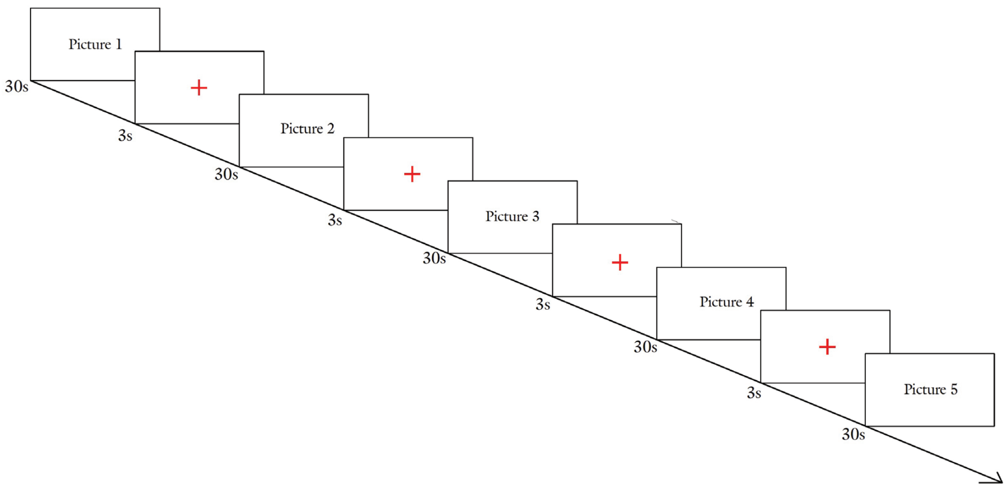


Figure 26. Experimental design

Brain waves were measured using the Neurosky device, while visual projection is achieved through a projector. For a better visual experience, a mock-up as an experimental setting in a U-shaped space 3.6x2.5x3 meters has been mounted.

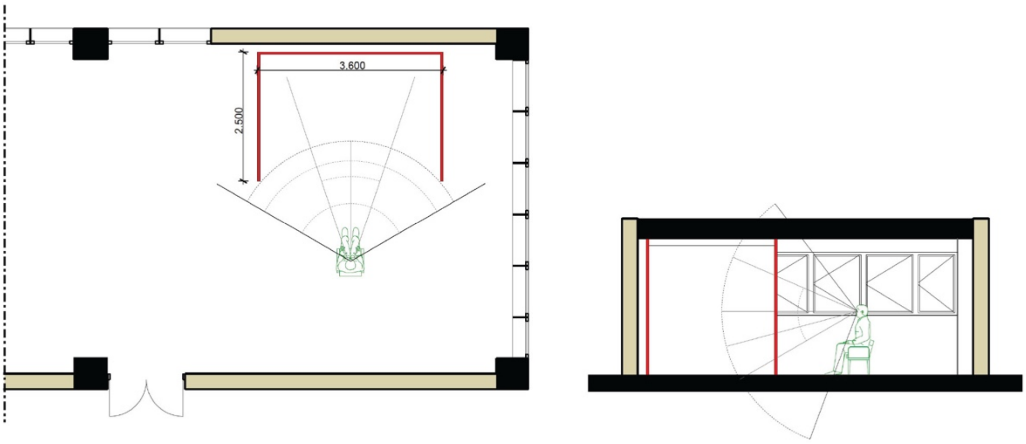


Figure 27. The mock-up experimental setting

The seating distance is considered appropriately to the standard line of sight in order to achieve a more realistic experience.

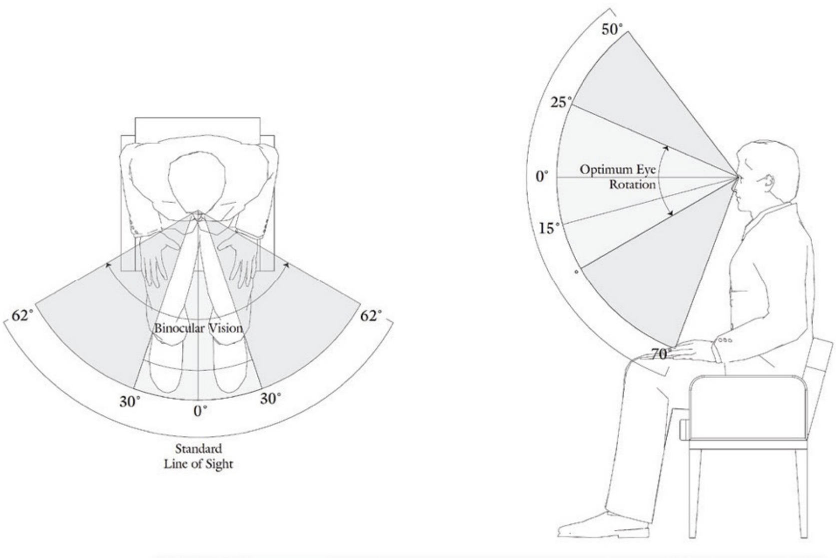


Figure 28. Standard line of sight analysis. Source:
https://www.extron.com/article/environconhumanfact?version=print

Before the start of the session, subjects were informed that the experiment was conducted to investigate aesthetic judgments, but no reference was made to the experimental aims. After this task was complete, subjects were presented with the rooms again in a paper-printed version, this time outside the mock-up room, where they each answered the questionnaire, which counts as part two of the experiment.

Figure 29. Mock-up experimental set up

In addition to the brain wave measurements, to understand and study subjective declaration of the subjects, a questionnaire type of Semantic Differential scale was used. The Semantic Differential is a scale designed in an attempt to measure the semantics or meanings of words. It is designed as an instrument in pairs of common verbal opposites to eliminate uncertainty about the meaning of the object being thought about. A scale is inserted between each pair of terms so that subjects can indicate both direction and intensity of each judgment. The subjects are asked to choose where their position lies to measure opinions (Osgood, Suci, & Tannenbaum, 1957, pp. 18–19). The questionnaire in this study has presented 11 pairs of opposing meanings to get a better understanding of subjective declarations. Figure 21 presents a template of the questionnaire.

4.3.2. PART 2: SUBJECTIVE DECLARATIONS - QUESTIONNAIRES

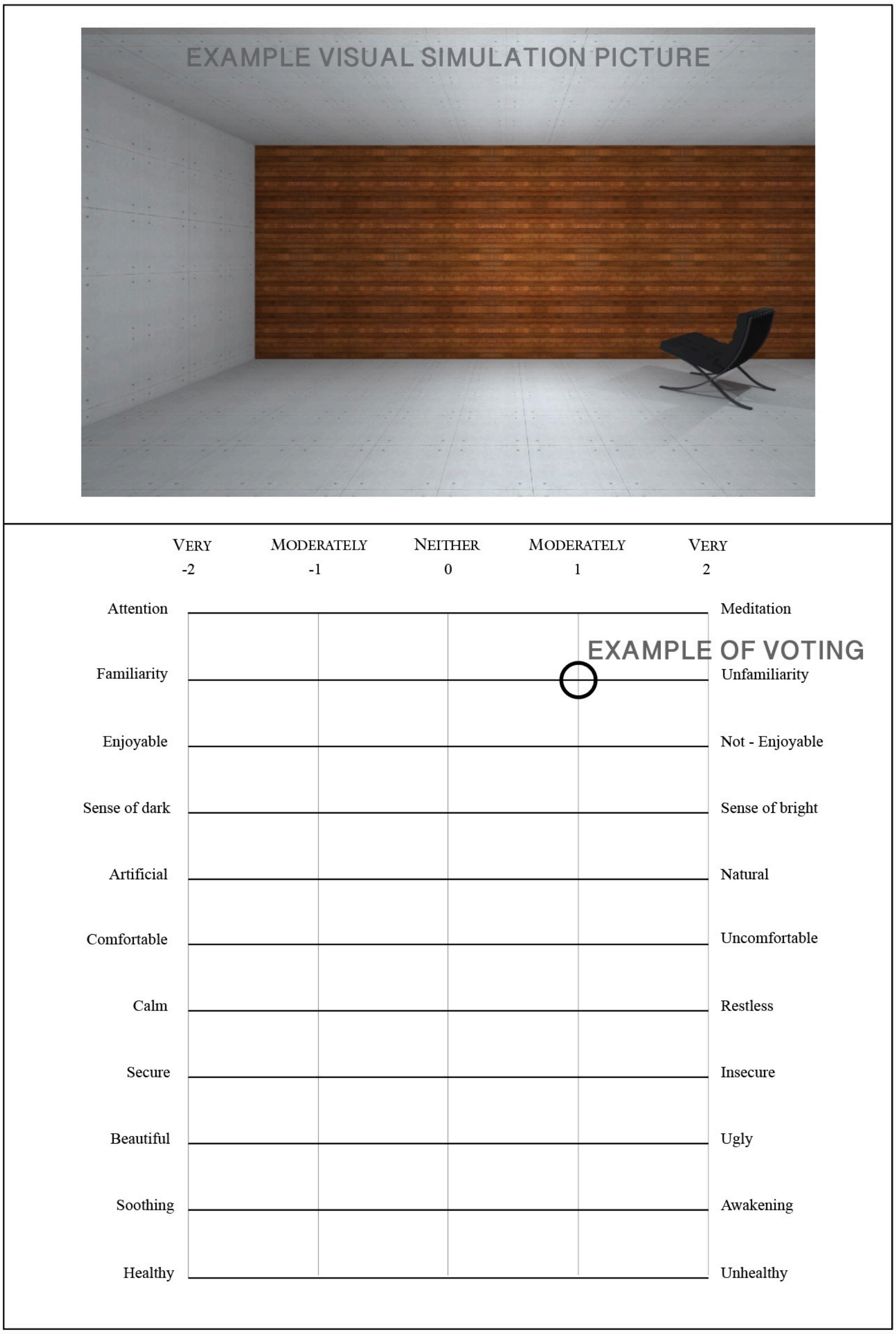


Figure 30. Questionnaire sample

4.4. RESULTS

4.4.1. BRAINWAVE DATA ANALYSIS

To assess the understanding of the results for the brainwaves, the values of Attention and Meditation for each second of the brain waves, (Gamma, Beta, Alpha, Theta, Delta) - converted to binary numbers, have been analyzed and later on were converted to an average value in a chart separated for each subject (Appendix 2). Attention and Meditation are both combinations of different brainwaves; thus, the analysis is made independently. Given the limited number of subjects, data from the binary numbers are interpreted in two ways: from an individual and an average point of view. In both Attention and Meditation analysis, we observed differences (Fig. 22) within groups that represent room pictures. However, to statistically determine differences between the groups towards understanding whether there is significant differentiation between them, further statistical analysis was conducted.

4.4.2. STATISTICAL ANALYSIS

4.4.2.1. ATTENTION VALUES

The results of this experiment were tested using standard statistical techniques. First, for both attention and meditation, we calculated the mean values for the rooms where each of the five rooms represented one independent variable (group) for 10 participants ($M=30.8$, $SD=5.79$). Our goal was to determine whether there are any statistically significant differences between the means of the five rooms (groups). The one-way analysis of variance (ANOVA) was used to detect any significant changes that could influence EEG recordings between the average values of participants for the five rooms. Statistical analysis data was produced using EXCEL 2019 (Microsoft Inc.). A p-value of <0.05 was considered significant.

The results showed that there were no statistically significant differences between group means as determined by one-way ANOVA: $F(4,45)=0.602$, $p=0.6$ (Appendix 2).

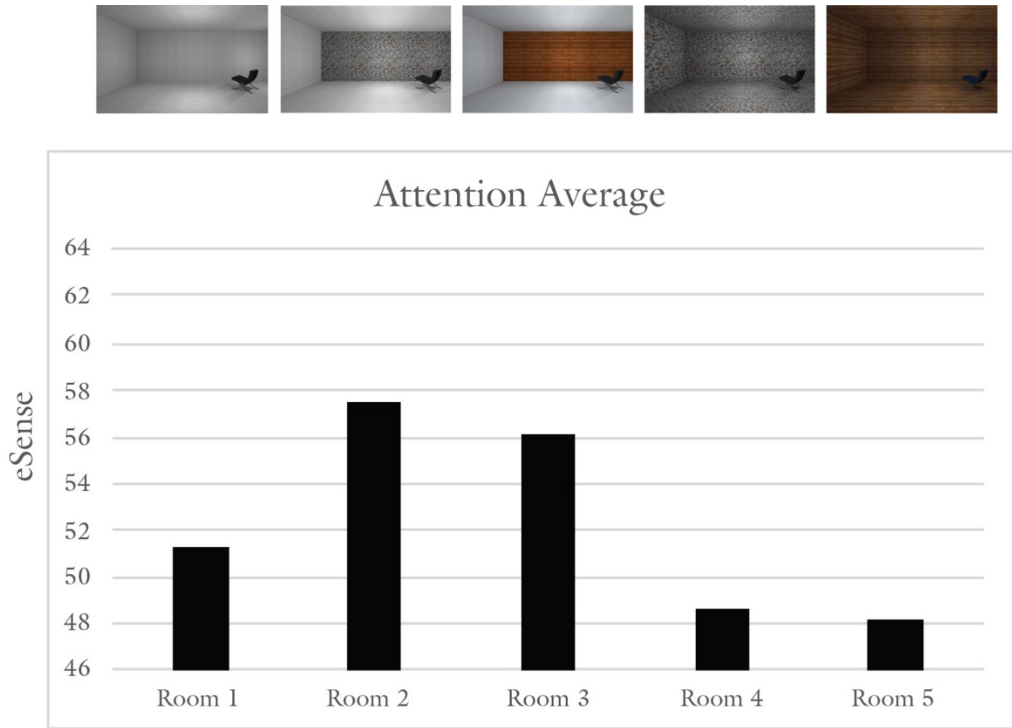


Figure 31. Attention average values

One of the participants has shown a highlighted difference in the mean value in picture number 4. As a result, a Grubb's test, also called the ESD (extreme studentized deviate), which is a test to detect outliers, has confirmed that the value is further from the rest but not a significant outlier ($P>0.05$). As a result, the participant has been included in the group of participants. However, on average, the tendency for the greatest attention has shown room number two, representing the combination of concrete and stone.

Picture 7. Room number 2 - highest mental effort

Meanwhile, another set of ANOVA analysis have been conducted in an individual level, where all 10 participants showed significant differences between pictures with an average p value of p=0.0000578 (Appendix 2).

The analysis revealed that the tendency for the highest statistical significance was showed in the raise of the attention for picture of Room number 2, which is in correlation with the aforementioned analysis, while picture of Room number 5, on average, has shown a statistically significant drop in the attention.

Picture 8. Left: Picture number 2. Right: Picture number 5

4.4.2.2. MEDITATION VALUES

The second set of analyses repeated the same statistical analysis procedure that has been conducted for the attention by investigating possible statistical significance between pictures representing groups. Consequently, the one-way analysis of variance (ANOVA) was used to detect any significant changes that in the same way could influence EEG recordings between the average values of participants for the five rooms: 5 (rooms representing independent variables) x 10 (participants for each treatment).

The results showed no statistically significant differences between group means as determined by one-way ANOVA: $F(4,45)=0.506$, $p=0.7$ (Appendix 2).

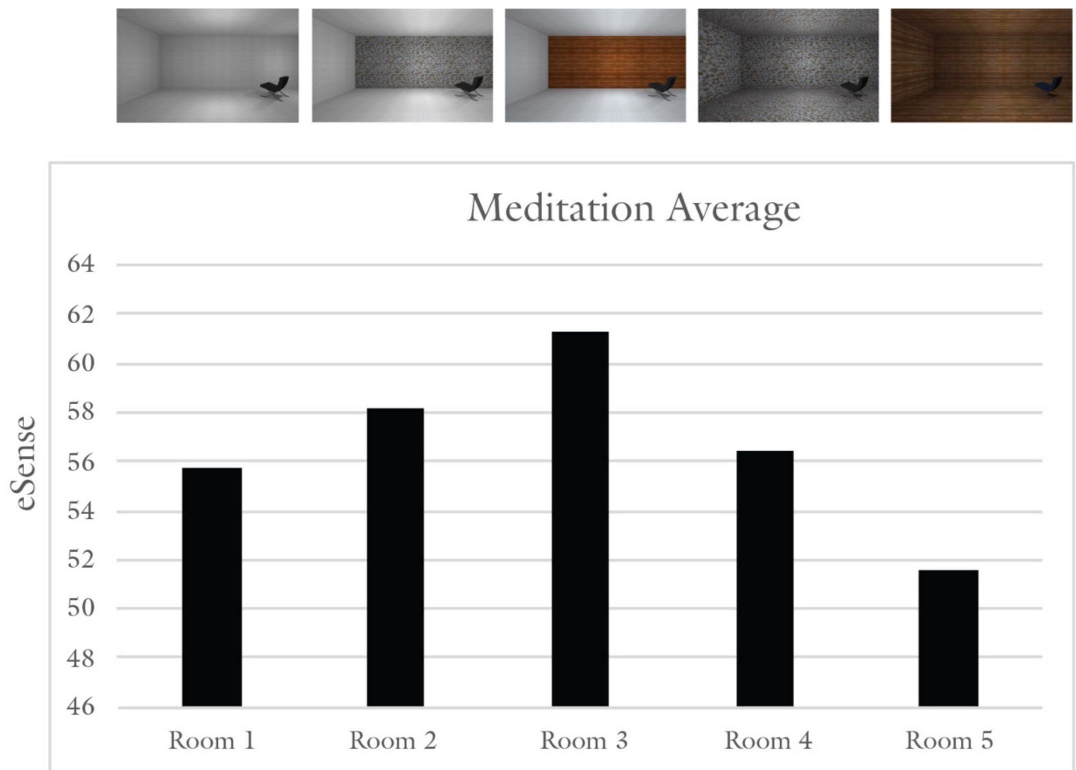


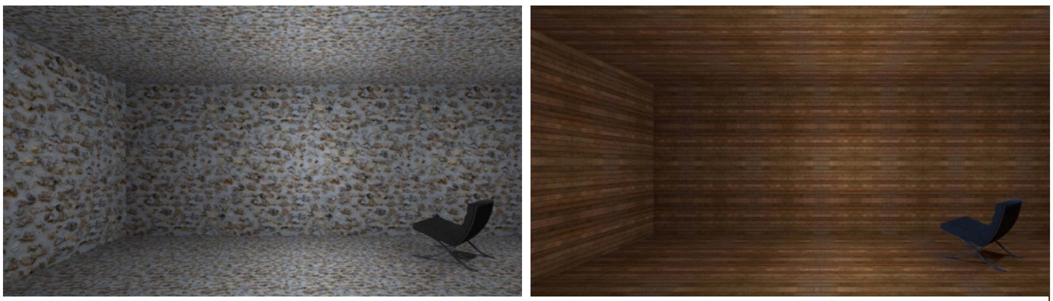
Figure 32. Meditation average values

However, on average, the tendency for the highest meditation has shown room number three, which represents the combination of concrete and wood shown in the picture below:

Picture 9. Room number 3 - highest meditation level

Moreover, similarly to the Attention analysis, another ANOVA test has been conducted to observe the significant difference of pictures on an individual level. 8 out of 10 participants have shown statistical significance in the difference between the pictures.

Contrary to the expectations, 33.3% of the participants have shown a significant increase in the meditation on picture number 4 (100% stone), while the tendency for the lowest meditation statistically significant has been observed in the picture number 5 (100% wood).



Picture 10. Left: Picture number 4. Right: Picture number 5

4.4.3. Alternative biorhythmic algorithms

In this experiment, in addition to the analysis of two measures of interest, we have taken into account two additional considerations provided by the biorhythms of the algorithms integrated into the analysis package – 'Familiarity' and 'Alertness.' It is worth mentioning that this type of analysis has only been used only this one time for the first experiment. The rest of the analysis for the proceeding experiment will again count on our intended measures, "Attention and Meditation." The reason we chose this alternative approach using these two additional algorithms is to have a broader perception about the way they correlate with Attention and Meditation and also to see if the "familiarity" and "awareness," posed as a question in the questionnaire, will correspond with the algorithm result of brain measurements for the same inquiry. This set of analyses highlighted, in particular, a raise of the familiarity value for room number three - consisting of the combination of wood and concrete. On the other hand, the results revealed that the same room showed the lowest alertness between all five rooms.

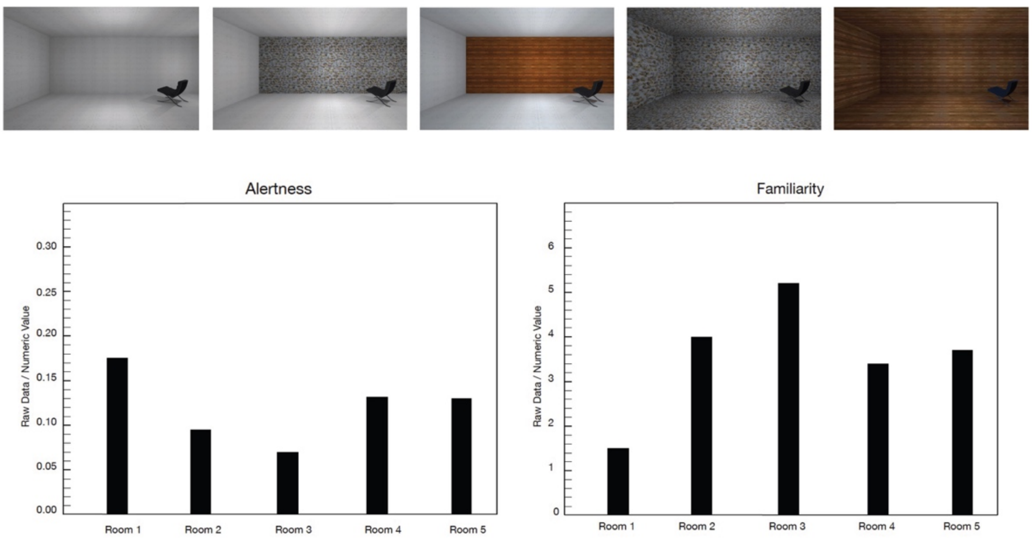


Figure 33. Results of biorhythmic algorithms of Alertness and Familiarity

4.4.4. Subjective Declarations

To assess the questionnaires of the subjective declaration, a Semantic Differential method was used, which offers a variety of questions towards feelings. The first set of analyses that we investigated highlighted the impact of different textures on subjective preferences. (Appendix 2A)

Picture 1, composed of an immersive light concrete environment, averaged the highest score in the field of the opposite subject between beautiful-ugly. Of 10 participants who completed the questionnaire, 7 of them estimated that this picture stands between the two highest values in terms of beauty. Whereas, the vast majority have said that this space gives them a sense of artificiality. Moreover, this picture tends to evoke the meditative feeling of people and the sense that the environment is bright.

Picture 2 on the other hand, in contrast to picture 1, in the questionnaire addressed to the participants, turned out to be more inclined towards raising attention than raising the meditative state by leaning towards the feeling of *non-familiarity* and *artificiality* with over 60% of participants evaluating it with moderately high or high value.

Remarkably, Picture 3, which represents a combination of wood and concrete, a usual case in our everyday environments, has further strengthened our confidence in the relationship between familiarity and meditation. In this regard, a significant correlation has been found by marking Picture 3 as the most familiar with 90% of the participants feeling a moderate to strong familiarity towards it. Similarly, the average meditative state of brainwaves of the 10 participants has reached the highest point of meditation during Picture 3.

In response to Picture 4, all of the participants (100%) indicated that the room immersed with stone makes their attention very high (maximum value), while, for over 60% of the participants, the same room gives over moderately a natural feeling. Moreover, seven other categories that have yielded moderate results are related to feeling unfamiliar, uncomfortable, restless, insecure, ugly, awakening, and unhealthy.

Picture 5 revealed a strong sense of naturality being rated as such with an above-average value by 70% of participants. On the other hand, the same picture is rated as the most meditative of all categories. The same value is estimated to be moderately ugly but yet, has given a sense of moderate healthiness as well. However, no significant correlation was found between high attention and unfamiliarity.

4.5. RETESTING

To verify the results of the first experiment, one of the participants was taken for retesting after two years. When asked if he remembers the experiment, he recalled the experiment, though not in detail, and agreed to have it tested again. For the retesting of the subject, a t-Test (two-sample assuming equal variances) was used to detect any significant changes that could influence EEG recordings between the average values of participants for the first time (March 2018) and the second time (March 2020) for the five rooms. Statistical analysis data was produced using EXCEL 2019 (Microsoft Inc.). A p-value of <0.05 was considered significant.

Similarly to the beforementioned methodology, the retesting has followed the same idea and the procedure of the experiment. Consequently, the subject has started the experiment with the first part of the experiment by observing the photographs while we measured brain waves and has continued to the second part of it with the completion of the questionnaire.

4.6. RESULTS OF THE RETESTING

4.6.1. BRAINWAVE DATA ANALYSIS

The results from the retesting of one participant indicate that both meditation and attention show a statistically significant change from the first time around (Fig. 35).

Attention: brainwave fluctuations throughout the whole pictures (5 rooms) between the first time and two years later on the second time, show a statistically significant rise t(8)=-4.48, p=0.001 in the second time (Appendix 2A).

Meditation: contrary to the attention, brainwave fluctuations throughout the whole pictures (5 rooms) show a statistically significant drop in the meditation in the second time, different from the first time t(8)=2.76, p=0.02. (Appendix 2A).

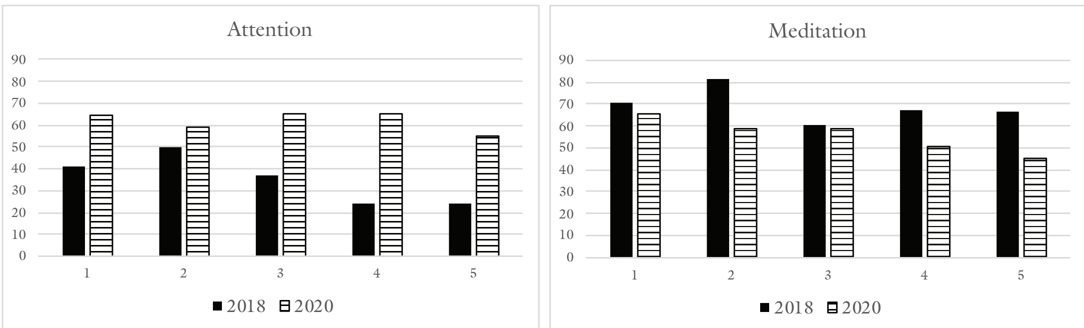


Figure 34. Comparison between Attention and Meditation in 2018 and 2020

In a general view, the first time of the experiment was characterized by highlighted difference between meditative values and those of attention, while in the second time of the experiment, the difference between the two is less emphasized. The picture that was said to have the impact of great meditation has shown a drop in the second time.

4.6.2. Subjective Declarations - Questionnaires

We can see from the questionnaires a great resemblance to the feeling in the two different years as opposed to the brain waves, where we could see a significant change. In most cases, the answers are almost the same, with very few changes. However, a t-Test: Two samples assuming equal variances have been used to detect any significant changes that could happen between participants' values for the first time (March 2018) and the second time (March 2020) during questionnaires.

Statistical analysis data was produced using EXCEL 2019 (Microsoft Inc.). A p-value of <0.05 was considered significant. To assess the data, we have compared the results of each room in pairs (Room 1: 2018 vs. Room 1: 2020) between two years for all five rooms, and none of the pairs have shown a significant change:

- Room 1:2018 vs. Room 1:2020 / p=0.5
- Room 2:2018 vs. Room 2:2020 / p=0.3
- Room 3:2018 vs. Room 3:2020 /p=0.4
- Room 4:2018 vs. Room 4:2020 /p=0.2
- Room 5:2018 vs. Room 5:2020 /p=0.2

4.7. Discussion

The results of our experiments strengthen our understanding of the relationship between brain dynamics and subjective declaration. The most striking result to emerge from the data is that between the two pictures with the highest value of Attention (Picture 2) and Meditation (Picture 3), we found a correlation between the risen values and the subjective declaration of familiarity / non-familiarity. Room number 2, which revealed the highest values of attention, was declared from 60% of the participants as unfamiliar. In comparison, Room number 3 showed moderate to a strong sense of familiarity with 90% of the participants. It is assumed that this underlines the correlation between the low mental effort and the familiar environment. No significant differences and abruptions have been observed besides the beforementioned cases. Additionally, alternative biorhythmic algorithms of Alertness and Familiarity have shown a rise in the familiarity in picture number three during a drop in the same picture's alertness. This strengthens the interrelationship between observed between familiarity and low alertness of the brain reaction with those of subjective declarations.

Given that our findings are based on a limited number of electrodes, results from such analyses should be treated with considerable caution. Perhaps the second photograph has increased so much attention as the presentation of a rough material immediately after the soft one (from concrete to stone).

We suggest that there is a possibility of a discrepancy between what people say and how they feel about architecture. This discrepancy between the brain waves and our thoughts on architecture suggests that perhaps architecture is a learned feeling. If wood associates with nature - forest or mountain, then it also associates with relaxation. Furthermore, when we ask people what they think of a wooden room, they would say that it would generally give them the feeling of meditation, but the brain waves show a different state.

Here are many factors that could have influenced changes in brain waves: the hierarchy of orders of the photos from soft to rough, from half to full, but what we see from these analyzes makes us wonder if this inconsistency is consistent over time. For this reason, it was thought that a retest would help us clarify this situation.

Another factor in this experiment's background was the analysis of whether the reaction would be different from materials that are commonly part of the interior than those that are not. For example, the target cultural background subjects for this study were Japanese nationality in Japan, where wood and concrete are most commonly used in an indoor-environments than stone. Therefore, we considered that one of the ways to analyze the brain reaction would be if we combined these materials in such a way as to observe if the brain would present any extraordinary reaction to the common/uncommon (familiar/unfamiliar) cases. As a result, this has also contributed to the final selection of materials.

Contrary to the expectations, Room number 4 which represented the 'uncommon' interior situation did not reveal any significant rise or drop in the values of either Attention or Meditation, albeit the subjective declaration of all of the participants (100%) indicated that particularly the room immersed with stone gives a feeling of a raised attention by evaluating it with the maximum amount.

4.8. CONCLUSION

This first experiment provided enough data to understand some of the relationships between brain dynamics and subjective statements. However, some critical issues have been raised from this first experience that require further in-depth study to get a clearer understanding:

(1) Familiarity: We have noticed a link between familiarity and brain response, especially when the increase in meditation has shown a relationship to the

familiar environment while the increase in attention to the non-familiar environments. It is plausible that a number of limitations might have influenced the results obtained. The first is the possibility that the displayed photographs' perception has not conveyed adequately the feeling of reality since the created environments have been 3D renderings - without opening and natural light. Given this limitation, we suggest that to investigate further and verify the relationship between familiarity and brain dynamics, the stimulus should represent environments from real photographs of interiors.
However, it is acceptable for us to think that the difference between familiarity and non-familiarity could influence the brain dynamics, thus, from this interpretation, an important question arises:

Q1: Is familiarity related to a higher meditative state?

(2)Memory: From the subjective statements, we noticed that the judgment did not change in the time between the two years, while the reaction of the brain waves underwent a statistically significant change. However, one limitation regarding this issue could be allocated to the limited number of subjects retested (1 out of 10). As a result, further data collection would be needed to determine precisely how consistent is the similarity of declarations after the repetition of the tests.

Despite the limitation mentioned above, we firmly believe that this evidence of the inconsistency between brain waves and subjective statements at two different times requires further study. These results point to the probability of another research question:

Q2: Does the judgment of the architecture come from a learned experience, and as such, it is consistent through time?

(3)Preference: From both of the above issues, it is impossible to avoid the question of whether our preference for architecture is based on memory, and whether we can associate it with any of the two states of mind that we have as a research point (Attention and Meditation). Therefore, to understand this issue in more depth, the next questions should be investigated further:

Q3: Do we tend to show preference to the environments that are familiar to us?
Q4: Is there a relationship between preference, familiarity, and brain dynamics?

The evidence from this study one more time points toward the idea that a substantial issue of this multidisciplinary approach to uncovering the possibilities of the relationship between architecture and neuroscience is that both of the topics are a complex entity where many factors come together. Architecturally wise, the design, function, colors, light, proportions, and combinations do not allow an easy understanding and solution to the issue.

In this context, the following chapter attempts to answer these questions, which also serve as a foundation for conducting and designing the next experiment.

CHAPTER 5

RESEARCH STUDY 2

CHAPTER 5:

RESEARCH STUDY 2

5.1. INTRODUCTION

In an attempt to deepen the understating of the interrelation between variables, brain dynamics, and subjective declarations, we organized the second experiment built upon the results and considerations of the first one. The second experiment, which proceeds very much in the same way as the first experiment, again, considered two aspects of analysis: psychological response (brain wave) and subjective declaration (questionnaire). After analyzing the results of the first experiment, some fundamental issues were raised, which we used to deepen our research further. Therefore, the previous experiment raised some questions that we will elaborate on and find answers for in this chapter.

5.2. EXPERIMENTAL DESIGN AND PROCEDURE

The experimental set-up for the second experiment bears a close resemblance to the first one; thus, it is built based on the premises mentioned above. However, we modified the variables and the type of visual stimulation based on the results, limitations, and possibilities encountered in the first experiment. Generally, the second experiment is, to some extent, a continuation of the first experiment and tends to expand its scope of analysis from a single-stimulus analysis of the first phase, in a more complex approach with multiple-stimuli in the second one. However, as mentioned in the previous chapter, due to the complexity of this study, we have found that there is a need for a progressive approach and elaboration to this research, by gradually increasing the number of target factors.

5.2.1. Experimental set-up considerations

The following considerations are drawn as recommendations from the limitations that we encountered in the first experiments, which assisted in the experimental set-up for the second experiment.

- *Cultural background*: Cultural background can have a significant impact on the perception of the environment. For example, in the first experiment, the subjects' cultural background was mostly of Japanese nationality (8 out of 10 participants), for it can thus reasonably be assumed that due to the commonality of wooden indoor environments in Japan, the connection to the wood would be much stronger than that of the stone. Therefore, we consider that an increase in the diversity of composition of the group must be taken into account to observe if the brain would present any extraordinary reaction to the common/uncommon (familiar/unfamiliar) cases in a broader range of factors.
- *Professional background:* In the previous experiment, 9 out of 10 participants had higher educational backgrounds in the field of architecture. As mentioned by (Kirk, Christensen, & Nygaard, 2009), the expertise impacts cognitive and perceptual systems, meaning that architects and non-architects perceive space differently. We can thus suggest that there is some likelihood that the results of our experiment do not represent an extended group of users. Therefore, for the second experiment, we suggest expanding the variety in terms of professional background. Ideally, we try to equalize the number between architects and non-architects so that we can verify the results of Kirk et al., (2009).
- *Subjective declaration:* In the first experiment, the questionnaire in the form of Semantic Differentials had a total of 11 opposing words to understand closely how the participants feel about those rooms. However, since the results have explicitly emphasized two areas

(familiarity and preference), we have considered that we will reduce the questionnaire to only these two premises for the second experiment.

- *Participants:* Despite the consideration of increasing the diversity of participants from the cultural and professional point of view, in this experiment, we also aim to increase the total number of participants by intending to double it.
- *Architectural Factors*: Given that the previous experiment did not show a significant statistical difference between the photographs, it is possible that limitation in the number of stimulating factors to only one (texture), which has resulted in a minimal change in architectural expressions, could have caused this. Moreover, as (Jamrozik et al., 2018) stated, "knowing the effect that environmental conditions have in isolation cannot predict their effect in combination," we consider that an increase in the architectural factors would raise the sense of the realness of the environment. To apply this more efficiently, we have decided to expand the categories from that of only 'texture' to 'texture, color, and proportions'.
- *Testing time*: From the first experiment, we noticed that the test time, which lasted 30 seconds, is likely that it could have been a long time and may have caused a possibility for loss of focus from what we intended. Therefore, we have discussed shortening the presentation time of stimulation based on similar researches.
- *Visual stimulation*: Based on our results, we suggest there is a possibility that perception from the displayed photographs has not conveyed the sense of reality adequately since the created environments have been 3D renderings - without opening and natural light. Given this limitation, we suggest that the visual stimulation should be presented from real photographs of interiors. We note that the images presented for this study are taken from open sources and all of the pictures are referenced at the end of this thesis.

- *Stimulation setting*: Lastly, for the first experiment, we built a mock-up room to simulate an immersed environment. However, due to some site reconstructions of the room used before, we could not continue to use the same mock-up for the second experiment. As a result, for the second time around, we used the lab environment as the physical space and a monitor for the visual stimulation. Thus, it is essential to note that certain limitations in the results are expected due to the change in this setting's mode.

5.2.2. Subjects

Nineteen volunteers have participated in this study (eight females; mean ± SD 31.0 ± 6.11). As intended, the group of participants has doubled and raised the variety of cultural backgrounds, which now consisted of 9 Japanese, 1 Korean, 1 Thai, 1 Taiwanese, 1 Kosovar, 1 Sri Lankan, 1 Moroccan, 1 Hungarian, 1 Iranian and 1 Spanish. Moreover, as reported above, we have also increased diversity in the professional background.

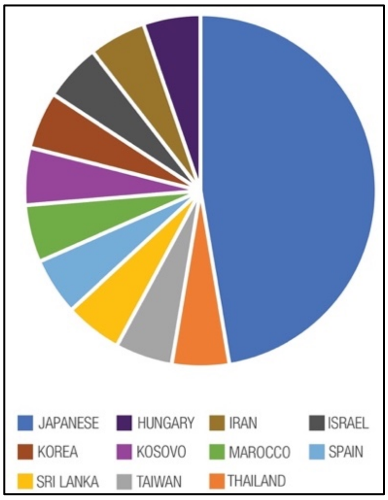


Figure 35. Participants by cultural background

Kirk et.al. (Kirk et al., 2009), on their brain study using fMRI, have proved that the brain correlates to aesthetic expertise. Their experiment on the judgment of architecture has tested two groups of people (architects and non-architects) exposed to architectural stimuli and controlled stimuli (faces). The results show that expertise impacts cognitive and perceptual systems. Therefore, we tent to bring together two groups of people, architects, and non-architects, to see the difference between their judgment and observation, as well as understand the impact of the cultural background. In this regard, we achieved to create a group in which the number that has no prior education on architecture would prevail. As a result, 12 participants were non-architects, and 7 were architects.

Before the start of the experiment, participants were informed that the research was related to the investigation of aesthetic judgments during the measurement of brain waves, but the experimental goals were not mentioned. This study was approved by the Ethics Committee of The University of Tokyo.

5.2.3. Testing time

Several authors have tried to understand how long it takes to perceive a certain situation. For example, Rayner et al., (2009) argue that while viewers can extract the gist of a scene from a brief 40 to 100 ms (milliseconds) exposure and readers only need to view the words in the text for 50 to 60 ms to read normally - it is different in the case of processing a scene. They further indicate that for viewers to be able to normally process a scene, they need it to last for at least 150ms. Our experimental idea bears close resemblance to theories and methodologies of brain-related studies such as (Cattan, Mendoza, Andreev, & Congedo, 2018; Kirk et al., 2009; Menzel, Kovács, Amado, Hayn-Leichsenring, & Redies, 2018). We refined our method of the time frame consideration as overviewed by (Sur & Sinha, 2009) on the event-related potential.

As mentioned by (Sur & Sinha, 2009), when the brain responds to specific events or stimuli, it generates very small voltages from its structures called *event-related potentials*. These potentials can be triggered by sensory, motor, or cognitive events. Furthermore, the authors have divided these potentials into two main categories: early waves (within 100ms), which they have described as "sensual" as they depend mainly on physical parameters, as well as subsequent waves, which are a reflection of information evaluation or "cognitive" processes. Similarly, (Cattan et al., 2018) on their study on virtual reality for gaming, highlight the event-related potential, in particular the oddball paradigm as an experimental design that presents repetitious stimuli flashed on the screen, typically in groups.

The studies above gave us an overview of the event-related potentials, which bare a close resemblance to our aims. Therefore, we altered our timeframe to 3000ms, by using three groups of pictures to be flashed on the screen, where the total screening per subject in one session would last 2 minutes and 50 seconds.

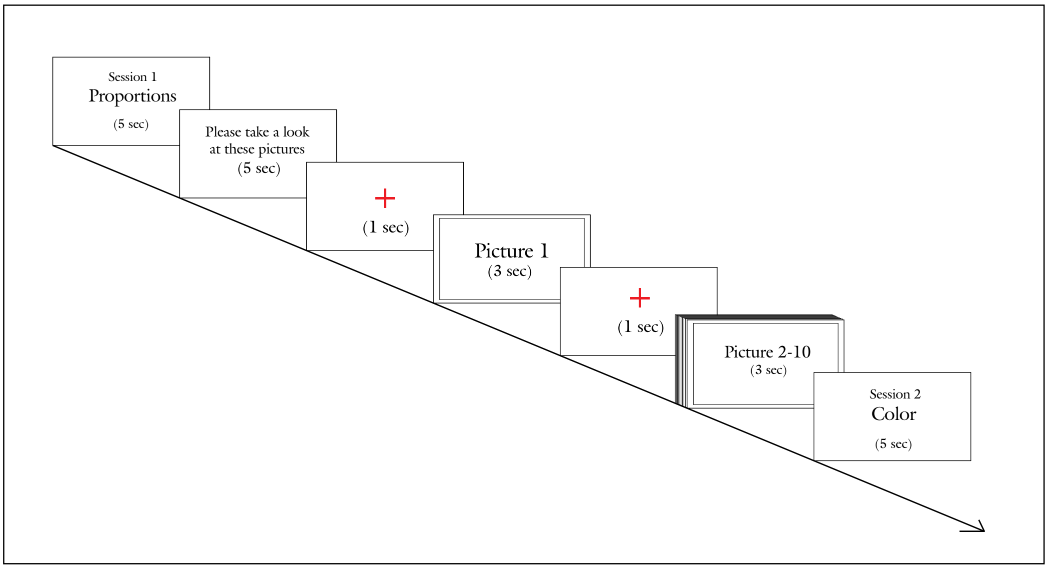


Figure 36. The sequence of events on trial

5.2.4. STIMULI SET

5.2.4.1. ARCHITECTURAL FACTORS

In the previous experiment, due to the complexity of factors that come together through indoor environments and because it was the first time to use the device, we decided to *simplify the building analysis to focus on one factor at a time*. In this regard, in order to achieve the goal of simplifying the analysis in as little factors as possible, it has been concluded that for the first test experiment, it is favored to eliminate unnecessary elements and limit the factors to texture variations only. However, contrary to expectations, the results of the previous methodology did not reveal a significant statistical difference between each of the rooms. Although we are still aware of the complexity and the limitations of extending the factors to the process of analyzing the results, we believe that adding more architectural factors would give us a more explicit understanding of the questions that arose from the previous experiment. As a result, the second experiment will consider these final categories: color, proportions, and texture.

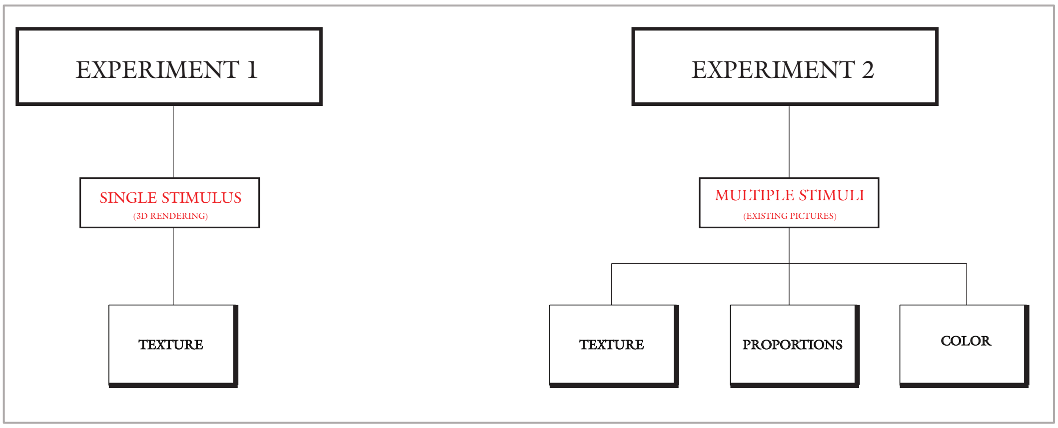


Figure 37. Evolution of the first experiment to the second experiment

Moreover, to reinforce the impact of the sense of reality, we made some substantial changes to the compilation of the second experiment. This included the replacement of 3D renderings with existent interior design, which would be presented through pictures taken from books, magazines, and open sources on the internet. Preparation for the visual stimulation has gone through a selection of interior design pictures that has considered a wide range of characteristics. The pictures are taken from the open sources on Internet and do not intend any commercial use other than for research purposes. Sources for every picture are listen in the Bibliography section. Below we will present considerations that have been taken into account for the selection of pictures in each target category (color, proportion, and texture). The complete sets of pictures are presented in Pic.11,12,13.

5.2.4.2. COLOR

Categorization for color divisions has taken into account:

- proportional distribution of colors in the physical aspect of the environment
- color palette
    - bright
    - pastel
- combinatorial variations in relation to the quantity and variety of colors
    - Monochromatic
    - Polychromatic (from 3 to over 5 colors)

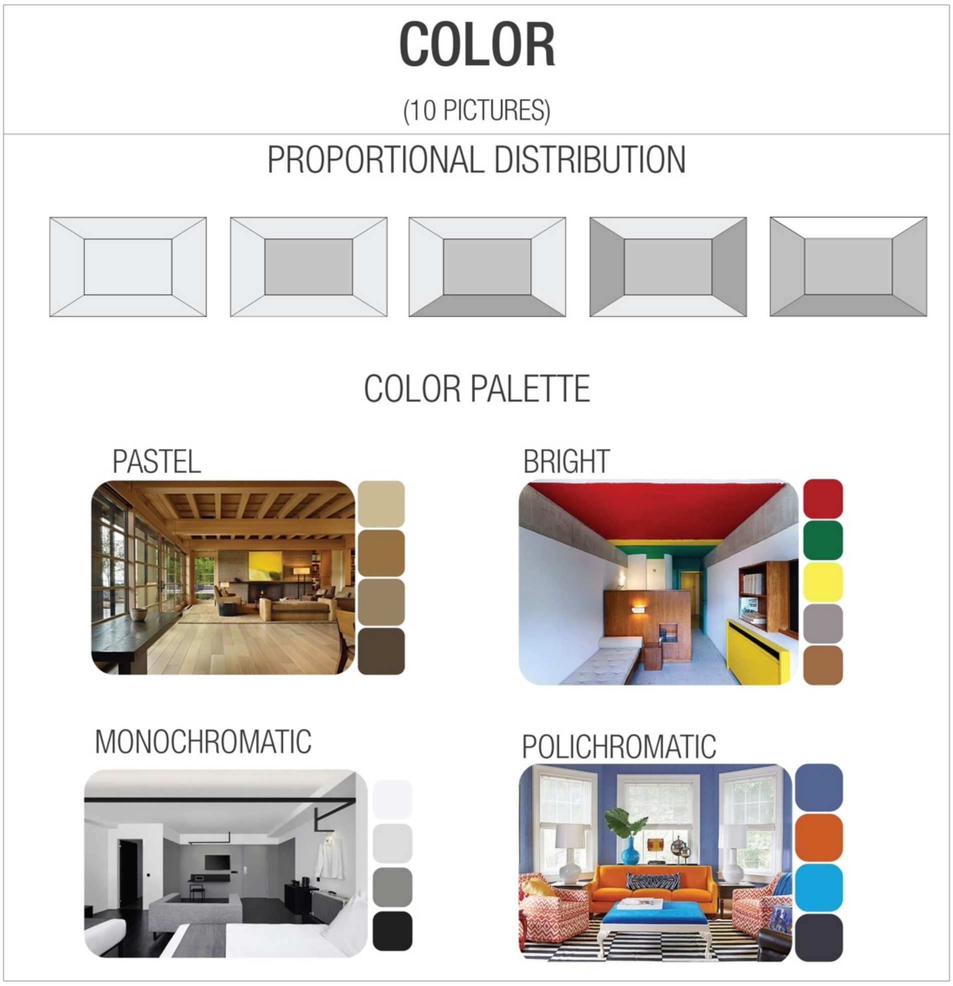


Figure 38. Diagrammatic example of the distribution of colors. Each dot represents on color

5.2.4.3. PROPORTIONS

Historically, proportional characteristics have played an important role in the design of architecture but also its perception. Therefore, to reach variations in terms of proportion, within the framework of this group, it has been proposed to include some of the characteristics of the historical proportional applications such as Golden Ratio, Georgian, Modular, Contemporary, and traditional Japanese. In coordination with these groups, it has been proposed to use some of the images of buildings designed by world-renowned architects such as Palladio and Le Corbusier. As a result, this group could be defined in two main categories: the height of the space and the ratio of openings in relation to the axes of the room.

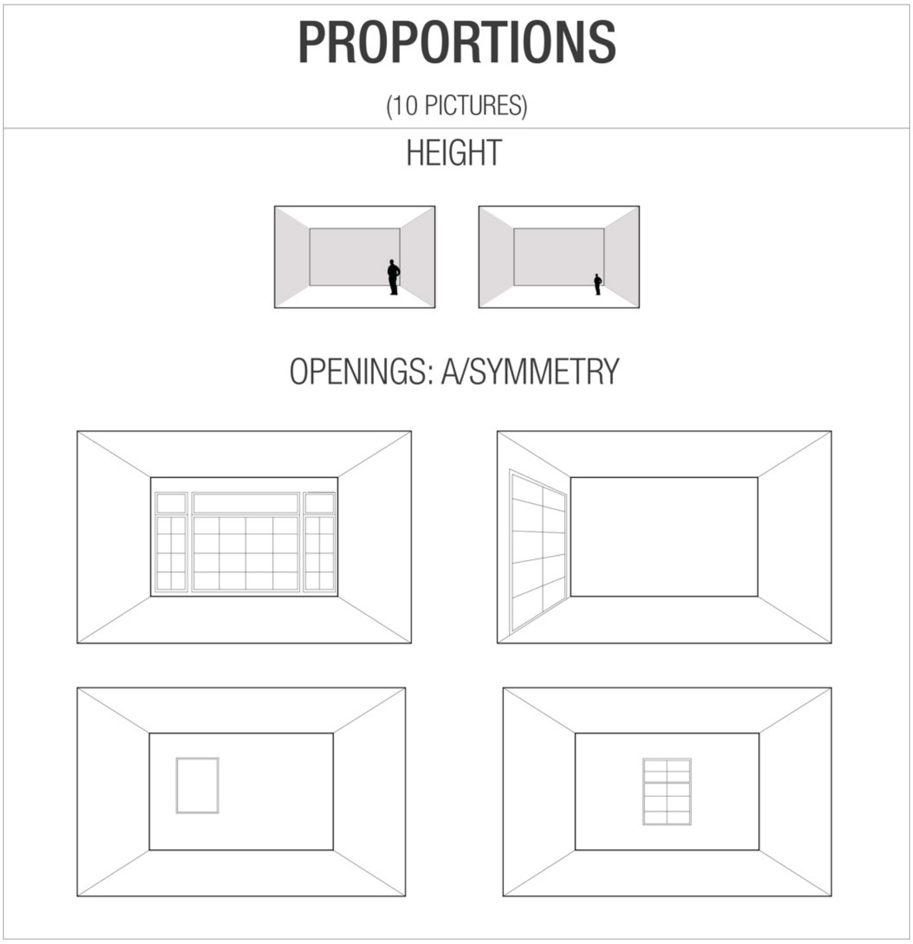


Figure 39. Diagrammatic example of proportion criteria

5.2.4.4. TEXTURE

We have elaborated on the aspect of texture in the previous experiment; therefore, the methodology of selecting its criteria in proportion to their distribution in space remains the same. However, the first experiment differs in the increase in the number of textures passing from 3 to 5, including tiles, concrete, wood, stone, and metal. Whereas Japanese interiors include cases of the use of tatami as well.

Moreover, properties of these materials such as reflection, semi-reflection, and absorption are also considered subcategories of these divisions.

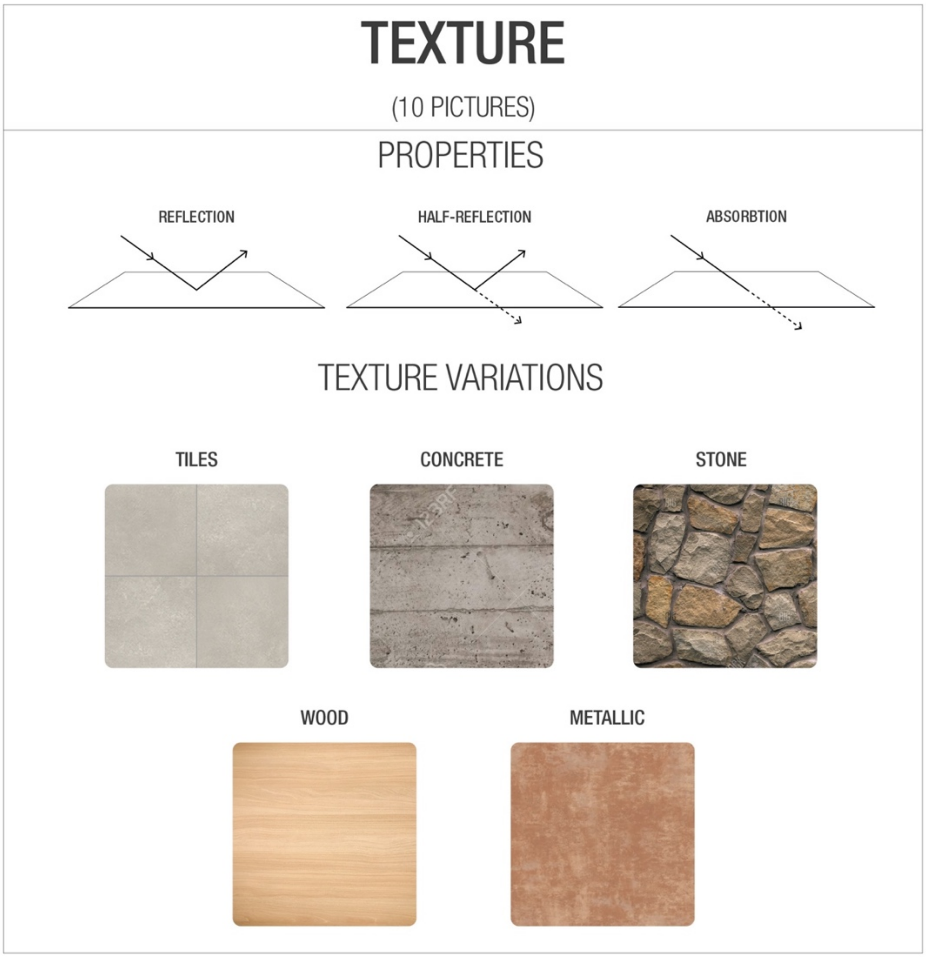
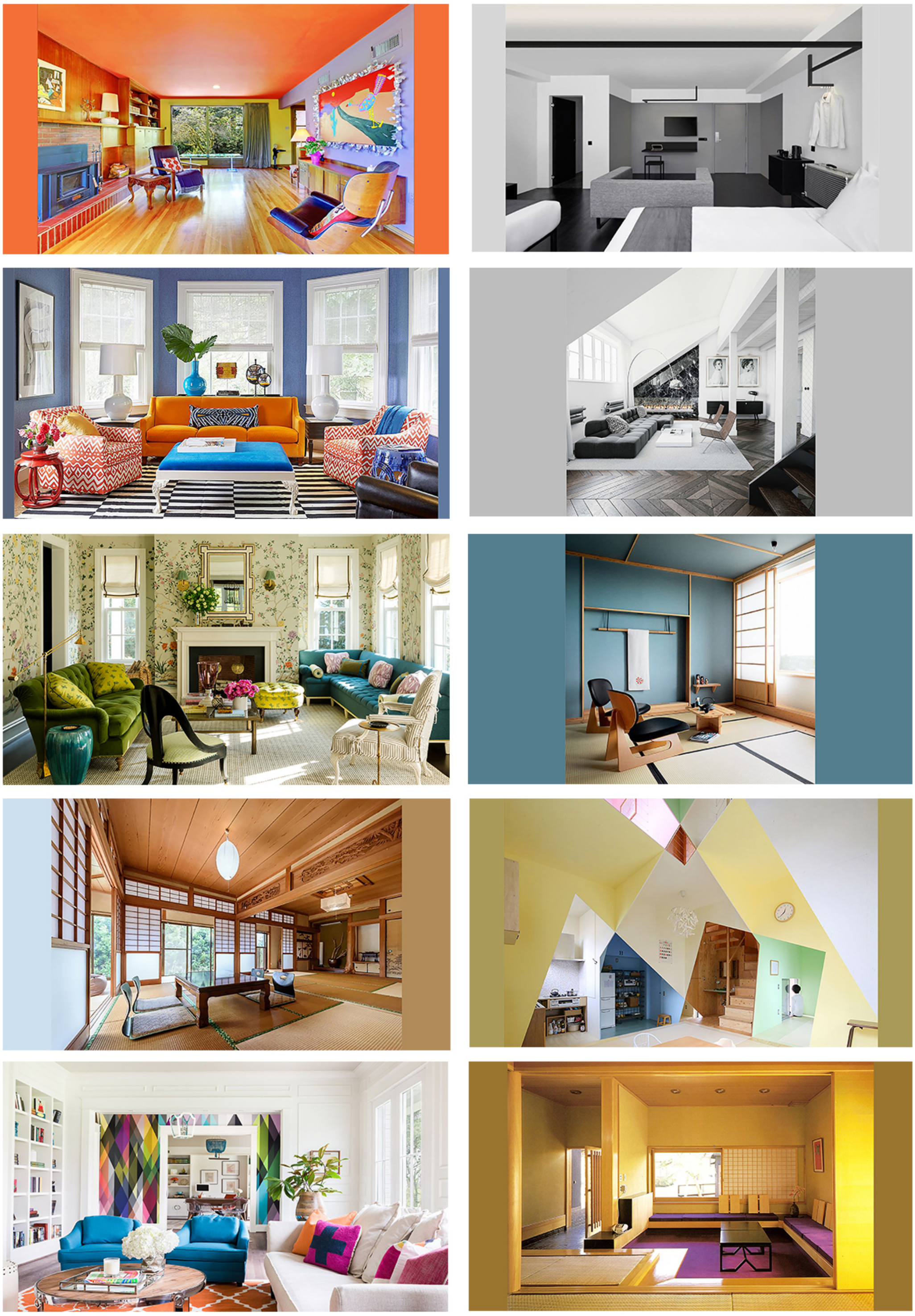
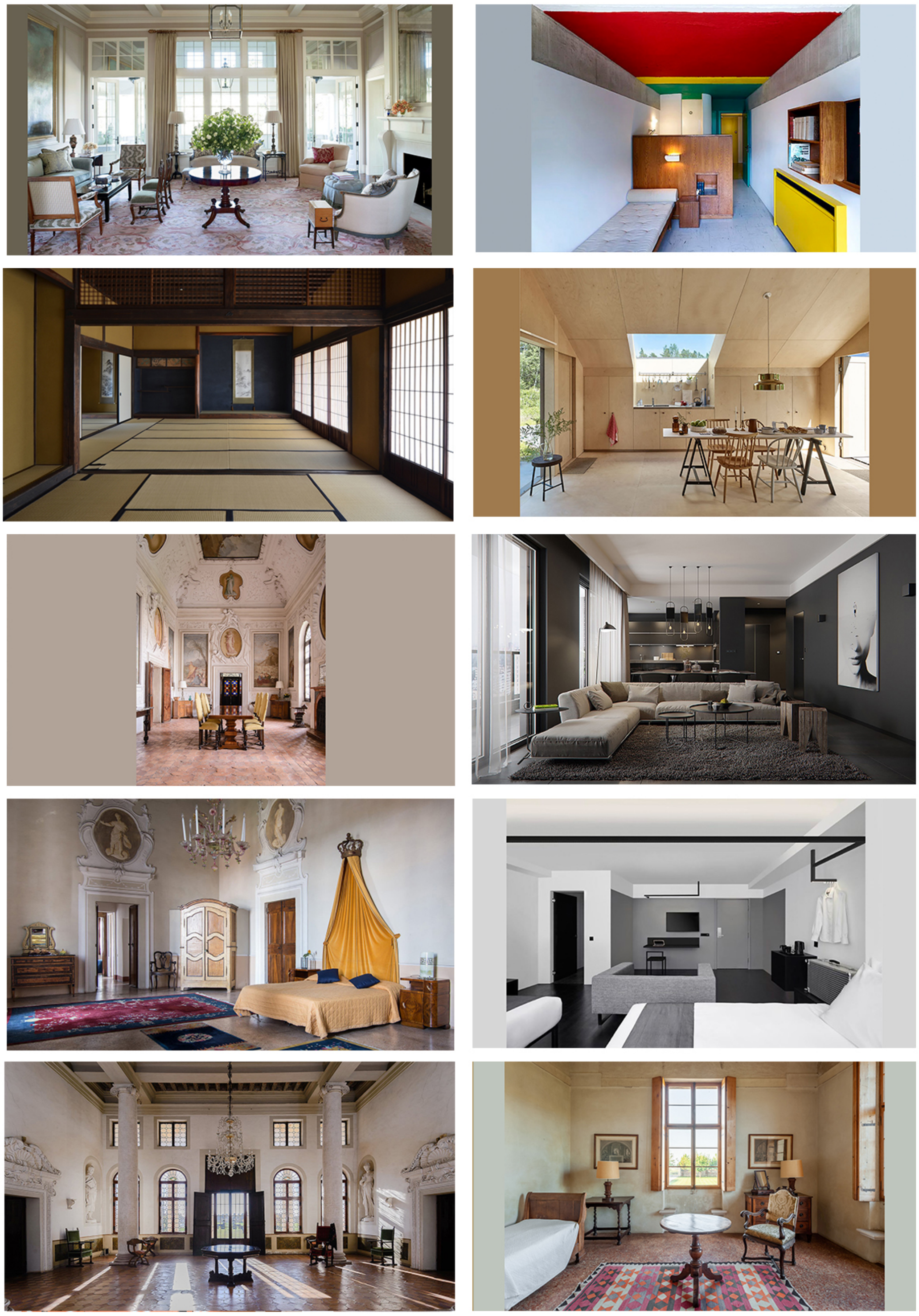


Figure 40. Criteria for selection of textures

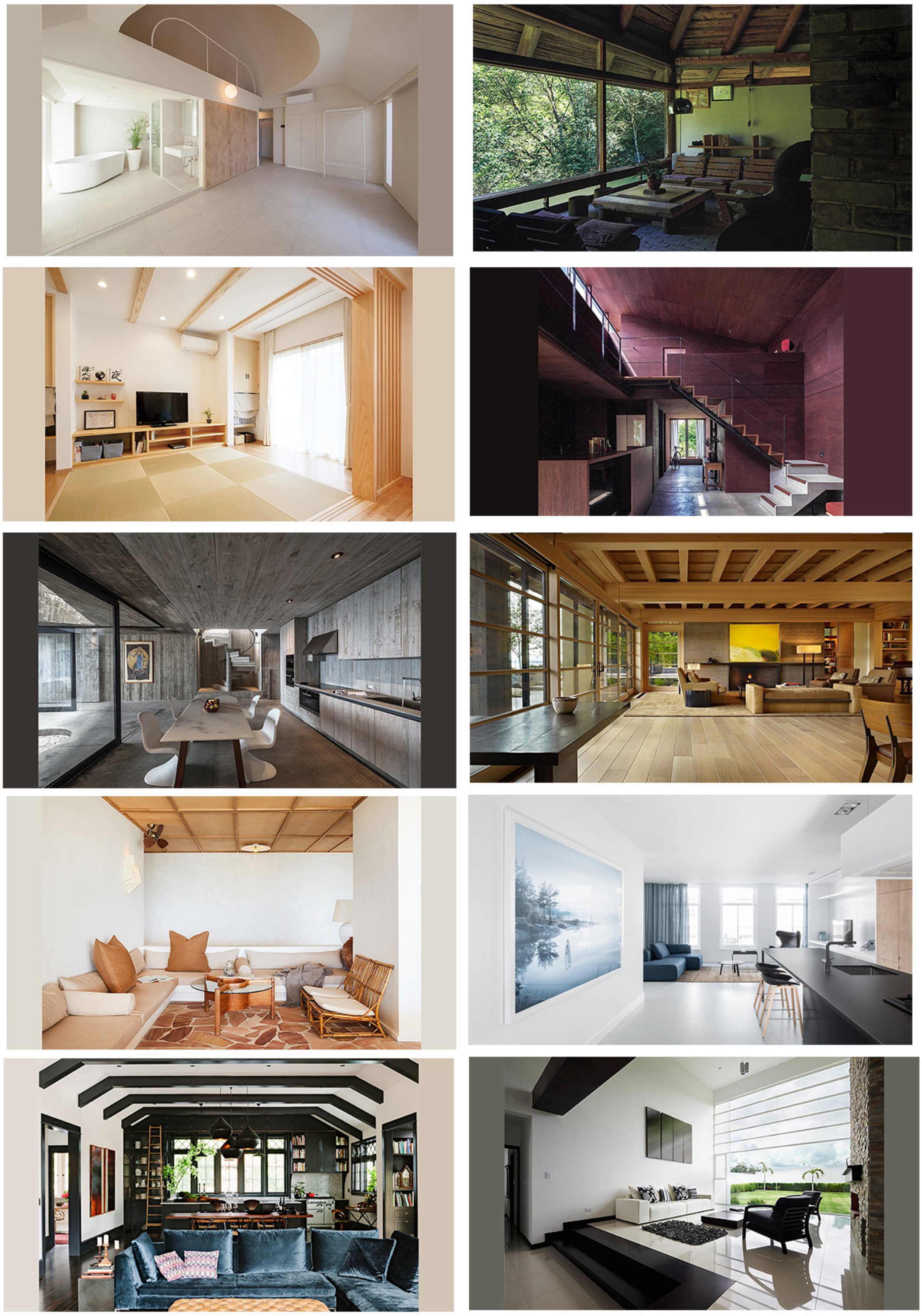
Each category was represented by 10 pictures representing before-mentioned categories which in total resulted in 30 pictures of indoor environments.



Picture 11. Final selection of pictures representing Color group



Picture 12. Final selection of pictures representing Proportions group


Picture 13. Final selection of pictures representing Texture group

5.2.5. Visual Display of Stimuli

The photo categories presented above are organized in the same order of visual display: starting with colors, proportions, and textures. The shift from one picture to the other has gone through a special screening consideration, too, so that to achieve more variations in the results of the brain measurements. As a result, it is proposed for the photos to be arranged in such a way as to contrast with each other. For example, in the case of color grouping, it has been suggested that switching from one photo to another include variations in the number of colors elaborated above. See graph:

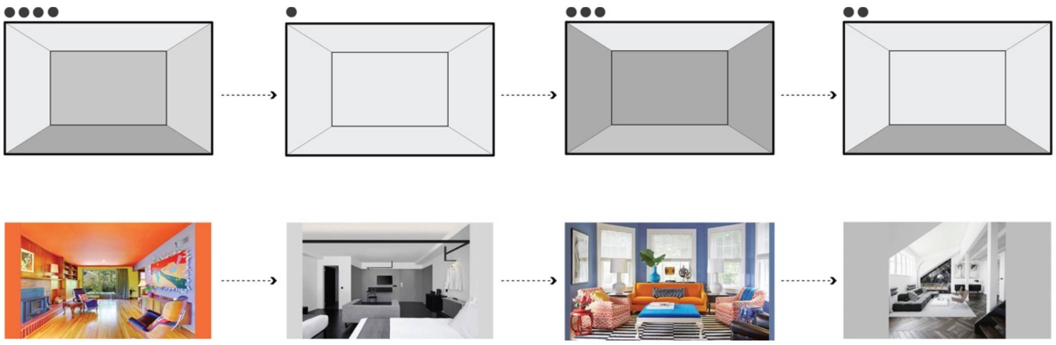


Figure 41. Chronological order selection for visual stimulation

5.3. Finalizing Experimental Set

Just as we have presented the progress of the experiment at the beginning of this chapter, the experiment is divided into two main parts:

- Observation
- Judgment

Both parts are made up of the same content consisting of three target categories of the built environment: color, proportions, and texture, including the same pictures. Observation included visual stimulation during the measurement of brain waves, while judgment included a questionnaire with only two questions that the subjects had to answer for each of the pictures they looked at. For details of each part of the experiments and elaboration will be presented next.

Figure 42. Experimental set-up for the second experiment

For interactive purposes, subjects have been given a tablet (Huawei Media Pad T3-7) in which they had a semantic differential bipolar slider designed in MAX Cycling 74 interactive language programming software.

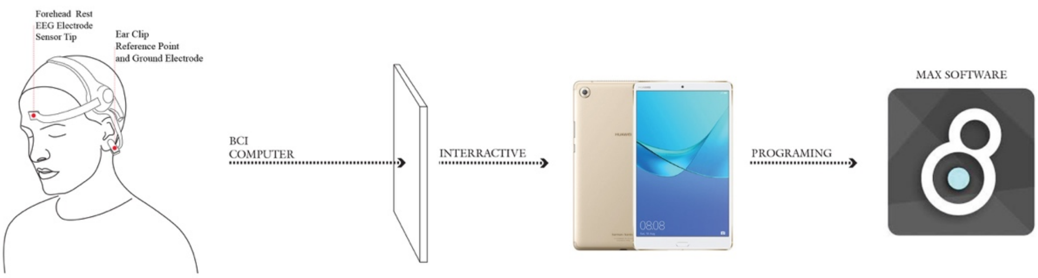


Figure 43. Interactive procedure for the finalized experimental set

5.3.1. Part 1: Observation

The first part of the experiment started with the screening of 30 pictures (10 pictures represented each category) representing the before-mentioned categories beginning with Colors, Proportion, and Texture. Each image lasted 3 seconds parted by a 1-second break through a fixation cross between each picture. Before every section, two displays (each lasting 5 seconds) appeared the first one introducing the name of the section: Section 1 / Colors; and the second display with a guidance line for the participants: "Please take a look at these pictures." The third display with the fixation remained in view for 1000ms before the pictures appeared. Participants have been asked to sit in front of the computer screen in the lab environment. The images were presented on a 25.6 inches monitor at a viewing distance of 90 cm.

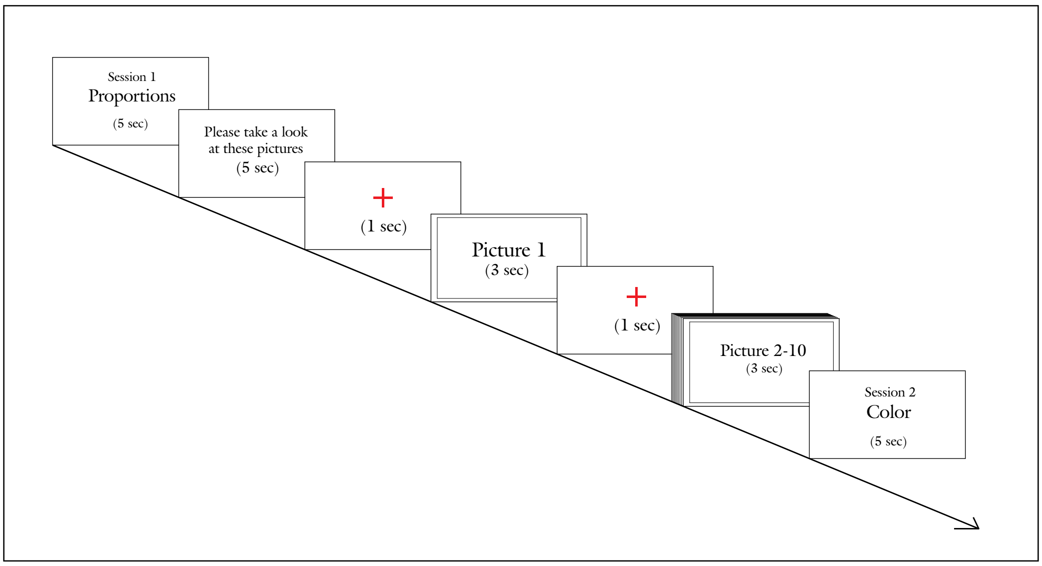


Figure 44. The sequence of events on trial.

During this part of the experiment, participants' brainwaves were measured using NeuroSky Headset Device (Chapter 3). Before the session, participants were given instructions on the procedure and were asked for written consent.

5.3.2. PART 2: JUDGMENT

Based on the questions raised by the conclusions of the previous chapter, this part of the research tends to cover three of the above-raised issues:

1)*Familiarity*: Through this section, we tend to answer the question raised in the previous experiment, whether familiarity is related to the meditative state of mind. To prove this, we ask the subjects to judge the familiarity they feel with the photos presented by giving on of these values: -3 (very unfamiliar); -2 (moderately unfamiliar); -1 (slightly unfamiliar); 0 (neither); 1 (slightly familiar); 2 (moderately familiar); 3 (very familiar).

Figure 45. Sample familiarity evaluation questionnaire

2)*Preference:* Similarly, through the same section and set of pictures, we will try to understand participants' preferences for architecture to associate these results to the relationship with any of the two states of mind that we have as a research point (Attention and Meditation). To achieve this, similar to the familiarity, we have asked participants to give value to the pictures they feel *pleasant* or *unpleasant* on a scale from -3 to 3.

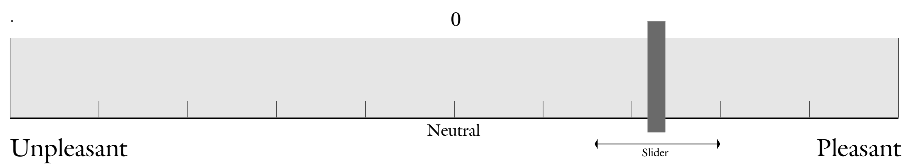


Figure 46. Sample pleasantness evaluation questionnaire

3)Memory: Lastly, given that the last experiment showed consistency of judgment in the time between two years, contrary to brainwaves that showed significant change, some of the subjects have been exposed to the '*11th picture'* which is a repetition of one of the pictures showed in the 10-picture set from each section. Unlike the first experiment where the repetition was done after two years, in this case, it would be within the same session. The reason is to observe if the judgment will be the same, more positive, or more negative. This way, we intended to observe and validate the consistency of the judgment.

5.4. RESULTS

The participants' brainwaves and subjective declarations were measured using standard statistical techniques. Before analyzing the results, for both Attention and Meditation, we calculated the mean values for 19 participants (M=31.0, SD=6.11) for all the rooms. The results have been assessed in three levels: Inter-group, Intra-group, and Individual basis.

Our goal was to determine whether there are any statistically significant differences in the measurements of the mean levels of Attention and Meditation as two set parameters particular to this study. As a result, we have aimed to reach this understanding firstly between the three groups of stimuli (Color, Proportions, and Texture), then the significant differences between individual rooms inside one group, and lastly, significant differences in the levels between Attention and Meditation of each room individually. We used a one-way analysis of variance (ANOVA) to detect any significant changes that could influence EEG recordings between participants' average values. Statistical analysis data was produced using EXCEL 2019 (Microsoft Inc.). A p-value of <0.05 was considered significant. Bonferroni tests were used for post-hoc tests of multiple comparisons (Appendix 3). T-Test: Two-Sample Assuming Equal Variances were used to detect any significant changes between the values of attention and meditation when compared to an individual level of each room.

5.4.1. PART 1: OBSERVATION RESULTS

5.4.1.1. INTER-GROUP ANALYSIS

The results showed that there were statistically significant differences between groups were determined by one-way ANOVA ($F(2,126) = 7.904$, $p=0.0005$). The differences in the values have been shown in the Attention level, while, in general, values of Meditation have shown no significant changes. As can be seen from Figure 47, a drop in the level of attention that has been observed in the third session, which represented the group of textures. This drop has been significant as determined by one-way ANOVA ($F(2,126) = 7.904$, $p=0.0005$). Meanwhile, the highest attention levels can be seen through the session of colors.

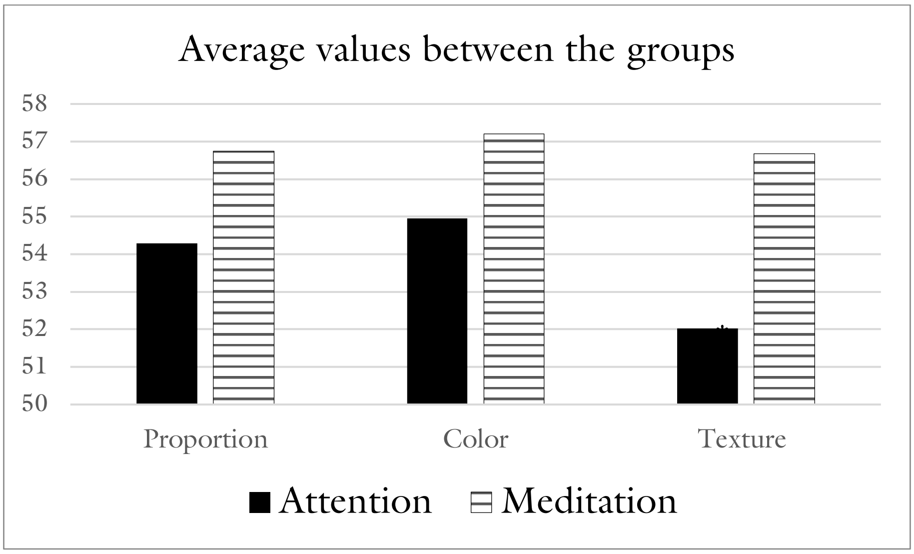


Figure 47. Average values between groups

5.4.1.2. INTRA-GROUP ANALYSIS

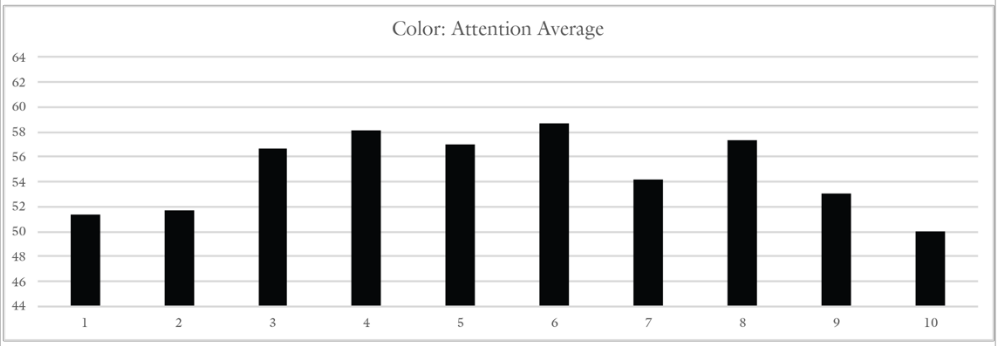
Differences between pictures within the groups have also shown a statistical significance. Based on the NeuroSky indications of "Attention" and "Meditation" values, which range from 0 - 100 (eSense meter), we have analyzed the tendencies for reduced (20-40), neutral (40-60) or slightly elevated/elevated (60<) levels. We have used this approach in an attempt to understand the effect of those pictures on these values. First, all participants' values in the form of binary numbers were separated for every participant in every group. Secondly, we have calculated the average values for all participants again for every group, and lastly, we have converted the binary numbers to graphical presentations for a clearer understanding. To understand this more practically, we will present below three brain dynamics graphs representing three groups (Color, Proportions, Texture), which we have achieved through the patented algorithmic approach offered by the device that we have used a means for evaluation. Statistical significant difference has been noted in all three groups: Colors: p-value: 0.00000801; Proportions: p-value: 0.000000218; Texture: 0.0000000198.

Colors - Attention Values

Color: Attention

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
51.6	51.5	52.5	60.7	57.1	58.4	54.4	59.7	52.3	49.5
50.8	53.6	53.3	59.4	56.1	61.6	53.2	56.9	54.1	49.9
50.7	51.8	57.9	57.1	57.8	58.8	51.6	58.1	53.1	48.8
52.3	50	63	55.3	57.2	56	57.4	54.8	52.7	52
51.3	51.725	56.675	58.125	57.05	58.7	54.15	57.375	53.05	50.05

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	205.5632	51.39079	0.547154
Room 2	4	206.9	51.725	2.1825
Room 3	4	226.7	56.675	23.4425
Room 4	4	232.5	58.125	5.7625
Room 5	4	228.2	57.05	0.496667
Room 6	4	234.8	58.7	5.266667
Room 7	4	216.6	54.15	6.01
Room 8	4	229.5	57.375	4.2625
Room 9	4	212.2	53.05	0.596667
Room 10	4	200.2	50.05	1.896667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	354.367	9	39.37412	7.802445	0.00000801	2.210697
Within Groups	151.3915	30	5.046382			
Total	505.7585	39				

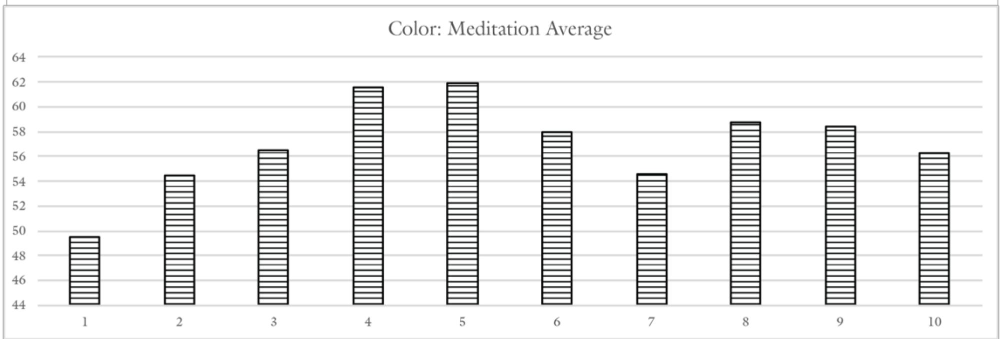
Figure 48. Brainwave attention dynamics through Color group

Colors - Meditation Values

Color: Meditation

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
48.6	55.3	51.3	62.7	62.7	62.2	53.8	55.1	60	57.8
46.5	57.1	52.3	62.7	61.5	58.8	54.7	57.4	58.8	55.9
49.8	53.8	58.9	60.1	61.2	58	54.5	60.3	58.5	54.8
53	51.7	63.3	60.8	62.2	52.8	55.3	62.4	56.4	56.5
49.475	54.475	56.45	61.575	61.9	57.95	54.575	58.8	58.425	56.25

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	197.9	49.475	7.3825
Room 2	4	217.9	54.475	5.2425
Room 3	4	225.8	56.45	32.22333
Room 4	4	246.3	61.575	1.769167
Room 5	4	247.6	61.9	0.46
Room 6	4	231.8	57.95	15.10333
Room 7	4	218.3	54.575	0.3825
Room 8	4	235.2	58.8	10.28667
Room 9	4	233.7	58.425	2.2425
Room 10	4	225	56.25	1.563333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	483.4363	9	53.71514	7.007313	2.18855E-05	2.210697
Within Groups	229.9675	30	7.665583			
Total	713.4038	39				

Figure 49. Brainwave meditation dynamics through Color group

Based on the NeuroSky indications of "Attention" and "Meditation" values, which range from 0 - 100 (eSense meter), we have analyzed the tendencies for reduced (20-40), neutral (40-60) or slightly elevated/elevated (60<) levels. We have used this approach to understand the effect of parameters that we have analyzed in correlation to these values.

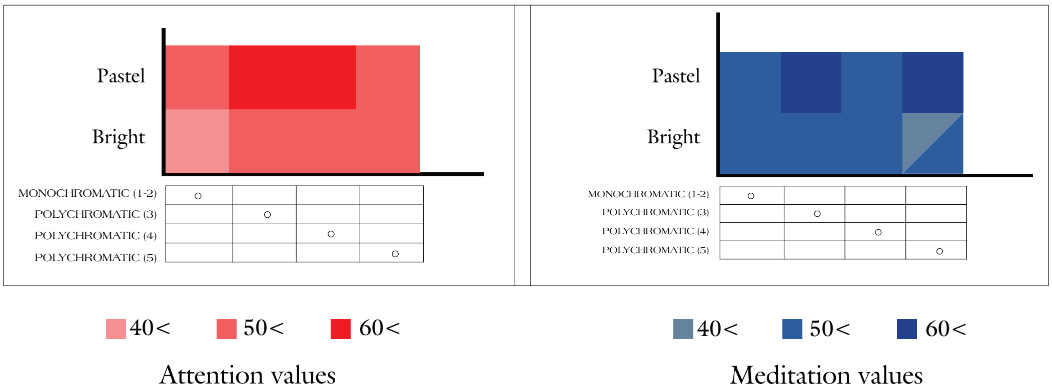


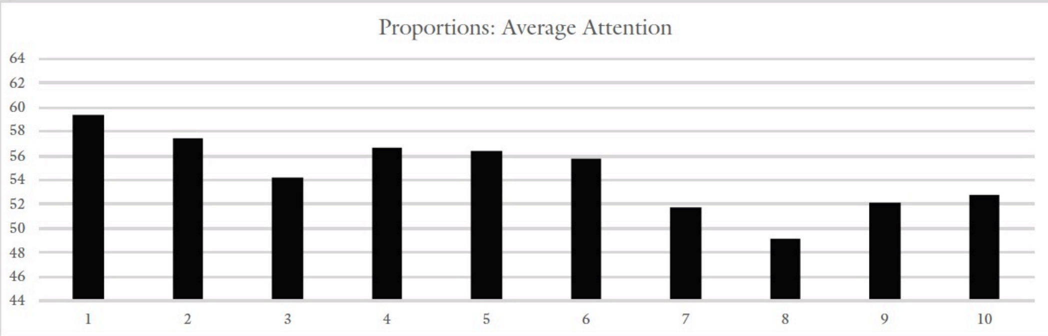
Figure 50. Algorithmic representation of the correlation between brain dynamics and architectural parameters

The highest attention has shown Room 4 and Room 6 characterized by pastel colors with low number of color variations. Similarly, high attention have shown Room 3 and Room 8, which, contrary to the aforementioned rooms, are characterized by the highest variations in the numbers of colors. The lowest attention has shown Room 1 and Room 2, which again present a contrast in the properties of the colors. On the other hand, the highest meditation value has shown Room 4 and Room 5, one monochromatic and other polychromatic but both characterized as bright environments. Lower meditation values has shown Room 1characterized with 5+ variations of colors. In the section 5.4.1.3. we will analyze rooms individually to reach a better understanding of each value per each room.

Proportions - Attention Values

Proportion: Attention

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
58.78947	60.57895	52.05263	56.36842	57.84211	53.42105	56.10526	46.52632	51.94737	53.57895
59.68421	58.42105	55.42105	56.05263	57.42105	52.73684	52.57895	51.47368	50.63158	54.36842
59.57895	56.78947	55	57.52632	55.68421	58.42105	47.57895	50.05263	51.84211	52.31579
59.68421	54.05263	54.42105	56.73684	54.73684	58.36842	50.47368	48.73684	53.78947	50.73684
59.43421	57.46053	54.22368	56.67105	56.42105	55.73684	51.68421	49.19737	52.05263	52.75



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	237.7368	59.43421	0.187211
Room 2	4	229.8421	57.46053	7.570406
Room 3	4	216.8947	54.22368	2.262927
Room 4	4	226.6842	56.67105	0.403278
Room 5	4	225.6842	56.42105	2.132964
Room 6	4	222.9474	55.73684	9.497692
Room 7	4	206.7368	51.68421	12.88827
Room 8	4	196.7895	49.19737	4.419898
Room 9	4	208.2105	52.05263	1.697138
Room 10	4	211	52.75	2.515928

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	352.7199	9	39.1911	8.993795	1.98352E-06	2.210697
Within Groups	130.7271	30	4.357572			
Total	483.4471	39				

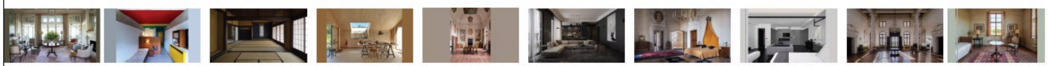
Figure 51. Brainwave attention dynamics through Proportions group

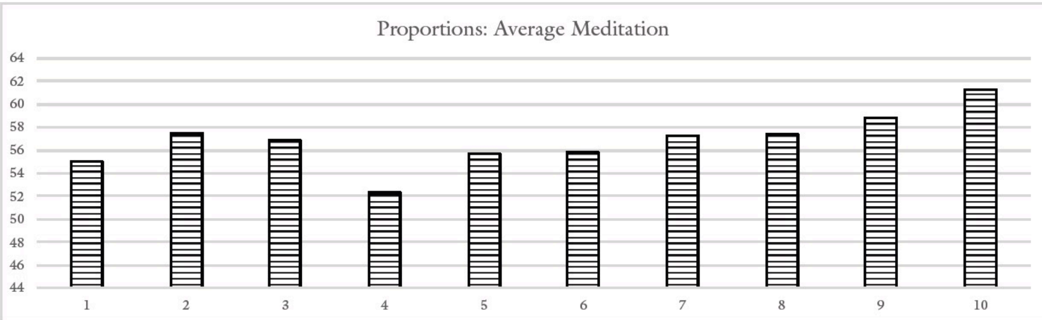
Proportions - Meditation Values

Proportion: Meditation

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
53.68421	57.78947	58.21053	*53.1578947*	54.31579	54.63157895	57.26316	57.94737	58.21053	60.94737
53.21053	57.21053	58.42105	50.05263	56.47368	54.63157895	57.84211	58.31579	57.31579	62.52632
57.10526	56.36842	56.26316	52.21053	55.52632	56.47368421	*57.4736842*	56.21053	59.63158	61.52632
56.26316	58.78947	54.73684	53.63158	56.42105	57.52631579	56.47368	56.89474	60.05263	60.10526
55.06579	57.53947	56.90789	52.26316	55.68421	55.81578947	57.26316	57.34211	58.80263	61.27632

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10





Anova: Single Factor

SUMMARY

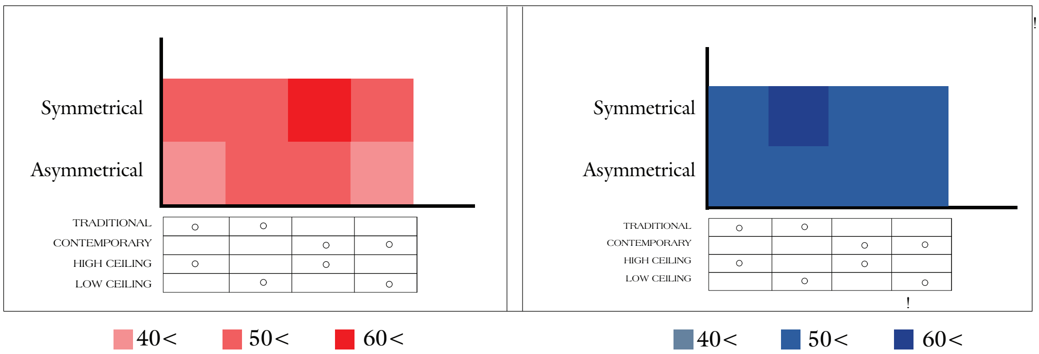
Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	220.2632	55.06579	3.647969
Room 2	4	230.1579	57.53947	1.034857
Room 3	4	227.6316	56.90789	3.03855
Room 4	4	209.0526	52.26316	2.520776
Room 5	4	222.7368	55.68421	1.021237
Room 6	4	223.2632	55.81579	2.054478
Room 7	4	229.0526	57.26316	0.334257
Room 8	4	229.3684	57.34211	0.931671
Room 9	4	235.2105	58.80263	1.603647
Room 10	4	245.1053	61.27632	1.034857

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	203.6749	9	22.63054	13.14025	3.40999E-08	2.210697
Within Groups	51.6669	30	1.72223			
Total	255.3418	39				

Figure 52. Brainwave meditation dynamics through Proportions group

In the case of proportions too, "Attention" and "Meditation" values which range from 0 - 100 (eSense meter), were analyzed in order to understand the tendencies for reduced (20-40), neutral (40-60) or slightly elevated / elevated (60<) levels.



Attention values

Meditation values

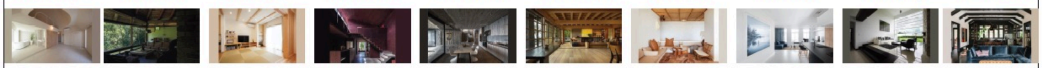
This set of analyses has highlighted the impact of bright rooms with wide opening like in the case of Room 1 which has showed the highest level of attention. Contrary to this, Room 8 which represents a room without openings and natural light has resulted with the lowest attention. It is important to note that these two rooms represent two opposite situations, which hence the opposite results. On the other hand, highest meditation values have shown the rooms characterized with symmetrical proportional axis - Room 9 and Room 10, which at the same time represent the building proportioned in golden section premises, design by Palladio. of golden section propo the reknowned architect Palladio. In contrast, the lowest meditation level has been observed in Room 4 which is the case of a contemporary wooden room characterized by asymmetrical proportional axis. Other rooms have shown a neutral attention and meditation levels.

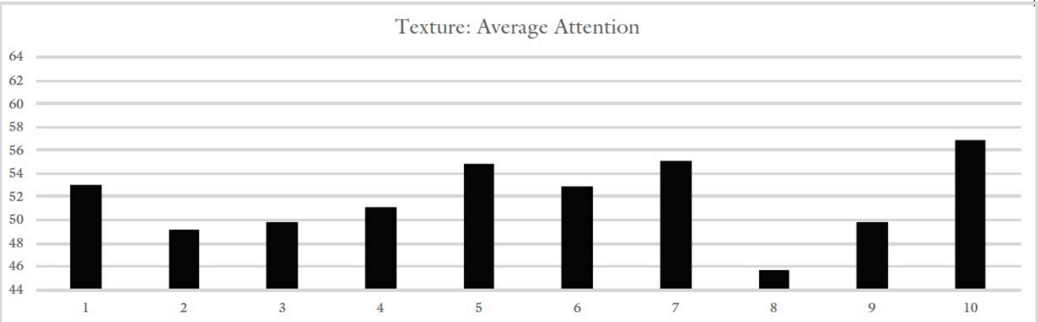
Texture - Attention Values

Texture: Attention

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
54.05263	50.31579	49.57895	48.26316	55.84211	51.89474	57.63158	47	44.31579	57.05263
54.21053	48.84211	48.57895	52.26316	54.78947	51.89474	57.57895	45.47368	48.78947	56.36842
51.05263	49.21053	50.05263	51.05263	54.57895	53.15789	53.68421	45.47368	53.21053	55.89474
52.68421	48.42105	50.84211	52.68421	53.84211	54.42105	51.26316	45	52.89474	58.21053
53	49.19737	49.76316	51.06579	54.76316	52.84211	55.03947	45.73684	49.80263	56.88158

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10





Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	212	53	2.155125
Room 2	4	196.7895	49.19737	0.659972
Room 3	4	199.0526	49.76316	0.894737
Room 4	4	204.2632	51.06579	3.969298
Room 5	4	219.0526	54.76316	0.682364
Room 6	4	211.3684	52.84211	1.462604
Room 7	4	220.1579	55.03947	9.755078
Room 8	4	182.9474	45.73684	0.759003
Room 9	4	199.2105	49.80263	17.4356
Room 10	4	227.5263	56.88158	1.010849

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	399.3397	9	44.37108	11.44038	1.58802E-07	2.210697
Within Groups	116.3539	30	3.878463			
Total	515.6936	39				

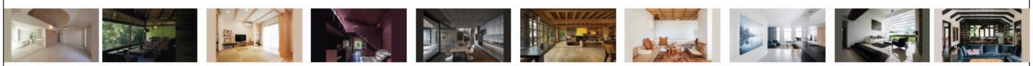
Figure 53. Brainwave attention dynamics through Texture group

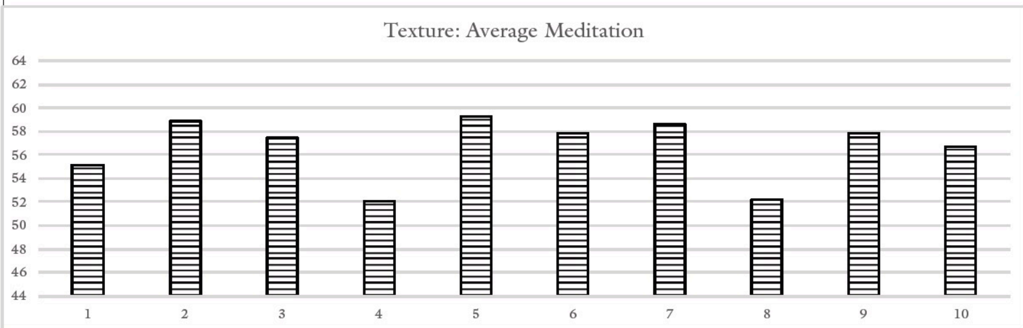
Texture - Meditation Values

Texture: Meditation

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
56.52632	54.57895	62.36842	51.31579	*56.315789*	61.15789	59.26316	52.10526	56.94737	56
54.10526	57.89474	59.73684	49.47368	60.05263	57.21053	58.36842	52.78947	56.78947	57.47368
55.368421	59.89474	55.94737	51.31579	61.42105	54.84211	60.31579	51.42105	58.47368	56.73684
54.78947	63.10526	51.89474	56.26316	59.10526	58	56.57895	52.36842	59.31579	56.52632
55.19737	58.86842	57.48684	52.09211	59.22368	57.80263	58.63158	52.17105	57.88158	56.68421

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10





Anova: Single Factor

SUMMARY

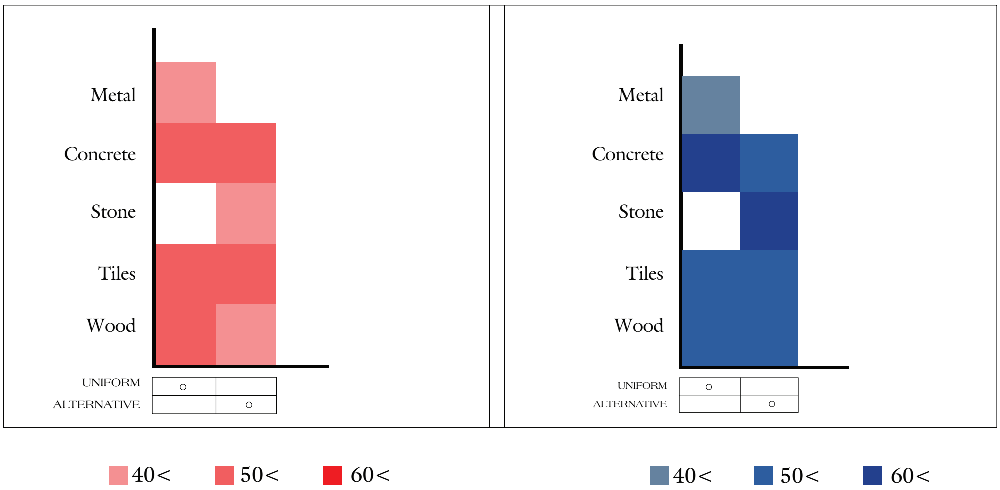
Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	5	275.9868	55.19737	0.788608
Room 2	5	294.3421	58.86842	9.58795
Room 3	5	287.4342	57.48684	15.63348
Room 4	5	260.4605	52.09211	6.364785
Room 5	5	296.1184	59.22368	3.496364
Room 6	5	289.0132	57.80263	5.103012
Room 7	5	293.1579	58.63158	1.879501
Room 8	5	260.8553	52.17105	0.247057
Room 9	5	289.4079	57.88158	1.118248
Room 10	5	283.4211	56.68421	0.279778

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	309.7151	9	34.41279	7.733422	1.7603E-06	2.124029
Within Groups	177.9952	40	4.449879			
Total	487.7103	49				

Figure 54. Brainwave meditation dynamics through Texture group

Lastly, we have assessed similarly the levels of Attention and Meditation values which range from 0 - 100 (eSense meter), were analyzed in order to understand the tendencies for reduced (20-40), neutral (40-60) or slightly elevated / elevated (60<) levels in the case of the group of Textures too.



Attention values

Meditation values

The set of analyses for texture group has emphasized the high levels of attention in cases where combination of uniform distribution of textures has been combined in the case of all wood, tiles, and concrete (Room 5, Room 6, Room 7, Room 10). In comparison, low attention values have shown Room 2 which is characterized with stones, but also represents the only picture which has greenery included. Similarly, Room 8 has shown the lowest attention level, and represents half-reflective properties of textures and cleanliness. On the other hand, highest meditation values have shown Room 2, Room 3, Room 5, Room 6, Room 7, Room 9. Lowest meditation levels have shown Room 4 which represents metallic and dark environment, and Room 8 which represents the opposite of that, light environment. In order to understand better the relationship between Attention and Meditation values for each room, we will present below all the cases of study.

5.4.1.3. Individual analysis

As presented in the first part of this chapter, all of the groups had a rich composition of characteristic features. Below, we will present the statistical findings for each photograph within the group, and we will analyze the results obtained from these analyses in particular. These analyses are built on the preconditions on which we built this experiment. Therefore, we will analyze the difference between their attention and meditation level for each room step by step. Significant changes are shown in the cases where p-values have been highlighted with yellow color. T-Test: Two-Sample Assuming Equal Variances were used to detect any significant changes between the values of attention and meditation when compared to an individual level of each room.

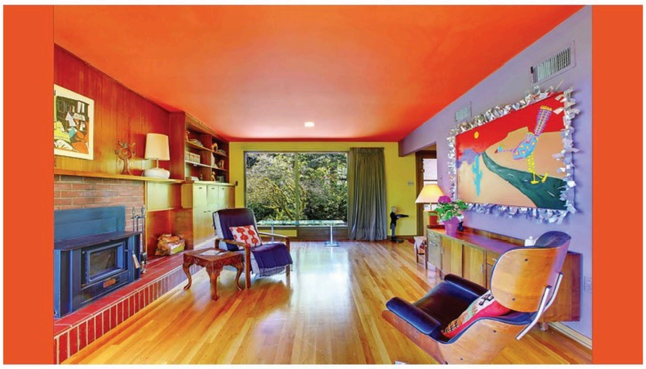
Colors

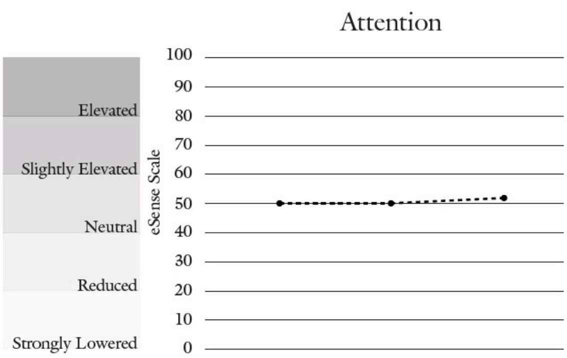
From the group of Colors, 4 Rooms have shown statistically significant differences between levels of Attention and Meditation. All of the rooms have shown higher Meditation levels. Below we will present each of those rooms and their characteristics.

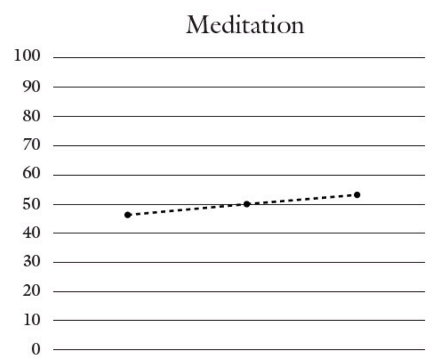
- Room number 4, a monochromatic example characterized with low number of color variation, and bright environment has shown statistically significant higher Meditation values.
- Room number 5, a polychromatic example, characterize with high number of color variations, bright environment has also shown statistically significant higher Meditation values.
- Room number 9, a polychromatic example with less variations than the previous room, also bright environment has shown statistically significant higher Meditation values than Attention.
- Lastly, Room 10, a room characterized with low number of color variations but an example of a contrast in colors; also representing clean and traditional Japanese environment, has shown statistically significant higher levels of Meditation.

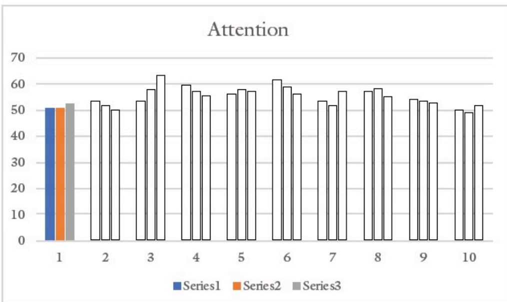
Colors

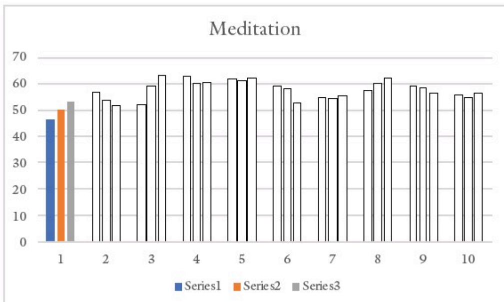
Color: Room 1







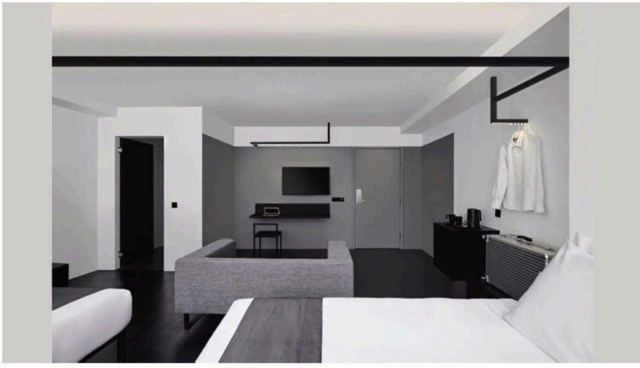


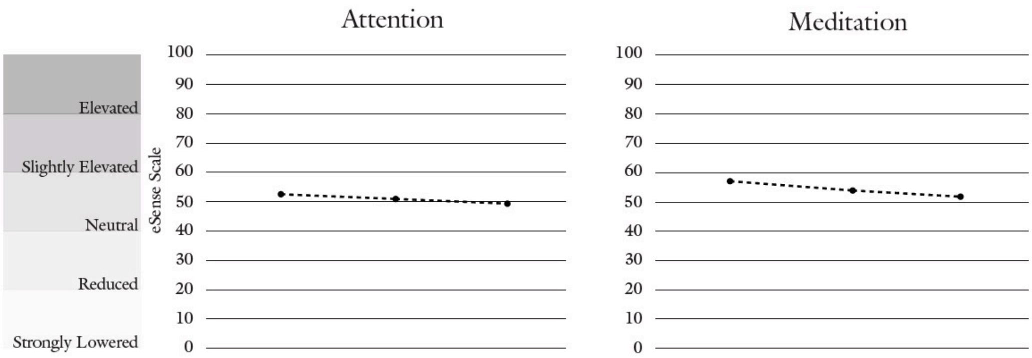


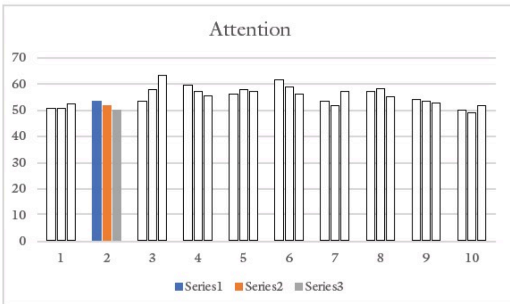
Statistical Analysis (Individual)

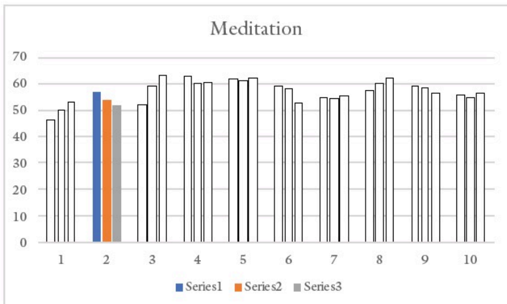
t-Test: Two-Sample Assuming Equal Variances		
	Room 1 (Attention)	*Room 1 (Meditation)*
Mean	51.35	49.475
Variance	0.563333333	7.3825
Observations	4	4
Pooled Variance	3.972916667	
Hypothesized Mean Diff	0	
df	6	
t Stat	1.330336608	
P(T<=t) one-tail	0.115868	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.231736001	
t Critical two-tail	2.446911851	

Color: Room 2





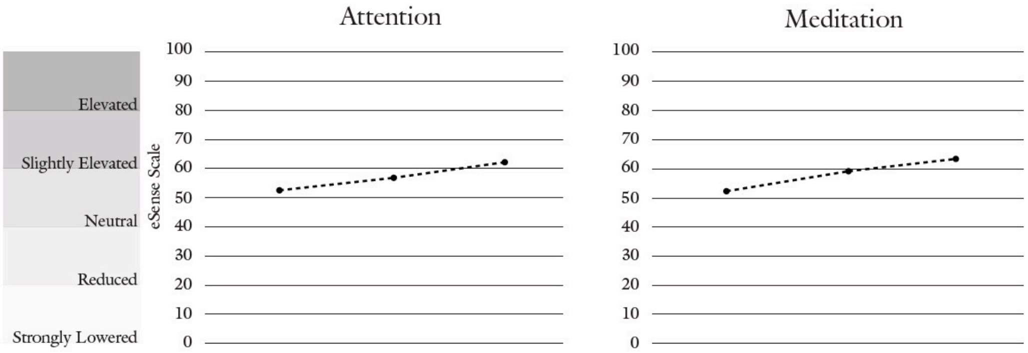


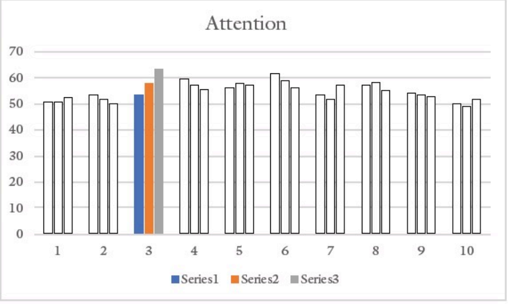


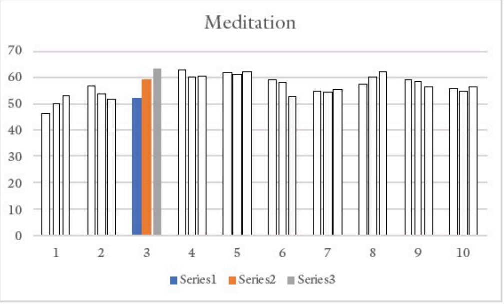
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 2 (Attention)	*Room 2 (Meditation)*
Mean	51.725	54.475
Variance	2.1825	5.2425
Observations	4	4
Pooled Variance	3.7125	
Hypothesized Mean Diff	0	
df	6	
t Stat	-2.018433569	
P(T<=t) one-tail	0.045047852	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.090095704	
t Critical two-tail	2.446911851	

Color: Room 3



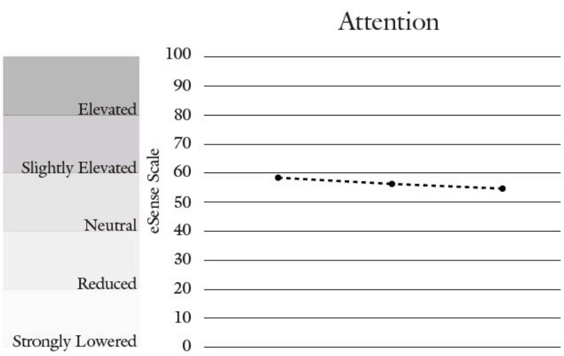


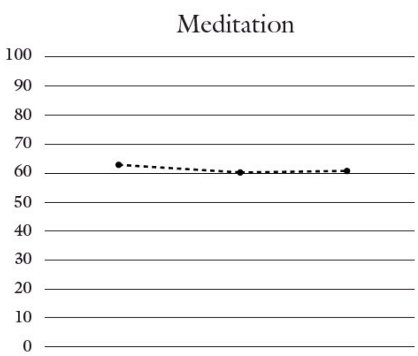


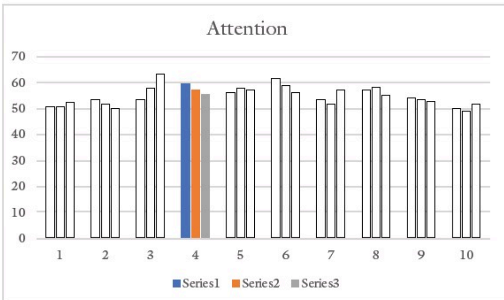
Statistical Analysis (Individual)

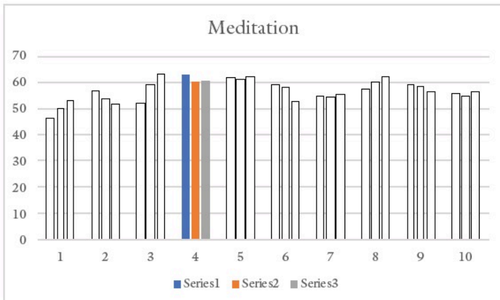
t-Test: Two-Sample Assuming Equal Variances		
	Room 3 (Attention)	*Room 3 (Meditation)*
Mean	56.675	56.45
Variance	23.4425	32.22333333
Observations	4	4
Pooled Variance	27.83291667	
Hypothesized Mean Diff	0	
df	6	
t Stat	0.060314003	
P(T<=t) one-tail	0.476932169	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.953864339	
t Critical two-tail	2.446911851	

Color: Room 4





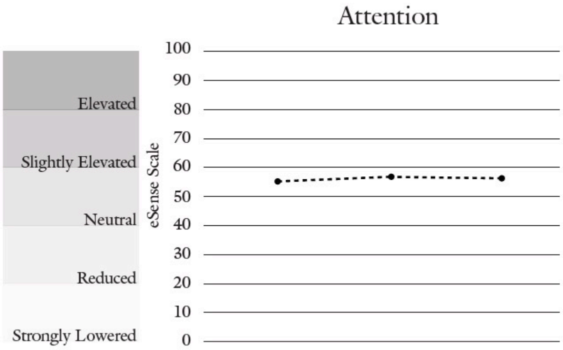


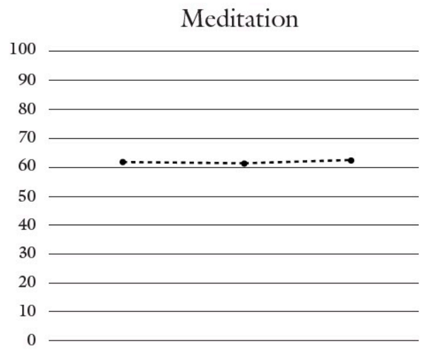


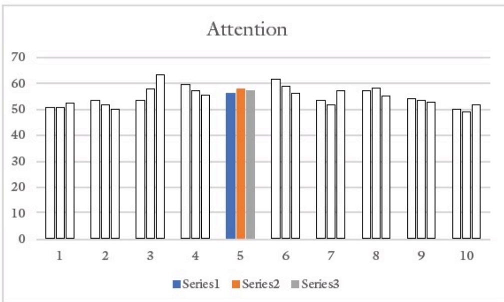
Statistical Analysis (Individual)

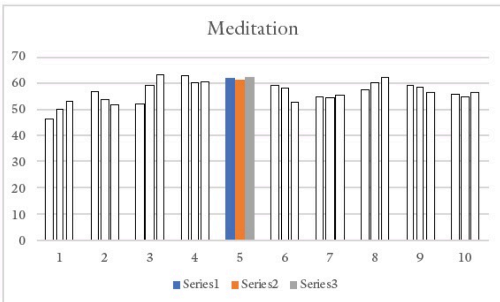
t-Test: Two-Sample Assuming Equal Variances		
	Room 4 (Attention)	*Room 4 (Meditation)*
Mean	58.125	61.575
Variance	5.7625	1.769166667
Observations	4	4
Pooled Variance	3.765833333	
Hypothesized Mean Diff	0	
df	6	
t Stat	-2.514221554	
P(T<=t) one-tail	0.022821026	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.045642053	
t Critical two-tail	2.446911851	

Color: Room 5





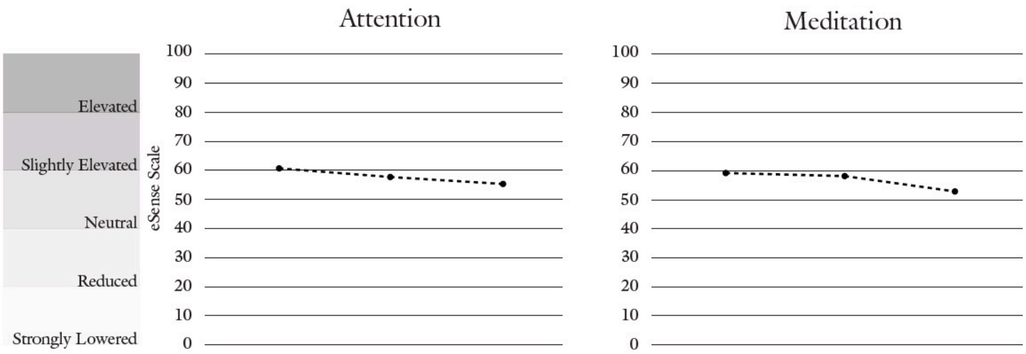


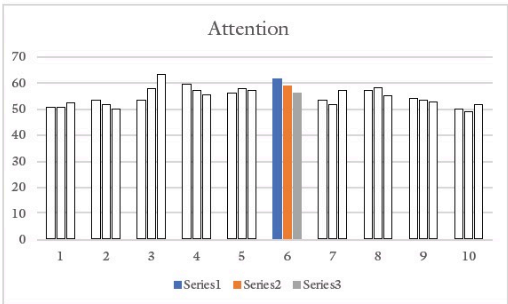


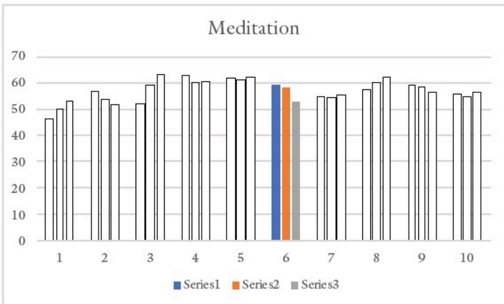
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 5 (Attention)	*Room 5 (Meditation)*
Mean	57.05	61.9
Variance	0.496666667	0.46
Observations	4	4
Pooled Variance	0.478333333	
Hypothesized Mean Diff	0	
df	6	
t Stat	-9.917253469	
P(T<=t) one-tail	3.03645E-05	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.0000607290	
t Critical two-tail	2.446911851	

Color: Room 6



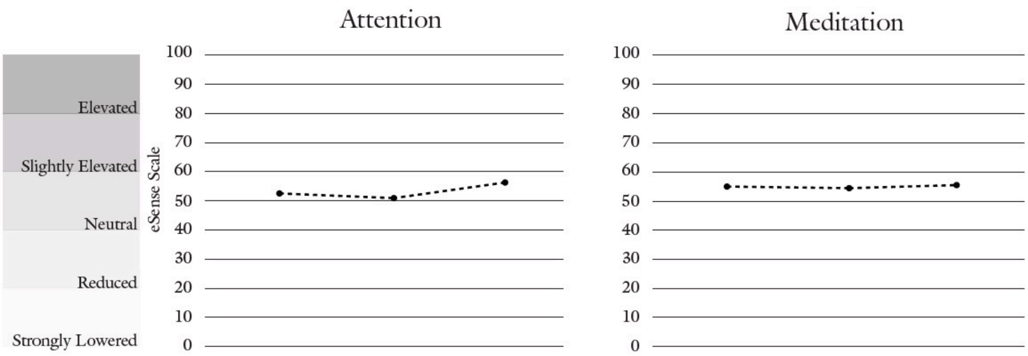


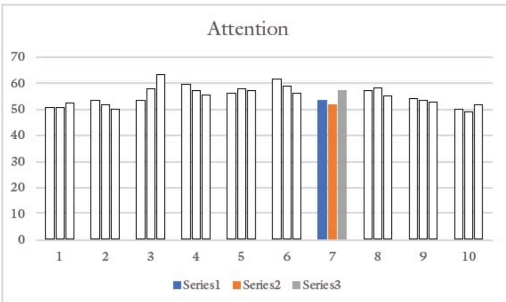


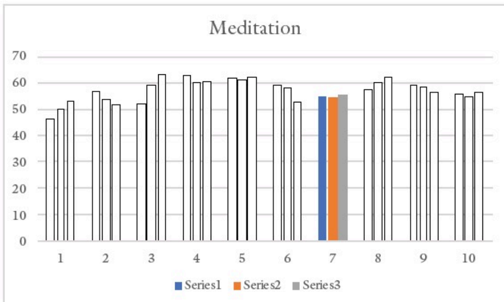
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 6 (Attention)	*Room 6 (Meditation)*
Mean	58.7	57.95
Variance	5.266666667	15.10333333
Observations	4	4
Pooled Variance	10.185	
Hypothesized Mean Diff	0	
df	6	
t Stat	0.332350047	
P(T<=t) one-tail	0.375464433	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.750928866	
t Critical two-tail	2.446911851	

Color: Room 7



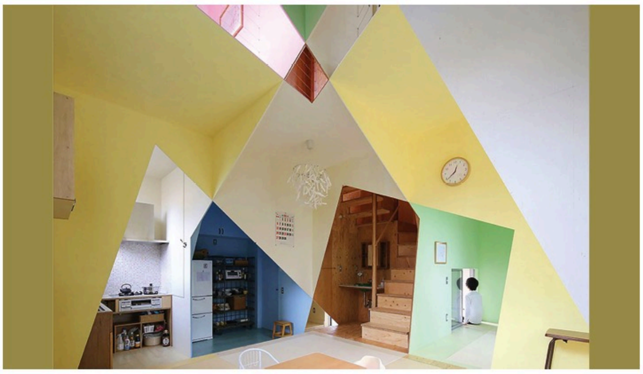


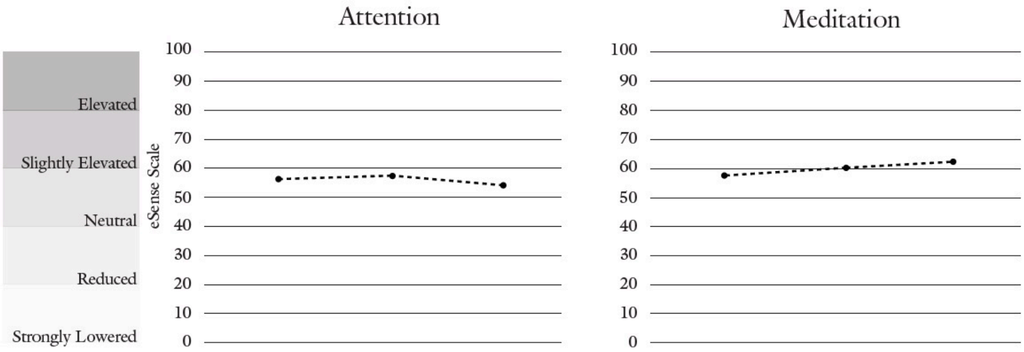


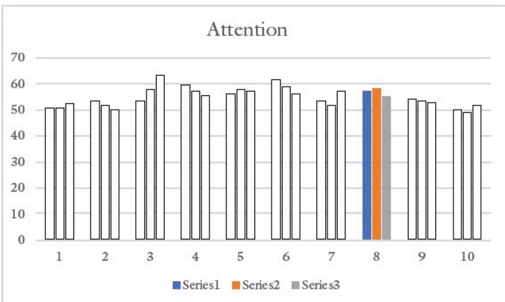
Statistical Analysis (Individual)

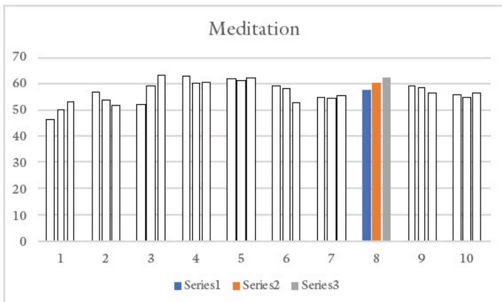
t-Test: Two-Sample Assuming Equal Variances		
	Room 7 (Attention)	*Room 7 (Meditation)*
Mean	54.15	54.575
Variance	6.01	0.3825
Observations	4	4
Pooled Variance	3.19625	
Hypothesized Mean Diff	0	
df	6	
t Stat	-0.336189045	
P(T<=t) one-tail	0.374087013	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.748174025	
t Critical two-tail	2.446911851	

Color: Room 8





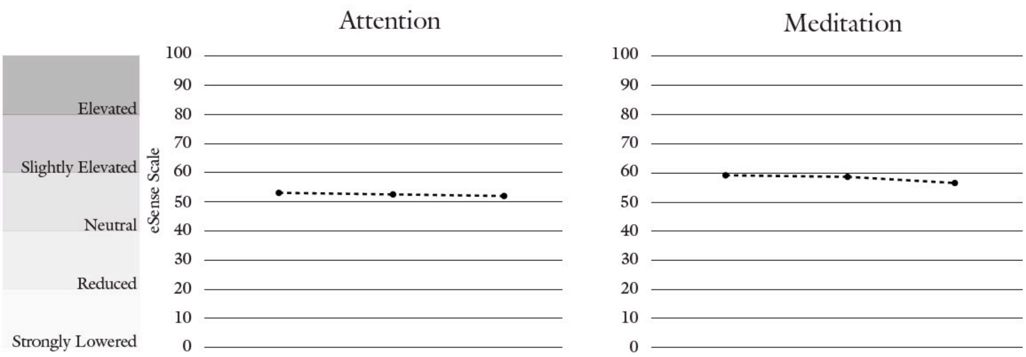


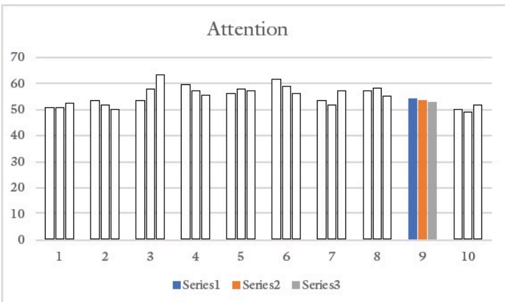


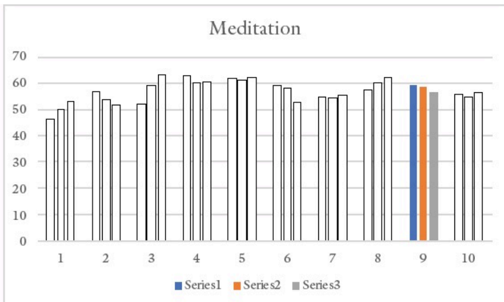
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 3 (Attention)	*Room 3 (Meditation)*
Mean	56.675	56.45
Variance	23.4425	32.22333333
Observations	4	4
Pooled Variance	27.83291667	
Hypothesized Mean Diff	0	
df	6	
t Stat	0.060314003	
P(T<=t) one-tail	0.476932169	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.953864339	
t Critical two-tail	2.446911851	

Color: Room 9



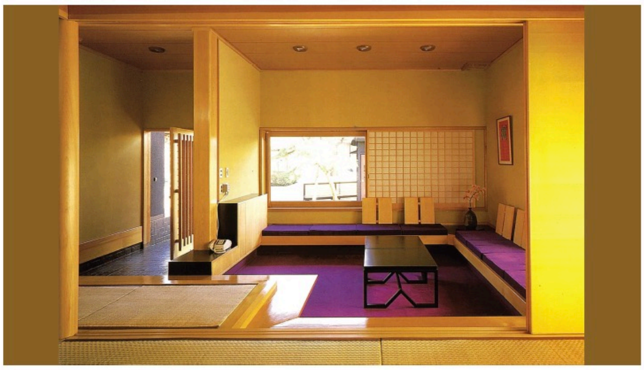


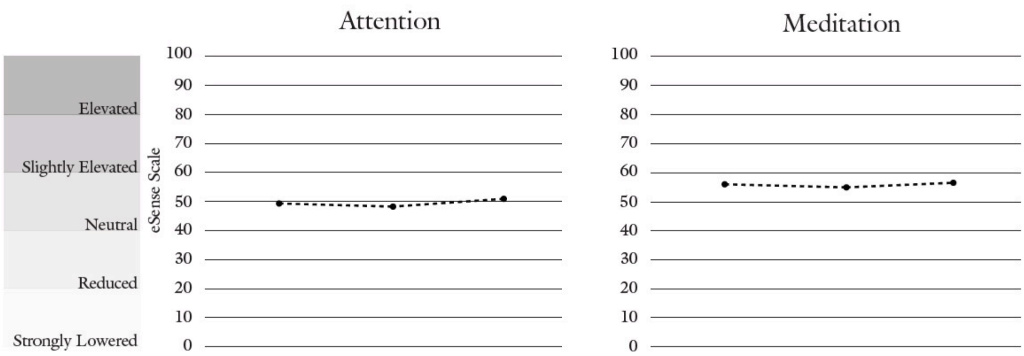


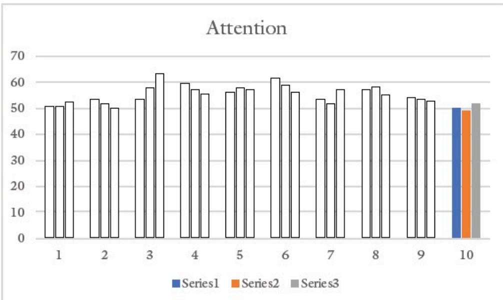
Statistical Analysis (Individual)

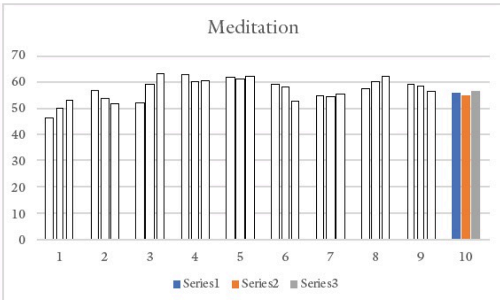
t-Test: Two-Sample Assuming Equal Variances		
	Room 9 (Attention)	*Room 9 (Meditation)*
Mean	53.05	58.425
Variance	0.596666667	2.2425
Observations	4	4
Pooled Variance	1.419583333	
Hypothesized Mean Diff	0	
df	6	
t Stat	-6.379887498	
P(T<=t) one-tail	0.000348628	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.000697256	
t Critical two-tail	2.446911851	

Color: Room 10









Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Pic 10	*Room 10*
Mean	50.05	56.25
Variance	1.896666667	1.563333333
Observations	4	4
Pooled Variance	1.73	
Hypothesized Mean Diff	0	
df	6	
t Stat	-6.666281299	
P(T<=t) one-tail	0.000275652	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.000551304	
t Critical two-tail	2.446911851	

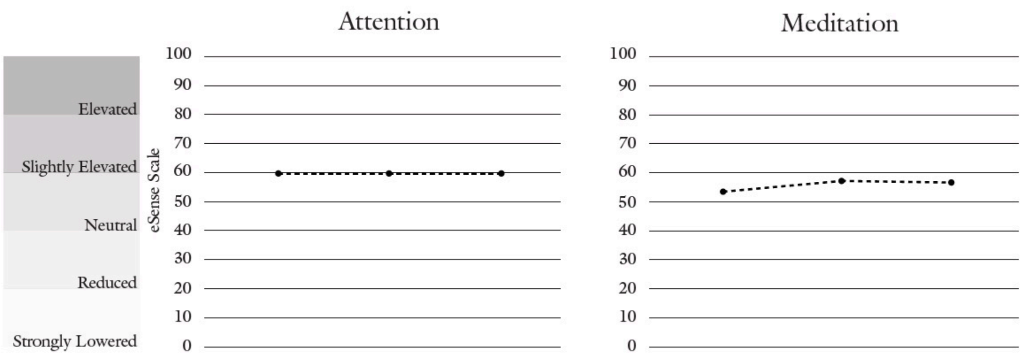
Proportions

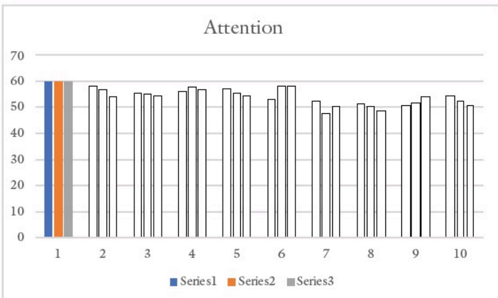
From the group of Proportions, 6 Rooms have shown statistically significant differences between levels of Attention and Meditation. Two of the rooms have shown significantly higher Attention levels, and six other rooms have shown higher statistically significant Meditation levels.

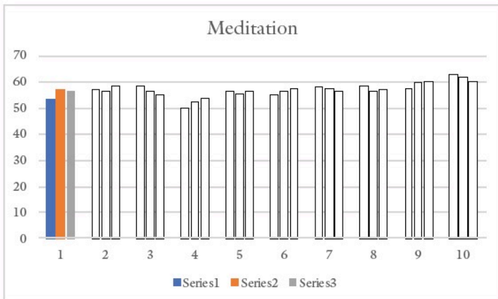
- Room 1, a Georgian style room, with high ceiling and high and wide openings and bright environment has shown a significant higher Attention values.
- Room 4, a room representing contemporary interior design, uniformly immersed in light wood, with Asymmetrical proportional characteristics and bright environment has shown statistically significant higher attention values.
- Room 7, which represents a classical room designed by the renowned architect Palladio, characterized with high ceiling and antique furnishings has showed a statistically significant higher Meditation values.
- Room 8, which represents an asymmetrical - low ceiling with no natural lighting environment has shown a statistically significant higher Meditation level.
- Room 9 and 10, both representing another set of examples of classical rooms designed by Palladion, characterized with high ceiling, bright environment and symmetrical proportional axis, have both shown statistically significant higher Meditation values.

Proportions

Proportion: Room 1



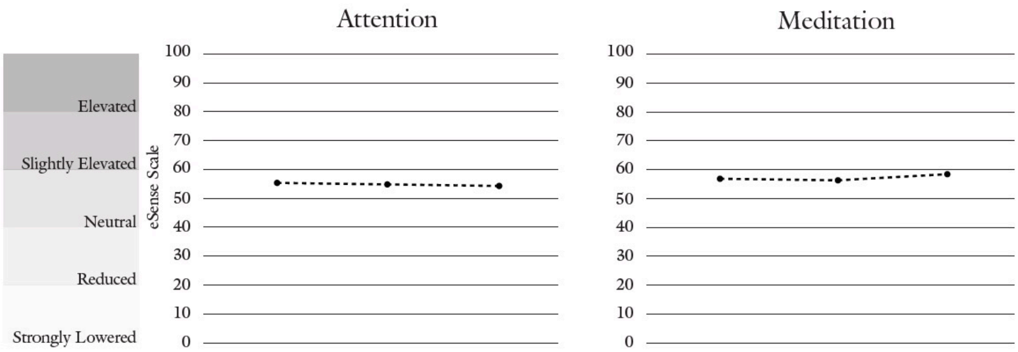


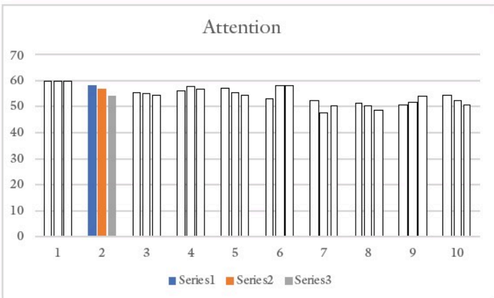


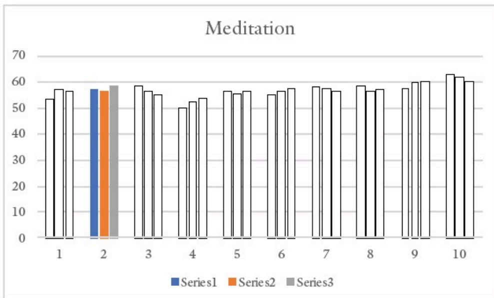
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 1 (Attention)	*Room 1 (Meditation)*
Mean	59.43421053	55.06578947
Variance	0.18721145	3.647968606
Observations	4	4
Pooled Variance	1.917590028	
Hypothesized Mean Diffe	0	
df	6	
t Stat	4.461301846	
P(T<=t) one-tail	0.002138524	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.004277047	
t Critical two-tail	2.446911851	

Proportion: Room 2



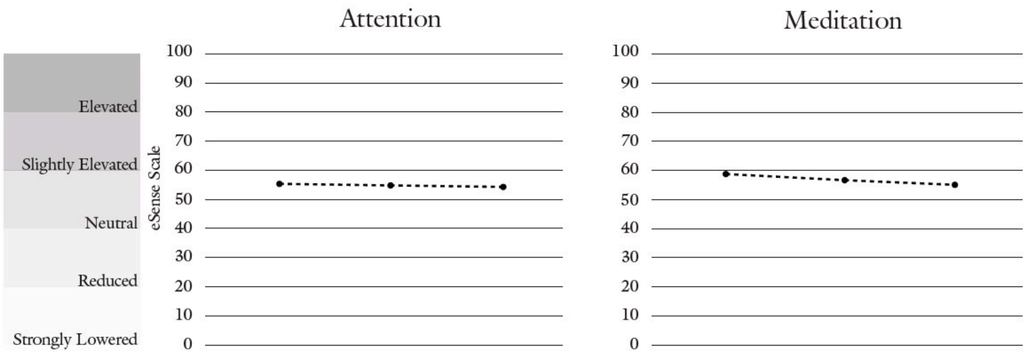


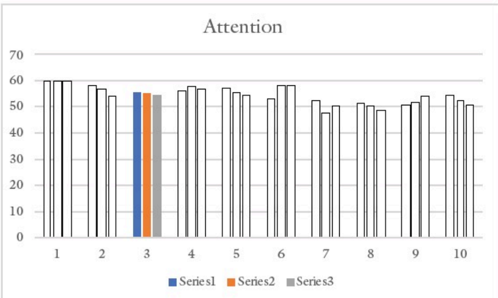


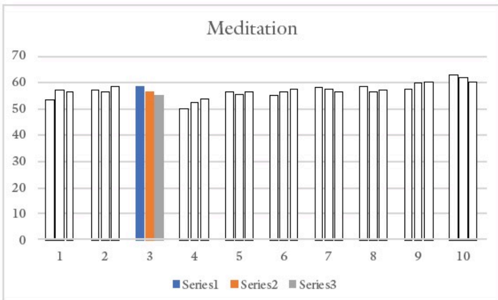
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 2 (Attention)	*Room 2 (Meditation)*
Mean	57.46052632	57.53947368
Variance	7.570406279	1.034856879
Observations	4	4
Pooled Variance	4.302631579	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-0.053825191	
P(T<=t) one-tail	0.479410933	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.958821866	
t Critical two-tail	2.446911851	

Proportion: Room 3



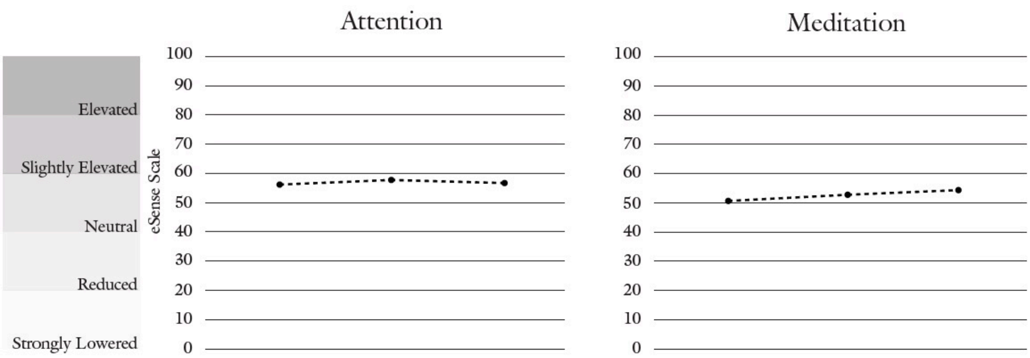


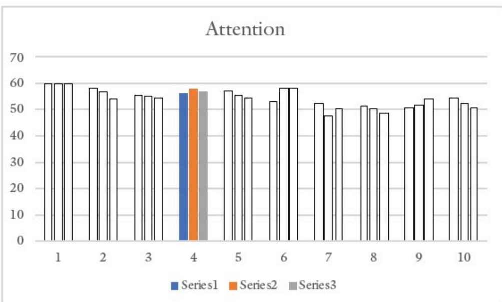


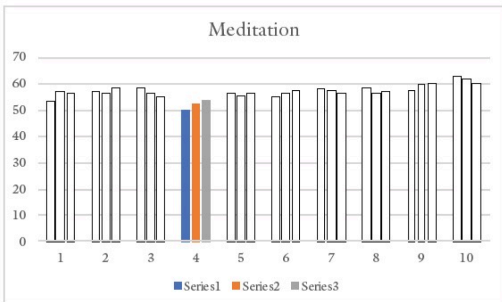
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 3 (Attention)	*Room 3 (Meditation)*
Mean	54.22368421	56.90789474
Variance	2.262927054	3.038550323
Observations	4	4
Pooled Variance	2.650738689	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-2.331568152	
P(T<=t) one-tail	0.029257514	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.058515029	
t Critical two-tail	2.446911851	

Proportion: Room 4



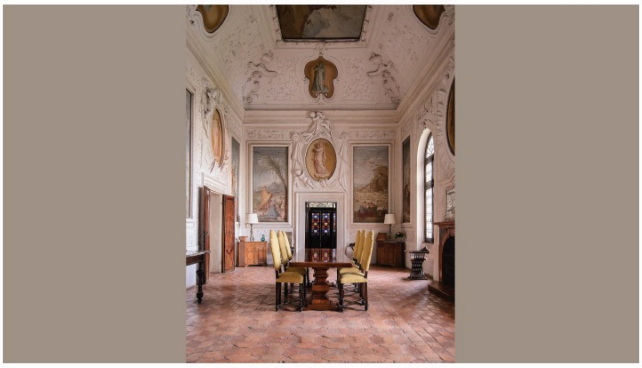


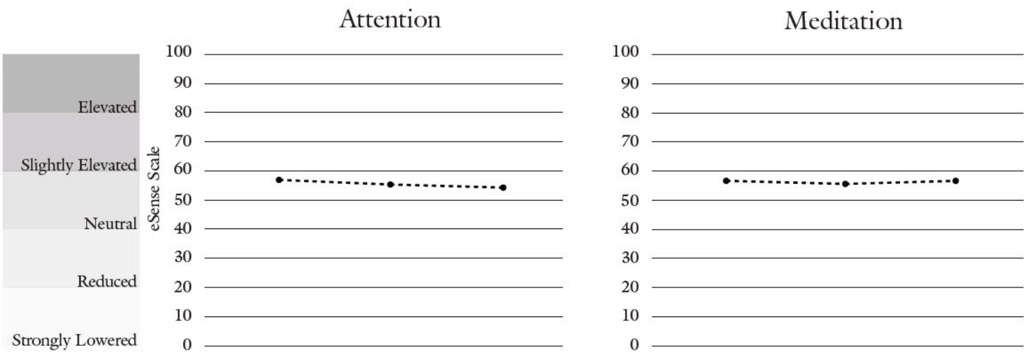


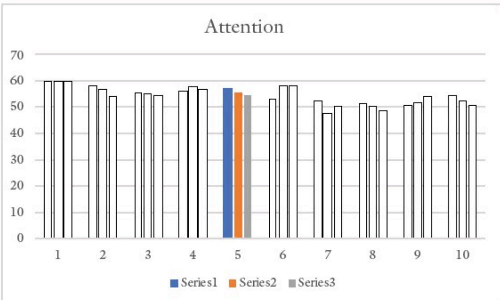
Statistical Analysis (Individual)

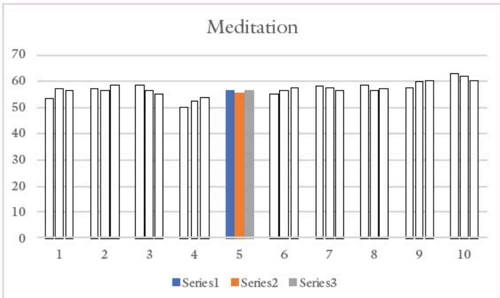
t-Test: Two-Sample Assuming Equal Variances		
	Room 4 (Attention)	*Room 4 (Meditation)*
Mean	56.67105263	52.26315789
Variance	0.403277932	2.520775623
Observations	4	4
Pooled Variance	1.462026777	
Hypothesized Mean Diffe	0	
df	6	
t Stat	5.155473384	
P(T<=t) one-tail	0.001051996	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.002103991	
t Critical two-tail	2.446911851	

Proportion: Room 5





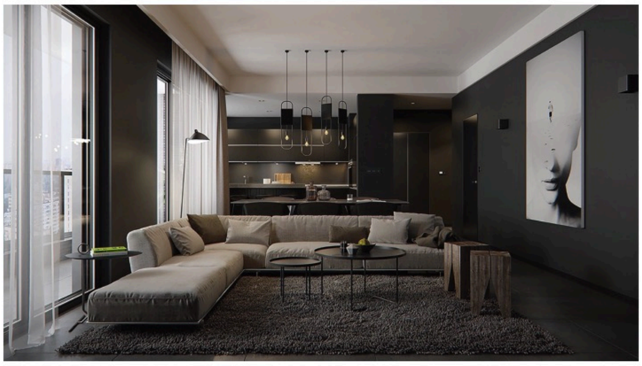


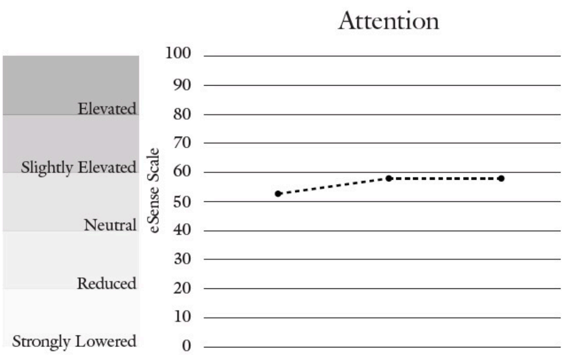


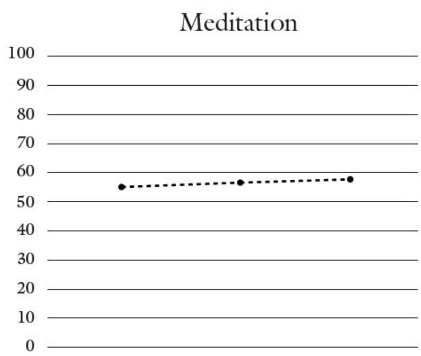
Statistical Analysis (Individual)

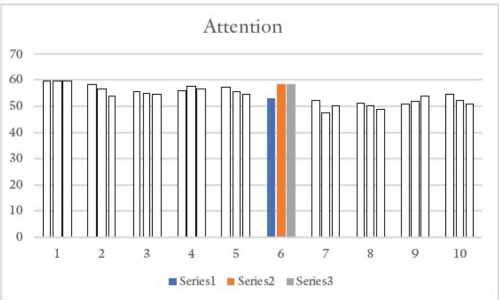
t-Test: Two-Sample Assuming Equal Variances		
	Room 5 (Attention)	*Room 5 (Meditation)*
Mean	56.42105263	55.68421053
Variance	2.132963989	1.021237304
Observations	4	4
Pooled Variance	1.577100646	
Hypothesized Mean Diffe	0	
df	6	
t Stat	0.829773819	
P(T<=t) one-tail	0.219213382	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.438426764	
t Critical two-tail	2.446911851	

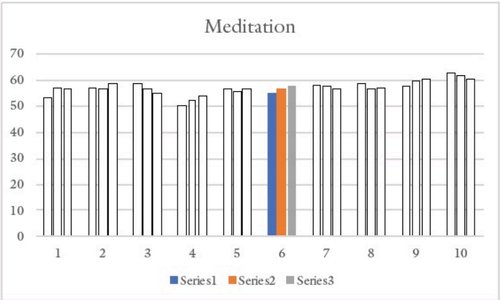
Proportion: Room 6







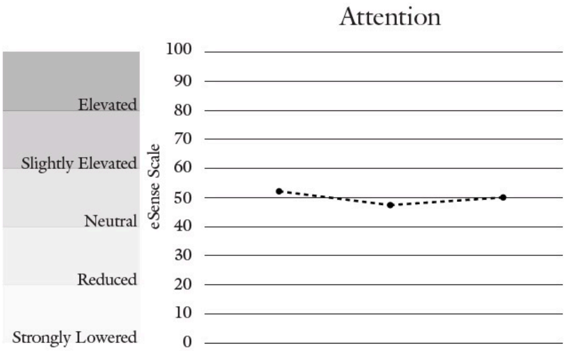


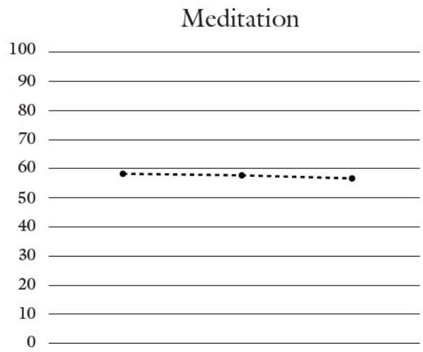


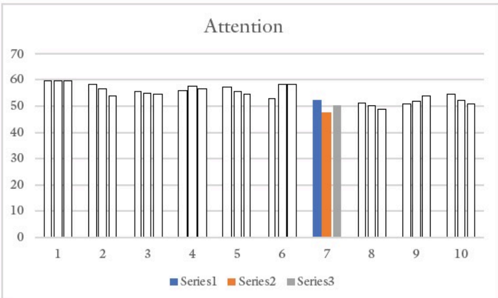
Statistical Analysis (Individual)

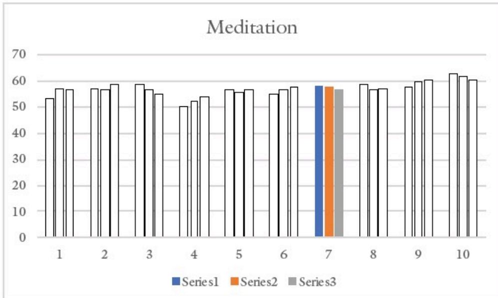
t-Test: Two-Sample Assuming Equal Variances		
	Room 6 (Attention)	*Room 6 (Meditation)*
Mean	55.73684211	55.81578947
Variance	9.497691597	2.054478301
Observations	4	4
Pooled Variance	5.776084949	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-0.046455364	
P(T<=t) one-tail	0.482227467	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.964454934	
t Critical two-tail	2.446911851	

Proportion: Room 7





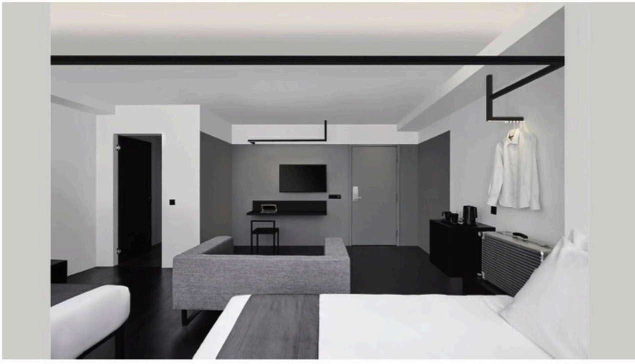


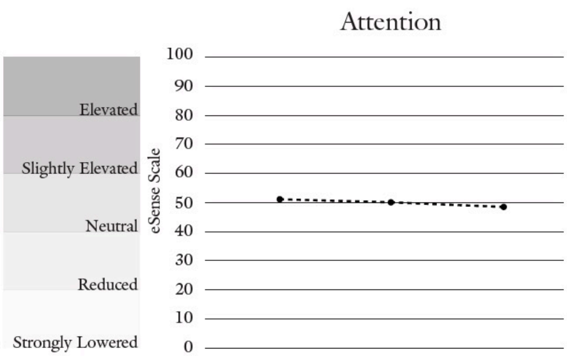


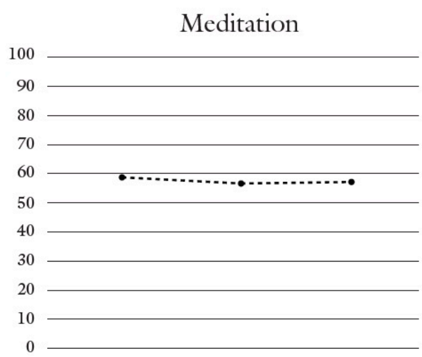
Statistical Analysis (Individual)

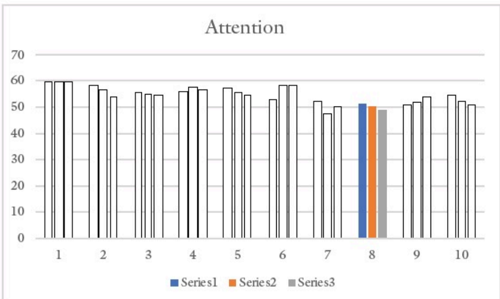
t-Test: Two-Sample Assuming Equal Variances		
	Room 7 (Attention)	*Room 7 (Meditation)*
Mean	51.68421053	57.26315789
Variance	12.88827331	0.334256694
Observations	4	4
Pooled Variance	6.611265005	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-3.068491887	
P(T<=t) one-tail	0.010992238	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.021984475	
t Critical two-tail	2.446911851	

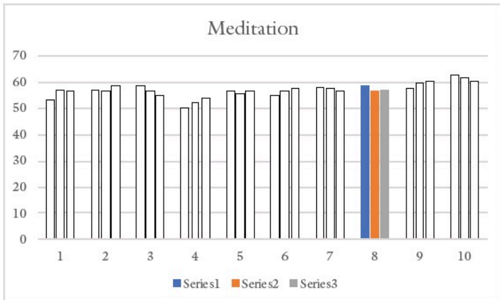
Proportion: Room 8







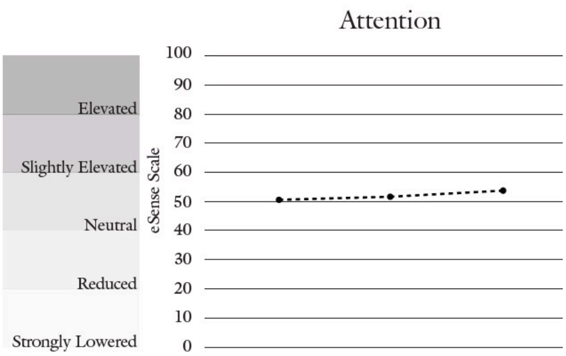


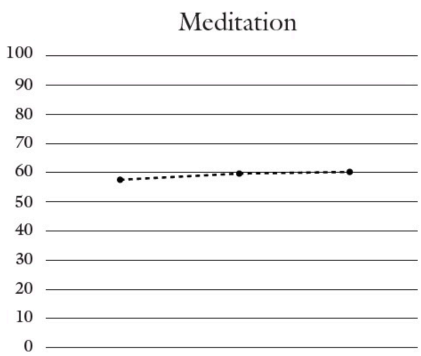


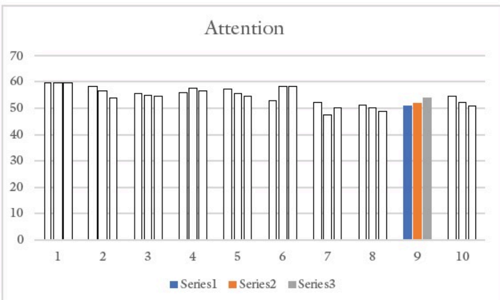
Statistical Analysis (Individual)

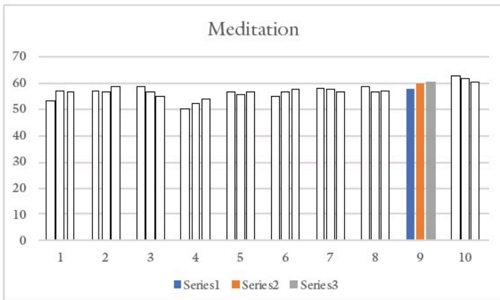
t-Test: Two-Sample Assuming Equal Variances		
	Room 8 (Attention)	*Room 8 (Meditation)*
Mean	49.19736842	57.34210526
Variance	4.41989843	0.931671283
Observations	4	4
Pooled Variance	2.675784857	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-7.041520675	
P(T<=t) one-tail	0.000205052	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.000410103	
t Critical two-tail	2.446911851	

Proportion: Room 9





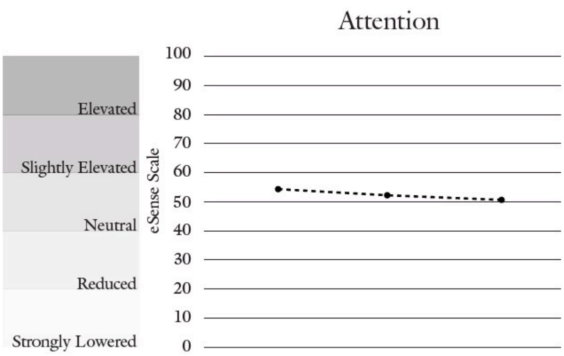


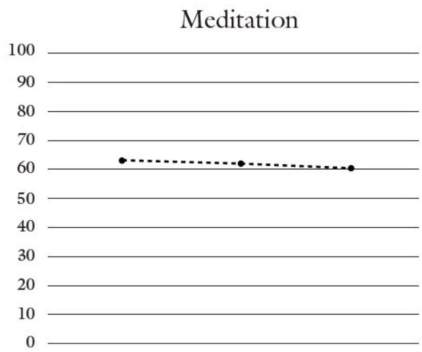


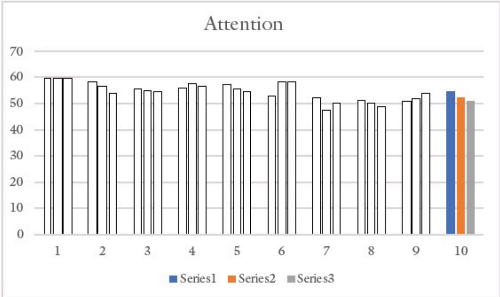
Statistical Analysis (Individual)

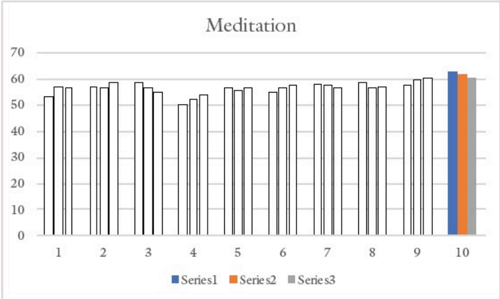
t-Test: Two-Sample Assuming Equal Variances		
	Room 9 (Attention)	*Room 9 (Meditation)*
Mean	52.05263158	58.80263158
Variance	1.697137581	1.603647276
Observations	4	4
Pooled Variance	1.650392428	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-7.430621835	
P(T<=t) one-tail	0.000152885	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.000305771	
t Critical two-tail	2.446911851	

Proportion: Room 10









Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 10 (Attention)	*Room 10 (Meditation)*
Mean	52.75	61.27631579
Variance	2.515927978	1.034856879
Observations	4	4
Pooled Variance	1.775392428	
Hypothesized Mean Diffe	0	
df	6	
t Stat	-9.049596797	
P(T<=t) one-tail	5.10295E-05	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.000102059	
t Critical two-tail	2.446911851	

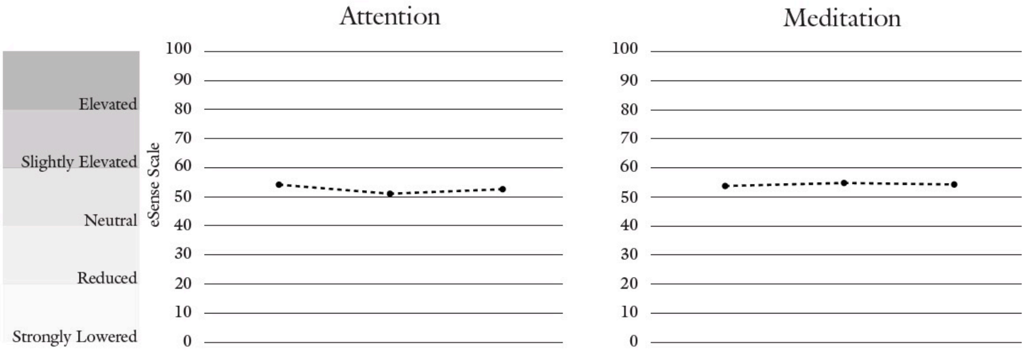
Texture

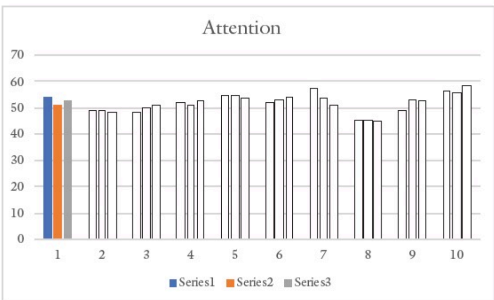
From the group of Texture, 6 Rooms have shown statistically significant differences between levels of Attention and Meditation. All of the rooms have shown significantly higher Meditation levels. Below we will elaborate all of the rooms of these cases:

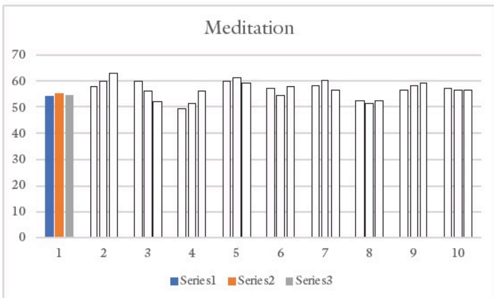
- Room 1, a room representing an environment of tiles in light color and uniformity of distribution. This rooms has shown a significant higher Meditation value.
- Room 2, which represents a room picked up for a stone environment, but at the same time is the only room that has incorporated greenery in it. It is worth mentioning that this room has shown the highest meditation of all rooms in all groups.
- Room 3 represents a contemporary Japanese environment but which includes tatami flooring. This room has also shown statistically significant higher Meditation value.
- Room 5, a room immersed in rough concrete, and generally representing a dark environment, has also shown a statistically significant higher meditation value.
- Room 6 is the room that represents wooden immersed situation in distribution of texture, with bright environment. This room has shown significantly higher meditation level.
- Lastly, Room 9, which represents a bright room with high reflection properties of tiles, and open space. This room has shown a statistically significant higher Meditation value.

Texture

Texture: Room 1



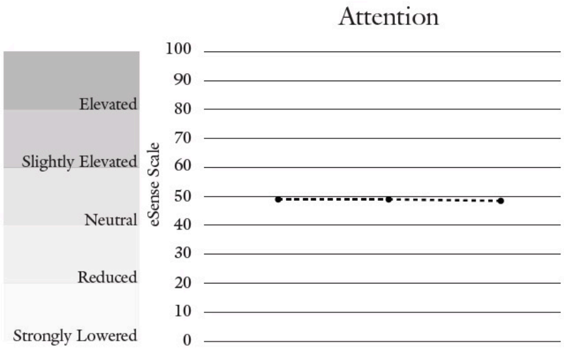


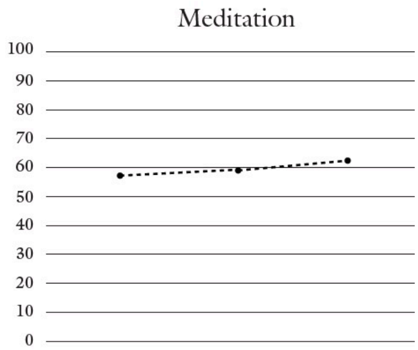


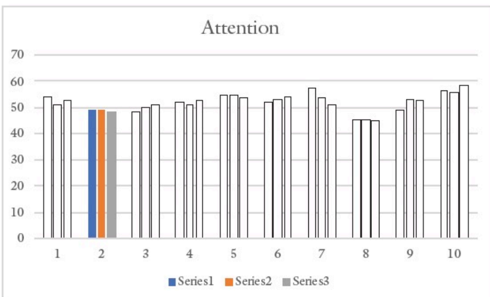
Statistical Analysis (Individual)

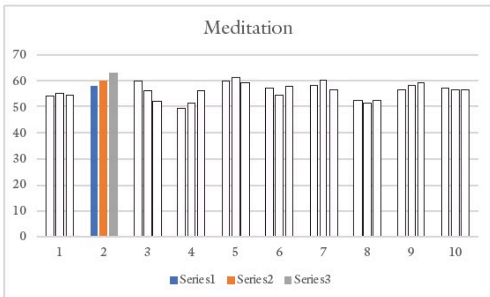
t-Test: Two-Sample Assuming Equal Variances		
	Room 1 (Attention)	*Room 1 (Meditation)*
Mean	53	55.19736842
Variance	2.155124654	1.051477378
Observations	4	4
Pooled Variance	1.603301016	
Hypothesized Mean Diff	0	
df	6	
t Stat	-2.45420221	
P(T<=t) one-tail	0.024753748	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.049507497	
t Critical two-tail	2.446911851	

Texture: Room 2





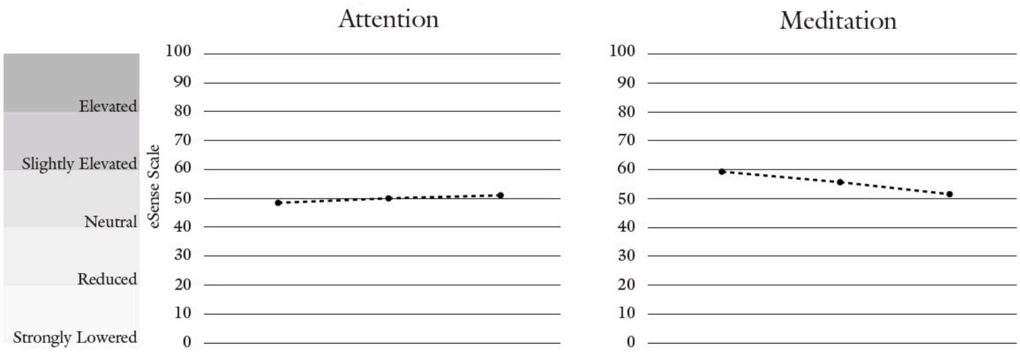


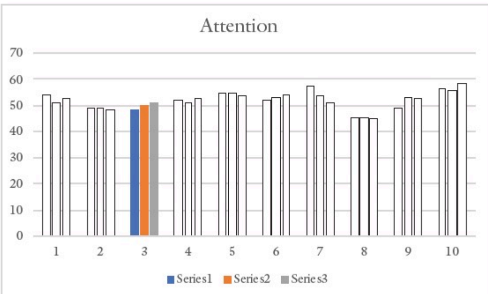


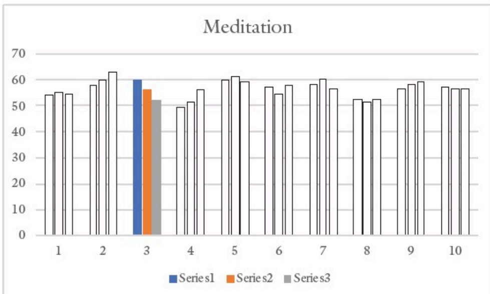
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 2 (Attention)	*Room 2 (Meditation)*
Mean	49.19736842	58.86842105
Variance	0.659972299	12.78393352
Observations	4	4
Pooled Variance	6.721952909	
Hypothesized Mean Diff	0	
df	6	
t Stat	-5.275225289	
P(T<=t) one-tail	0.000936895	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.001873789	
t Critical two-tail	2.446911851	

Texture: Room 3



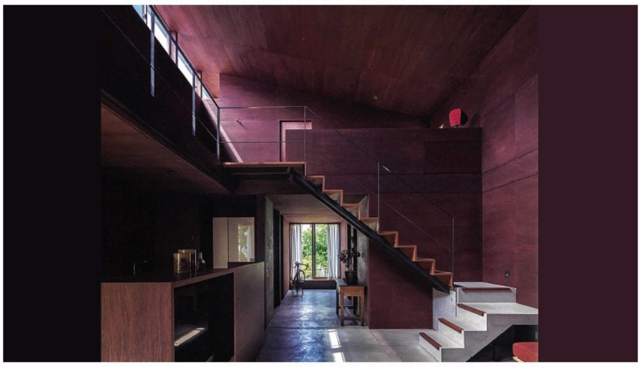


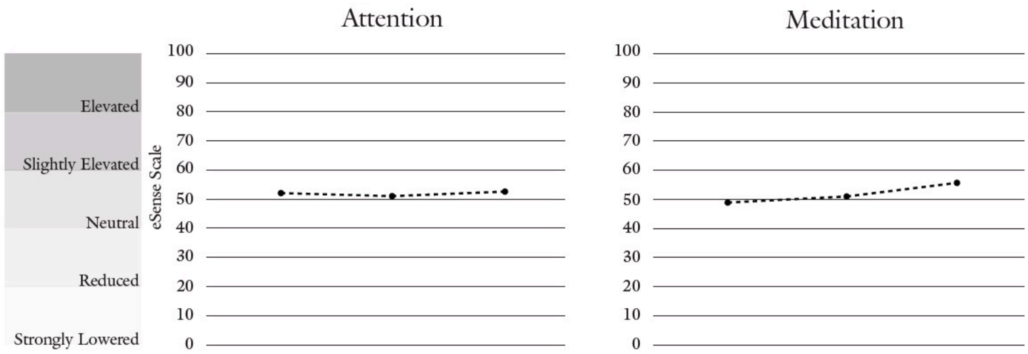


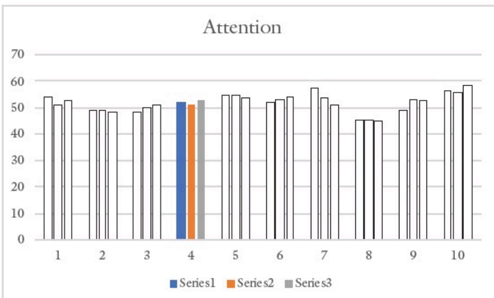
Statistical Analysis (Individual)

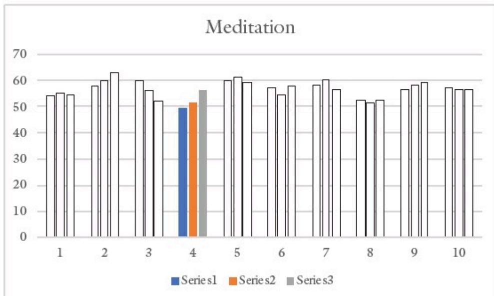
t-Test: Two-Sample Assuming Equal Variances		
	Room 3 (Attention)	*Room 3 (Meditation)*
Mean	49.76315789	57.48684211
Variance	0.894736842	20.84464451
Observations	4	4
Pooled Variance	10.86969067	
Hypothesized Mean Diff	0	
df	6	
t Stat	-3.313072306	
P(T<=t) one-tail	0.008071443	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.016142887	
t Critical two-tail	2.446911851	

Texture: Room 4





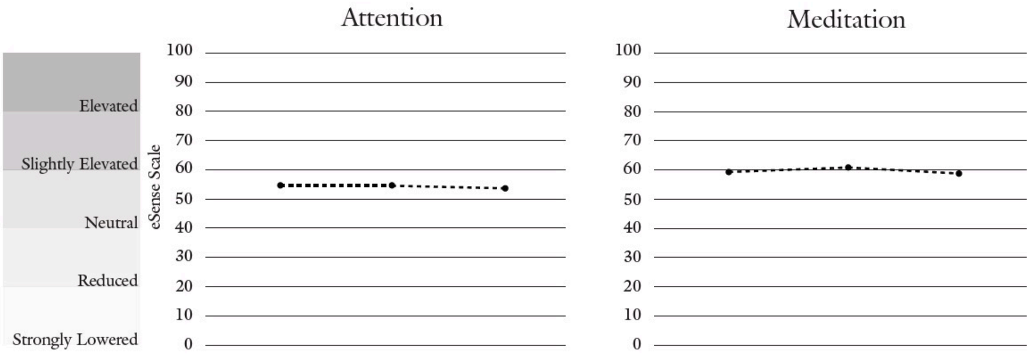


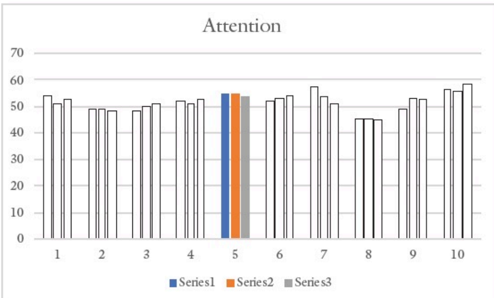


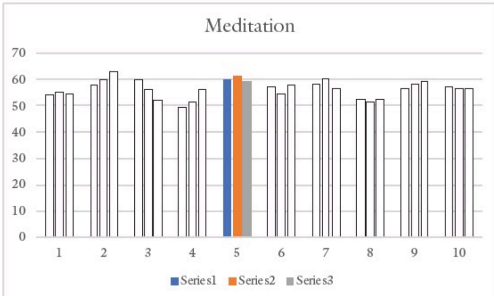
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 4 (Attention)	*Room 4 (Meditation)*
Mean	51.06578947	52.09210526
Variance	3.969298246	8.486380425
Observations	4	4
Pooled Variance	6.227839335	
Hypothesized Mean Diff	0	
df	6	
t Stat	-0.581603897	
P(T<=t) one-tail	0.291004672	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.582009345	
t Critical two-tail	2.446911851	

Texture: Room 5



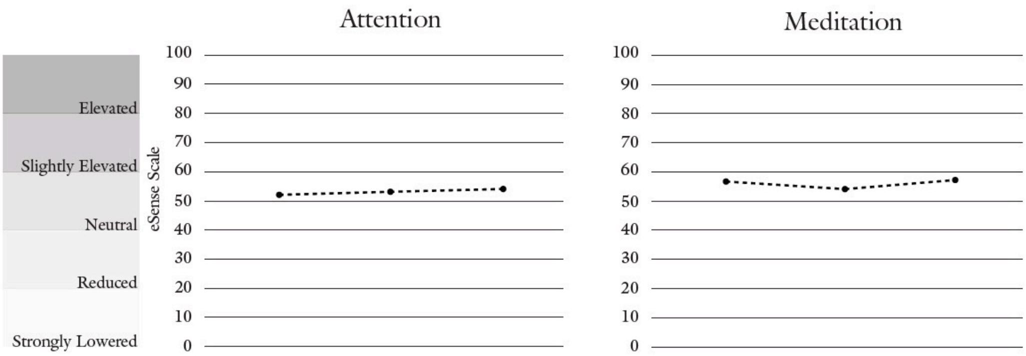


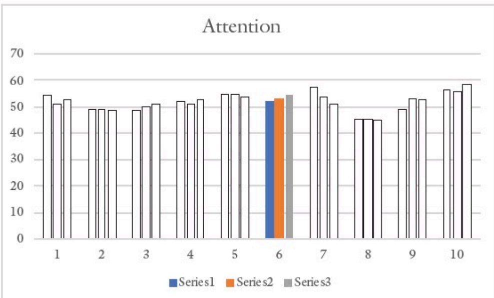


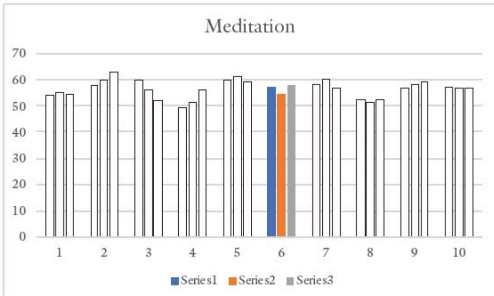
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 5 (Attention)	*Room 5 (Meditation)*
Mean	54.76315789	59.22368421
Variance	0.682363804	4.661819021
Observations	4	4
Pooled Variance	2.672091413	
Hypothesized Mean Diff	0	
df	6	
t Stat	-3.859005949	
P(T<=t) one-tail	0.004185976	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.008371953	
t Critical two-tail	2.446911851	

Texture: Room 6



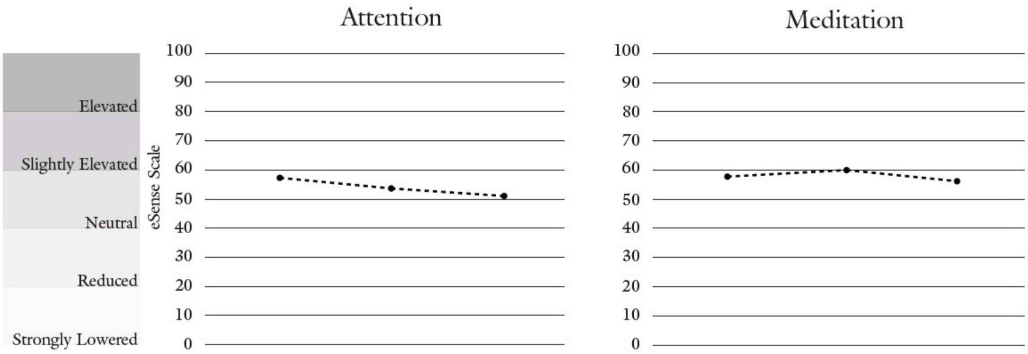


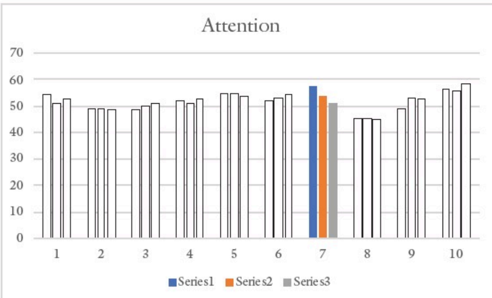


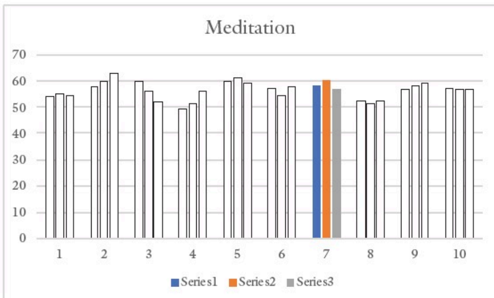
Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 6 (Attention)	*Room 6 (Meditation)*
Mean	52.84210526	57.80263158
Variance	1.462603878	6.80401662
Observations	4	4
Pooled Variance	4.133310249	
Hypothesized Mean Diff	0	
df	6	
t Stat	-3.45059313	
P(T<=t) one-tail	0.00681155	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.013623099	
t Critical two-tail	2.446911851	

Texture: Room 7



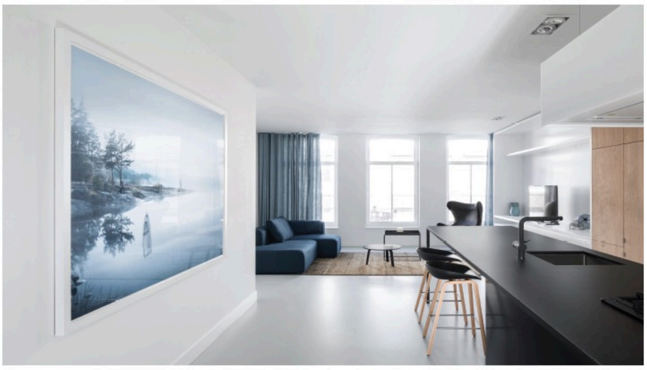


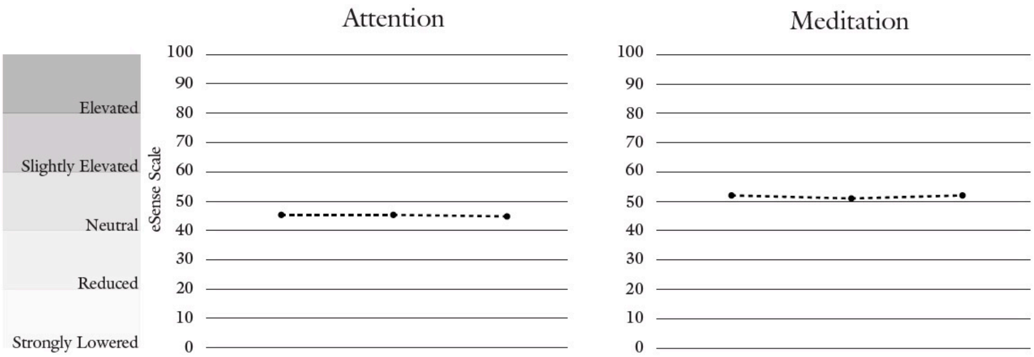


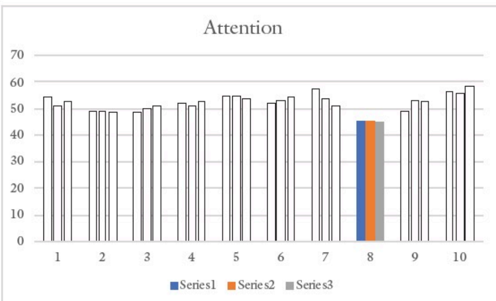
Statistical Analysis (Individual)

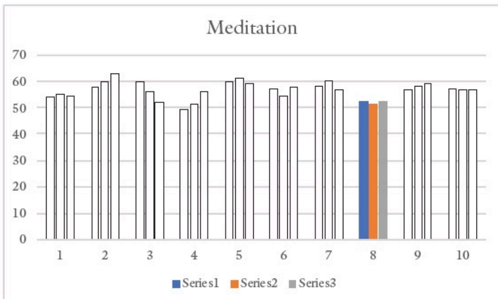
t-Test: Two-Sample Assuming Equal Variances		
	Room 7 (Attention)	*Room 7 (Meditation)*
Mean	55.03947368	58.63157895
Variance	9.755078486	2.506001847
Observations	4	4
Pooled Variance	6.130540166	
Hypothesized Mean Diff	0	
df	6	
t Stat	-2.051703888	
P(T<=t) one-tail	0.043019419	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.086038838	
t Critical two-tail	2.446911851	

Texture: Room 8







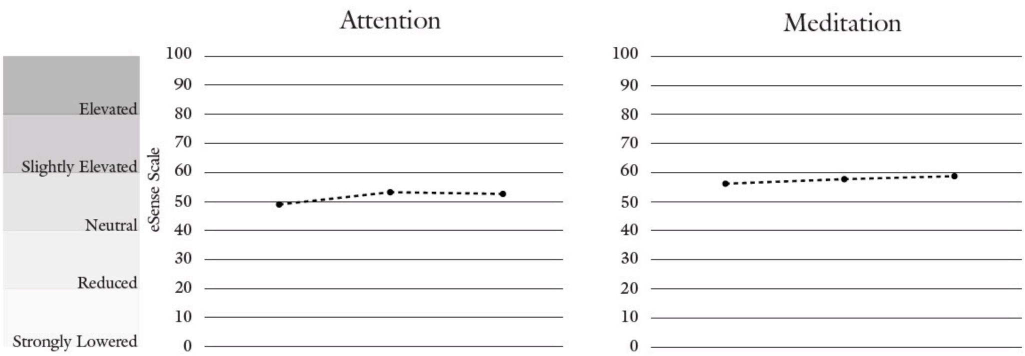


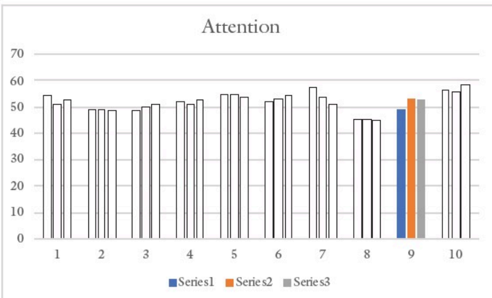
Statistical Analysis (Individual)

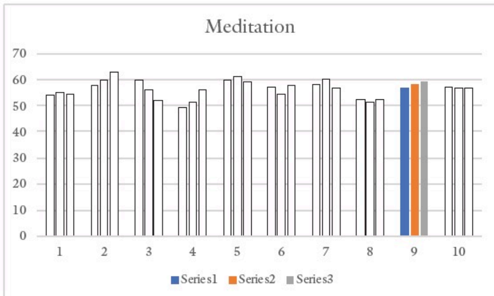
t-Test: Two-Sample Assuming Equal Variances

	Room 8 (Attention)	*Room 8 (Meditation)*
Mean	45.73684211	52.17105263
Variance	0.75900277	0.329409049
Observations	4	4
Pooled Variance	0.54420591	
Hypothesized Mean Diff	0	
df	6	
t Stat	-12.33470133	
P(T<=t) one-tail	8.65738E-06	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	1.73148E-05	
t Critical two-tail	2.446911851	

Texture: Room 9



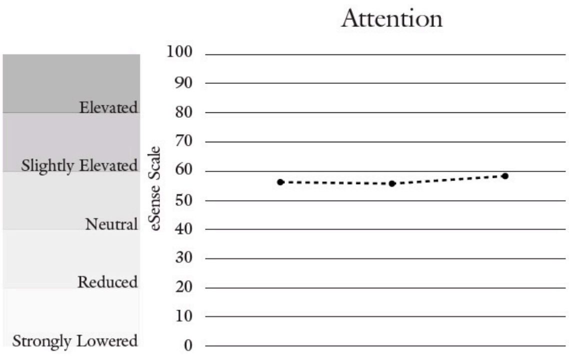


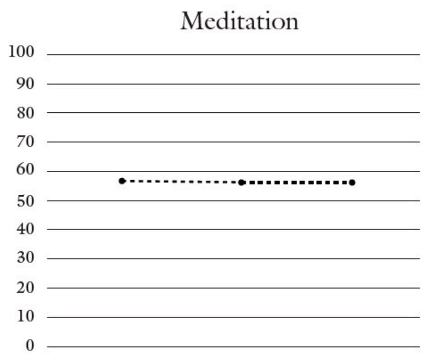


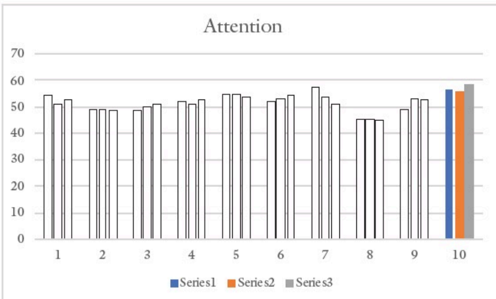
Statistical Analysis (Individual)

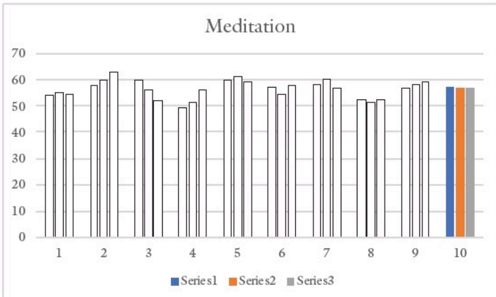
t-Test: Two-Sample Assuming Equal Variances		
	Room 9 (Attention)	*Room 9 (Meditation)*
Mean	49.80263158	57.88157895
Variance	17.43559557	1.49099723
Observations	4	4
Pooled Variance	9.463296399	
Hypothesized Mean Diff	0	
df	6	
t Stat	-3.71405692	
P(T<=t) one-tail	0.004960927	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.009921854	
t Critical two-tail	2.446911851	

Texture: Room 10









Statistical Analysis (Individual)

t-Test: Two-Sample Assuming Equal Variances		
	Room 10 (Attention)	*Room 10 (Meditation)*
Mean	56.88157895	56.68421053
Variance	1.010849492	0.373037858
Observations	4	4
Pooled Variance	0.691943675	
Hypothesized Mean Diff	0	
df	6	
t Stat	0.335550038	
P(T<=t) one-tail	0.374316146	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.748632291	
t Critical two-tail	2.446911851	

5.4.2. Part 2: Judgment Results

5.4.2.1. Preference

Subjective declarations have shown a trend slightly different from that of the brain waves. In the semantic differential ratings between "pleasantness" and "unpleasantness" of the pictures, in the group of pictures with colors, two most pleasant environments resulted in two traditional Japanese rooms, where one of them was characterized by a soft blue color which is an unusual example of a typical Japanese environment, and the other one represents a familiar Japanese environment (Appendix 5).

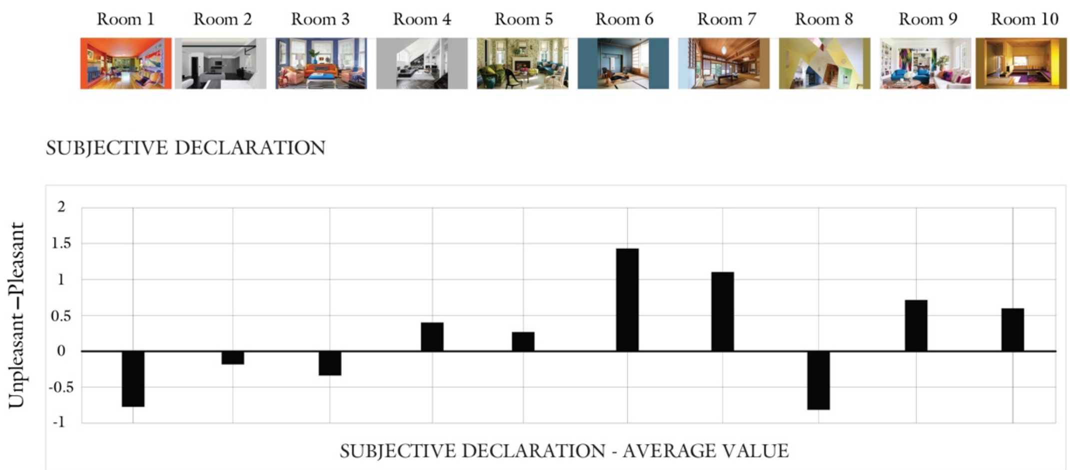
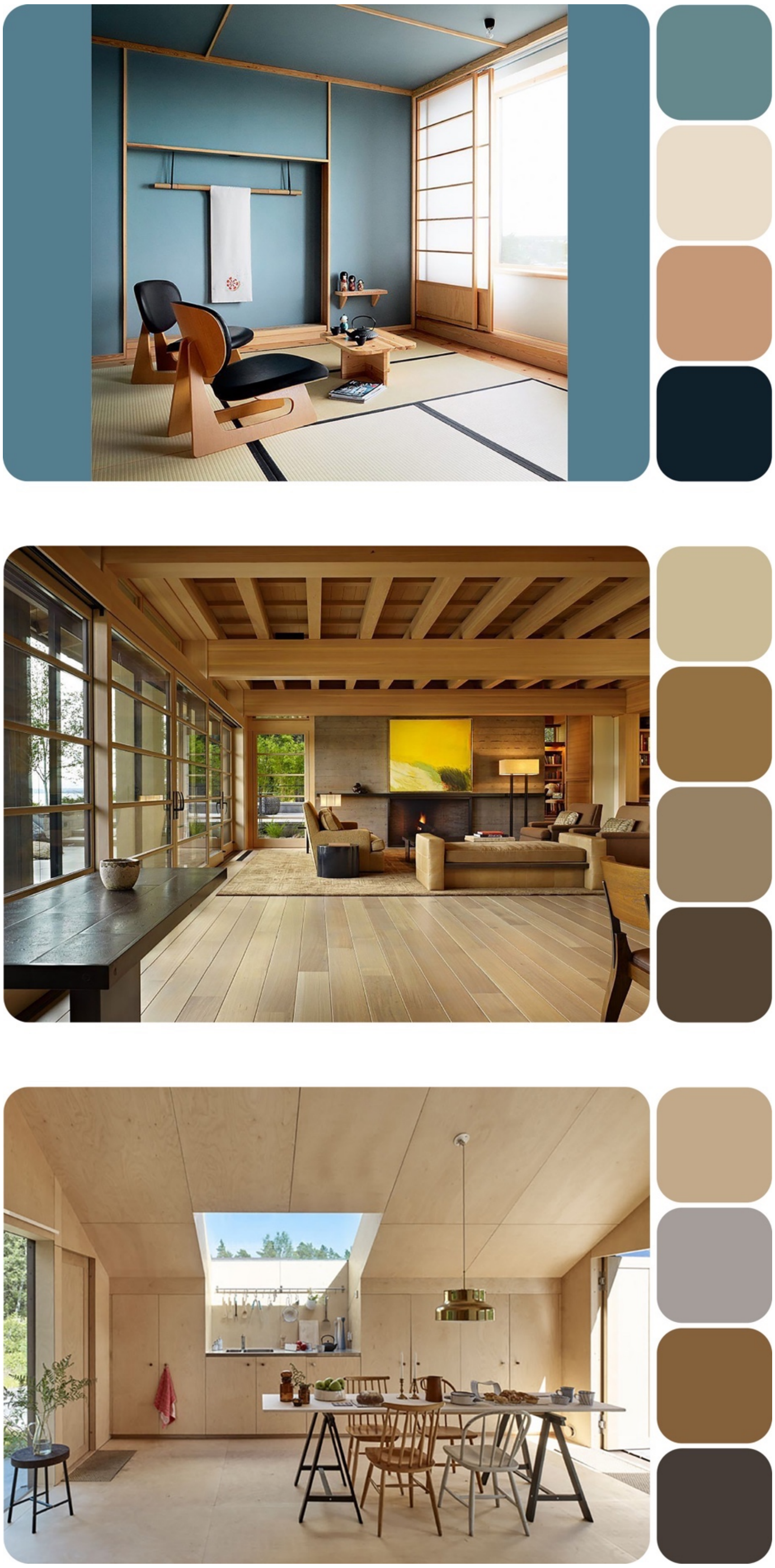


Figure 55. Color Average judgment on pleasantness

Regarding unpleasantness in this category, the overall response to this question was surprisingly persistent within participants. The highest negative value goes to the three images, which represent cases of a polychromatic interior 5+colors (Room 1, Room 3, Room 8). Interestingly, unpleasantness has been related to the image, which represents a case of a monochromatic interior (1 color) as well (Appendix 3).

Below we will present three most pleasant pictures as judged by the participants. These picture all share uniformity of the distribution of texture, low variation in colors, and wooden environments.



Picture 14. Rooms judged highly pleasant

Regarding proportions, a pronounced sense of pleasantness is observed in the case of a contemporary room with asymmetrical features and dominated by wood paneling (Room 4), while the second most pleasant room is the Georgian style room with a high ceiling and many openings (Room 1).

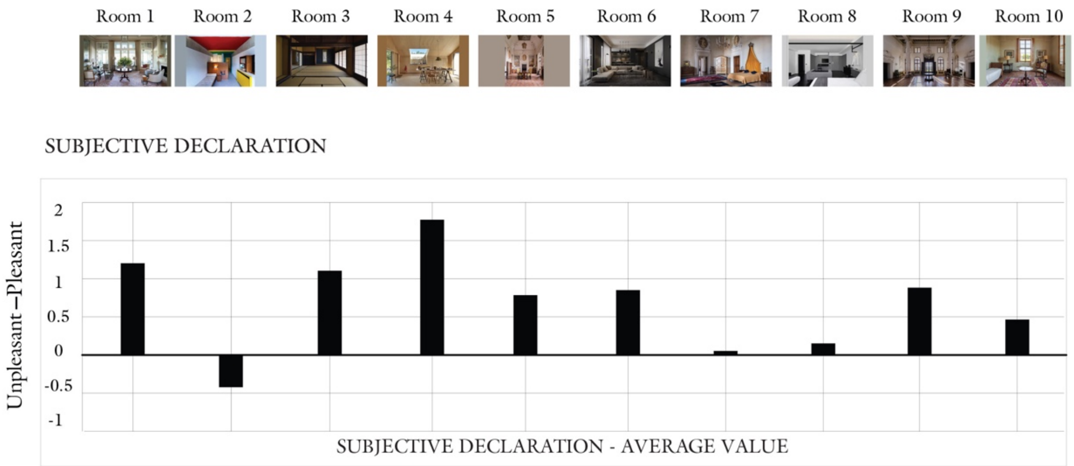


Figure 56. Proportions average judgment on pleasantness

In terms of unpleasantness, unlike the previous category, only one photo has marked negative values represented by a room characterized by polychromatic bright colors (yellow, red and green) and the roughness of the material such as exposed concrete (Picture 15).

Picture 15. Room judged with lowest pleasantness

Lastly, Texture group photos are photos with the highest values of pleasantness on average compared to the two groupings mentioned above. The most pleasant picture regarding texture based on the evaluation is indicated to be the wood-enclosed environment (Room 6). Other distinctive components of this room are brightness and uniformity in the distribution of the materials.

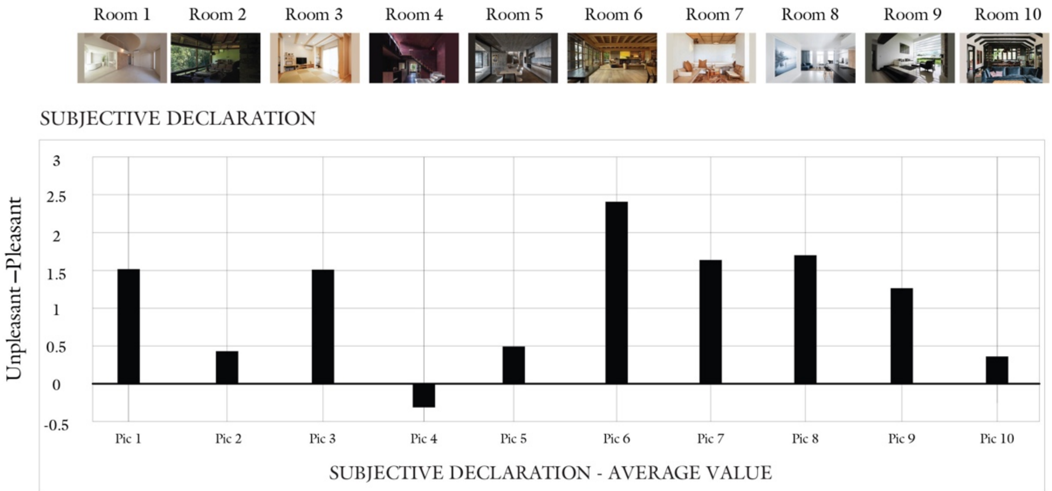


Figure 57. Texture average judgment on pleasantness

The brightness in the second most pleasant image is also characterized by the whiteness of texture with a semi-reflective surface. Comparable values have two other cases with similar characteristics, namely cleanliness, and simplicity. In comparison, the only image that has resulted in negative value is the environment where the primary and predominant finish material is metal.

Picture 16. Lowest pleasantess in the group of Texture

5.4.2.2. FAMILIARITY

Subjective declarations results towards familiarity have revealed a remarkable resemblance of the relationship between preference and familiarity in most of the cases. However, despite the resemblance, there are still some striking differences between the two. In the case of familiarity as well, a scale of 7 values has been presented (-3 to 3) where each of the numbers represented a subjective evaluation: -3 (very unfamiliar); -2 (moderately unfamiliar); -1 (slightly unfamiliar); 0 (neither); 1 (slightly familiar); 2 (moderately familiar); 3 (very familiar).

In the group of pictures with colors, numbers from 1 to 10 close to charts represent rooms' number, while the y-axis represents the values mentioned above. Overall, this comparative table reveals that there is a tendency to match between environments that we prefer to those we are familiar with.

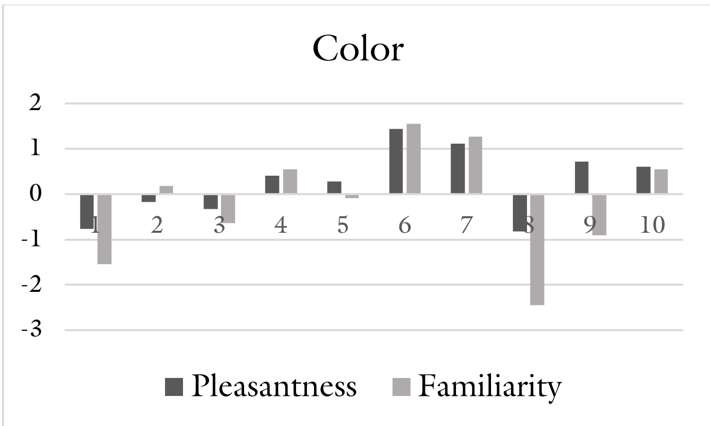


Figure 58. Comparison between pleasantness and familiarity as judged by participants

However, two cases in particular (Room 8 and Room 9) have shown a less equivalent correlation between the two aspects. This result offers compelling evidence that even if we are very unfamiliar to an environment, there is a possibility that not every time the familiarity and preference are mutually experienced. In the group of pictures that represented proportions, we can again recognize a tendency for equivalence between pleasantness and familiarity, albeit in less proportional value.

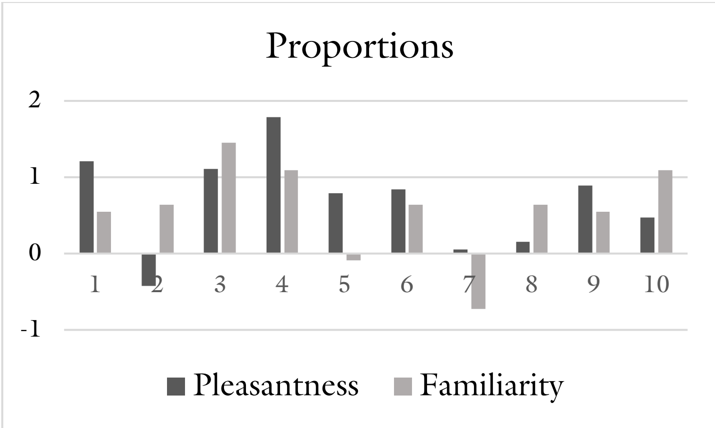


Figure 59. Comparison between pleasantness and familiarity in second group

A distinctive difference between the two has been shown in Room 1, Room 2, Room5, and Room 7. Room number 2 is the only case where familiarity is high while preference is significantly low. It is also worth mentioning that the highest familiarity has been observed in the wooden room (Room 6), but that did not correspond to the highest pleasantness presented in the contemporary room (number 4). Lastly, the group of textures has shown the highest differences between familiarity and preference. 70% of the participant's responses showed high preference even though the pictures were unfamiliar to them.

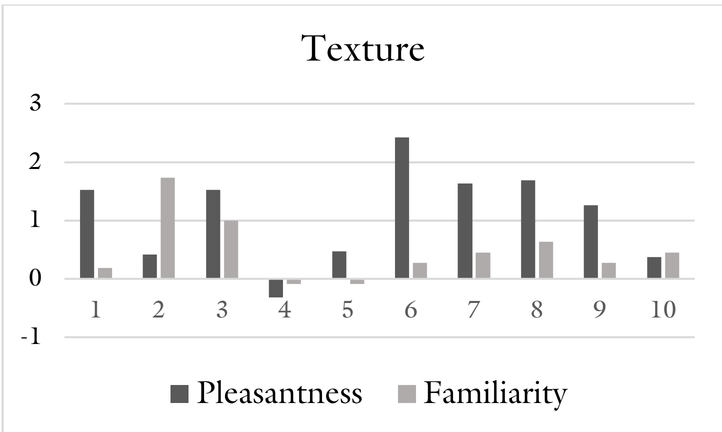


Figure 60. Comparison between pleasantness and familiarity in texture group

5.4.2.3. MEMORY

Taking into consideration that the last experiment showed consistency of judgment between two years, different to that of brainwaves that showed significant change, this time, some of the subjects had been exposed to the '*11th picture'*, which is a random repetition of one of the pictures showed in the 10-picture set. This way, we intended to observe the consistency of the judgment. This test's result has been analyzed through a two-fold approach: 1) brainwave analysis on the change between first impression and repetition; 2) evaluation values analysis based on the judgment.

T-Test: two-sample assuming equal variances was used to detect any significant changes that could influence EEG recordings between the average values of participants for the first time and the second time after repetition. Statistical analysis data was produced using EXCEL 2019 (Microsoft Inc.). A p-value of <0.05 was considered significant. No significant difference was found between the averages of those related to neither Attention average values nor Meditation. However, from the results, we can observe a tendency for a drop in the attention level and raise the meditation level after repetition.

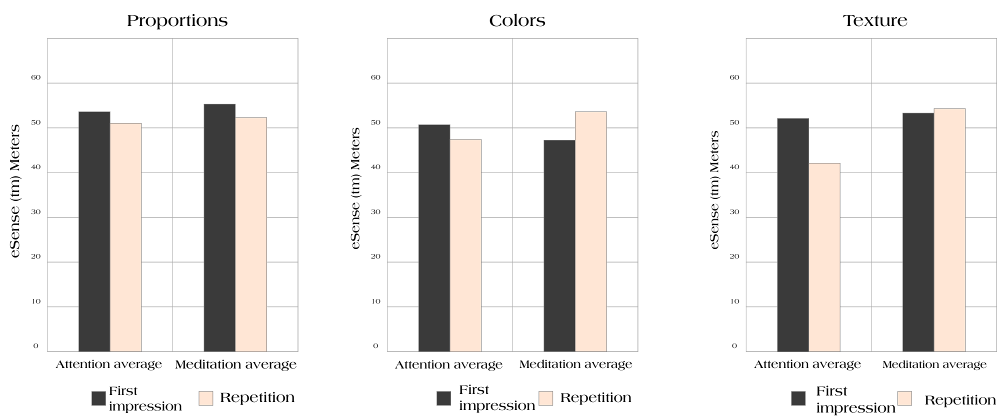


Figure 61. Comparison of brain dynamics between the first time and the repetition of the stimuli

Meanwhile, further analysis has shown a difference in the judgment of architecture between the first and second time of presentation of stimuli. In the proportion groups, 15 out of 19 cases have been exposed to the "11th picture," and in 6 cases, participants judged the picture more positively, while in 9 cases judged it the same way as for the first time. There were no lower values in this group.

In the Color group, of 19 participants, 12 got to respond to the repetitive picture. 92% of the participants judged the picture the same or more positively for the first time, and only 8% gave a lower value. In the last group, the texture group, 17 out of 19 participants were randomly exposed to the 11th picture, and 13 of them judged the picture more positively or the same as the first time, while 9 of them has a drawback on the pleasantness. These analyses reveal that, on average, pictures tended to be judged as more pleasant when seen for the second time in 89.3% of the participants, while 10.7% felt less positive about their judgment after the repetition (Fig.64).

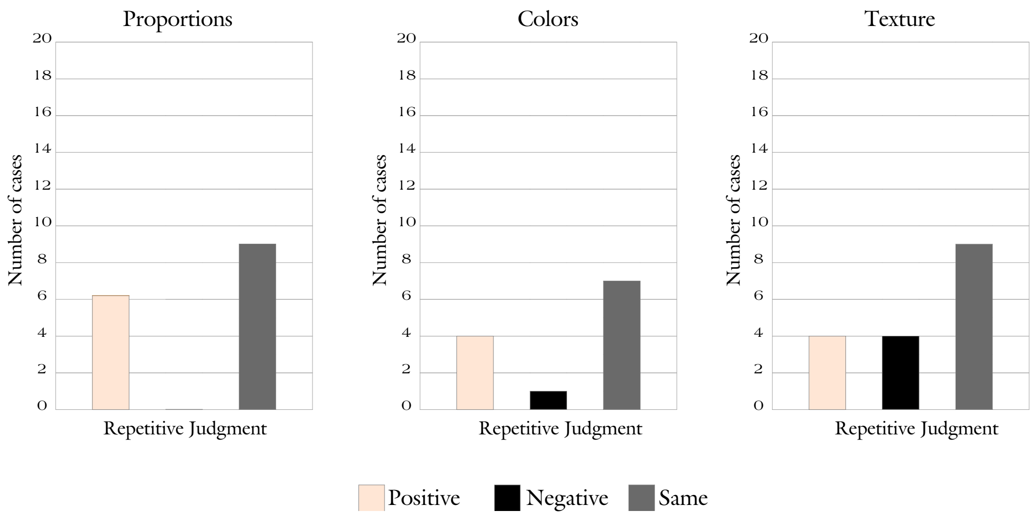


Figure 62. Graphs of results from repetitive judgment

5.4.2.4. RESPONSE TIME

Another feature that has been analyzed in this research is the average time spent for the judgment of the pictures and the relationship between the length of the response in regard to the evaluation given for pleasantness.

Color	Proportions	Texture
Time: 14 s	Time: 7.2 s	Time: 8.5 s

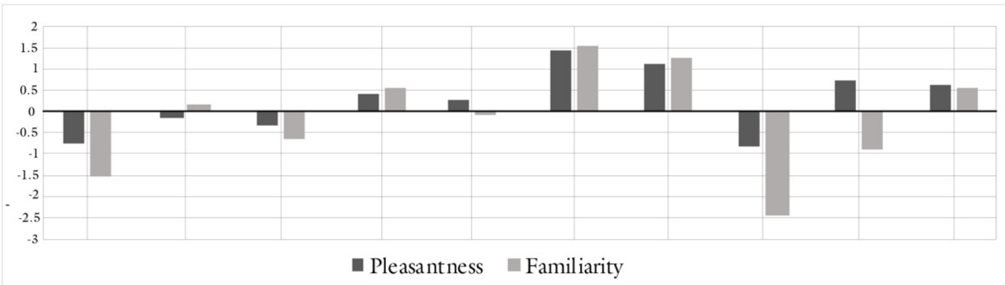
Picture 17. Longest answer time for judgment

As can be observed from the Pic. 14, strikingly, two of the photographs that showed the longest time of response correspond to the two of the lowest rating during the trial, while one of them (Proportions group) corresponds to the first lower average rating of all the photographs presented. Another interesting observation regarding answering time has been in the difference between architects and non-architects. In general, architects could observe and judge the picture as fast as for 2 seconds, while a non-architect could observe and judge one picture for as long as 14 seconds. It is worth recognizing that this difference exists, since indicates that professional background can be a means for different perceptions and observations.

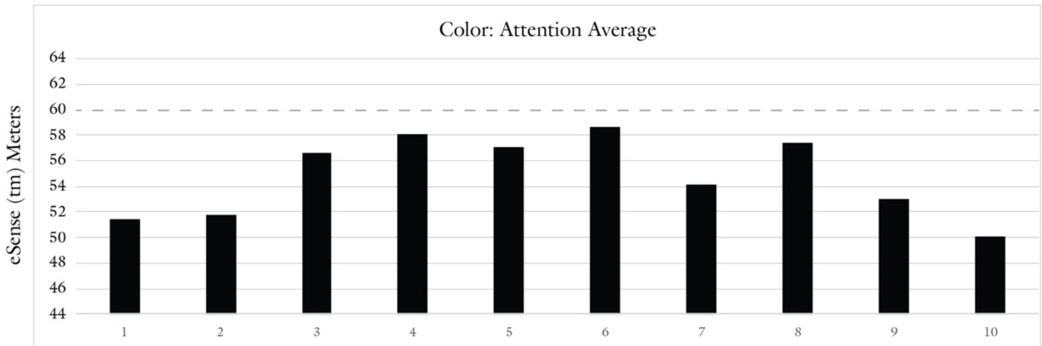
5.4.2.5. OBSERVATION VS. JUDGMENT

For a more detailed visualization of the values through all the pictures between pleasantness familiarity and brain dynamics, clustered columns for the three groups will be presented below (Fig. 65, 66, 67). In each of the pictures presented below, in three levels we can see and compare this interrelation.

SUBJECTIVE DECLARATION



BRAIN WAVE DATA ANALYSIS



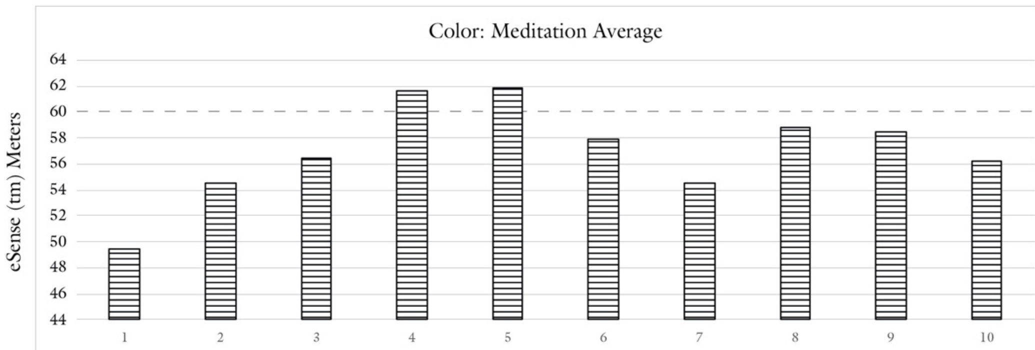
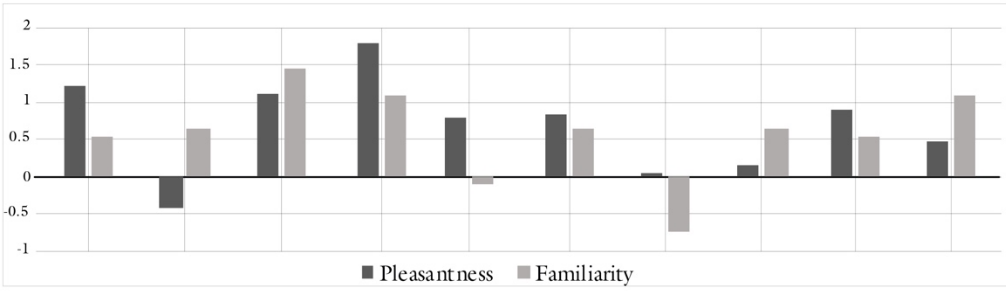
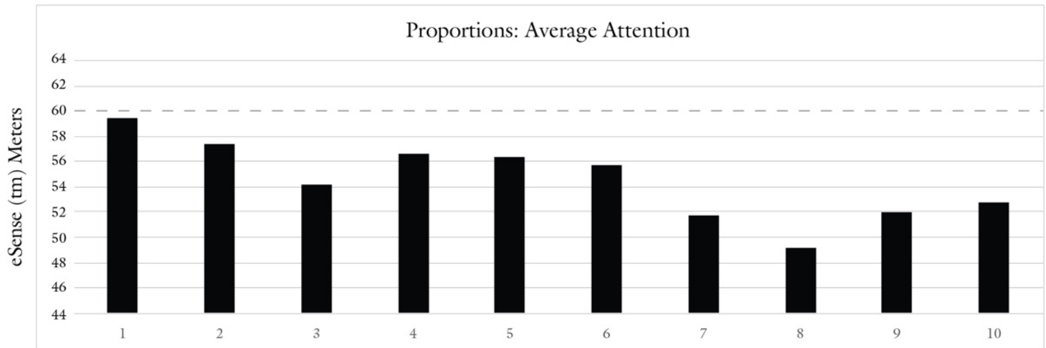


Figure 63. Combined results for Color group

SUBJECTIVE DECLARATION



BRAIN WAVE DATA ANALYSIS



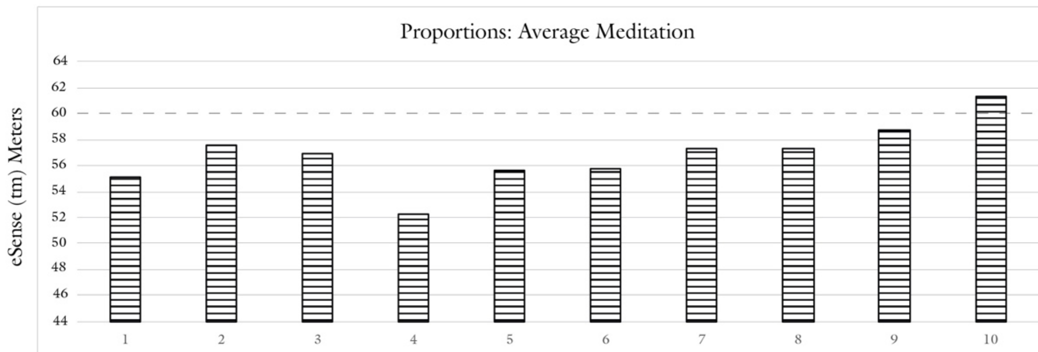
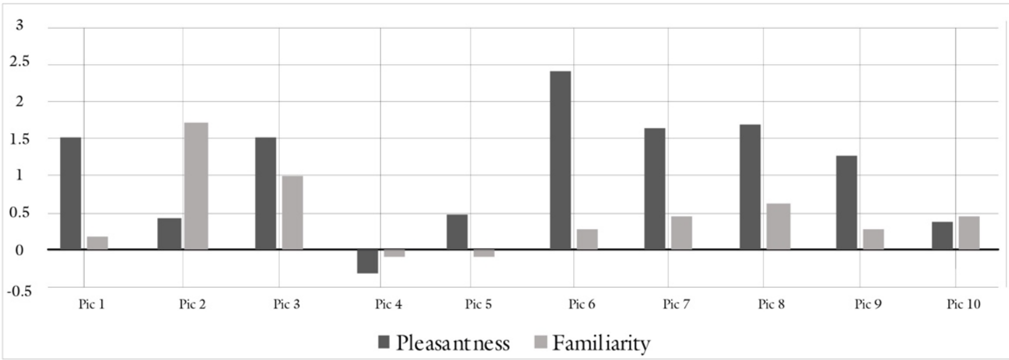
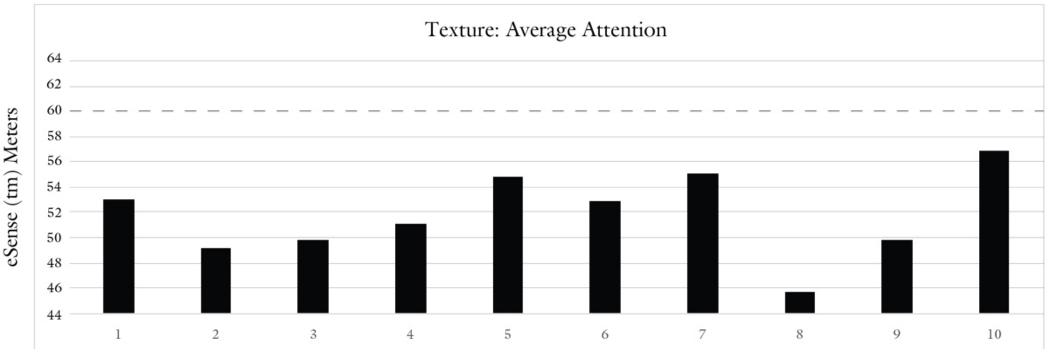


Figure 64. Combined results for Proportions group

SUBJECTIVE DECLARATION



BRAIN WAVE DATA ANALYSIS



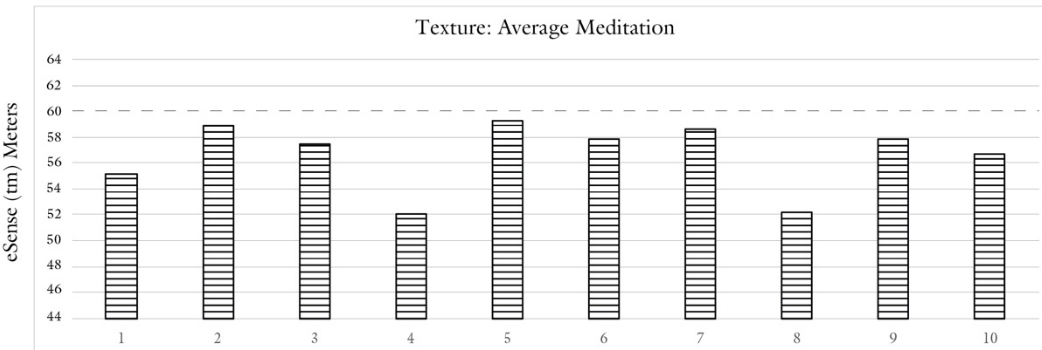


Figure 65. Combined results for Texture group

5.4.2.6. Differences in Observation between Architects and Non-Architects

One of the most remarkable results that emerged from the data is the distinction of observation values between architects and non-architects, which concurs well with Kirk et al. 's study (2009) who claimed that the brain correlates to aesthetic expertise and that the expertise impacts the cognitive and perceptual system. Therefore, through our experiment results, a significant statistical difference in the attention levels of one of the group analysis between architects and non-architects ($t(4)=52.4$, $p=0.00000079$).

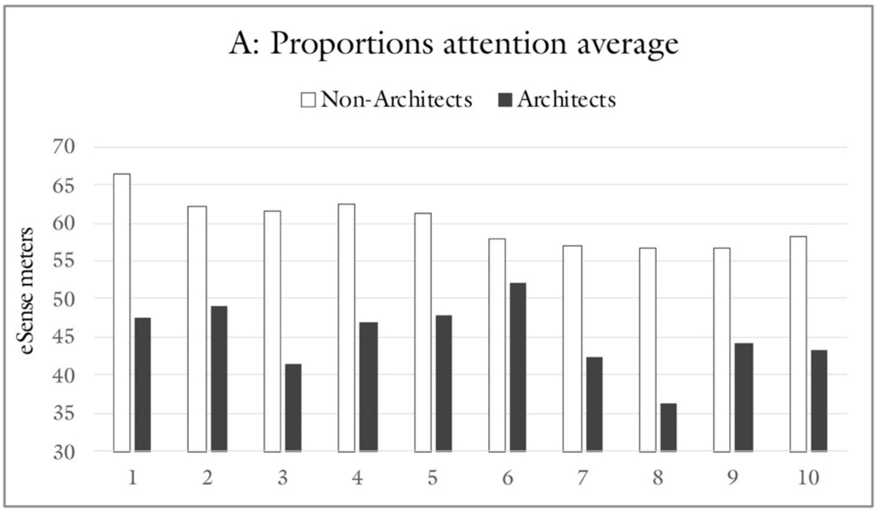


Figure 66. Difference in perception between architects and non-architects

5.5. Discussions and Conclusions

5.5.1. Novelty vs. familiarity

The results of the experiment show a significant difference in the brainwave's fluctuations between the three groups of stimuli, within each of the groups of stimuli, as well as in an individual basis, which support the assumption that brain dynamics differ between different architectural environments. The correlation between "pleasantness – unpleasantness" and "familiarity – nonfamiliarity" on the one hand and "attention – meditation" as brain dynamics on the other is evident, and the variability in the results has confirmed the complexity of intertwining these disciplines.

These results are consistent with previous findings (Bruya & Tang, 2018), who elaborated Daniel Kahneman's book "*Attention and Effort*," which is linked with the concepts of attention and effort in an attempt to identify the interdependence of one another. The concepts elaborated in this article are closely related to our findings as they explain in detail the concepts of attention and meditation. According to them, the difference between meditation and attention is that meditation is an activity in which the person concentrates his focus on a single thought, while attention is a process in which more extensive commitment and focus is required.

Kahneman presents familiarity as an indicator of attention and pleasantness. Furthermore, it involves the importance of the level of practice (e.g., in games), whereas the number of repetitions increases, the effort decreases, which matches the thesis of familiarity. However, it should be noted that although increasing familiarity can reduce effort, this does not necessarily reduce attention since attention can correlate to engagement too. From this perspective, Bruya and Tang conclude that "perhaps attention is not an effort but a combination of enhanced sensitivity and responsiveness within a specific context.

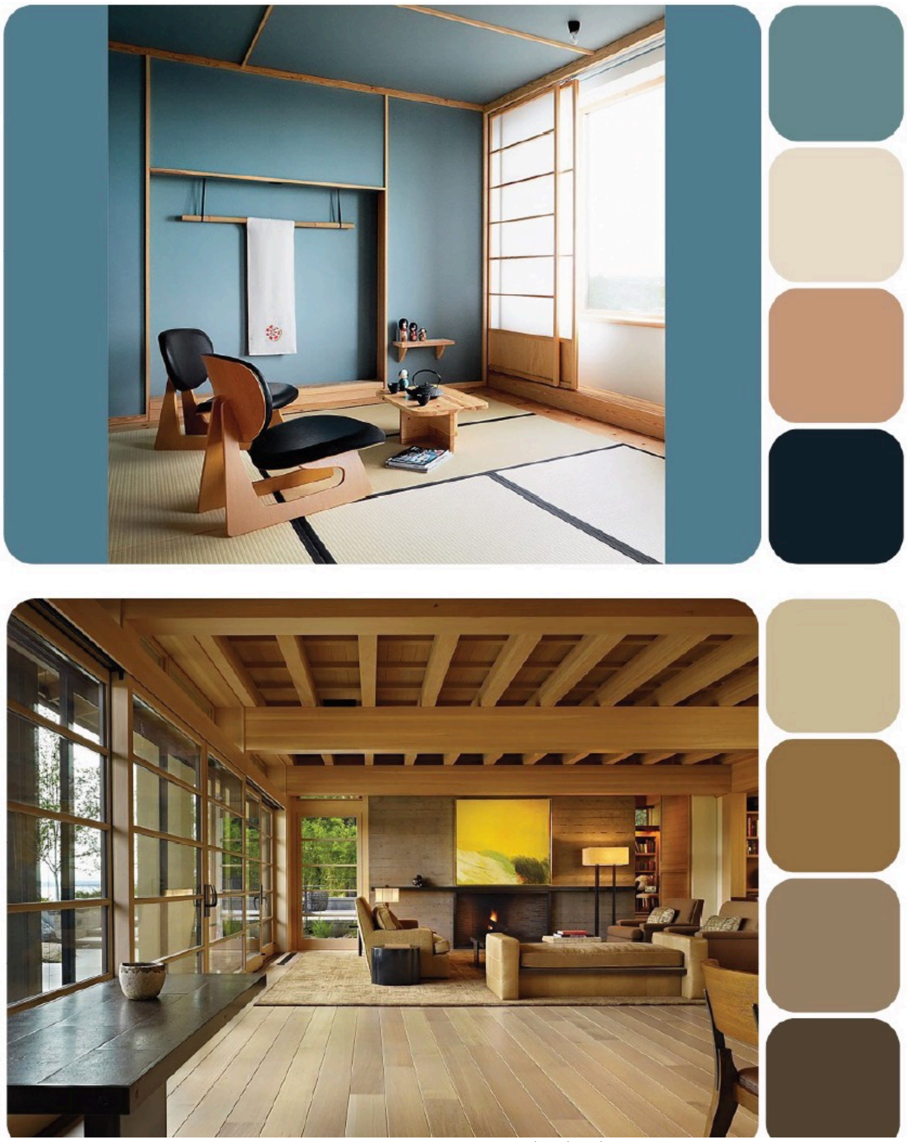
5.5.2. MENTAL EFFORT / FAMILIARITY AND PLEASANTNESS

The study cases for this section of discussion will consider three typologies of results between brain dynamics and subjective declaration:

1. High Attention / High familiarity / High pleasantness
2. High Attention / Low familiarity / Low pleasantness
3. High Meditation / High familiarity / Low pleasantness

1. High Attention / High familiarity / High pleasantness

Three of the highest pleasant pictures were, at the same time, three of the most familiar ones for the participants. This remarkable result that emerged from the data has been associated with high values of attention and was related to characteristics such as uniformity of distribution of textures primarily in wooden environments. The observed correlation regarding wooden environments could be attributed as being a result of the relatively higher number of Japanese nationals as part of the experiment (9 out of 19) as wood is commonly used in Japanese indoor environments.



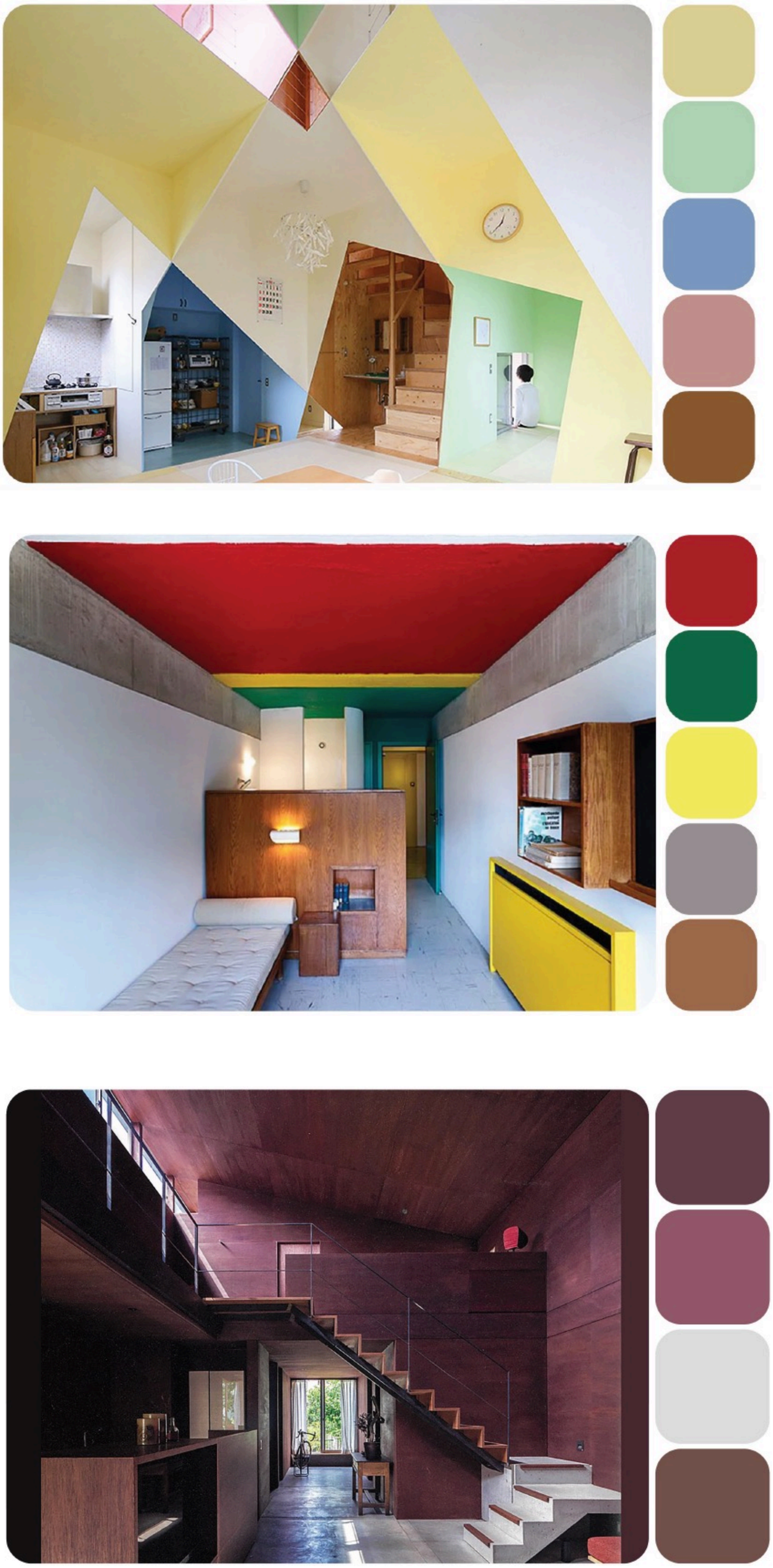
Picture 18. Rooms representing high pleasantness

Picture 19. Room representing high pleasantness

The three pictures presented above show both pleasantness, familiarity, and high alertness in the participants' average values. The results obtained from the brainwave analysis could be interpreted in two ways: on the one hand, the analysis revealed a correspondence between pleasantness and elevated levels of attention, which informs us about the tendency of cognitive "awakening" to the environments we tend to like. If we rely on Bruya & Tang's research (2018), we could interpret it as a need for commitment and engagement with the environments we like and with which we feel familiar.

2. High Attention / Low familiarity / Low pleasantness

On the other hand, three pictures that have shown the lowest pleasantness and the lowest familiarity to the participants are pictures representing rooms of multiple colors and asymmetrical proportional axis. Simultaneously, similarly to the example mentioned above of the high familiarity and high pleasantness picture, this has also shown an elevated level of attention. We can understand this as a mental commitment to analyze and relate to a novel environmental novel that arouses curiosity or commitment.



Picture 20. Rooms representing low pleasantness

As might have been expected, our findings highlighted a reduction in the meditative state towards the room consisting of metallic textures, which, due to its rarity of the use in every-day life environment, was chosen as one of the 'uncommon' rooms in the group. This would appear to indicate that a low level of meditation or 'calmness' could point with relation to the unfamiliarity with the environment. We cannot rule out that familiarity might have influenced the consistency of the high rate of pleasantness towards traditional Japanese environments due to the suggestion, as mentioned above, regarding the impact of the cultural background.

3. High Meditation / High familiarity / Low pleasantness

Our study could be linked with Li's argument (2013, p. 177) who argues that "unpleasant does not lead to stress." In their experiment, a sample of odor preference was obtained where the stimulus element was Japanese cedar. Although the subjects evaluated it as "preferable," there were cases when the subjects did not like the smell, but blood tests showed that there was no increase in blood pressure. This has brought authors to conclude that this could have happened because "human physiology has adapted to the natural environment and that the smell of natural matter does not lead to stress even though it is perceived as pleasant."

A striking resemblance to this example is found in the only room where we incorporated greenery. That room has marked great familiarity, small pleasantness but has triumphed with the value of meditation. Therefore, we could also comment on this case where people are familiar with that environment, they do not necessarily like it, but it does not bring you stress.
Although greenery was not particularly the target interest of research in this experiment, we noticed an increase in the average meditative state of the participants when the only picture presented in the photo series was opened to the greenery. Although this is beyond the scope of this study, we think that

special importance in the future should be given to the relationship between brain waves and greenery.

Picture 21. Green room representing highest levels of Meditation

5.5.3. DIAGRAMMATIC INTERPRETATION OF RESULTS

To interpret this data in an architectural language, we have created charts for each of the groups indicating the tendencies for the relationship between brain dynamics and architectural factors. Greater attention values have shown rooms with multiple colors, asymmetrical proportional axis, and room categorized by a uniform distribution of materials. On the other hand, higher meditation levels have shown rooms with the symmetrical proportional axis, pastel colors. Meanwhile, variations in the texture distribution, particularly concrete and stone, have shown elevation in meditation. However, a significant reduction has been observed in the room made of metallic textures. From the analysis of brain waves, we can notice the average values increase or decrease depending on the combinations of indoor environments. In the table below, we present the mental effort visually for each category in particular:

Factors			Obersvation (Brainwave evaluation)	
Classification			Attention High	Meditation High
Color	Type	Bright		
		Pastel		
	Composition	Monochromatic C		
		Monochromatic B&W		○
		Polychromatic		○
Proportions	Ceiling	High	○	
		Low		
	Balance	Symmetrical	○	○
		Asymmetrical		
Texture	Distribution	Uniformly	○	
		Variations	○	
	Material	Wood		
		Tiles		
		Concrete	○	
		Stone		○
		Metal		
		Golden Ration		○
		The Modulor	○	
		Japanese Traditional		○
		Georgian	○	
		Green		○

Figure 67. Comparison between architectural factors and brain wave results

Factors			Judgment (Subjective declaration)	
Classification			Pleasant	Unpleasant
Color	Type	Bright		○
		Pastel	○	
	Composition	Monochromatic C	○	
		Monochromatic B&W		○
		Polychromatic		○
Proportions	Ceiling	High	○	
		Low	○	
	Balance	Symmetrical	○	
		Asymmetrical	○	○
Texture	Distribution	Uniformly	○	○
		Variations	○	○
	Material	Wood	○	
		Tiles	○	
		Concrete		
		Stone		
		Metal		○
		Golden Ration		
		The Modulor		○
		Japanese Traditional	○	
		Georgian	○	
		Green		

Figure 68. Judgment in relationship to architectural factors

From the judgments' and observations' results, it is fundamental to note that the evaluation of pleasantness and familiarity has emphasized considerable evidence for a thorough understanding of the relationship between the two. Results from the three target groups of stimuli (Color, Proportions, and Texture) have underlined insights that we could discuss further while uncovering other significant outcomes. We consider that it is fundamental for some factors to be discussed more particularly. As explained before, we have set specific criteria for each category, expecting that they emphasize the differences. As anticipated, the evidence of this study strengthen the idea and understanding of the interrelation between mental effort, pleasantness and familiarity

CHAPTER 6

Discussions and Conclusions

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Discussions and Conclusions

Two previous chapters of the research study have included their results and discussions within them. However, this chapter will present a final overview and discussion from the research question to the final insights and contributions. This chapter is separated into four main sections. The first section will answer the research questions through the results and discussions of the research design, the second section will present limitations, third section will present conclusions, and the final section future recommendations. We will try to extract the findings from each analyzed category that substantially added to our understanding of this research.

6.1. Answering research questions

The general aim of this research was to examine the relationship between architecture and neuroscience from an architectural point of view and present the potential of interrelation between these two fields of study. The goal was to analyze the possibilities that architects could have in using tools provided by the field of neuroscience, the experimentation process and interpretation of results, and the potential of implementing those results in the design processes.

6.1.1. Architectural elements: in isolation or combination?

During the 1970s, the Gestalt School of Psychology promoted the idea that "the whole is different than the sum of parts"(Ashihara & Riggs, 1992; Fuller, 1990). Interestingly, this theory has also found interpretation in discussion of our results in the context of the research studies we have presented. As Rasmussen (1962) has compared, we do not pay attention to letters as independent parts of the sentence but perceive the sentence and its idea as complete. Consequently, understanding the effect that environmental conditions of isolated parts have on us cannot predict the effect that their combination would have (Jamrozik et al., 2018, pp. 190–191).

We could see that the tendency of previous studies of similar methodology to achieve an understanding of this issue has been mainly through the isolation of architectural elements as well (curvatures, interior design styles) - mostly seen in combination with Brainwave measurements and Virtual Reality, through original 3-Dimensional (3D) renderings.

Initially, we considered that it is essential to follow this trend, so we also started our analysis with 3D renderings explicitly made for this study, which aimed to understand the impact of different textures in relation to brain waves, as isolated premises. However, the results of these analyzes did not show significant differences from one mode to another, although we have tried to make the chronological order of the stimuli as pronounced as possible. As a result, we considered it important to conduct comparative research to understand what brain oscillation would be like in spaces representing real environments of existing interiors and where factors would combine.

From the second approach, we have reached values that have shown significant change and, as such, increased our interest in a deeper understanding of these results. However, we are aware that it is difficult to compare these two studies with each other since the stimulus in the second case was not in isolation as it was in the first. Therefore, research studies are treated as separate from each other, although the secondary research is built upon the first one.

Our research has proven that, in some cases, the results of both studies have been opposed. This confirms the thesis that many factors influence our behavior towards architecture, so it is not easy to name a single influential cause. Despite the apparent differences between the two studies, we have tried to make the selection of photos for the second experiment consistent with the first one so that we have at least close similarities between stimuli. Nevertheless, interestingly, despite our assumptions that similar pictures (Room 5 from the first experiment vs. immersed wood interior from the second) would give similar results, results extracted for this case have shown contradiction between the brain waves and the judgments.

Picture 22. An example of texture in isolation and in combination

From this part of the research we can draw two main conclusions:

- This contradiction requires particularly special attention to the treatment of this research in the future. We consider that in order to achieve a sustainable empirical summary that could help decision-making processes in architecture, a large number of trials need to be collected, and experimental sections repeated, as well as a larger number of subjects, need to be tested.
- The difference in results compared to 3D rendering and real photos has opened the possibility that in the future, it should be considered for experiments to be conducted in real environments – in-situ.

6.1.2. Wearable devices: independent journey or multidisciplinary approach?

The use of neuroscience equipment has been a new experience in this research. The collaboration between these two fields' success lies precisely in the multidisciplinary interaction between architecture and neuroscience. Despite this, the purpose of this research was to understand whether the independent use of these devices could help architects in architectural design's decision-making processes.

Our journey in this research has been independent, based on the algorithms provided by the neuroscientific devices. The reliability in the use of these devices has been confirmed by researches presented in the section on the validity of brain devices. Therefore, our individual basis approach has come with confidence in their use, which has been proven in previous scientific studies. From this experience, we can draw these conclusions:

- Selection of the device: Device rankings are based on the number of electrodes they provide and their accuracy. Unfortunately, our research has been limited financially, so following our capacities, we have chosen to use a one-electrode device. However, we recommend that in the future, if the budget allows, priority should be given to those devices that have more than one electrodes. In this way, the results can be obtained from more parts of the brain and not necessarily limited to the forehead.

- Interpretation of results: We derived the results from the algorithms provided by the device itself. We have adopted the two modalities designed by the company - that of "Meditation" and "Attention" to identify whether any of them will show sensitivity to architectural factors. 'Meditation' and 'Attention' can have different forms of explanation, so special attention should be paid to their definition, which must necessarily be done in line with scientific and professional definitions. Furthermore, in addition to these two modalities, this device also provides raw data, which is information about each brain wave in particular (Alpha, Beta, Gamma, Delta, Theta). Therefore, we recommend that in order to understand the meaning of each of the brain waves in more detail in relation to the moments in which it is a trigger, professional cooperation in the field should be necessary.

- Getting familiar with the device: Although the device was received positively and enthusiastically by the majority of the participants, there were also cases where participants showed signs of nervousness, which was reflected in high values of attention. In such cases, we are forced to do additional tests to verify whether they can be considered outliers. Therefore, before the final recording of the experiment, it is recommended that several trials be conducted until it is verified that the participant is comfortable and familiar with the device.

6.1.3. User centered design: from Non-Architects to Architects

The correlation between professional background and perception of architecture is of interest mentioning especially because this research, in particular, emphasizes the importance of the shift in focus from architects to users, and how the design of the architecture affects them - regardless of the architects who design the houses based on their taste. This issue is consistent with several authors who have reinforced the idea and the importance of human-centered design (Pallasmaa, 2012), (Caroline Constant, 2015), (Hall, 1969), (Ashihara & Riggs, 1992), (Neutra, 1954), (De Botton, 2008). Moreover, this confirms previous findings in the literature (Kirk et al., 2009) of the relationship between the expertise and the brain dynamics. This correlation demonstrates just how important it is to have an empirical basis for measuring architecture perceptions for decision-making processes.

Another insight worth mentioning is that our experiment has revealed that non-architects take more time to judge an environment, and it is they who mostly judge interiors more positively. Architects, on the other hand, tended to judge an environment faster but more negatively. A possible reason could be that architects are more exposed to the analysis of architectural environments, so they judge faster and tend to be more critical. However, this also highlights the difference and importance of recognizing the judgment of non-architects since most of the time, architects design for them, and recognizing their ideas would be crucial in decision-making processes.

6.2. LIMITATIONS

Valuable lessons were drawn from the limitations that we encountered through this research. We are aware that the course of the results of our research may have been influenced by several of them. These limitations reveal the difficulty of collecting data on a developing field of research such as neuroarchitecture.

Developing wearable devices

Firstly, one of the most critical limitations lies in the fact that wearable devices are in the developing process; as a result, they contain their limitations of use. The device that we used in our research, the Neurosky device, collects information from one sensor in the forehead (prefrontal cortex), and as such, is limited in the understanding of a broader range of brain data. Currently, the Neurosky device is under development and constantly changing and improving, so that anticipates that there might be some inaccuracies in this regard. Architects use several neuroscientific devices to fulfill their research needs, albeit the devices are not mainly designed to accommodate specific needs. So, maybe the future could see neuroarchitecture as a function of the development of the device.

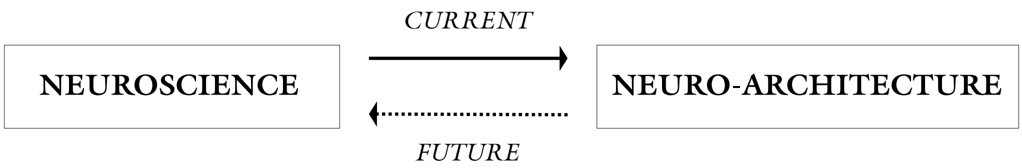

Figure 69. Neuroarchitecture as a function of the development of future neuroscientific device

Moreover, there is another significant limitation to the reading of raw data of the brain waves offered by the wearable device. For this study we have only used the data drawn by the algorithms; however, it is worth noting that previous studies have shown potential in understanding the relationship between stimuli and brain waves as separate, however, due to the lack of cooperation with the professionals of the field, we have not managed to expand the meaning of the raw data.

Architectural parameters and visual representation

An important source of uncertainty and error should be considered in evaluating and determining the parameters. It is essential to underline the limitation brought by the two methodologies of treating these parameters: in isolation or combination. Generally speaking, treating architectural parameters in isolation can give more precise ideas and concrete feedback to the study's targetted elements - texture, color, proportions. On the other hand, evaluation through visual stimulation by 3D renderings tends to create a detached feeling from the sense of reality. Aware of this issue, we tended to strengthen the feeling towards the second experiment's sense of reality through pictures of real environments. However, one downside from the increase in the number of factors such as light or furniture may have triggered a deviation of the focus from the parameters targeted for the research, resulting in the inconsistency of the outcome. Although one of the main ideas of this study is to understand the similarities and the differences that may occur using the first or the second method of study, caution must be taken when deciding for a final evaluation methodology.

Concepts and Definitions

Another limitation that could have influenced the interpretation of the results are definitions of the concepts used for the two dimensions of interest of this study – Attention and Meditation. As mentioned in the previous chapter, one of the references that we based our interpretations on was that of (Bruya & Tang, 2018) who retraced arguments of the interrelation between concepts of mental effort and familiarity from the book "*Attention and Effort*," Daniel Kahneman. Additionally, our findings supported other studies such as Li (2013), who have also argued about the relationship between stress and pleasantness. Despite this, there are still limitations in the interrelation between these concepts and the translation of these concepts through algorithms. We are aware that the device used for this research has its own patented algorithms that do mathematical calculations and give results of specific values for Meditation, Attention, Familiarity, Alertness, and other areas of mental effort. However, we are limited in understanding of how the developers of these algorithms define these concepts. For this reason, we think the results obtained from the algorithms must be handled with reservations while increasing the collaboration between professionals and architects, which would facilitate the interpretation of the data, respectively, would facilitate access to the raw data.

Memory

Our experiment has taken into account the dimension of memory by doing repetitions of experiments. In the first experiment, we repeated the testing of one participant after two years, while in the second experiment, in the absence of time, we used the repetition of the visual stimulation between the same session by randomly repeating one of the photographs. Unfortunately, we were unable to investigate significant differences in a progressive approach (after one week, after one month, after six months, after one year), so understanding the relationship between familiarity and preference in different time spans in brain dynamics change is limited.

On the other hand, the impact that long-term memory has on the perception of these environments is also significant. Some participants may have been exposed in the past to wood environments for longer periods while those with stone to shorter periods. Therefore, another potential limitation of the interpretation of results should be considered in regard to the difference between long-term experience and short-term experience that participants have with those environments.

In our study, memory results have provided valuable information for architects. On the one hand, we established similarity between the trial for the first time and that for the second time; On the other hand, we have observed that the trial for the second time, had the tendency to be judged as more pleasantly in 89.3% of the participants, while 10.7% felt less positive about their judgment after the repetition.

However, a significant source of uncertainty in the second experiment's method is the time frame of the repetition of the photograph, which is exhibited within a short period after the first one. Therefore, even though participants have tended to give a higher evaluation to the photo after seeing it for the second time, it is plausible that a limitation should be considered if the same participants are asked to judge an environment where they spend more extended time or are very familiar to it for a second time.

Consequently, we consider that to achieve the maximum statistical accuracy in experimental design, it is crucial to consider the dimension of the memory. Therefore, further data collection is required to test the relationship between familiarity and pleasantness, potentially by testing the subjects on proven facts that they have a long-standing relationship to those environments.

Experimental design

Sample size

To maximize statistical accuracy and create a database that would have served as the optimal value of the findings, the sample size needs to be larger. Hence, it is plausible several limitations may arise in our study due to the small test sample. It is recommended that in order to verify these hypotheses in the future, a larger number of trials should be compiled so that empirical evidence is based on more subjects.

Medium of visual stimulation and the physical setting

Care should also be taken when considering the medium of experimental design. For this research, we have used visual stimulation as a medium to assess and test participants. However, several limitations can be drawn from this methodology. First, visual stimulations are methods that condition the development of the experiment in the laboratory environment. To achieve high statistical accuracy, this environment must be carefully controlled. Our limitations lie in particular in the medium's change for the visual stimulation between the first experiment and the second experiment. For the first experiment, we have built a mock-up room in order to simulate an immersed environment through a projector which influences a feeling of three-dimensional perception of the stimuli. However, due to some site reconstructions of the room used before, we could not continue to use the same mock-up for the second experiment. As a result, for the second time around, we have used the lab environment as the physical space and PC monitor for the visual stimulation, which might have influenced a sense of two-dimensional stimuli. Thus, it is important to note that certain limitations in results are expected due to the change in the mode of this setting of experimental design.

Limitation of culture and language

Lastly, an additional possible source of error might be the cultural difference, particularly the language difference. This research was compiled by a researcher with no Japanese cultural background; therefore, the functionality of this research, including questionnaires, was developed in English. For example, the difference in the meaning, usage, and understanding of the word 'familiarity' and 'preference' in the English language might differ in the Japanese language. Hence, the limitation might come in the fact if this difference is implied in the same way for Japanese participants.

In addition to language, another limitation, as mentioned in sections above, maybe the environmental conditions and influence during participants' upbringing. In the second experiment, we had a variety of cultural backgrounds of participants' so that this condition may have influenced perceptions and outcomes regarding familiarity and preference. This suggests that cultural background is an important aspect and needs to be clearly classified in the database creation processes for this type of research.

6.3. CONCLUSIONS

This research has raised many questions in need of further examination regarding experimental design and the medium of stimulation. For this research, we used visual stimulation as a means of testing the subjects. However, we consider that special attention should be paid for the process of experimental design and the accuracy of the statistical analysis of the stimulus medium. In principle, we believe that it would be promising to promote these tests in real environments so that feedback comes from environments in which users directly spend time.

The evidence from this research is compelling for the benefit of the collaborative approach between architecture and neuroscience especially since this collaborative approach has been increasingly recognized and pushed forwards by several authors who have focused their research on this opportunity (Albright, 2015; Eberhard, 2009; Edelstein & Macagno, 2011; Pallasmaa et al., 2009).

For architectural design, it is undoubtedly a challenging task to apply the build-test-learn development steps, since the possibility to design a building is given once in a while and there is no second chance to demolish and rebuild it in case its function does not get validated. To date, building designs are merely based on the designer's taste and intuition, which has neglected the needs and behaviors of the users. Over the years, this has resulted in building conditions such as sick building syndrome, which affects office workers, typically marked by headaches and respiratory problems, attributed to unhealthy or stressful factors in the working environment. These symptoms appear to be linked to the time spent in a building, though no specific illness or cause can be identified.[1]

Historically architects have used drawings to communicate their design ideas, which later included perspective and axonometric projections, as well as models as a physical representation of the structures. The latest development of Building Information Modelling (BIM), has given a possibility to visualize a three-dimensional look of the future building (inside and outside) and

[1] Wikipedia, accessed Feb 16, 2019, https://en.wikipedia.org/wiki/Sick_building_syndrome

making it able to walk-through it, which has simplified the understanding of blueprints which can be a difficult task for a non-professional. To bridge the gap between 'building by intuition' and 'building by evidence,' it is possible for architects to consider the new window of opportunity opened by the field of Neuroscience in order to expand their creativity through evidence-based design.

In conclusion, neuroscience displays excellent potential to provide new applied science tools for 21st-century engineering. As a result, just as a joint effort of architects, mechanical engineers, electrical engineers, construction engineers, is needed to complete an architectural project, the need to introduce the contribution of neuroscientists in this process is equally important. This synergy would add to the understanding of human experience in the architectural environment. Therefore, we think that the involvement of behavioral studies is crucial for future considerations as an included part of the life cycle management for buildings.

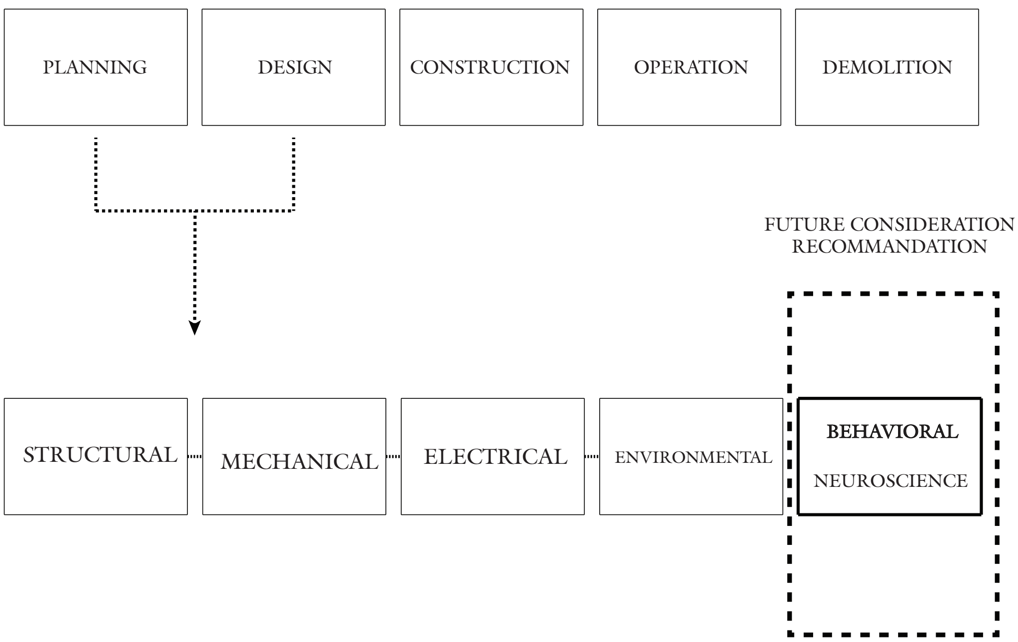

Figure 70. Behavioral analysis as part of life cycle management

6.4. FUTURE RECOMMENDATIONS

Through this section, we have tried to render the results that we have drawn from this research into possibilities for the future so that architects can have the opportunity to achieve the use of this data in their design processes.

6.4.1. DATABASE

Getting back to what is the main focus of this study, scientifically evaluating users' responses to various environments, is it indisputable the importance of starting with some database of validated responses by appropriate users to different environments. This way, we could create clusters as follows:

- architectural elements: texture, form/shape, function, colors, noise, light intensity and proportions
- subjects: children, young adults, middle-aged adults, older adults
- environments in which the subjects have been tested: home environment, office, hospital, school etc.

The collection in the database would follow the process of gathering initial data about particular factors (X, Y, Z), followed by testing of the assumptions that's designs A, B, C, for factors X, Y, Z are optimal for a specific environment (home, office, residential area, etc.). These recommendations proceede in the next section, which anticipates the necessity of the creation of living labs.

6.4.2. LIVING LABS

Living labs have gained recognition in sustainability as a research idea in the form of laboratories that function as territorial (spatial) concepts. These Labs are design platform that could bring together interdisciplinary experts to develop, expand and test – in actual living environments – new technologies and strategies and addresses challenges related to human health in architectural design. It aims to engage all stakeholders at the earlier stage of the co-creation process for discovering usages and behaviors through live scenarios in real or virtual environments. This would be a good opportunity for services such as Neuro Oscillation Analysis and its interpretation by doing real-time experiments to give feedback to architectural offices who require tests before the actual design gets built. This works as an accelerator between Architect' ideas and their clients into an evidence-based design. This way, not only architectural offices get validation on their design before its construction, but also, this works towards a close consideration of user's needs and behaviors. Lastly, another technology used recently for similar types of experiments is also Virtual Reality (VR). Based on the previous studies, we believe that VR is a promising method of evaluation and experimental design and needs to be paid special attention.

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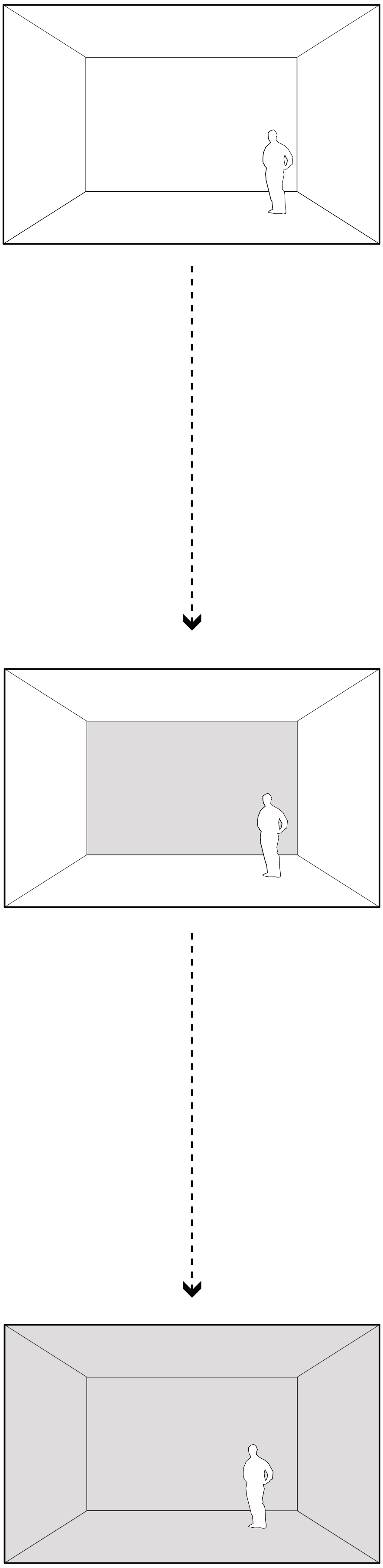
Appendices

Appendix 1: Research Study 1

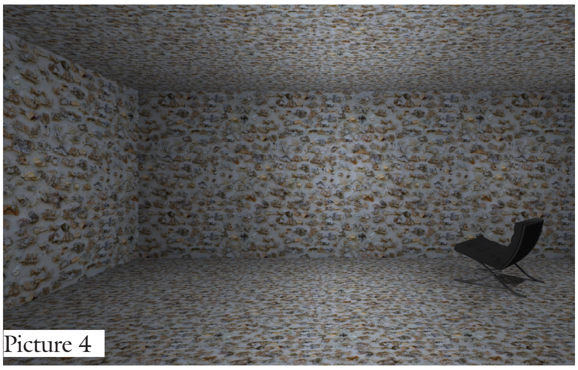
Final Selection of Stimuli



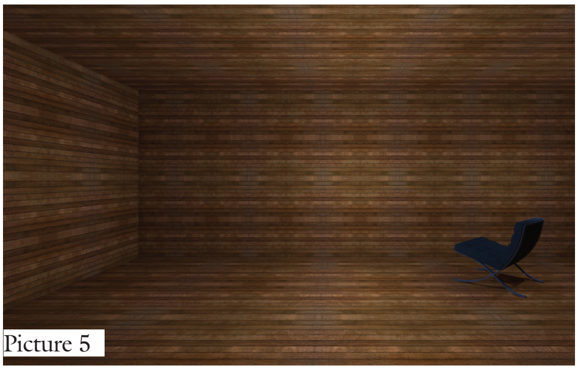
Picture 1

Picture 2

Picture 3



Picture 4



Picture 5

Appendix 2: Research Study 1

Appendix 2: Research study 1

Statistical Analysis

	Attention				
People	Pic 1	Pic 2	Pic 3	Pic 4	Pic 5
Partic. 1	55.9	67.1	75.9	53.9	74.3
Partic. 2	60.6	74	59.7	69.5	68.2
Partic. 3	40.9	50.2	37.1	24.2	23.9
Partic. 4	86.4	90.3	76.9	58.4	84.4
Partic. 5	32.2	44.7	35.2	29.2	34.3
Partic. 6	41.2	62.8	79.5	52.1	37.2
Partic. 7	67.6	40.5	45.5	40.8	40.7
Partic. 8	42.4	43.5	27.6	30	26.8
Partic. 9	26.9	44	45.6	53.3	57.2
Partic. 10	84.6	77.2	70.4	66.1	48.9
Average	53.87	59.43	55.34	47.75	49.59

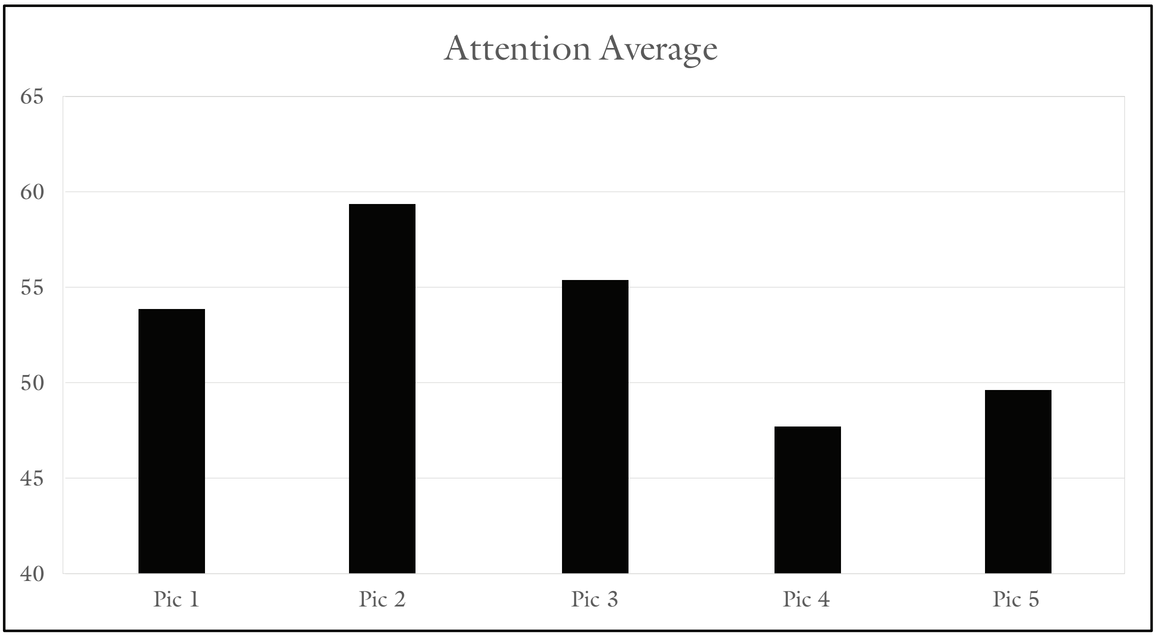
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Pic 1	10	538.7	53.87	433.0823
Pic 2	10	594.3	59.43	300.3957
Pic 3	10	553.4	55.34	379.6204
Pic 4	10	477.5	47.75	252.5361
Pic 5	10	495.9	49.59	430.3032

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	865.7592	4	216.4398	0.602582	0.66274	2.578739
Within Groups	16163.44	45	359.1876			
Total	17029.2	49				



Statistical Analysis

People	Meditation pic 1	pic 2	pic 3	pic 4	pic 5
Partic. 1	73.2	65.6	73.5	77.8	60.5
Partic. 2	48.5	34	50.4	41.8	50.7
Partic. 3	70.6	81.8	60.7	67.2	66.8
Partic. 4	54	64.2	72.9	76.7	56.6
Partic. 5	38.1	56.9	65	43.1	41.7
Partic. 6	53.8	53.5	54.4	52.5	50
Partic. 7	26.9	56.4	53	47.3	50.1
Partic. 8	84.6	66.3	60.4	44.9	36.3
Partic. 9	52	46	39.6	56.7	44.9
Partic. 10	27.7	44.1	41.7	33.3	35.6
Average	52.94	56.88	57.16	54.13	49.32

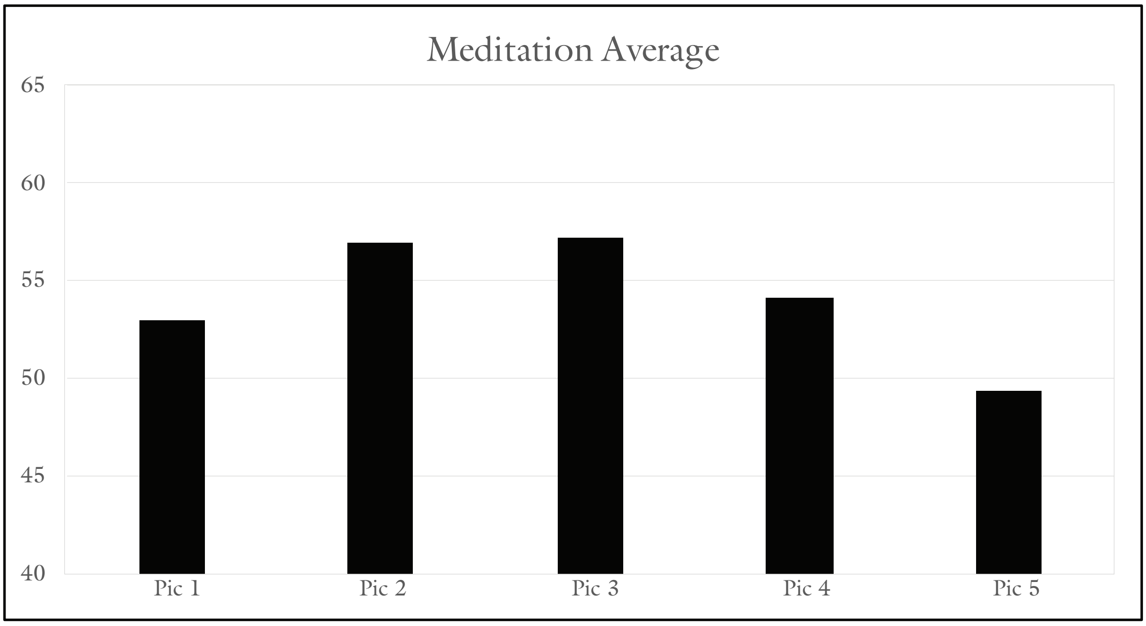
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
pic 1	10	529.4	52.94	364.7249
pic 2	10	568.8	56.88	184.024
pic 3	10	571.6	57.16	135.2471
pic 4	10	541.3	54.13	232.1312
pic 5	10	493.2	49.32	102.4307

ANOVA

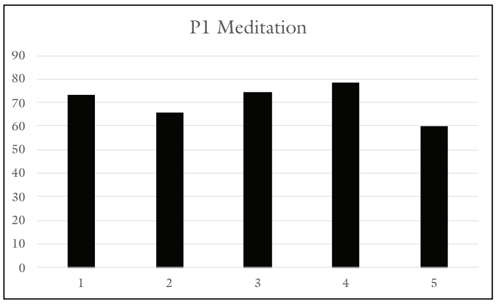
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	412.8592	4	103.2148	0.506671	0.731016	2.578739
Within Groups	9167.021	45	203.7116			
Total	9579.88	49				



Statistical Analysis (Individual)

P1 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
90	66	75	84	54
84	64	67	80	67
77	80	60	67	77
66	74	44	63	75
56	54	47	60	67
61	61	41	61	69
69	64	54	74	69
70	61	74	81	57
70	57	81	87	66
75	40	93	94	61
63	35	93	93	60
60	37	88	100	69
61	61	93	93	67
67	75	78	93	69
74	75	75	83	64
80	88	78	83	57
91	83	74	81	66
88	84	90	88	67
94	75	94	84	70
100	66	94	90	69
90	61	93	64	51
81	48	83	66	54
77	50	84	81	54
78	54	83	75	54
70	69	74	83	41
51	80	67	66	24
56	87	57	64	38
56	88	51	63	48
73.39286	65.60714	74.46429	78.60714	60.14286



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	28	2055	73.39286	171.2844
Picture 2	28	1837	65.60714	231.877
Picture 3	28	2085	74.46429	269.0728
Picture 4	28	2201	78.60714	140.6177
Picture 5	28	1684	60.14286	141.9048

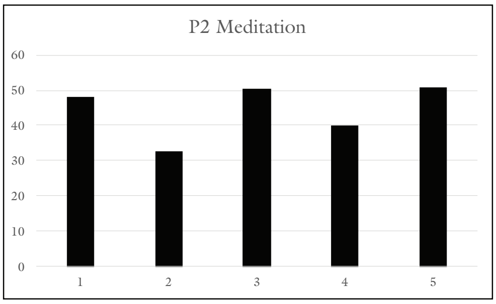
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6188.114	4	1547.029	8.101691	0.0000069	2.438739
Within Groups	25778.43	135	190.9513			
Total	31966.54	139				

Statistical Analysis (Individual)

P2 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
53	50	61	35	88
51	23	57	43	69
20	26	40	27	50
30	20	63	23	44
41	34	67	44	35
23	34	43	29	37
51	37	70	44	35
37	38	53	27	38
34	27	35	17	23
47	27	53	21	20
37	17	17	13	29
41	26	26	34	43
41	24	37	29	69
51	30	23	38	67
57	29	51	41	78
70	27	30	41	63
67	37	37	60	63
70	41	56	75	60
60	37	43	88	50
54	34	75	67	40
48	30	67	57	44
44	40	60	43	47
41	54	64	27	44
47	61	41	30	57
60	47	57	11	40
54	21	54	21	50
63	23	64	24	51
50	7	63	38	50
41	24	47	75	69
57	53	60	83	69
48	32.6	50.46667	40.16667	50.73333



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1440	48	157.4483
Picture 2	30	978	32.6	142.8
Picture 3	30	1514	50.46667	222.8092
Picture 4	30	1205	40.16667	426.0747
Picture 5	30	1522	50.73333	263.1678

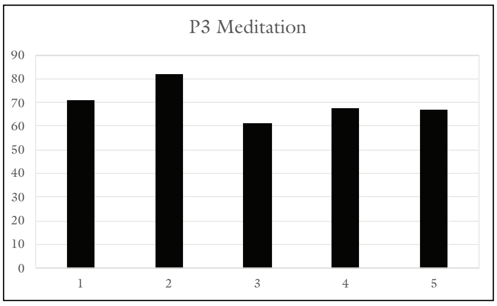
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7411.093	4	1852.773	7.641563	0.0000129	2.434065
Within Groups	35156.7	145	242.46			
Total	42567.79	149				

Statistical Analysis (Individual)

P3 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
61	53	54	69	66
64	63	69	75	87
64	77	70	80	88
57	91	51	77	77
64	100	56	64	70
74	97	44	51	63
66	90	57	43	60
83	81	69	43	61
81	75	64	54	63
80	80	78	57	64
84	78	70	64	60
67	88	63	67	60
70	93	67	61	54
80	88	64	81	54
80	93	67	93	57
77	87	64	100	66
84	83	60	90	74
78	81	43	77	78
80	75	29	63	78
80	81	37	56	74
67	84	47	66	77
66	96	57	67	74
60	96	70	75	66
63	96	80	75	61
70	96	78	70	51
74	87	83	70	51
66	80	69	61	56
70	63	61	67	75
64	50	57	64	74
64	54	48	51	66
71.26667	81.86667	60.86667	67.7	66.83333



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	2138	71.26667	66.34023
Picture 2	30	2456	81.86667	185.0851
Picture 3	30	1826	60.86667	164.1885
Picture 4	30	2031	67.7	180.2862
Picture 5	30	2005	66.83333	99.52299

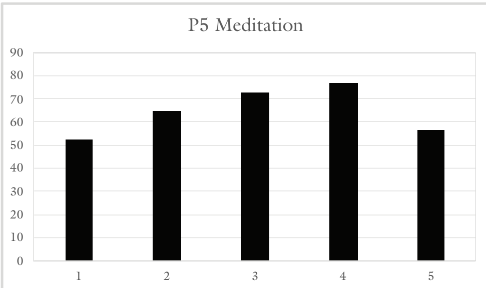
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7221.827	4	1805.457	12.981	0.00000000464	2.434065
Within Groups	20167.27	145	139.0846			
Total	27389.09	149				

Statistical Analysis (Individual)

P5 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
30	80	41	87	64
17	88	37	80	47
23	66	37	90	34
24	41	44	87	29
30	44	50	84	41
47	44	43	96	43
51	64	38	78	56
69	87	34	74	54
77	87	50	74	54
61	84	77	78	47
64	90	90	77	57
43	78	100	80	77
13	83	91	87	70
37	80	70	83	88
37	60	78	78	70
54	56	69	74	56
74	67	84	80	64
77	60	90	74	77
80	69	90	91	80
57	63	97	90	83
74	41	97	53	75
44	50	94	67	56
37	40	84	51	48
48	66	81	67	47
34	74	80	93	47
60	70	97	75	38
75	66	96	69	35
84	47	81	57	50
77	48	84	51	47
70	51	84	74	54
52.26667	64.8	72.93333	76.63333	56.26667



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1568	52.26667	435.6506
Picture 2	30	1944	64.8	254.5793
Picture 3	30	2188	72.93333	500.2023
Picture 4	30	2299	76.63333	144.9299
Picture 5	30	1688	56.26667	240.6851

ANOVA

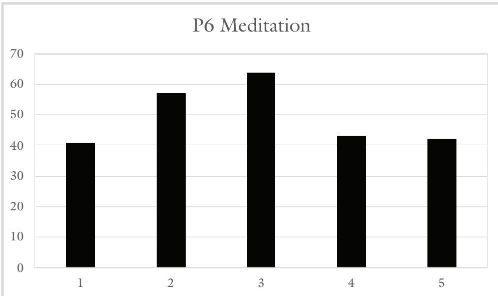
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13075.17	4	3268.793	10.37023	0.000000205	2.434065
Within Groups	45705.37	145	315.2094			
Total	58780.54	149				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P6 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
63	44	54	61	48
56	47	54	57	44
34	64	57	41	41
24	66	53	44	56
13	77	60	47	41
13	69	61	48	38
34	70	44	54	35
44	60	47	43	23
41	63	50	38	30
54	74	41	26	29
47	56	51	26	41
29	60	67	44	50
29	63	69	47	41
27	64	78	44	56
16	74	64	29	48
21	80	53	23	41
44	61	37	20	35
44	47	50	34	29
61	38	78	40	24
57	41	84	34	27
48	48	97	41	37
69	50	91	38	35
44	41	77	53	50
50	35	70	61	40
57	38	64	60	34
34	50	75	53	48
54		67	41	48
53		69	53	74
27		80	41	69
35		75	54	50
40.73333	56.92308	63.9	43.16667	42.06667



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1222	40.73333	235.5816
Picture 2	26	1480	56.92308	174.8738
Picture 3	30	1917	63.9	220.8517
Picture 4	30	1295	43.16667	126.6954
Picture 5	30	1262	42.06667	142.6851

ANOVA

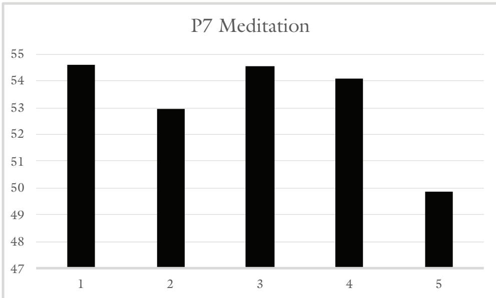
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12802.24	4	3200.56	17.7526	7.99717E-12	2.435854
Within Groups	25420.45	141	180.2869			
Total	38222.68	145				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P7 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
24	24	35	74	37
47	41	40	66	40
51	56	47	57	35
67	69	56	60	38
66	75	64	51	47
57	60	61	54	56
57	53	67	60	74
50	47	53	38	77
51	37	66	40	63
50	41	74	44	61
53	51	56	29	51
56	56	69	37	50
51	66	53	44	53
50	61	54	38	53
47	66	50	47	53
54	61	41	50	48
63	54	40	56	53
53	67	26	60	51
53	69	37	69	54
47	53	43	75	50
51	40	54	66	53
53	21	57	66	43
60	24	60	60	50
69	40	67	60	57
57	48	69	61	48
77	53	66	56	64
63	50	63	54	41
53	60	61	56	34
57	70	56	50	35
51	75	51	44	27
54.6	52.93333	54.53333	54.06667	49.86667



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1638	54.6	84.11034
Picture 2	30	1588	52.93333	214.1333
Picture 3	30	1636	54.53333	137.7747
Picture 4	30	1622	54.06667	129.6506
Picture 5	30	1496	49.86667	128.7402

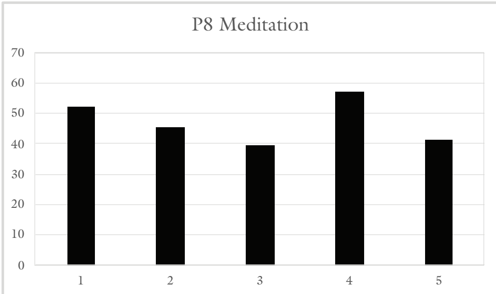
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	470.1333	4	117.5333	0.846283	0.498047	2.434065
Within Groups	20137.87	145	138.8818			
Total	20608	149				

Statistical Analysis (Individual)

P8 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
51	48	51	38	47
57	41	37	40	64
53	41	14	53	66
44	41	11	50	53
48	37	13	43	54
60	48	29	43	30
50	54	41	34	17
60	44	64	40	20
64	53	57	48	27
53	38	57	51	40
74	37	64	66	47
70	48	63	69	48
56	48	63	69	37
60	54	50	69	37
53	48	41	69	34
40	40	21	64	41
48	35	17	67	38
48	38	23	60	38
48	37	27	67	30
48	50	27	78	24
48	63	35	67	35
38	60	47	77	26
51	57	44	67	41
48	47	40	69	38
48	30	41	74	48
48	43	43	63	51
50	43	41	47	51
50	44	44	35	61
50	43	41	41	57
52.27586	45.17241	39.51724	57.17241	41.37931



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	29	1516	52.27586	62.56404
Picture 2	29	1310	45.17241	60.50493
Picture 3	29	1146	39.51724	250.5443
Picture 4	29	1658	57.17241	189.5049
Picture 5	29	1200	41.37931	164.3867

ANOVA

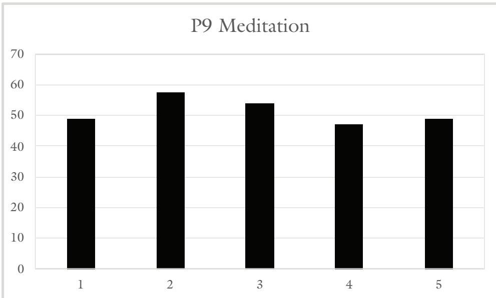
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6443.31	4	1610.828	11.07091	7.8673E-08	2.436317
Within Groups	20370.14	140	145.501			
Total	26813.45	144				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P9 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
30	43	44	30	56
35	40	48	40	56
40	50	57	26	60
40	50	53	44	48
47	60	61	47	38
51	78	57	54	24
48	70	44	64	20
50	63	43	63	41
51	57	51	63	40
38	61	56	56	50
41	74	56	57	50
41	74	61	48	21
27	84	57	40	30
37	69	43	38	30
40	53	35	51	41
53	48	41	53	66
74	38	50	60	67
69	43	67	57	66
70	56	81	35	60
56	57	77	38	47
50	60	67	37	43
56	64	53	24	43
48	56	50	38	54
57	60	51	41	56
63	57	54	51	53
63	51	63	56	54
64	51	61	54	50
57	51	60	57	56
41	50	38	50	67
37	51	43		74
49.13333	57.3	54.06667	47.31034	48.7



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1474	49.13333	145.7057
Picture 2	30	1719	57.3	124.769
Picture 3	30	1622	54.06667	114.892
Picture 4	29	1372	47.31034	124.7931
Picture 5	30	1461	48.7	197.7345

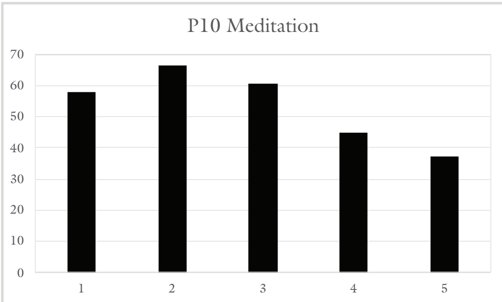
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2114.746	4	528.6864	3.731147	0.00640158	2.434503
Within Groups	20404.14	144	141.6954			
Total	22518.89	148				

Statistical Analysis (Individual)

P10 MEDITATION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
67	66	75	63	20
57	77	63	51	30
51	64	74	51	26
53	56	78	37	41
54	56	75	61	44
50	48	78	64	37
51	63	67	70	47
40	78	61	74	38
35	75	69	57	35
48	81	78	56	38
54	75	70	43	37
67	70	67	35	40
74	81	57	34	44
78	80	64	23	50
78	75	61	21	56
77	74	63	30	38
69	69	74	35	35
67	61	66	40	35
75	61	61	47	17
67	53	60	41	34
77	54	70	43	37
69	74	64	40	38
54	64	78	38	44
53	64	67	37	47
57	60	41	34	44
53	48	34	40	41
51	57	23	48	38
48	61	29	48	34
40	63	35	57	37
38	69	41	53	30
43	69	43	37	26
57	77	53	29	35
57.875	66.34375	60.59375	44.90625	37.28125



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	32	1852	57.875	160.371
Picture 2	32	2123	66.34375	91.13609
Picture 3	32	1939	60.59375	236.8942
Picture 4	32	1437	44.90625	170.8619
Picture 5	32	1193	37.28125	65.56351

ANOVA

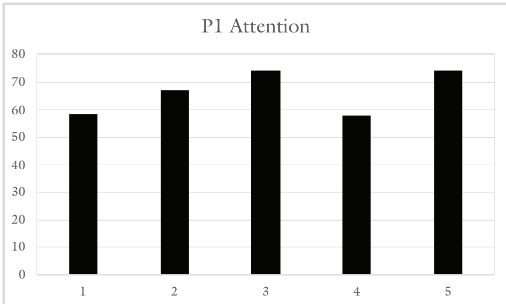
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18280.78	4	4570.194	31.52612	3.28803E-19	2.430002
Within Groups	22469.63	155	144.9653			
Total	40750.4	159				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P1 Attention

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
43	60	51	75	44
48	74	34	51	51
60	88	50	50	53
67	90	53	70	37
70	83	74	80	35
54	78	77	83	37
61	78	66	75	56
69	83	81	63	78
67	78	77	57	91
75	83	90	50	96
61	74	91	47	100
63	84	90	50	77
74	84	87	61	66
67	78	84	61	67
63	64	90	69	60
67	51	87	75	77
56	51	84	69	70
47	34	84	61	74
41	44	77	50	64
40	41	77	53	66
38	44	67	51	87
60	47	66	56	91
66	57	74	67	100
66	53	77	63	97
70	66	78	48	100
50	83	75	35	100
56	66	61	20	97
41	63	70	23	100
58.57143	67.10714	74	57.60714	73.96429



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	28	1640	58.57143	122.5503
Picture 2	28	1879	67.10714	268.914
Picture 3	28	2072	74	196.8148
Picture 4	28	1613	57.60714	234.0251
Picture 5	28	2071	73.96429	468.332

ANOVA

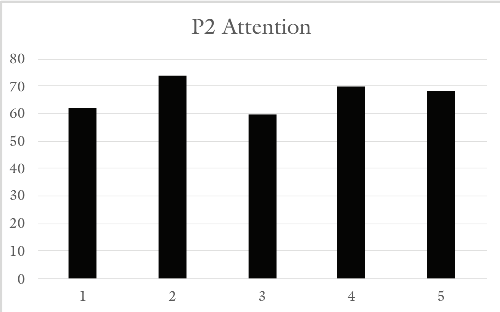
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7111.071	4	1777.768	6.887176	0.000045	2.438739
Within Groups	34847.18	135	258.1272			
Total	41958.25	139				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P2 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
51	51	51	93	63
50	75	54	80	54
47	96	63	84	69
41	93	69	69	75
38	81	66	57	56
41	75	51	70	78
44	56	47	60	67
48	50	54	57	48
69	69	47	61	81
70	67	50	53	63
70	67	50	69	77
78	70	43	81	90
70	53	40	74	66
66	64	57	67	75
78	66	60	74	66
61	60	57	50	74
63	75	70	60	84
66	63	63	74	81
50	60	67	56	81
64	77	78	70	87
54	67	57	51	80
60	77	67	61	90
83	84	77	70	84
84	83	70	80	66
87	100	90	100	61
81	87	64	91	48
66	84	48	84	43
69	88	51	81	35
63	88	54	61	47
48	91	78	57	57
62	73.9	59.76667	69.83333	68.2



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1860	62	194.6207
Picture 2	30	2217	73.9	188.1621
Picture 3	30	1793	59.76667	139.0816
Picture 4	30	2095	69.83333	170.9713
Picture 5	30	2046	68.2	218.4414

ANOVA

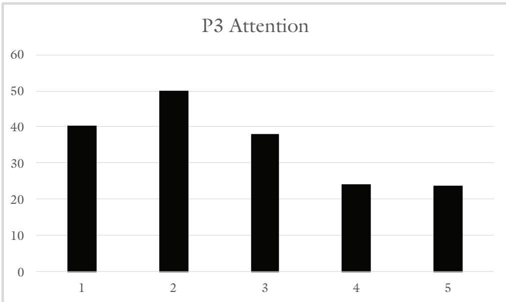
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4021.827	4	1005.457	5.516745	0.000366	2.434065
Within Groups	26427.03	145	182.2554			
Total	30448.86	149				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P3 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
29	30	47	34	30
17	40	38	23	37
17	47	35	29	51
16	44	20	34	40
30	50	29	21	26
43	53	24	17	20
67	56	24	3	10
60	54	50	11	1
54	54	30	16	4
64	50	38	23	14
60	51	48	26	8
54	63	37	26	38
54	64	38	27	30
41	61	41	29	24
38	61	43	29	21
34	67	38	14	7
29	51	38	1	8
38	48	30	1	24
38	43	21	1	35
54	37	34	13	27
64	44	41	17	35
60	50	41	20	20
40	44	51	34	41
30	50	50	17	37
23	44	43	37	29
26	47	41	56	23
30	51	51	41	1
23	51	34	51	20
41	51	43	43	23
43	50	40	26	27
40.56667	50.2	37.93333	24	23.7



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1217	40.56667	237.0126
Picture 2	30	1506	50.2	64.16552
Picture 3	30	1138	37.93333	75.09885
Picture 4	30	720	24	193.931
Picture 5	30	711	23.7	164.8379

ANOVA

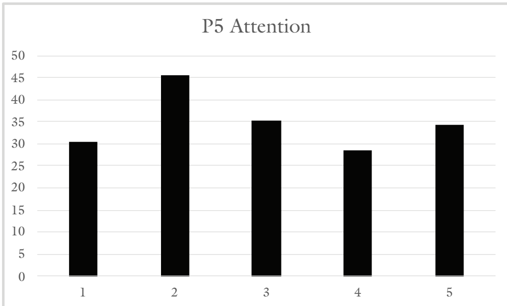
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15567.91	4	3891.977	26.47438	0.000000000000000172	2.434065
Within Groups	21316.33	145	147.0092			
Total	36884.24	149				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P5 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
60	54	13	16	44
34	51	23	23	17
24	44	27	24	8
13	40	27	34	23
3	40	30	34	30
7	44	21	35	60
1	47	23	27	67
21	53	27	21	53
27	57	44	37	38
37	48	57	30	10
44	54	54	30	4
47	35	53	38	21
30	47	40	38	26
30	30	43	40	50
29	21	53	26	51
27	27	56	34	38
47	17	53	27	34
50	44	26	20	21
54	54	21	26	23
47	61	13	23	24
41	66	10	4	34
21	60	27	14	40
11	64	26	21	56
24	64	35	26	74
26	53	44	47	51
43	54	53	40	44
40	40	48	41	21
26	37	43	27	10
20	34	47	20	24
26	23	21	37	34
30.33333	45.43333	35.26667	28.66667	34.33333



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	910	30.33333	225.5402
Picture 2	30	1363	45.43333	173.9092
Picture 3	30	1058	35.26667	211.0299
Picture 4	30	860	28.66667	88.09195
Picture 5	30	1030	34.33333	322.5747

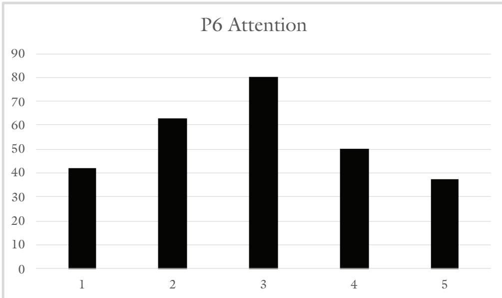
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5132.16	4	1283.04	6.282353	0.000109	2.434065
Within Groups	29613.23	145	204.2292			
Total	34745.39	149				

Statistical Analysis (Individual)

P6 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
30	81	64	100	43
47	61	78	78	48
41	54	90	48	41
20	41	64	27	57
38	60	91	26	35
51	44	83	51	48
51	57	69	53	50
51	63	88	61	23
27	54	70	54	47
41	60	64	40	23
48	61	56	38	34
60	43	50	30	41
60	38	50	20	30
54	67	56	10	41
23	69	81	13	35
27	83	91	26	57
3	100	87	56	67
1	80	94	75	67
7	83	93	88	67
34	75	94	83	48
61	69	100	60	41
83	66	100	61	24
60	48	96	54	21
41	54	88	57	35
35	48	93	70	24
38	75	84	51	24
54		87	48	21
53		80	44	7
66		81	41	1
53		78		17
41.93333	62.84615	80	50.44828	37.23333



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	1258	41.93333	359.9264
Picture 2	26	1634	62.84615	231.6554
Picture 3	30	2400	80	218.2759
Picture 4	29	1463	50.44828	486.6133
Picture 5	30	1117	37.23333	286.4609

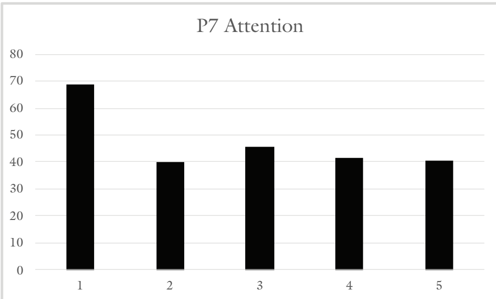
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	35470.04	4	8867.511	27.90294	0.000000000000000048266	2.436317
Within Groups	44491.79	140	317.7985			
Total	79961.83	144				

Statistical Analysis (Individual)

P7 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
53	37	57	30	61
78	29	64	44	56
84	63	66	44	51
84	75	80	41	47
91	57	84	30	53
87	80	80	35	50
81	61	64	17	51
84	81	53	11	48
83	91	40	21	29
80	84	35	16	21
74	100	29	8	21
70	78	40	41	20
78	61	54	37	27
75	56	48	44	51
77	34	74	69	70
74	34	70	57	64
66	35	50	70	77
57	34	40	66	63
67	16	11	70	35
67	4	1	69	41
61	1	1	74	24
54	1	3	60	23
48	1	11	54	44
41	1	29	43	43
54	1	38	40	37
75	1	48	41	30
66	1	50	35	4
63	14	47	35	13
47	21	51	27	27
51	41	51	23	37
69	39.76667	45.63333	41.73333	40.6



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	2070	69	182.8276
Picture 2	30	1193	39.76667	1029.702
Picture 3	30	1369	45.63333	541.5506
Picture 4	30	1252	41.73333	353.1678
Picture 5	30	1218	40.6	314.6621

ANOVA

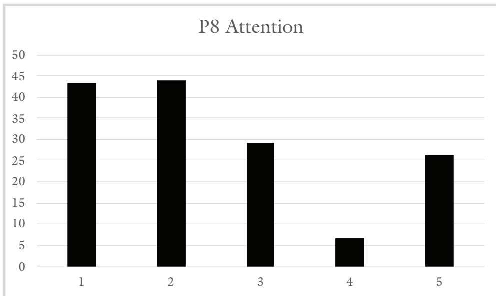
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18188.57	4	4547.143	9.387514	0.0000009	2.434065
Within Groups	70235.4	145	484.3821			
Total	88423.97	149				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P8 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
48	24	30	23	40
54	17	24	17	34
64	17	17	11	26
80	43	1	1	13
87	43	10	1	7
80	44	26	1	21
78	54	43	1	24
61	40	47	3	48
56	50	67	3	50
56	41	56	10	41
41	38	43	14	40
48	37	43	7	30
38	40	11	7	27
47	37	17	7	21
54	50	29	7	26
34	51	40	1	20
44	37	47	8	13
16	40	30	3	11
16	29	17	7	8
16	27	17	3	13
16	40	23	1	27
23	67	14	1	21
30	66	26	4	21
20	83	34	16	26
20	74	29	10	27
20	51	37	17	35
35	48	26	1	35
35	41	30	1	38
35	48	16	10	23
43.17241	44.03448	29.31034	6.758621	26.41379



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	29	1252	43.17241	453.0049
Picture 2	29	1277	44.03448	227.6773
Picture 3	29	850	29.31034	219.5074
Picture 4	29	196	6.758621	36.61823
Picture 5	29	766	26.41379	129.5369

ANOVA

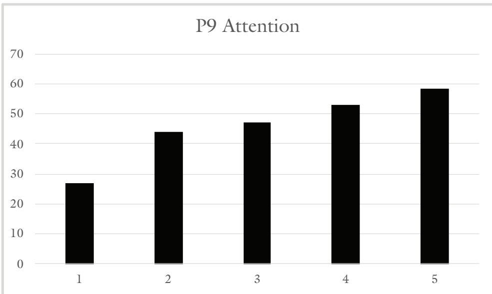
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	26794.79	4	6698.697	31.40962	0.00000000000000001152	2.436317
Within Groups	29857.66	140	213.269			
Total	56652.44	144				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P9 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
40	27	21	40	69
40	35	37	48	66
16	43	44	41	66
11	75	43	26	70
29	74	41	23	78
17	77	20	21	69
21	56	21	50	50
17	17	29	44	53
16	17	23	51	43
16	1	26	64	48
34	16	26	44	56
38	34	30	50	38
17	37	27	63	50
27	63	44	48	61
3	51	48	61	64
1	29	54	69	67
16	47	75	53	48
1	14	75	74	44
11	23	88	78	47
29	26	90	75	57
43	27	67	74	66
47	38	77	69	53
41	54	77	57	60
41	64	77	57	66
47	61	75	67	74
51	69	67	41	78
61	69	38	48	64
38	69	37	53	57
16	56	26		44
23	56	16		50
26.93333	44.16667	47.3	53.17857	58.53333



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	808	26.93333	248.754
Picture 2	30	1325	44.16667	458.2816
Picture 3	30	1419	47.3	542.5621
Picture 4	28	1489	53.17857	236.4484
Picture 5	30	1756	58.53333	118.6713

ANOVA

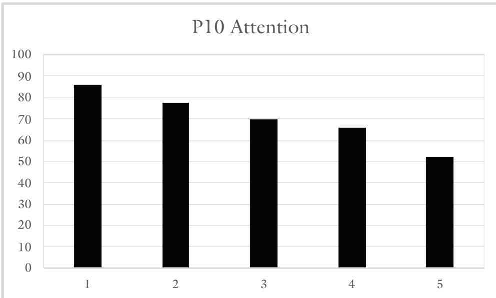
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17212.28	4	4303.069	13.35837	0.0000000028	2.434947
Within Groups	46063.91	143	322.1252			
Total	63276.18	147				

Appendix 2: Research study 1

Statistical Analysis (Individual)

P10 ATTENTION

Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
90	67	53	57	56
80	75	40	54	61
83	84	29	40	50
83	69	37	53	44
81	81	47	64	56
66	93	74	69	47
66	81	80	67	66
78	96	80	56	56
90	87	81	48	66
100	80	70	56	70
100	75	69	60	64
100	67	77	70	78
100	70	69	90	56
91	67	64	70	53
97	67	70	88	54
100	78	74	81	40
87	67	94	57	47
81	74	100	66	48
78	84	100	60	41
90	81	96	66	53
96	94	80	81	51
91	84	75	77	56
83	80	63	70	66
67	84	60	63	75
66	74	67	69	63
83	80	51	75	41
84	78	66	64	30
93	63	69	70	21
97	75	69	67	23
77	66	87	70	26
85.93333	77.36667	69.7	65.93333	51.93333



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Picture 1	30	2578	85.93333	116.0644
Picture 2	30	2321	77.36667	77.06782
Picture 3	30	2091	69.7	307.8724
Picture 4	30	1978	65.93333	123.3057
Picture 5	30	1558	51.93333	207.9954

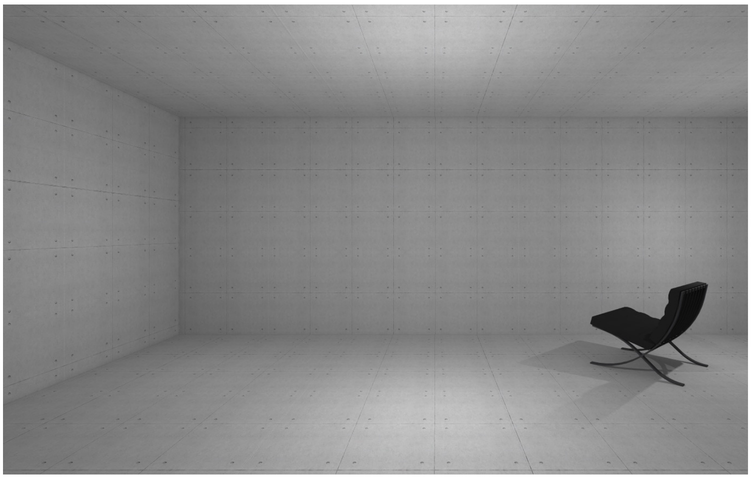
ANOVA

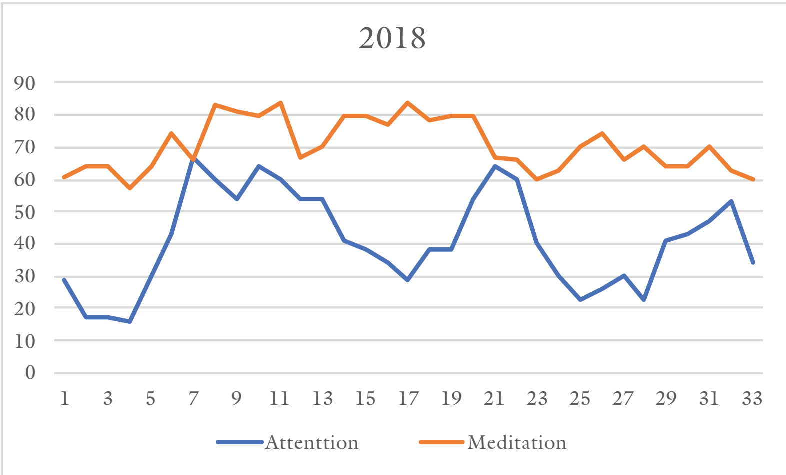
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19530.63	4	4882.657	29.33211	0.0000000000000000000719	2.434065
Within Groups	24136.87	145	166.4611			
Total	43667.49	149				

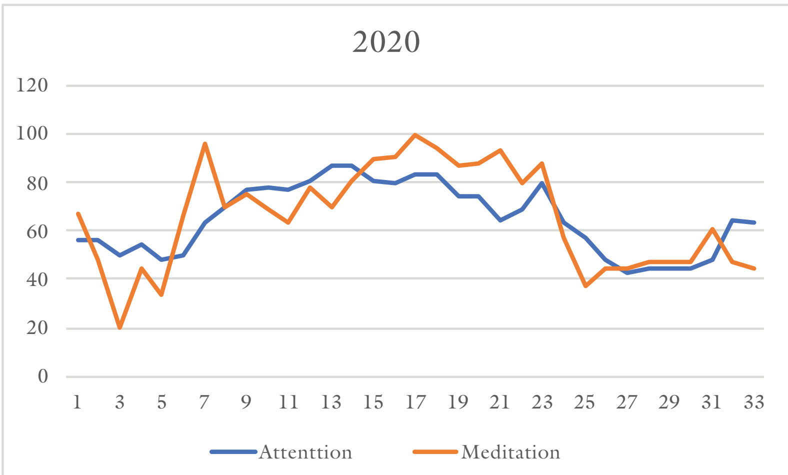
Appendix 2A: Research Study 1

Appendix 2A: Research study 1

Repetition: Comparative Results

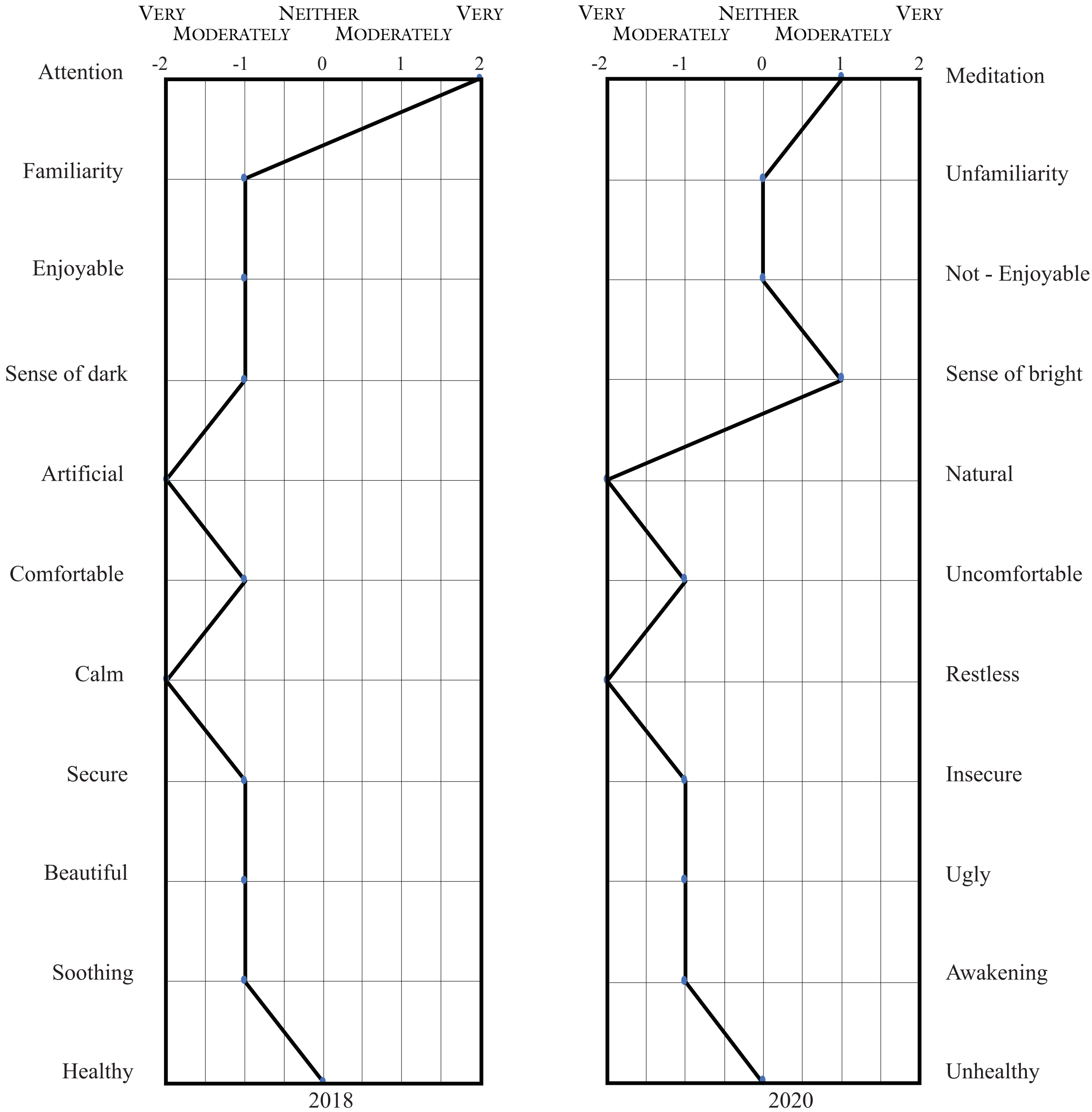






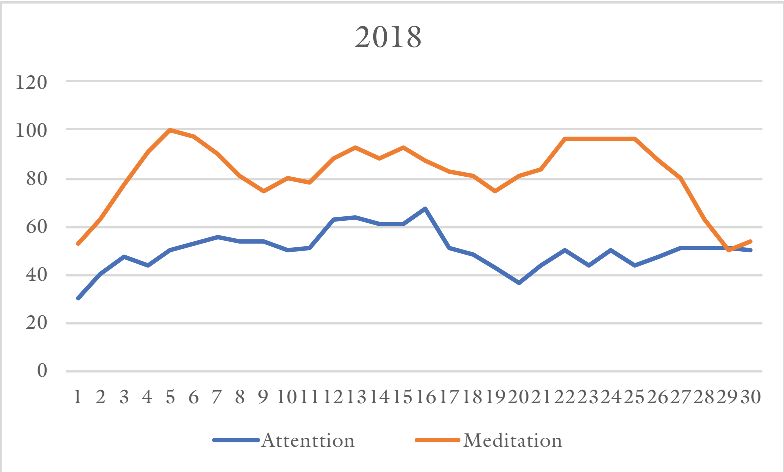
Appendix 2A: Research study 1

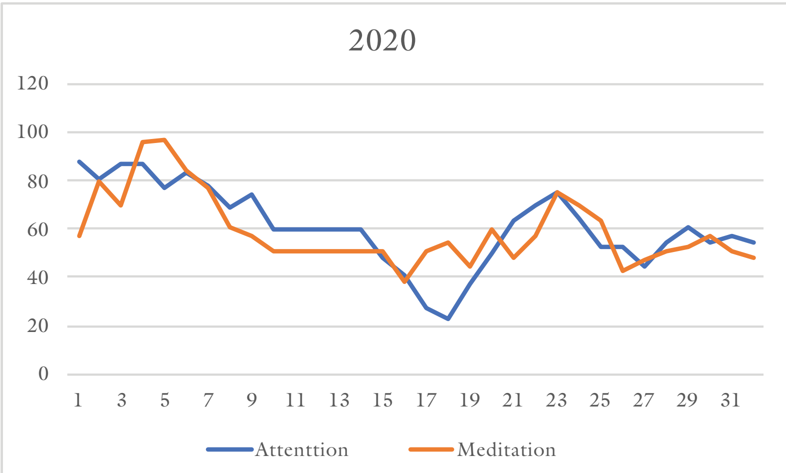
Repetition: Comparative Results



Appendix 2A: Research study 1

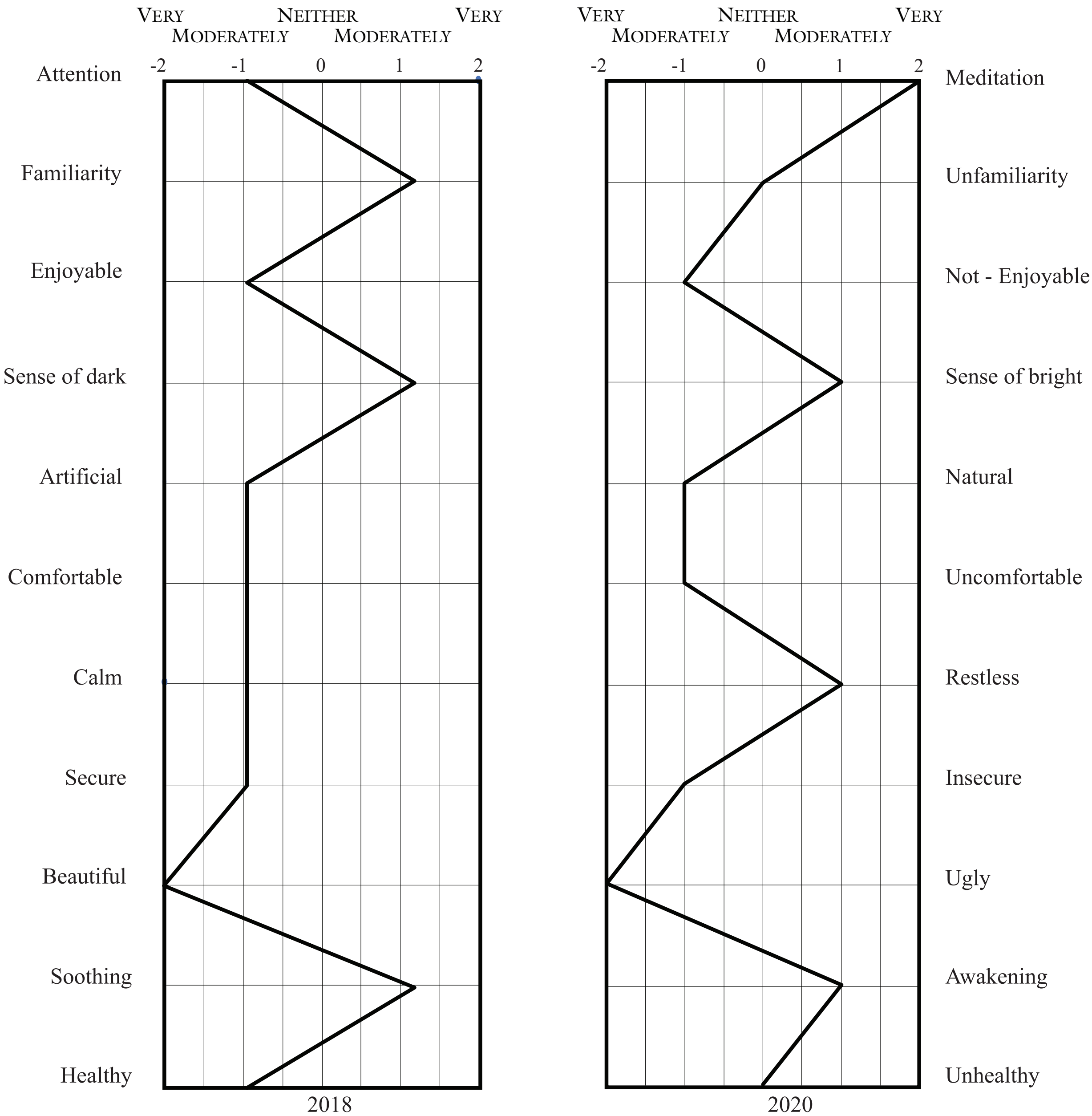
Repetition: Comparative Results





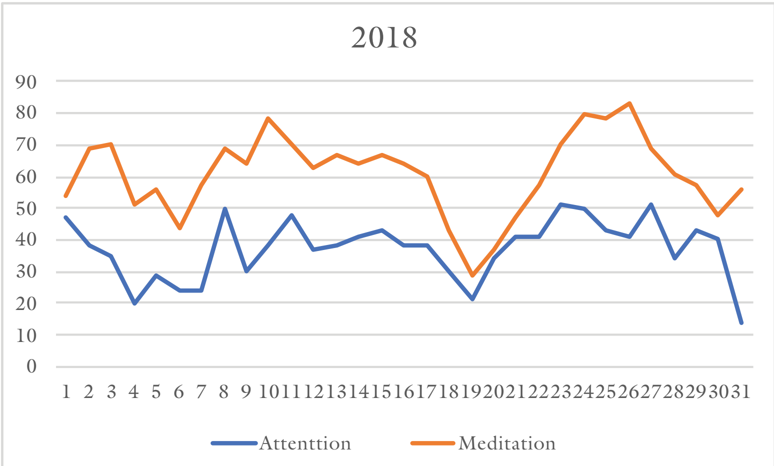
Appendix 2A: Research study 1

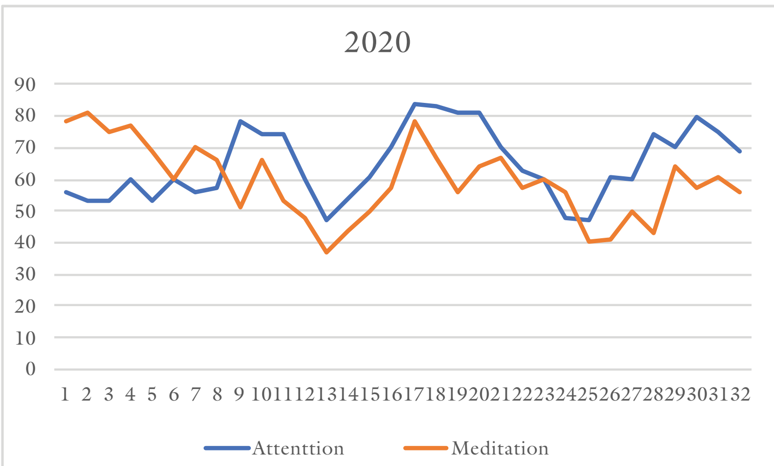
Repetition: Comparative Results



Appendix 2A: Research study 1

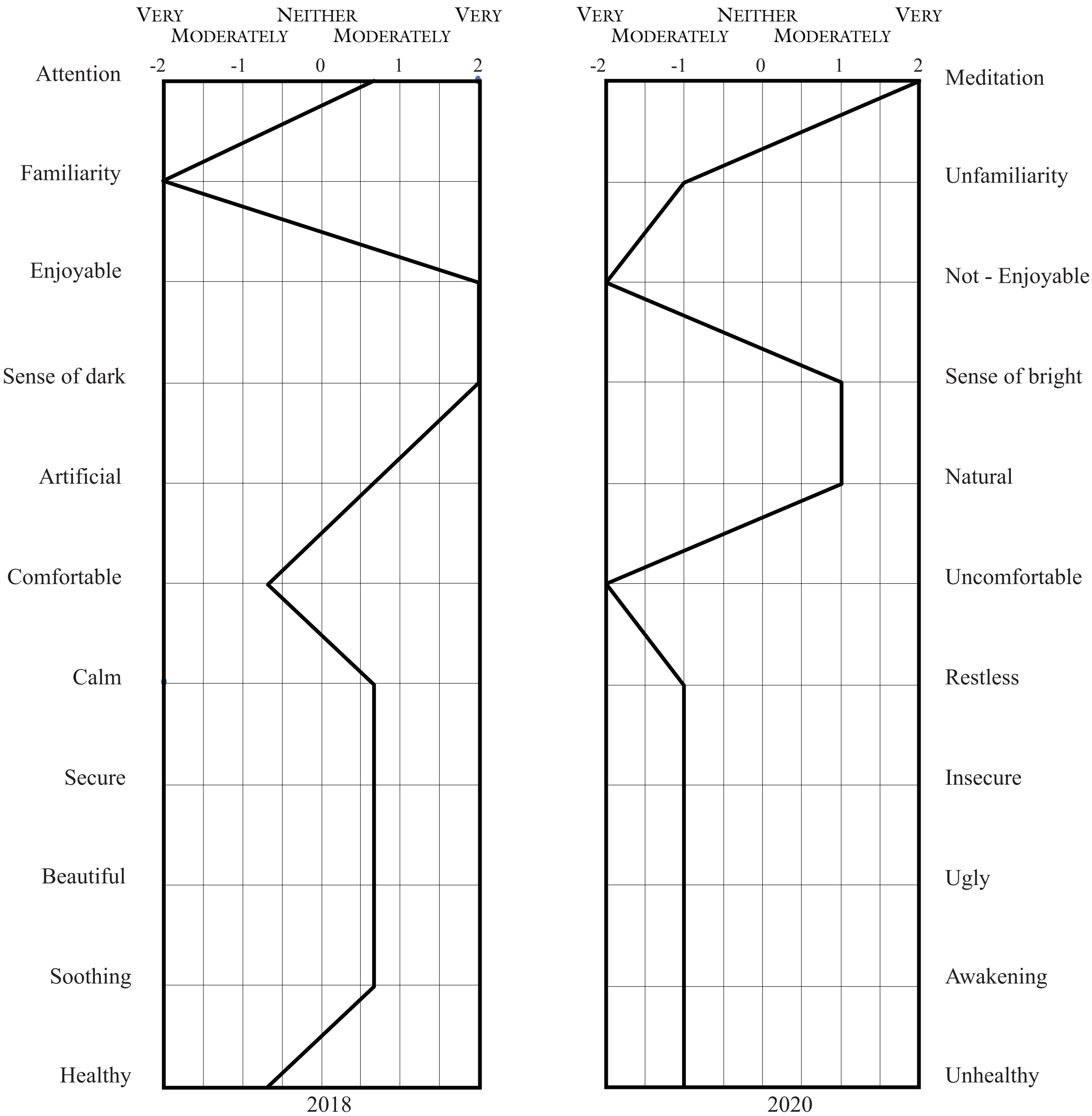
Repetition: Comparative Results

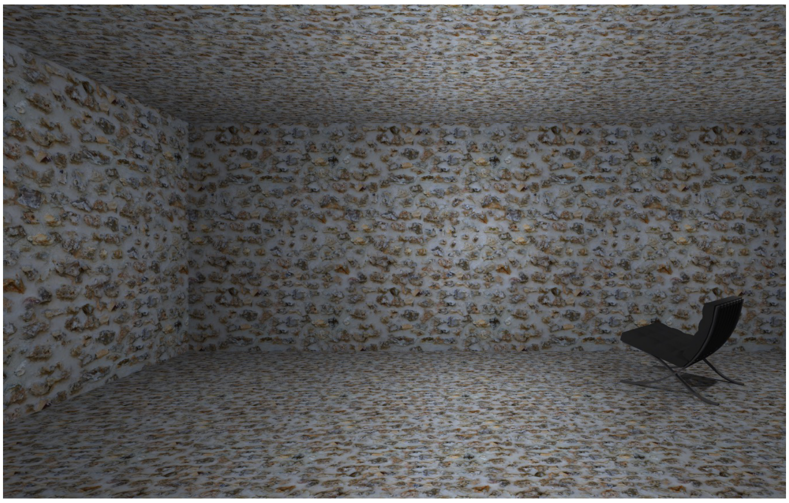


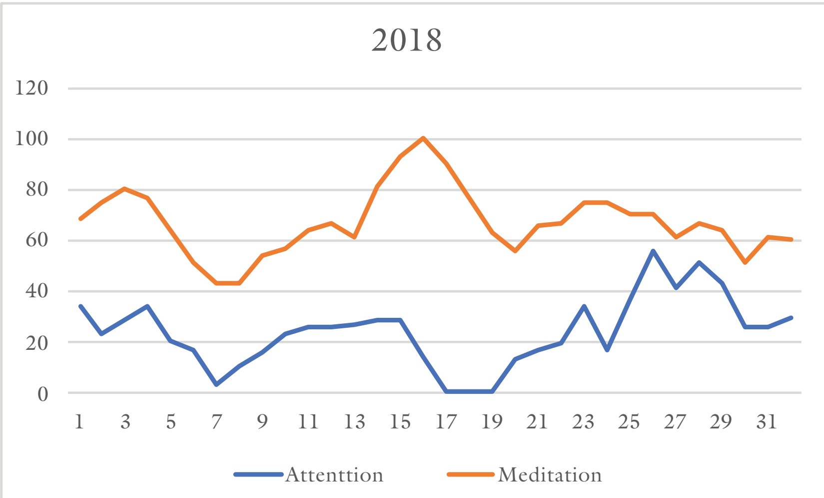


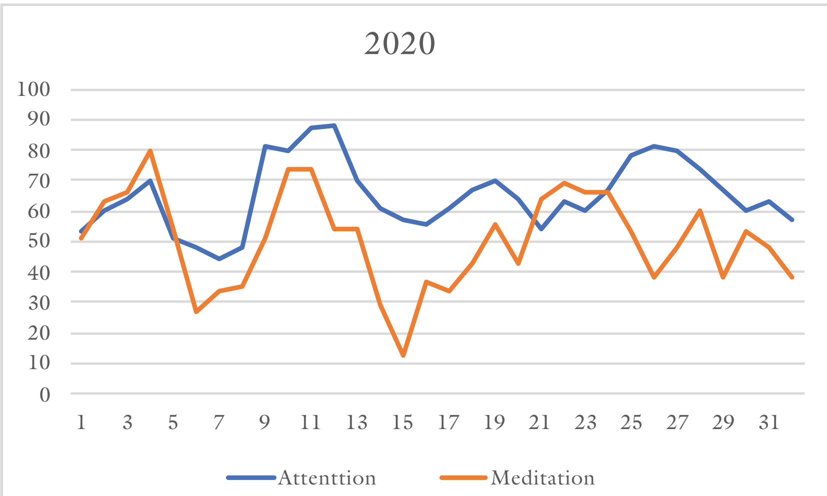
Appendix 2A: Research study 1

Repetition: Comparative Results

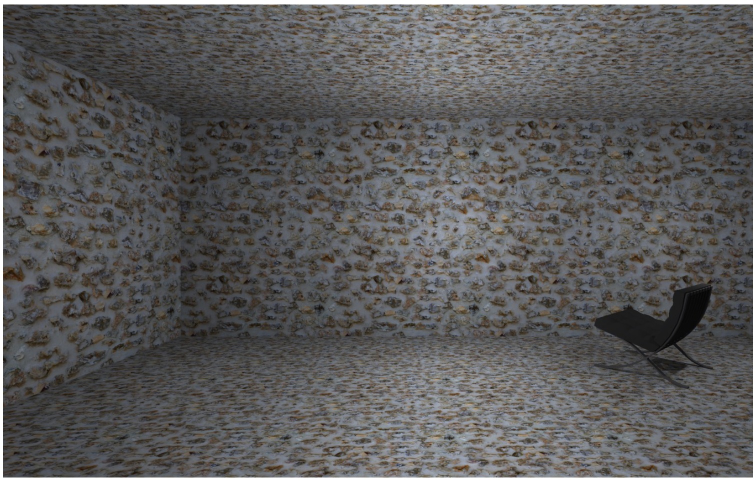


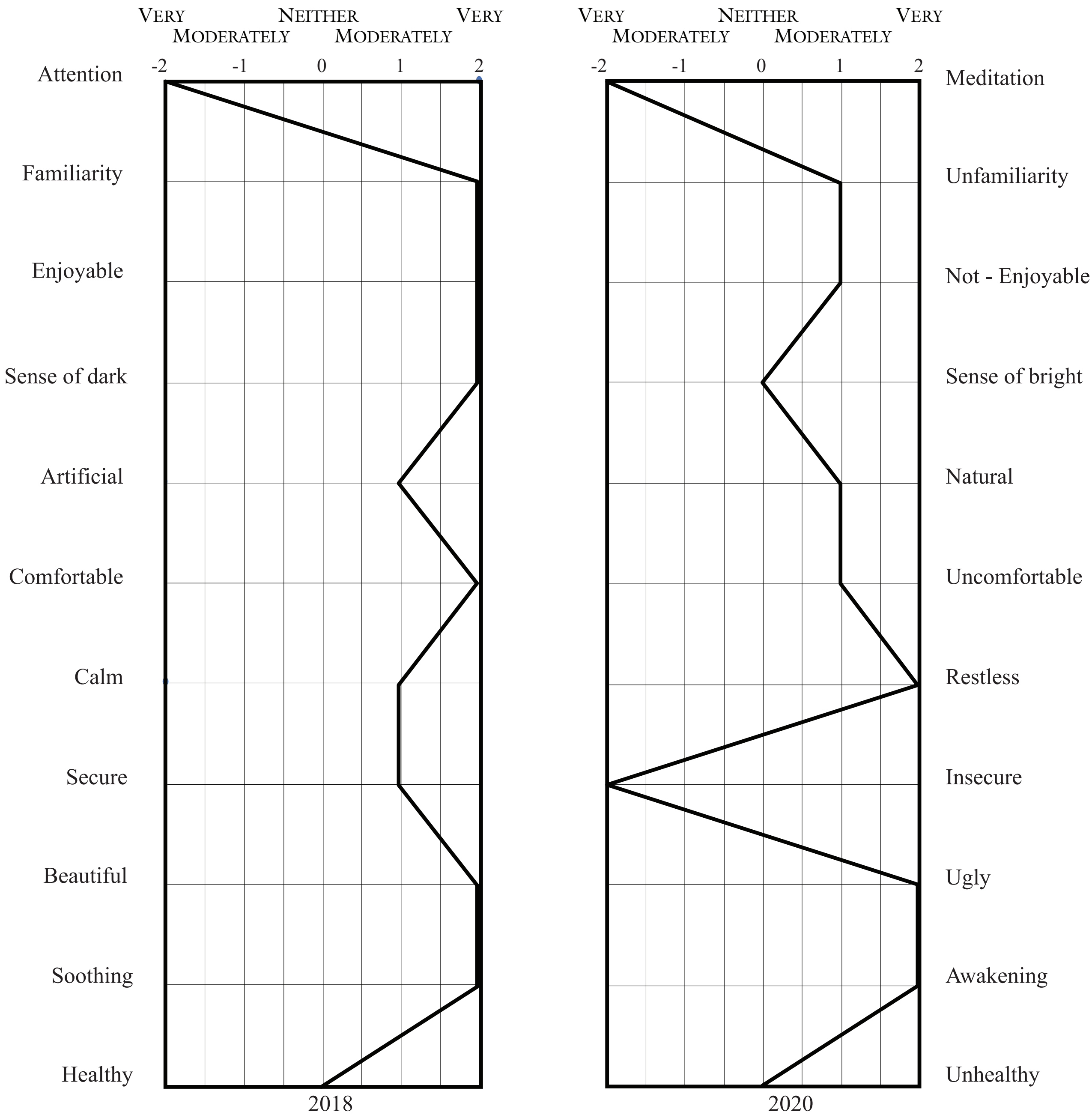


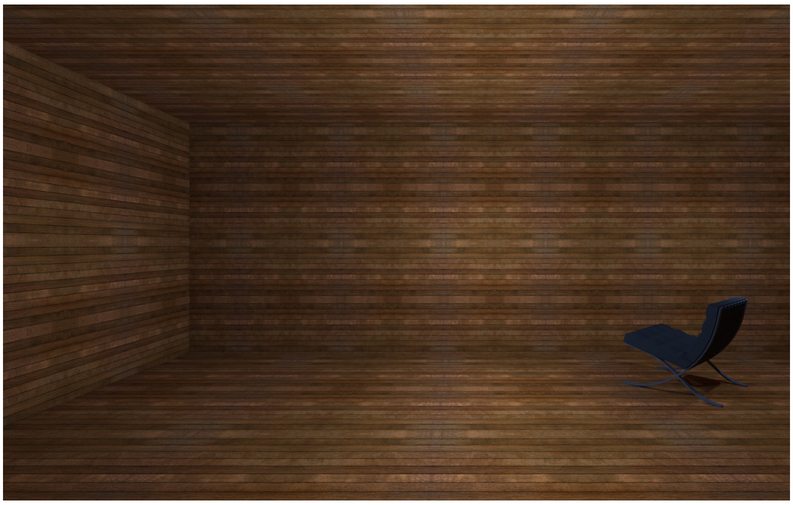

2018
120
100
80
60
40
20
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Attenttion
Meditation

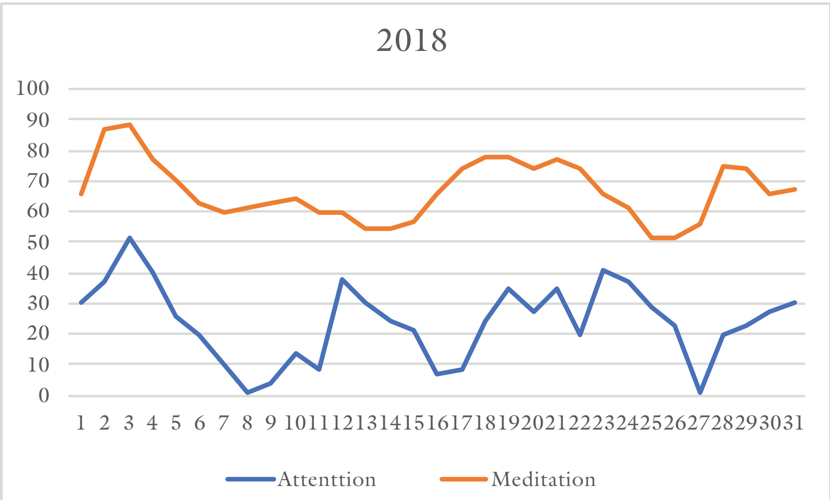

2020
100
90
80
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Attenttion
Meditation

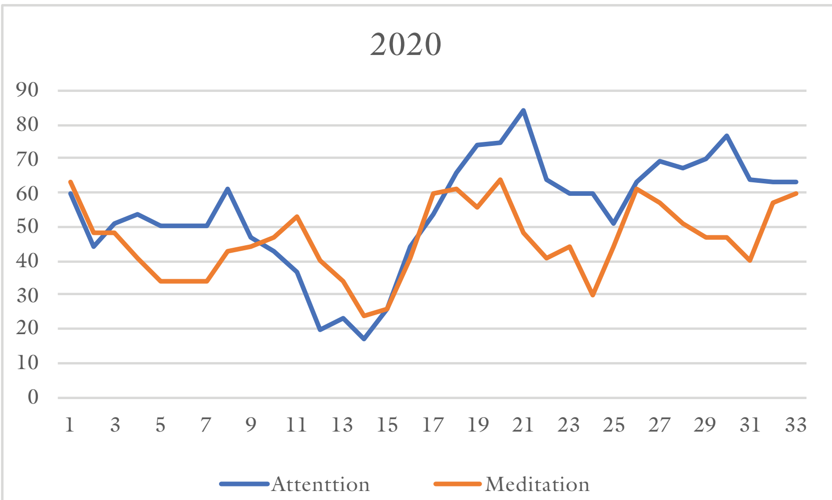
Appendix 2A: Research study 1
Repetition: Comparative Results





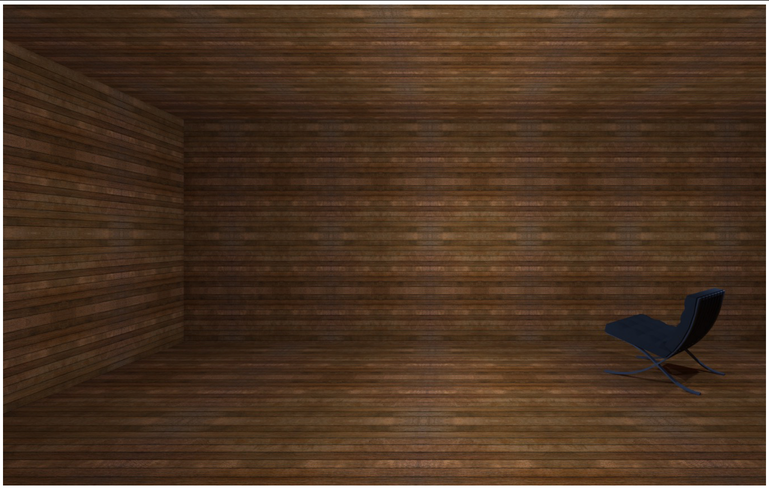


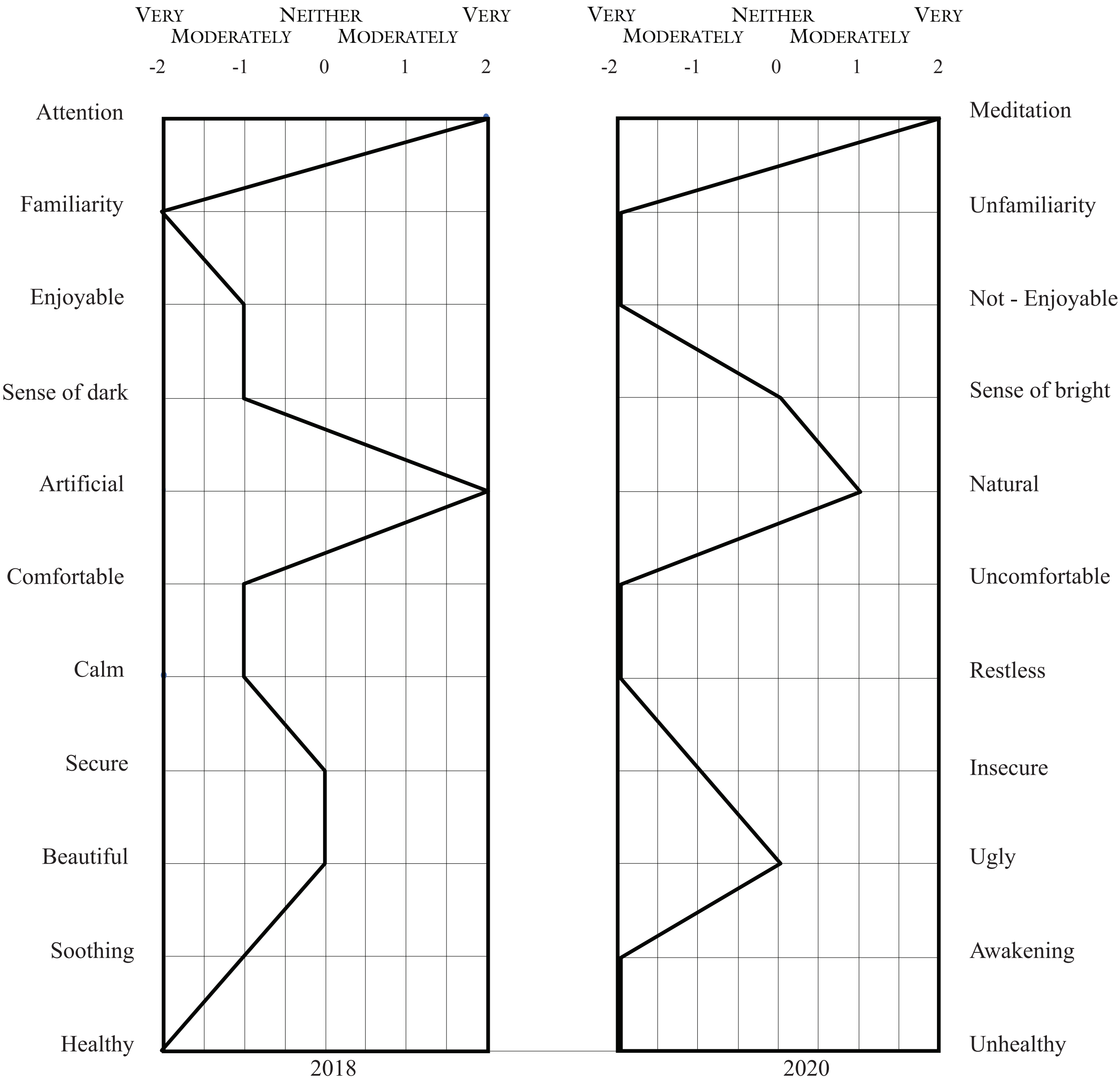

2018
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10111213141516171819202122232425262728293031
Attenttion
Meditation


2020
90
80
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Attenttion
Meditation

Appendix 2A: Research study 1

Repetition: Comparative Results

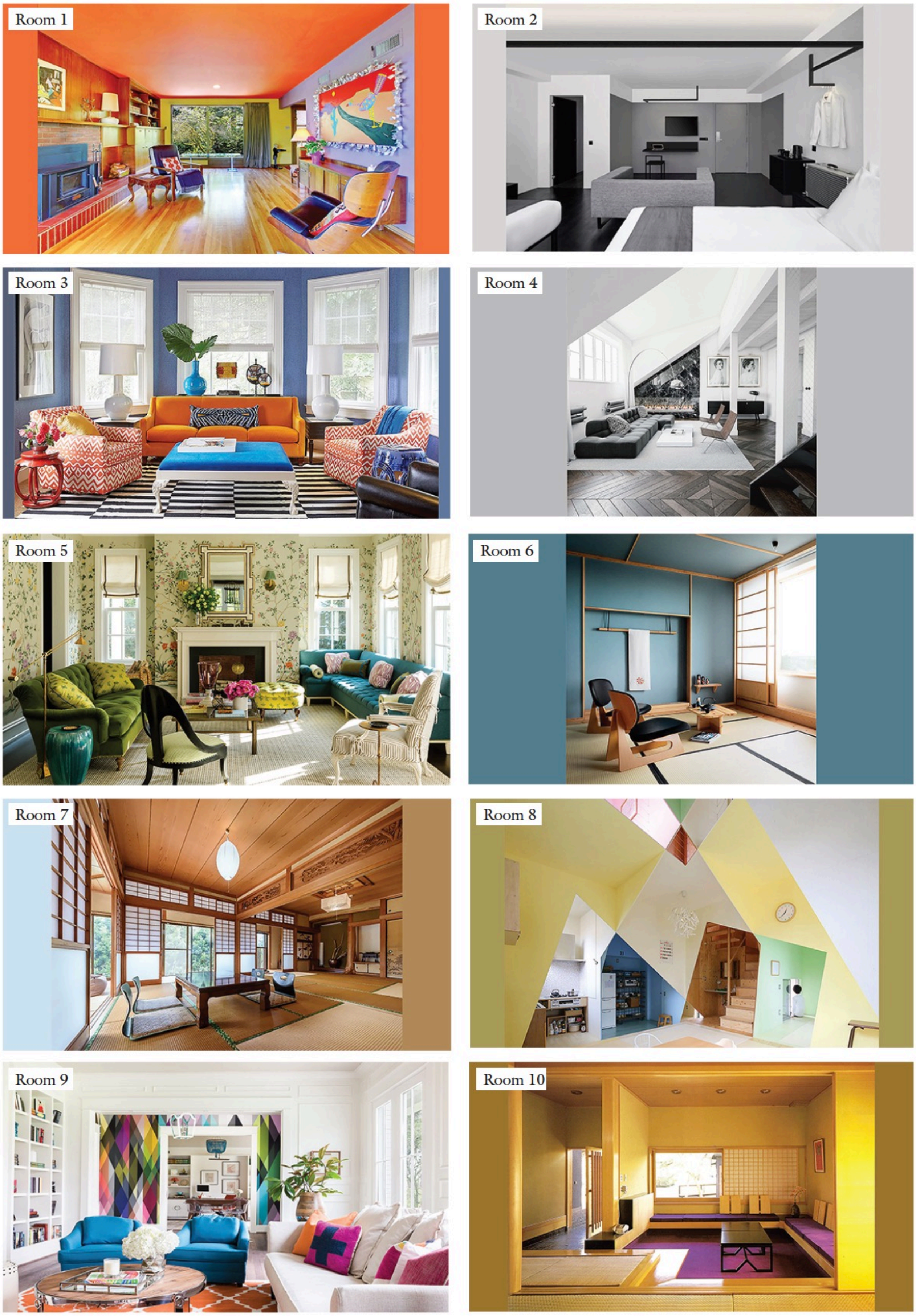




Appendix 3: Research Study 2

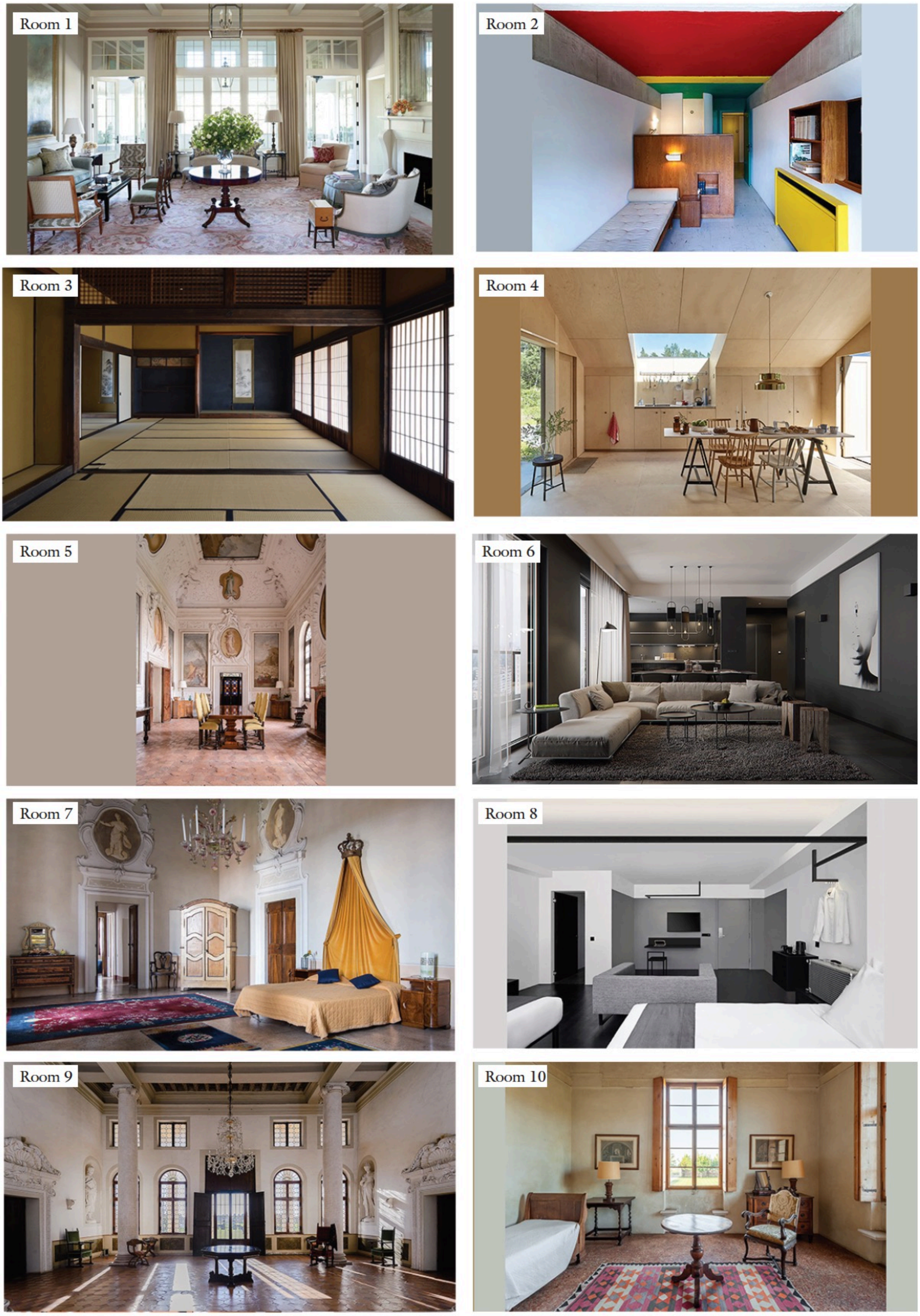
Appendix 3: Research study 2

Final Selection of Stimuli



Appendix 3: Research study 2

Final Selection of Stimuli



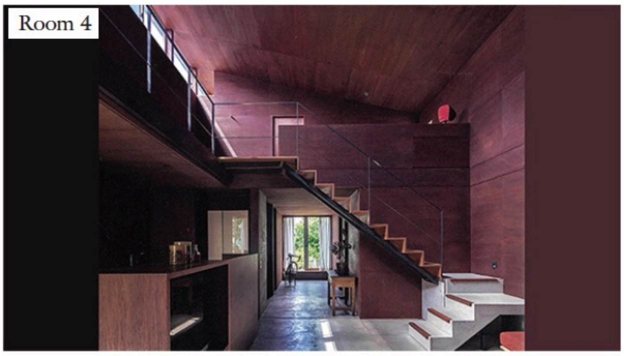
Appendix 3: Research study 2

Final Selection of Stimuli

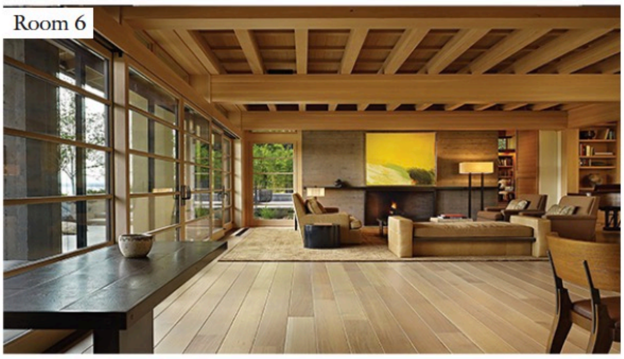

Room 1


Room 2

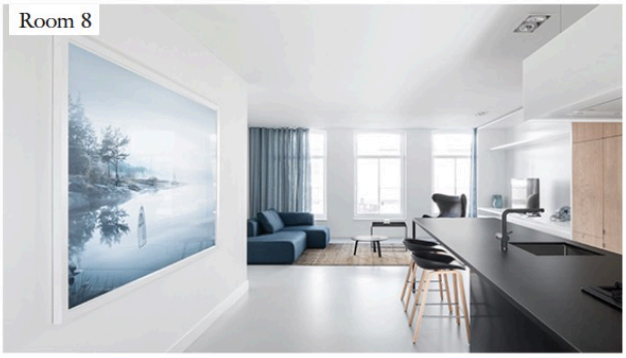

Room 3


Room 4


Room 5


Room 6


Room 7


Room 8


Room 9

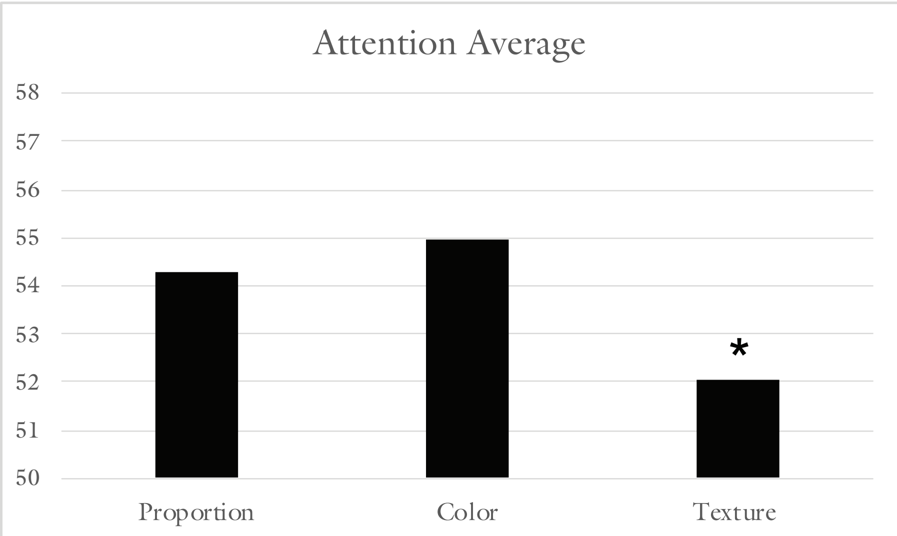

Room 10

Appendix 4: Research Study 2

Appendix 4: Research study 2

Statistical Analysis

Average Attention		
Proportion	Color	Texture
58.78947	51.68421	54.05263
59.68421	50.84211	54.21053
59.57895	50.73684	51.05263
59.68421	52.31579	52.68421
60.57895	51.52632	50.31579
58.42105	53.63158	48.84211
56.78947	51.84211	49.21053
54.05263	50	48.42105
52.05263	52.57895	49.57895
55.42105	53.36842	48.57895
55	57.94737	50.05263
54.42105	63.05263	50.84211
56.36842	60.78947	48.26316
56.05263	59.42105	52.26316
57.52632	57.15789	51.05263
56.73684	55.36842	52.68421
57.84211	57.10526	55.84211
57.42105	56.15789	54.78947
55.68421	57.89474	54.57895
54.73684	57.21053	53.84211
53.42105	58.42105	51.89474
52.73684	61.63158	51.89474
58.42105	58.89474	53.15789
58.36842	56	54.42105
56.10526	54.47368	57.63158
52.57895	53.21053	57.57895
47.57895	51.63158	53.68421
50.47368	57.47368	51.26316
46.52632	59.73684	47
51.47368	56.05263	45.47368
50.05263	58.15789	45.47368
48.73684	54.89474	45
51.94737	52.36842	44.31579
50.63158	54.15789	48.78947
51.84211	53.15789	53.21053
53.78947	52.78947	52.89474
53.57895	49.52632	57.05263
54.36842	49.94737	56.36842
52.31579	48.89474	55.89474
50.73684	52	58.21053
50.63158	55.47368	55.33333
46.38889	54.89474	54.66667
55.3	58.61538	54.5625
54.29876	54.95434	52.02165



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Proportion	43	2334.847	54.29876	13.41095
Color	43	2363.036	54.95434	12.35103
Texture	43	2236.931	52.02165	12.90281

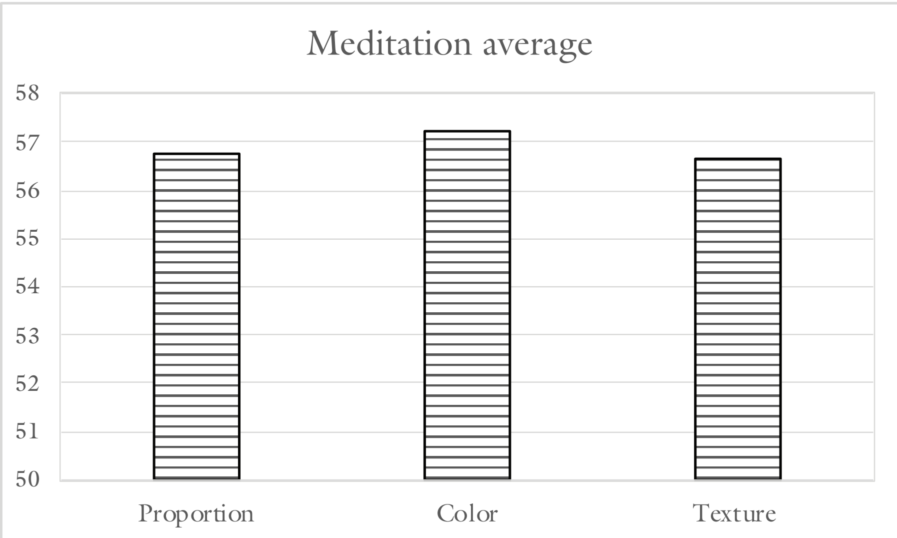
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	203.7579	2	101.879	7.904786	0.000583	3.0681
Within Groups	1623.921	126	12.88826			
Total	1827.679	128				

Appendix 4: Research study 2

Statistical Analysis

Average Meditation		
Proportion	Color	Texture
53.68421	48.63158	56.52632
53.21053	46.52632	54.10526
57.10526	49.89474	55.36842
56.26316	53	54.78947
57.78947	55.31579	54.57895
57.21053	57.10526	57.89474
56.36842	53.84211	59.89474
58.78947	51.78947	63.10526
58.21053	51.31579	62.36842
58.42105	52.31579	59.73684
56.26316	58.94737	55.94737
54.73684	63.31579	51.89474
53.15789	62.78947	51.31579
50.05263	62.78947	49.47368
52.21053	60.15789	51.31579
53.63158	60.84211	56.26316
54.31579	62.73684	56.31579
56.47368	61.52632	60.05263
55.52632	61.21053	61.42105
56.42105	62.21053	59.10526
54.63158	62.21053	61.15789
54.63158	58.89474	57.21053
56.47368	58	54.84211
57.52632	52.84211	58
57.26316	53.89474	59.26316
57.84211	54.78947	58.36842
57.47368	54.57895	60.31579
56.47368	55.36842	56.57895
57.94737	55.15789	52.10526
58.31579	57.42105	52.78947
56.21053	60.36842	51.42105
56.89474	62.42105	52.36842
58.21053	60	56.94737
57.31579	58.89474	56.78947
59.63158	58.52632	58.47368
60.05263	56.42105	59.31579
60.94737	57.89474	56
62.52632	55.94737	57.47368
61.52632	54.84211	56.73684
60.10526	56.57895	56.52632
58.42105	55.68421	57.22222
52.22222	58.73684	58.44444
57.7	64.38462	57
56.7485	57.21213	56.67034



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
53.68421	42	2386.501	56.82146	6.58558
48.63158	42	2411.49	57.41643	16.93933
56.52632	42	2380.298	56.67377	10.4752

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.98278	2	6.491388	0.572768	0.565459	3.069894
Within Groups	1394.004	123	11.33337			
Total	1406.987	125				

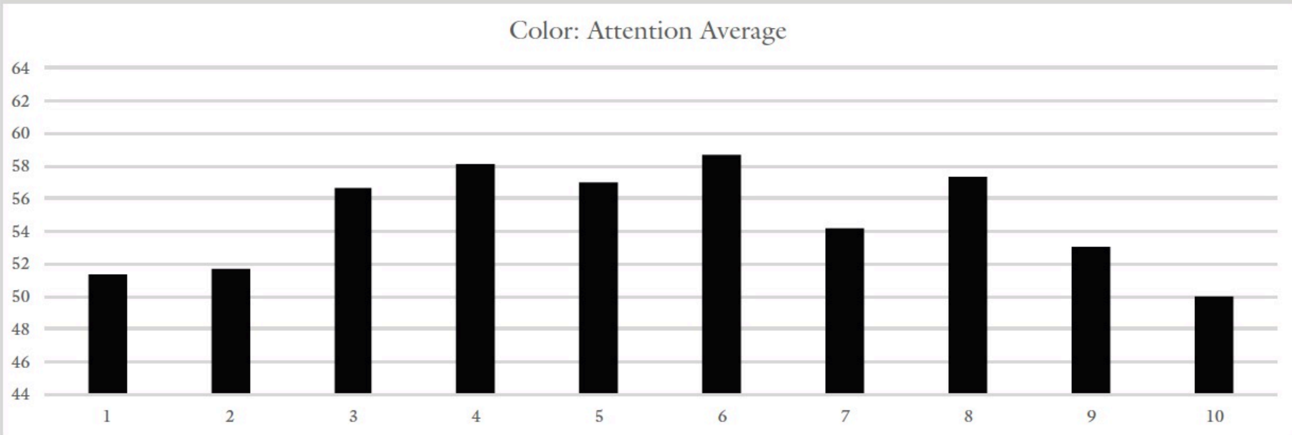
Appendix 4: Research study 2

Statistical Analysis (Individual)

Color: Attention

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
51.6	51.5	52.5	60.7	57.1	58.4	54.4	59.7	52.3	49.5
50.8	53.6	53.3	59.4	56.1	61.6	53.2	56.9	54.1	49.9
50.7	51.8	57.9	57.1	57.8	58.8	51.6	58.1	53.1	48.8
52.3	50	63	55.3	57.2	56	57.4	54.8	52.7	52
51.3	51.725	56.675	58.125	57.05	58.7	54.15	57.375	53.05	50.05

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
									



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	205.5632	51.39079	0.547154
Room 2	4	206.9	51.725	2.1825
Room 3	4	226.7	56.675	23.4425
Room 4	4	232.5	58.125	5.7625
Room 5	4	228.2	57.05	0.496667
Room 6	4	234.8	58.7	5.266667
Room 7	4	216.6	54.15	6.01
Room 8	4	229.5	57.375	4.2625
Room 9	4	212.2	53.05	0.596667
Room 10	4	200.2	50.05	1.896667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	354.367	9	39.37412	7.802445	0.00000801	2.210697
Within Groups	151.3915	30	5.046382			
Total	505.7585	39				

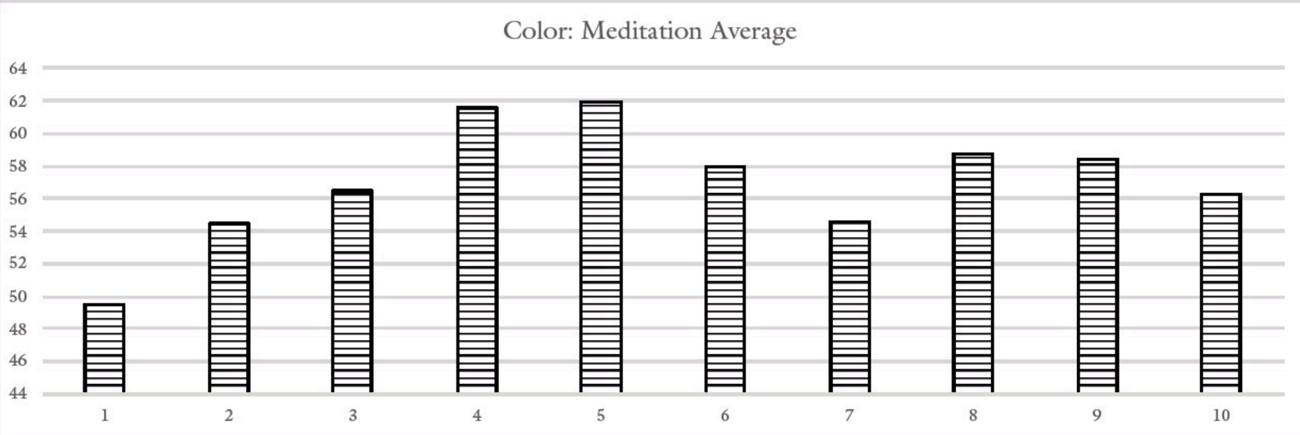
Appendix 4: Research study 2

Statistical Analysis (Individual)

Color: Meditation

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
48.6	55.3	51.3	62.7	62.7	62.2	53.8	55.1	60	57.8
46.5	57.1	52.3	62.7	61.5	58.8	54.7	57.4	58.8	55.9
49.8	53.8	58.9	60.1	61.2	58	54.5	60.3	58.5	54.8
53	51.7	63.3	60.8	62.2	52.8	55.3	62.4	56.4	56.5
49.475	54.475	56.45	61.575	61.9	57.95	54.575	58.8	58.425	56.25

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	197.9	49.475	7.3825
Room 2	4	217.9	54.475	5.2425
Room 3	4	225.8	56.45	32.22333
Room 4	4	246.3	61.575	1.769167
Room 5	4	247.6	61.9	0.46
Room 6	4	231.8	57.95	15.10333
Room 7	4	218.3	54.575	0.3825
Room 8	4	235.2	58.8	10.28667
Room 9	4	233.7	58.425	2.2425
Room 10	4	225	56.25	1.563333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	483.4363	9	53.71514	7.007313	2.18855E-05	2.210697
Within Groups	229.9675	30	7.665583			
Total	713.4038	39				

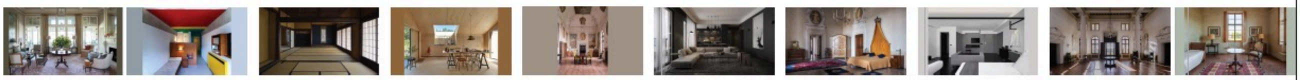
Appendix 4: Research study 2

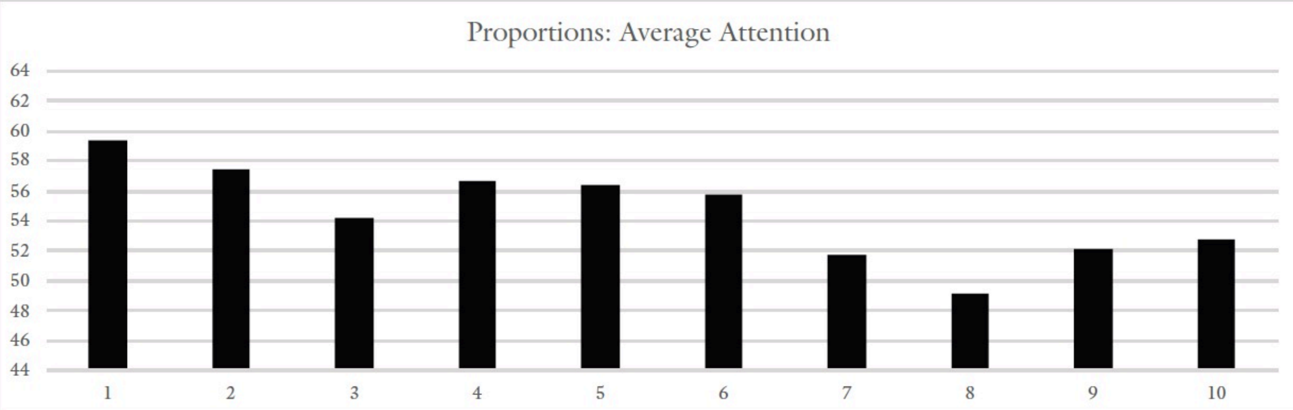
Statistical Analysis (Individual)

Proportion: Attention

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
58.78947	60.57895	52.05263	56.36842	57.84211	53.42105	56.10526	46.52632	51.94737	53.57895
59.68421	58.42105	55.42105	56.05263	57.42105	52.73684	52.57895	51.47368	50.63158	54.36842
59.57895	56.78947	55	57.52632	55.68421	58.42105	47.57895	50.05263	51.84211	52.31579
59.68421	54.05263	54.42105	56.73684	54.73684	58.36842	50.47368	48.73684	53.78947	50.73684
59.43421	57.46053	54.22368	56.67105	56.42105	55.73684	51.68421	49.19737	52.05263	52.75

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10





Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	237.7368	59.43421	0.187211
Room 2	4	229.8421	57.46053	7.570406
Room 3	4	216.8947	54.22368	2.262927
Room 4	4	226.6842	56.67105	0.403278
Room 5	4	225.6842	56.42105	2.132964
Room 6	4	222.9474	55.73684	9.497692
Room 7	4	206.7368	51.68421	12.88827
Room 8	4	196.7895	49.19737	4.419898
Room 9	4	208.2105	52.05263	1.697138
Room 10	4	211	52.75	2.515928

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	352.7199	9	39.1911	8.993795	1.98352E-06	2.210697
Within Groups	130.7271	30	4.357572			
Total	483.4471	39				

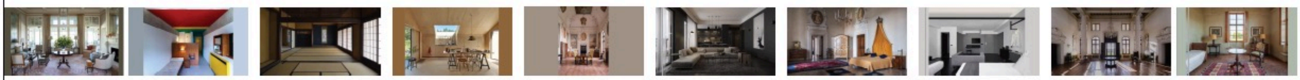
Appendix 4: Research study 2

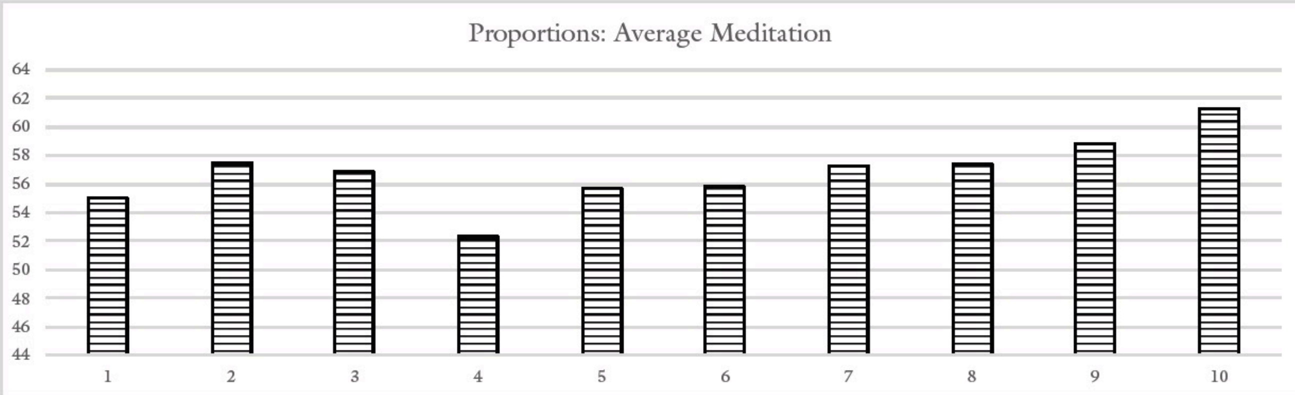
Statistical Analysis (Individual)

Proportion: Meditation

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
53.68421	57.78947	58.21053	*53.1578947*	54.31579	54.63157895	57.26316	57.94737	58.21053	60.94737
53.21053	57.21053	58.42105	50.05263	56.47368	54.63157895	57.84211	58.31579	57.31579	62.52632
57.10526	56.36842	56.26316	52.21053	55.52632	56.47368421	*57.4736842*	56.21053	59.63158	61.52632
56.26316	58.78947	54.73684	53.63158	56.42105	57.52631579	56.47368	56.89474	60.05263	60.10526
55.06579	57.53947	56.90789	52.26316	55.68421	55.81578947	57.26316	57.34211	58.80263	61.27632

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10





Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	220.2632	55.06579	3.647969
Room 2	4	230.1579	57.53947	1.034857
Room 3	4	227.6316	56.90789	3.03855
Room 4	4	209.0526	52.26316	2.520776
Room 5	4	222.7368	55.68421	1.021237
Room 6	4	223.2632	55.81579	2.054478
Room 7	4	229.0526	57.26316	0.334257
Room 8	4	229.3684	57.34211	0.931671
Room 9	4	235.2105	58.80263	1.603647
Room 10	4	245.1053	61.27632	1.034857

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	203.6749	9	22.63054	13.14025	3.40999E-08	2.210697
Within Groups	51.6669	30	1.72223			
Total	255.3418	39				

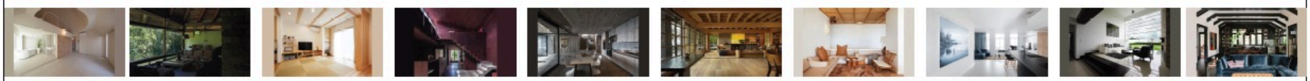
Appendix 4: Research study 2

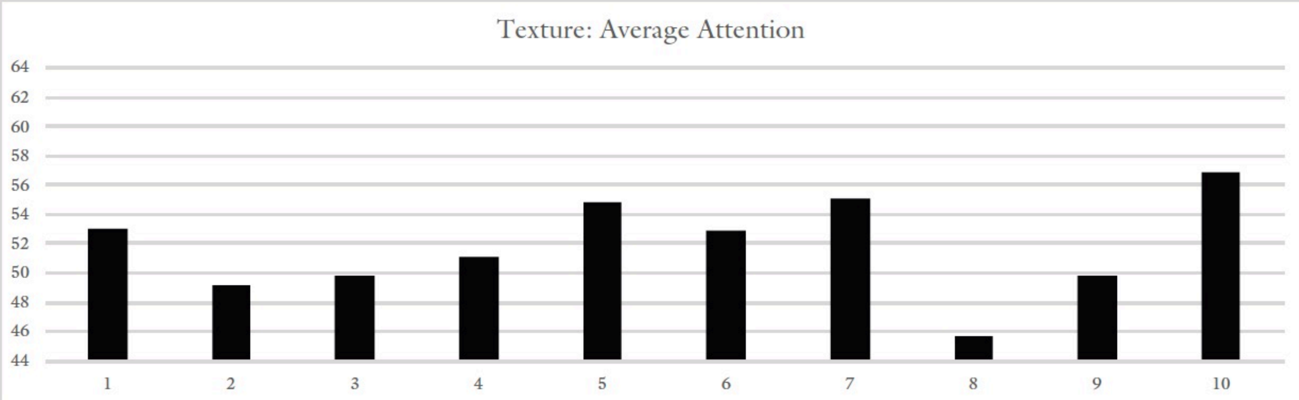
Statistical Analysis (Individual)

Texture: Attention

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
54.05263	50.31579	49.57895	48.26316	55.84211	51.89474	57.63158	47	44.31579	57.05263
54.21053	48.84211	48.57895	52.26316	54.78947	51.89474	57.57895	45.47368	48.78947	56.36842
51.05263	49.21053	50.05263	51.05263	54.57895	53.15789	53.68421	45.47368	53.21053	55.89474
52.68421	48.42105	50.84211	52.68421	53.84211	54.42105	51.26316	45	52.89474	58.21053
53	49.19737	49.76316	51.06579	54.76316	52.84211	55.03947	45.73684	49.80263	56.88158

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10





Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	4	212	53	2.155125
Room 2	4	196.7895	49.19737	0.659972
Room 3	4	199.0526	49.76316	0.894737
Room 4	4	204.2632	51.06579	3.969298
Room 5	4	219.0526	54.76316	0.682364
Room 6	4	211.3684	52.84211	1.462604
Room 7	4	220.1579	55.03947	9.755078
Room 8	4	182.9474	45.73684	0.759003
Room 9	4	199.2105	49.80263	17.4356
Room 10	4	227.5263	56.88158	1.010849

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	399.3397	9	44.37108	11.44038	1.58802E-07	2.210697
Within Groups	116.3539	30	3.878463			
Total	515.6936	39				

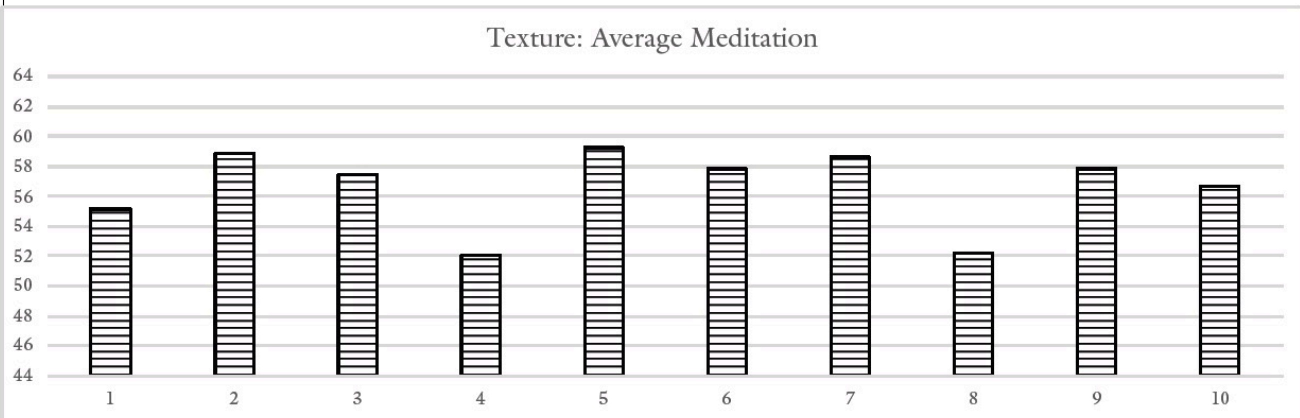
Appendix 4: Research study 2

Statistical Analysis (Individual)

Proportion: Meditation

Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
56.52632	54.57895	62.36842	51.31579	*56.315789*	61.15789	59.26316	52.10526	56.94737	56
54.10526	57.89474	59.73684	49.47368	60.05263	57.21053	58.36842	52.78947	56.78947	57.47368
55.368421	59.89474	55.94737	51.31579	61.42105	54.84211	60.31579	51.42105	58.47368	56.73684
54.78947	63.10526	51.89474	56.26316	59.10526	58	56.57895	52.36842	59.31579	56.52632
55.19737	58.86842	57.48684	52.09211	59.22368	57.80263	58.63158	52.17105	57.88158	56.68421

Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9 Room 10



Anova: Single Factor

SUMMARY

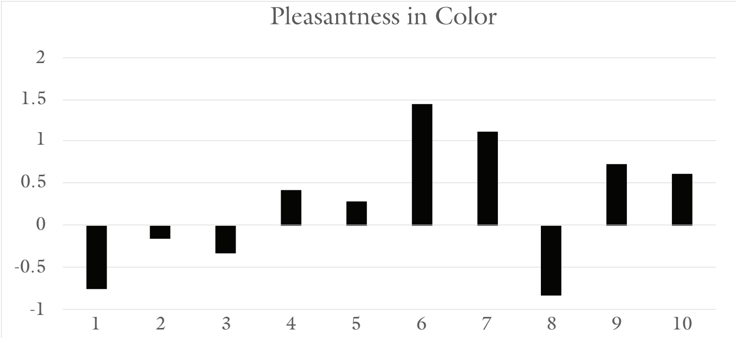
Groups	*Count*	*Sum*	*Average*	*Variance*
Room 1	5	275.9868	55.19737	0.788608
Room 2	5	294.3421	58.86842	9.58795
Room 3	5	287.4342	57.48684	15.63348
Room 4	5	260.4605	52.09211	6.364785
Room 5	5	296.1184	59.22368	3.496364
Room 6	5	289.0132	57.80263	5.103012
Room 7	5	293.1579	58.63158	1.879501
Room 8	5	260.8553	52.17105	0.247057
Room 9	5	289.4079	57.88158	1.118248
Room 10	5	283.4211	56.68421	0.279778

ANOVA

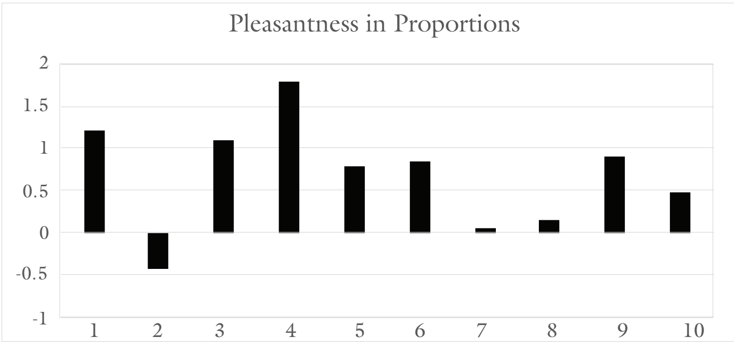
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	309.7151	9	34.41279	7.733422	1.7603E-06	2.124029
Within Groups	177.9952	40	4.449879			
Total	487.7103	49				

Appendix 5: Research study 2

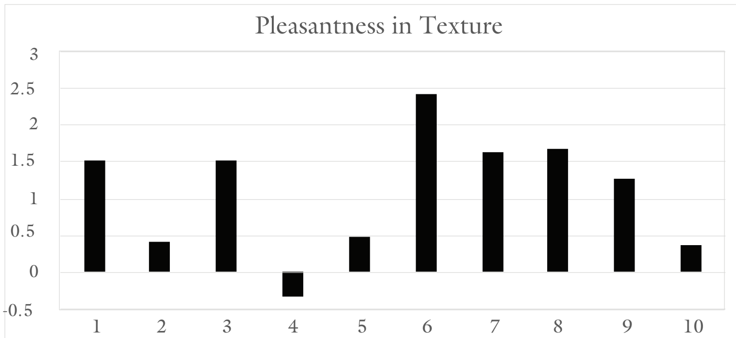
Judgment: Pleasantness



Color	Judgement																		
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	Av
Room 1	-1	1	2	-3	-1	-5	-3	4	-1		0	-2	0	-2	1	-4	-2	0	0	-0.764706
Room 2	1	-2	2	0	0	-1	0	-4	0		0	-1	0	0	-1	-1	-1	4	1	-0.166667
Room 3	1	1	0	1	0	1	-1	1	-2		1	-1	0	0	0	-3	-2	-1	-2	-0.333333
Room 4	0	-1	1	-1	0	0	1		0		0	1	-1	0	0	1	1	4	1	0.411765
Room 5	1	2	0	1	-1	1	2	1	-1		1	1	0	0	0	-1	-1	1	-2	0.277778
Room 6	3	0	2	4	0	0	1	-1	3		0	4	1	3	1	0	1	1	3	1.444444
Room 7	-1	2	1	1	0	4	1		0		1	1	1	1	4	0	0	2	1	1.117647
Room 8	1	-1	0	-4	0	-3	-3		-3		2	-1	0	0	-1	0	-2	2	-1	-0.823529
Room 9	3	2	1	0	-1	2	0	3	-3		3	2	2	0	0	-1	-2	3	-1	0.722222
Room 10	1	1	1	1	0	-1	2	2	-1		3	-1	0	0	5	-1	-3	2	0	0.611111



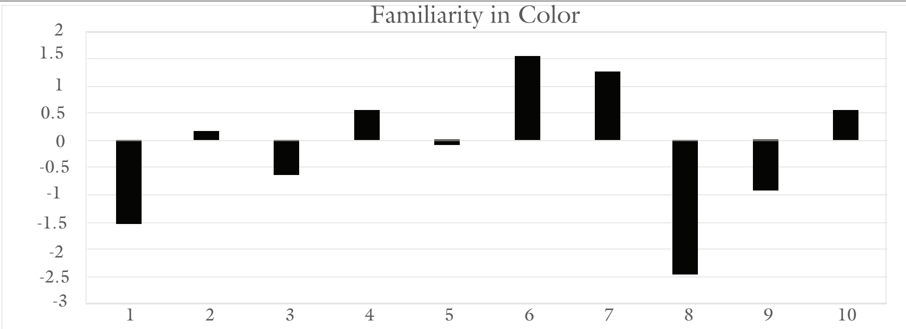
Proportion	Judgement																		
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	Av
Room 1	1	1	1	0	1	2	0	4	0	4	0	2	1	0	4	0	0	3	-1	1.210526
Room 2	-1	0	0	0	-2	-4	-3	2	-1	2	0	-2	0	0	1	0	-1	2	-1	-0.421053
Room 3	0	1	1	2	1	4	2	-1	1	0	0	2	0	0	2	0	3	0	3	1.105263
Room 4	1	1	4	4	2	0	2	-1	2	4	0	2	1	1	3	1	2	3	2	1.789474
Room 5	0	0	0	1	-1	2	-2	1	0	5	0	1	0	1	1	0	2	3	1	0.789474
Room 6	0	1	3	0	0	-2	1	1	2	2	0	1	0	0	0	1	1	4	1	0.842105
Room 7	-1	0	1	-2	0	1	-2	-1	0	2	0	0	0	0	2	-1	0	3	-1	0.052632
Room 8	1	-1	0	0	0	-1	0	-3	0	4	0	0	0	0	0	1	-1	2	1	0.157895
Room 9	1	0	0	-1	1	2	-1	2	0	4	0	1	0	2	1	0	2	2	1	0.894737
Room 10	0	1	1	2	1	-2	0	0	0	4	0	0	0	2	2	0	0	1	-3	0.473684



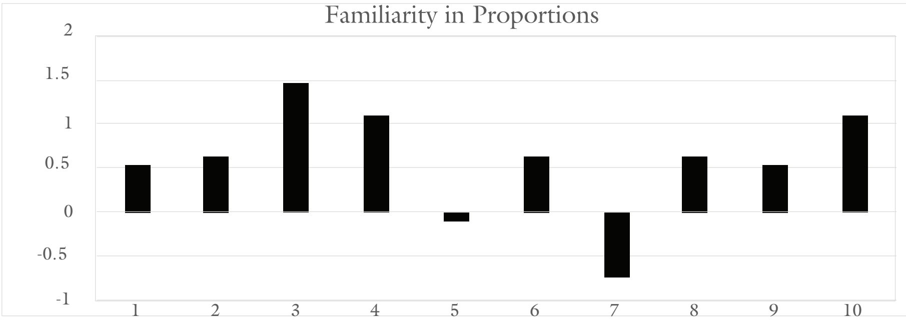
Texture	Judgement																		
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	Av
Room 1	1	1	0	2	1	0	1	2	0	4	0	4	3	0	2	1	0	4	3	1.526316
Room 2	1	0	1	3	1	-1	0	0	0	0	0	-3	1	0	3	2	-3	1	2	0.421053
Room 3	0	2	1	4	0	2	2	0	0	0	1	4	1	1	4	2	0	2	3	1.526316
Room 4	0	-1	1	2	0	-3	2	0	0	-1	0	-2	-5	0	0	0	-1	1	1	-0.315789
Room 5	0	0	1	3	0	-1	-1	1	0	4	0	0	-1	0	2	2	-2	1	0	0.473684
Room 6	2	3	4	3	2	3	3	3	0	4	1	2	2	1	5	1	1	4	2	2.421053
Room 7	1	2	2	3	1	-2	2	2	0	5	0	2	0	0	4	1	5	3	0	1.631579
Room 8	1	2	2	0	0	-2	2	2	0	5	0	4	1	1	4	2	1	4	3	1.684211
Room 9	1	2	1	2	0	-3	0	1	1	4	0	3	3	1	4	0	-1	4	1	1.263158
Room 10	0	1	4	1	0	-5	2	0	0	5	0	0	0	0	1	0	0	0	-2	0.368421

Appendix 5: Research study 2

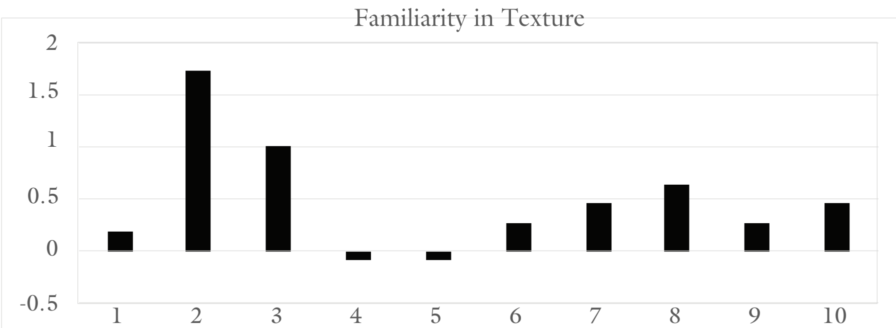
Judgment: Familiarity



	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
P1	1	0	-1	1	-1	1	1	-1	-1	1
P2	-3	2	-3	2	-1	2	1	-2	1	1
P3	-1	1	1	2	1	3	3	-3	-1	2
P4	-2	1	-2	0	-1	2	2	-2	-1	1
P5	-2	-2	0	-1	-1	1	2	-3	-1	0
P6	-2	1	-1	2	-1	-1	0	-3	-2	-3
P7	-1	-3	-3	-3	0	-1	0	-3	-3	-2
P8	-3	-1	-3	-2	-2	2	2	-3	-2	-1
P9	-2	1	-1	1	-1	2	3	-3	-2	1
P10	-1	1	3	2	3	3	0	-2	1	3
P11	-1	1	3	2	3	3	0	-2	1	3
	-1.545455	0.181818	-0.636364	0.545455	-0.090909	1.545455	1.272727	-2.454545	-0.909091	0.545455



	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
P1	-1	0	1	1	-2	-1	-2	0	0	1
P2	1	2	2	1	-1	2	-3	2	-1	2
P3	-1	0	3	1	3	-1	2	2	3	3
P4	0	0	2	2	0	2	-1	1	-1	0
P5	1	-1	1	0	-2	1	-2	0	-1	1
P6	-1	-1	2	1	0	3	-2	1	0	0
P7	0	-1	0	1	1	-3	-2	-3	0	0
P8	0	1	3	-1	-2	-3	-2	-2	0	-1
P9	1	1	2	2	2	3	0	2	0	2
P10	3	3	0	2	0	2	2	2	3	2
P11	3	3	0	2	0	2	2	2	3	2
	0.545455	0.636364	1.454545	1.090909	-0.090909	0.636364	-0.727273	0.636364	0.545455	1.090909



	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
P1	2	2	1	-1	-1	1	1	0	0	0
P2	3	3	2	3	3	3	2	2	2	2
P3	-1	3	3	-3	2	-1	-2	-1	1	0
P4	1	2	2	1	-1	0	1	1	-1	-1
P5	-2	2	3	-1	-2	2	1	0	-1	0
P6	-1	-1	0	-2	-2	-2	1	1	-1	2
P7	0	1	1	-2	-2	2	-3	-2	1	0
P8	-3	-1	-2	-2	-3	-3	-3	-2	-3	-3
P9	1	2	3	0	-1	1	1	2	-1	1
P10	1	3	-1	3	3	0	3	3	3	2
P11	1	3	-1	3	3	0	3	3	3	2
	0.181818	1.727273	1	-0.090909	-0.090909	0.272727	0.454545	0.636364	0.272727	0.454545