A CORRELATION STUDY BETWEEN THE SUBJECTIVE AND OBJECTIVE (EYE TRACKING) MEASURES DURING THE EVALUATION OF VISUAL CLASSICAL AESTHETICS

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

by

Bighna Kalyan Nayak

(Roll no.156105021)

Department of Design

Indian Institute of Technology Guwahati

Guwahati-781039

INDIA

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Department of Design

Indian Institute of Technology Guwahati

Guwahati, Assam – 781039

CERTIFICATE

This is to certify that the work in this thesis entitled "**A Correlation Study Between the Subjective and Objective (Eye-Tracking) Measures During the Evaluation of Visual Classical Aesthetics**" has been carried out under my guidance and supervision and is a bonafide work of Bighna Kalyan Nayak. This work, submitted for the degree of Doctor of Philosophy, is original and contains no materials previously published or written by any other person for a degree or diploma at IIT Guwahati or any other institute or university. All the requirements, including mandatory coursework as per the rules and regulations mentioned in the Ph.D. ordinance for submitting the thesis for the Ph.D. degree of the Indian Institute of Technology, Guwahati, have been fulfilled.

Date: 28th October, 2022

Sougata Karmakar.

Prof. Sougata Karmakar, Ph.D
Professor
Department of Design
Indian Institute of Technology Guwahati
Guwahati - 781039, Assam, India.

Department of Design
Indian Institute of Technology Guwahati
Guwahati, Assam – 781039

DECLARATION

I hereby declare that the work contained in this thesis entitled "**A Correlation Study Between the Subjective and Objective (Eye-Tracking) Measures During the Evaluation of Visual Classical Aesthetics**" is carried out by me, a bonafide student of the Department of Design, Indian Institute of Technology Guwahati, Assam, India under the guidance of Prof. Sougata Karmakar at the Department of Design, Indian Institute of Technology Guwahati, Assam. This work is done for the award of Doctor of Philosophy. **It has not been submitted elsewhere for any other degree or diploma.** The work contained in this thesis is original and has been done by me under the guidance of my supervisor. I have followed the guidelines provided by the institute in preparing the thesis. I have confirmed the norms and guidelines given in the ethical codes of conduct of the institute.

Date: 28th October, 2022

Bighna Kalyan Nayak

Bighna Kalyan Nayak
Roll No. 156105021
Department of Design
Indian Institute of Technology, Guwahati
Guwahati- 781039, Assam, India.

Dedicated to My Parents

(Shri. Narahari Nayak and Smt. Kshyamamani Nayak),

My Wife (Swati Choudhury) and my son (Nyasan Nayak)

My Brother (Bidya Kalyan Nayak) and my sister in law (Debashree Das)

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Bighna Kalyan Nayak

IIT, Guwahati

Executive summary

1 Introduction

The term aesthetics is used broadly to encompass the perception, production, and response to art, as well as interactions with objects and senses that evoke an intense feeling, often of pleasure (Chatterjee and Vartanian, 2014). Aesthetic judgment by people can be categorized as visual, tactile, and kinaesthetic (visual and haptic) judgment. Visual aesthetics can be further classified as classical and expressive aesthetics (Lavie and Tractinsky, 2004). Both the classical and expressive aesthetics can be measured by subjective and objective evaluation techniques. While classical aesthetics deals with visual clarity, simplicity, well-organised, clean, symmetry, etc., expressive aesthetics encompasses creativity, originality, fascinating design, special effects, etc. (Moshagen and Thielsch, 2010; Tuch et al., 2012). The present research is only limited to aesthetics study in visual classical aesthetics.

Evaluation of aesthetics for any visual (two-dimensional and three-dimensional) is very important in today's scenario. The success of any product in the market is very much dependent upon its aesthetic appeal, while functionality/ usability and utility aspects are almost saturated. Visual aesthetics plays a crucial role in attracting consumers and leading to positive emotional changes, which results in purchase intention. It is well known that 'seeing is believing, and believing is buying'. Thus, the visual perception of any product/image plays a decisive role in consumer behavior.

It is important to evaluate by incorporating aesthetic features in the consumer product during its design and development. Improper assessment of the aesthetic values of a product may lead to market failure. Aesthetics appraisal and preference directly determined people's purchase intention (Ackler et al., 2015). Aesthetics evaluation methods are increasingly gaining momentum in the design industry to ensure aesthetic product value and attract consumers (Cristensen and Ball, 2016).

1.1 Problem statement

Traditionally followed aesthetics evaluation methods are primarily subjective and generally used questionnaire survey-based user response. In many instances, product aesthetics evaluation is biased by the designer's own perception. Thus, the commonly followed aesthetics evaluation methods are qualitative, where subjective biases are predominant (Lima and Wangehein, 2021). The application of eye tracking technology for comparing visual behavior and visual attention of people provides a scientific measure to evaluate visual aesthetics (Liu et al., 2020). Eye tracking technology are now being widely used in the field of aesthetics evaluation. Since eye tracking technology enables capturing objective data of visual scanning behavior with high-resolution data acquisition and a strong correlation with emotional changes, the eye tracking tool has been found to be a suitable scientific method to be explored for aesthetics evaluation (Tian et al., 2015). The lack of a well-established correlation matrix between people's perceived aesthetics and captured eye tracking variables during aesthetics appraisal of any visual makes it difficult for the designer to adopt eye tracking technology as the trustworthy or reliable method for the objective evaluation of aesthetics (Guo et al., 2016). Hence, in the present research, an attempt has been made to explore the correlation between subjective perception of aesthetics and objective measures of aesthetics using an eye tracker.

1.2 Research gap and research question

Following literature review, it is observed that various researchers across the globe have used different variables (complexity, composition, symmetry, balance, pleasant, interesting, randomness or order, contrast, preference, etc.) for evaluating and describing aesthetics in their diverse domains of research. Out of all these variables, it has been found that the most widely used variables for aesthetics evaluation are complexity and composition. These two variables have been used as a measure of aesthetics across diverse fields (e.g., painting, sculpture, product design, film, animation, etc.)

Literature also indicates that researchers have used sub-variables like quantity, variety, order etc for judging complexity. The composition of a visual has been evaluated in terms of symmetry, balance, proportion etc). In the present thesis, the research gap has been presented in the form of a schematic diagram, and various research questions have been mapped with the identified research gaps. Please find below the list of research questions:

RQ1: What are the key determinants of classical visual aesthetics?

RQ2: What is the current status of research in the domain of objective evaluation of visual classical aesthetic?

RQ3: Is there any association between the aesthetic perception of a visual with perceived complexity and perceived composition during the subjective evaluation?

RQ4: Is there any association between perceived complexity and descriptive qualities (number of points, curve angle ratio, figure background ratio, type of symmetry) of a visual?

RQ5: Is there any association between perceived composition and descriptive qualities (number of points, curve angle ratio, figure background ratio, type of symmetry) of a visual?

RQ6: Is there any association between the perceived complexity of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

RQ7: Is there any association between the perceived composition of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

RQ8: Is there any association between determinants of classical visual aesthetics (complexity and composition) with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

RQ9: Is there any association between aesthetic perception of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

1.3 Aim

To establish a correlation between the subjective and objective (eye-tracking) measures during the evaluation of visual classical aesthetics.

1.4 Objectives

To initiate the research, a hypothesis has been postulated as 'subjective measures of the perceived level of aesthetics for a visual is significantly correlated with the objective measures (eye tracking variable – fixation duration, fixation count, etc.'. To achieve the aim of the current research following objectives were set.

- To determine the list of variables that could be used by researchers as measures of aesthetic evaluation across diverse fields (e.g., painting, sculpture, product design, film, animation, etc.).
- To assess aesthetics through subjective measures.
- To assess aesthetics through objective measures (eye-tracking).
- To study the level of correlation between the subjective and objective measures of aesthetics.

2 Research description with observation

At the beginning of the research, two groups of stimuli (random monochromatic 2D shape) were prepared by varying descriptive characteristics of the shapes (such as the number of points, curve angle ratio, figure background ratio, and symmetry). One group was for studying complexity, and another was for studying composition. In each group, there were 30 stimuli. No specific symmetry was followed in complexity stimuli, but in composition stimuli, symmetry was maintained, and the number of points was kept constant.

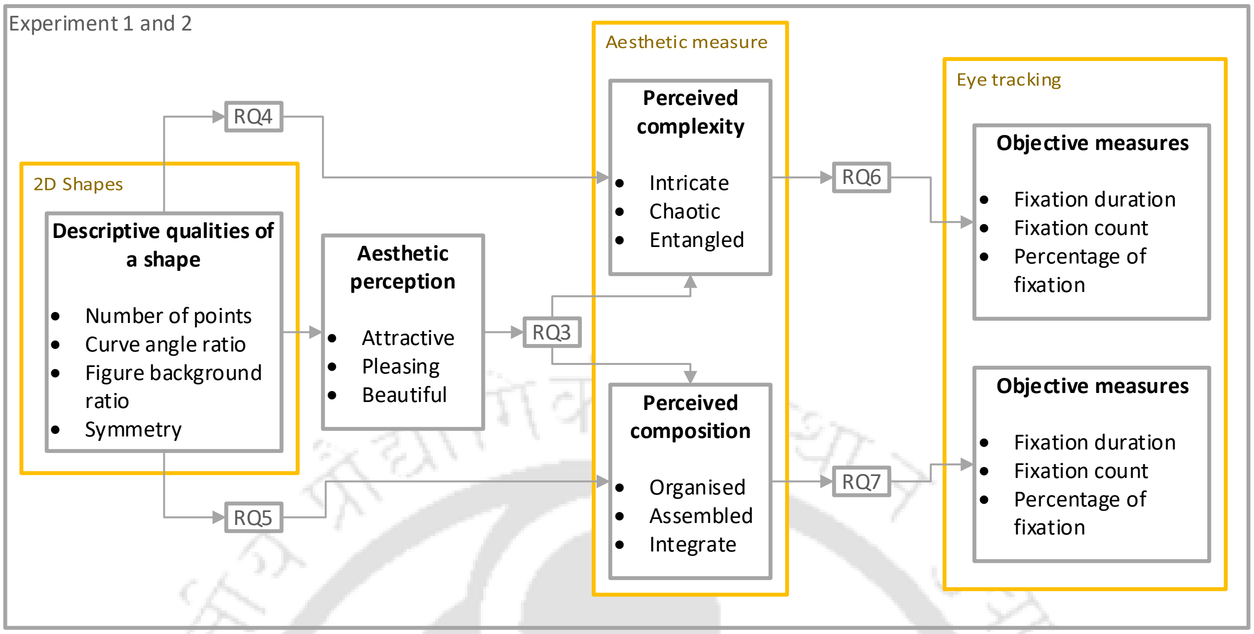
Stimuli were presented to 85 participants, and finally, the ten most meaningful shapes out of 30 stimuli in each group were shorted for the next level of the experiment. Here it is worth mentioning that the meaningfulness of the stimuli is necessary for the aesthetic appraisal of any visual (Marković, 2012).

Semi-structured interviews and their after-transcription coding were done to identify the synonyms of aesthetics, composition, and complexity, which the participants generally understand. One hundred participants participated in the study and reported that attractive, pleasing, and beautiful are the most preferred synonyms for aesthetics. Similarly, words like intricate, chaotic, and entangled are the most preferred synonyms for complexity, whereas words like organized, assemble, and integrate, were selected for composition. Various judging criteria for aesthetic, complexity, and composition were also determined based on the responses received from the participants.

After preparing stimuli and finalizing the experimental protocol, the whole research was planned in 3 phases (Study-1, Study-2, and Study-3).

In study-1 (Fig. 1), each of the 10 meaningful stimuli (identified during stimuli preparation) for studying complexity and composition were utilized to investigate the association between aesthetic perception of the particular stimuli and its perceived complexity or perceived composition. A total of 85 volunteers participated in this study, and their subjective responses were collected on a 7-point Likert scale regarding the aesthetics perception, perceived complexity, or perceived composition against each stimulus. Following the intercorrelation study, in the case of stimuli prepared for complexity evaluation, it was observed that perceived complexity is significantly correlated (Spearman coefficient, $r = 0.333$) with perceived aesthetics. It was also noticed that the descriptive qualities like the number of points and curve angle ratio significantly correlated with perceived complexity.

In the case of stimuli prepared for composition evaluation, it was observed that perceived composition was significantly correlated (Spearman coefficient, $r = 0.631$) with perceived aesthetics. It was also noticed that the descriptive qualities like the number of points, curve angle ratio, figure-background ratio, and symmetry were significantly correlated with perceived composition.



Schematic diagram for evaluation of visual classical aesthetics of 2D shapes using both subjective and objective measures

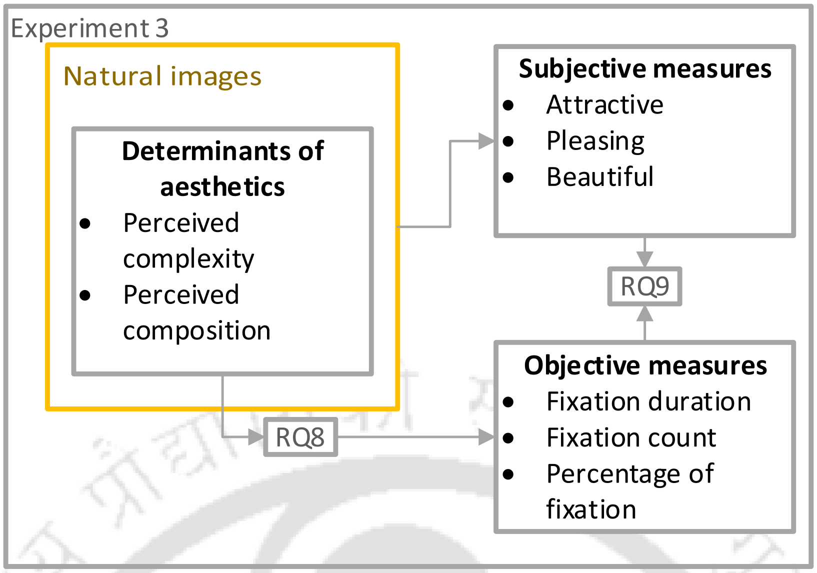
In study 2, out of the 10 meaningful stimuli for complexity, three stimuli representative of the low, neutral, and high levels of complexity were identified based on the subjective rating. Similarly, another three stimuli, which are representative of the low, neutral, and highly composed, were identified from the 10 meaningful stimuli initially used for the composition study. Both the sets (complexity and compositions) of three stimuli were further utilized for studying the association between perceived complexity (or perceived composition) and eye tracking variables (fixation duration, fixation count, average fixation duration, percentage of fixation, revisits, and first fixation duration.

Following the eye-tracking experiment and their after-correlation study, it was revealed that the perceived complexity of the stimuli was significantly correlated with fixation duration, fixation count, and percentage of fixation. Same phenomena were also observed for perceived composition and aforesaid eye tracking variables. Independent sample Kruskal-Wallis test expressed that fixation count, fixation duration, and fixation percent varied significantly across three different levels of complexity of the stimuli.

Similar observations were also noticed for three different levels of the composition of the stimuli. Ordinal logistic regression analysis was conducted to examine the influence of perceived complexity and perceived composition (independent variables) on eye tracking variables (dependent variables). For both the independent variables, the (OLR) results revealed that fixation count contributes significantly to predicting perceived complexity and composition but other variables like fixation duration and percentage of fixation were unable to predict perceived complexity and composition. Thus, it can be concluded that it is very difficult to judge the perceived complexity and composition based on eye tracking variables, as the prediction capability of eye tracking variables (except fixation count) is very low in determining perceived complexity and composition.

In study 3 (Fig. 2), the association between determinants of aesthetics (perceived composition and perceived complexity) and eye tracking variables were investigated. Further associations between perceived aesthetics and eye tracking variables were explored in this study. In this experiment, six colorful natural stimuli with different levels of perceived aesthetics (as rated by the participant) were selected from a random list of 30 images. Stimuli were presented to 26 participants during the eye-tracking study to capture data on eye-tracking variables.

Participants were also asked to rate the stimuli on a 7-point Likert scale for the level of both complexity and composition. Independent sample Kruskal-Wallis test reveals that fixation duration and fixation percent were significantly different levels of perceived aesthetics represented by natural stimuli. The study result indicated that variation of levels of perceived aesthetics could be identified from the eye tracking by measuring the eye tracking variables like fixation duration and percentage of fixation.



Schematic diagram for evaluation of visual classical aesthetics of 2D natural stimuli using both subjective and objective measures.

3 Discussion

The results indicate that aesthetic perception is highly variable and difficult to narrow down to a simple function of complexity and composition alone. One of the interesting outcomes was that perceived complexity was found significantly correlated with the number of points, curve angle ratio, and perceived aesthetics. Similarly, the perceived composition was significantly correlated with the number of points, curve angle ratio, figure background ratio, symmetry, and perceived aesthetics. It indicated if descriptive characteristics (number of points, curve angle ratio, figure background ratio, type of symmetry) of 2D shapes are altered, it would directly impact the perception of complexity and composition, thereby influencing aesthetic perception. In experiment 1, interviews with participants suggest that most of the factors that influence aesthetic perception are directly or indirectly part of perceived complexity or composition.

Following experiment 2, using three stimuli of different perceived aesthetic levels, it was noticed that perceived complexity was significantly correlated (positive) with a few eye tracking variables, namely fixation duration, fixation count, and percentage of fixation. It means an increase in complexity level contributes to a high value of aforesaid eye tracking variables. In the case of composition, eye tracking variables like fixation duration, fixation count, and percentage of fixation were found to be significantly correlated (negative). It can be stated that better composition of the stimuli leads to a reduction of values of earlier mentioned eye tracking variables. Independent sample Kruskal-Wallis test expressed that fixation count, fixation duration, and fixation percent varied significantly across three different levels of complexity of the stimuli. Similar observations were also noticed for three different stimuli composition levels. Out of various eye tracking variables in current research, only Fixation duration, Fixation count, and Percentage of fixation have been directly impacted by the change in the perceived level of complexity and composition.

To examine the influence of perceived complexity and composition (independent variables) on eye tracking variables (dependent variables), an Ordinal Logistic regression analysis was conducted. The OLR result observed that both perceived complexity and composition could be predicted using fixation count but not other eye tracking variables. Thus, it can be concluded that it is very difficult to judge the perceived complexity and composition based on eye tracking variables, as the prediction capability of eye tracking variable (except fixation count) are very low in determining perceived complexity and composition.

The Study with natural stimuli where both levels of complexity and composition vary simultaneously showed that fixation duration and percentage of fixation varied significantly across stimuli of different levels of perceived aesthetics. It was noticed that the stimuli with lower and high level of perceived aesthetics have a higher level of fixation duration and percentage of fixation. Thus, it can be concluded that the level of perceived aesthetics could be identified from the eye tracking by measuring the variables like fixation duration and percentage of fixation.

3.1 Key contributions of the present research

The present research work enriches the existing knowledge of cognitive ergonomics in aesthetics evaluation by utilizing both eye-tracking data and subjective ratings. The novel contribution of the current research is explained below:

3.1.1 Contribution to knowledgebase

The evaluation medium for most aesthetics studies starts with collecting subjective data. Then the data is analyzed to conclude certain hypotheses. As discussed in the research problem, the variables were different in different studies. Therefore, to identify the aesthetic variables that can be considered in all the fields is helpful for researchers to acquire basic knowledge in data collection, analysis, and interpretation. Those aesthetic variables can be used and referred by designers and researchers for the aesthetic evaluation of specific user populations for any visuals. Biometric technology like eye tracker is used to vary the same result objectively. This enables researchers and ergonomists to find out an alternating way to identify the aesthetic experience, which may lead to the identification of improvement in an aesthetic object. The protocol followed in the experiment can be utilized to design studies in a similar kind of research. Hence, the establishment of a design philosophy for developing a new methodology in ergonomic design considerations and enhancing the evaluation technique is used as knowledgebases.

3.1.2 Contribution toward methodological perspective

The methodological protocols that can provide visible contributions for researchers in the evaluation of aesthetics consist of doing a content analysis of the qualitative data, developing the 2D stimuli with regenerative coding, and both intra and inter-correlation of aesthetic variables, and operating and analyzing the eye-tracking experiment. From the data analysis, the statistical analysis of the aesthetic evaluation consists of normality testing using skewness and kurtosis, spearman correlation, Kruskal Wallis test for one-way ANOVA followed by the post hoc analysis, ordinal logistic regression to determine the significant predictor. Determining the aesthetic variables that can be evaluated through an eye tracker will significantly contribute to variable identification in a diverse aesthetic field. The analysis of existing subjective aesthetics evaluation techniques compared with the presented objective evaluation technique through the eye tracker is considered a novel methodological contribution. The proposed methodology can be used as an alternative to the unreliable subjective rating that can be adopted globally as a design evaluation technique.

3.2 Novelty

- This is the first kind of study which tried to find a correlation between subjective measures (in terms of complexity and composition) of visual classical aesthetics and objective measure of aesthetics (eye-tracking variables).

- The current study established a correlation between descriptive characteristics of the visual stimuli and subjective perception of complexity and composition in the case of random 2D monochromatic shape. This type of study involving 2D shapes is unique as the majority of earlier studies related to aesthetic evaluation deal with complex images.

- The methodology (regenerative programming) adopted for generating visual stimuli for evaluation of complexity and composition by manipulating various descriptive qualities (number of points, curve angle ratio, variation of symmetry, figure background relation) is novel and can be followed by future researchers for their stimuli preparation.

3.3 Limitations

Even if how much a researcher tried to track down the finest conceivable experimental protocol and execute the experiment accordingly. The probability of having a limitation of less research work is never possible. The foreseeable limitations of the present research could be considered for further exploration of the future research scope.

- Current research deals with an eye-tracking study. Collecting a large sample size of subjects is not possible with the eye-tracking experiment, as manual data extraction and segregation of eye-tracking data is a tedious and time-consuming task. Therefore, limited sources and time constraints forced to limit the sample size to 26. Similarly, for the interview, only 37 persons were considered, followed by 100 subjects in online sub-variable selection. Doing content analysis and transcription coding for all persons was a resource-consuming task.

- This research did not explore the different socio-demographic details of the subjects. All the participated subjects are from different parts of India and are associated with an educational institute in India. Apart from the demography, the gender-based aesthetic evaluation was not performed.

- There are many environmental factors that control aesthetics, and kind of impossible to address all. Even one of the most challenging tasks in aesthetic research is to control those environmental factors like light, noise, temperature, aesthetic attitude, repetition, subject's earlier exposure, etc.

- This research used eye-tracking data for objective evaluation. Other biometric techniques like EEG and facial EMG are not explored to follow the same methodology.

• The current experiment is conducted in a lab set in a controlled environment. Particularly, the eye-tracking experiment was a planned simulation of the actual aesthetic experience. As the experiment was conducted in the lab in a controlled environment, it is difficult to compare the artificial simulation with the natural environment. Further studies can be planned in natural environmental conditions.

4 Conclusions

The present study with 2D monochromatic shapes is a stepping stone for the objective evaluation of aesthetics based on eye tracking variables. It was successful to a great extent to establish an experimental protocol for evaluating aesthetics involving both subjective and objective measures and thereafter, their correlation. Moreover, the current study disclosed the correlation between descriptive characteristics of a visual (Number of points, curve angle ratio, figure background ratio, and symmetry) with perceived complexity or composition and association with perceived aesthetics. Further research as the extension of current research by involving different influencing factors (Color, Form, Texture, etc.) will provide detailed information regarding objective measures of aesthetics.

The resulting plots didn't follow the inverted bell curve theory, but it did offer a convenient method to evaluate the relationship between the aesthetic and eye tracking variables. These findings constitute empirical evidence for the relation between aesthetic perception and eye tracking variables. Therefore, contribute to knowledge in the field of visual classical aesthetics. The results of experiments conveyed that to achieve higher aesthetic perception, there should be a balance between complexity and composition.

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Introduction

Abstract

Aesthetics is often perceived as a pleasurable and desirable experience. Though the field of aesthetics is old and evolving, there is still a lot of ambiguity in understanding and evaluating aesthetics. This research on aesthetics revolves around two critical concerns: one on the variables of aesthetics and another on the evaluation of aesthetics. Therefore, in this chapter, the effort has been made to understand the aesthetics in-depth and dissect its problems. This introductory chapter starts with the etymology of aesthetics and aesthetic perception details. Then the chapter slowly moves to the morphological description of aesthetics, where structural and functional models related to aesthetics are discussed. The problem statement and research gap represented the overall problem in the aesthetic evaluation. From there, the aim, objectives, and rationale of this research work have been framed. Finally, the hypothesis of the research was outlined along with the expected outcome of the research work. At the end of this chapter, the organization of the dissertation is represented through a framework for better understanding. This chapter aims to set the context of the research so that this dissertation would be a valuable source for researchers who want to study and evaluate aesthetics.

1.1 Etymology of Aesthetics

Aesthetics is the study of beauty and taste, whether in the form of comic, the tragic, or the sublime. The term "aesthetic" functions as an adjective; therefore, several words are found like aesthetic emotion, aesthetic judgment, aesthetic object, aesthetic experience, etc. Broadly aesthetics is studied in psychology, philosophy, and neurology. The concept of aesthetic experience may appear unclear due to different theoretical frameworks, and it's also challenging to attend to its specifics. Aesthetic experience is a state of mind influenced by aesthetic objects. According to philosophy, an aesthetic object may be natural or artwork. But aesthetics couldn't explain why one is a work of art and the other not (Shelley, 2017). This means every object comes under the jurisdiction of aesthetic experience. As per both philosophy and psychology, during an aesthetic experience, subject and object should be present (Kant, 1790).

During an aesthetic experience, the object engages with the subject's mind while leaving an impression on them. That impression is hedonic, positive or negative, and subjects are unaware of the surrounding environment (Mcclelland, 2005). During this phase, the attention level of the subject is observed to be very high, and the attention is centered on a limited stimulus field while losing self-consciousness with no sense of time. It is also called "Narrowing of consciousness" (Csikszentmihalyi, 1975). A similar state of attention level can be observed in many psychological theories related to aesthetic experience like Maslow's peak experiences (Maslow, 1964), (Tellegen and Atkinson, 1974), the concept of absorption, and Czikszentmihalyi's notion of flow (Csikszentmihalyi, 1975), etc.

This study leads to the question while laying the direction of the existing research, "Is there any definition of aesthetics without the subject itself?". Fenner, 2003 tried to address the question; he clarified whether the subject is psychologically guided by a certain kind of object's properties during an aesthetic judgment. Functionalist theory of aesthetics says that "if a thing is made to function well; if its construction is well suited to the job it has to do, then that thing will be beautiful" (Osborne, 1970). This theory was developed from Socrates's philosophy that says "aesthetic attitude was a derivative of the practical, useful value of an object" (Borev, 1985), and it's been the base of the industrial revolution that deprives the evaluation of aesthetics, merging it with functionality. Louis Sullivan's quoted phrase "form follows function" is derived from the same philosophy.

Opposite to the above-described theory, Kant's philosophy says that only in the absence of a purpose during an aesthetic judgment qualifies to have an actual aesthetic experience. Again, as per Kant, "The interest is in the object's properties intrinsically and not instrumentally" (Borev, 1985). Lavie and Tractinsky, 2004, have compared these extreme views on aesthetic judgment and reported their non-suitability in modern society. As described by (Osborne, 1970), designer theories are driven by the requirements and derived from the designer's intuition. But with time, the developed approach and technologies are made to attain these extreme philosophies to evaluate aesthetics with both their instrumental and aesthetic merits.

1.2 Aesthetic Perception

The word 'aesthetic' has its roots in the early Greek αίσθητά (aestheta), denoting 'things perceptible by the senses, as opposed to νοητά (noeta) – 'things thinkable or immaterial' (OED, 2019). The research area exploring aesthetic properties and experience is mostly represented in the philosophical discipline. The central question on aesthetics is based upon perception. In modern times, Alexander Baumgarten used the word aesthetics in his book named "Aesthetica" (Bennett, 1996). Initially, the idea of aesthetics was not popular, but with time and with the development of experimental psychology, the field of aesthetics is considered as a field of science.

Humans can sense in a variety of ways. While having a perceptual experience, five basic senses (smell, taste, vision, hearing, and touch) comes to play. But perceptually, a human can experience more than that, like pain, hunger, temperature, etc. All these senses are wired to a specific part of the brain and can be mapped through various biometric equipment in current times. Therefore, new fields like science aesthetics and cognitive ergonomics have emerged for perceptual studies. The main concern with the perception study is that perception can be linked to different sensory modalities and require both subject and object. The perceptual study is known as psychophysics, and in this research methodology, the evaluation of aesthetics is done by following the principles of psychophysics. In the coming part of the thesis, we can explore how aesthetics can be evaluated by visual sensory mode through the interview, questionnaire (subjective), and eye-tracking (objective).

Perception is hedonic in nature. Literature accepts this sensory pleasure as beauty, and the visual objects from which this pleasure is derived are beautiful. The concept of beauty provided a foundation for aesthetics. It can be traced to Plato and Aristotle from the nineteenth century. For example, Plato denounced art because he regarded it as a mere imitation of imperfect manifestations of beautiful ideal forms. In this ancient Greek thought, we see the beginnings of aesthetics as being concerned with the core subject of perception via the concepts of art and beauty.

As the discipline of aesthetics developed, the idea of beauty was gradually transformed from being an objective property of artifacts to a subjective property of perceptions. Eighteenth-century philosophers in this transformation, such as Hutcheson, Shaftesbury, Burke, and Hume – were somewhat subjectivized but stayed in objective properties (Dickie, 1974). By the nineteenth century, beauty no longer resides in the object but "in the eye of the beholder." The philosopher Arthur Schopenhauer, for example, thought that anything could be beautiful – it just depends on directing aesthetic attention. William Blake said, "Every eye sees differently. As the eye, such the object." (Frye, 2013). The objective-subjective duality of perception remains closely connected to issues in contemporary aesthetics and has a bearing on the current thesis in its methodological choices and interpretation of results. This thesis does not focus on the concept of beauty but rather investigates the subjective aesthetic perception (how much an image is liked?) in relation to the perception of visual complexity and perception of visual composition (how good a work of art is).

The word Aesthetic is a particular kind of experience, object, property, concept, or judgment. In trying to construct a definition of the aesthetic, philosophy attempts to clarify the relationship between the various aspects of it. We observed that all the aspects of the aesthetic are closely interconnected, and we should be mindful of their relationships in our analysis of visual aesthetics. To summarise this preliminary discussion of aesthetics, we can say that the field is mainly concerned with aesthetics' perceptions, properties, and practices. The discussion started with the philosophical theories related to aesthetics and focused on the discursive discourse of the field. It was observed that all fields of aesthetics are connected to the study of perception as everything we know is perceived to us via the senses. Particularly in modern times, objects are increasingly designed to be well perceived. Therefore, in the current situation, perhaps we should look for answers to questions like how we perceive and what are the visual cues to perceive. This is one motivation for the current thesis to evaluate perceptual aesthetics and its measures through objective means. The next chapter will further develop this investigation into modern aesthetic evaluation techniques.

Before diving further into this research work, it is necessary to clarify its text to offer a foundation for the remaining research. The above-discussed key points are visual aesthetic elements and how philosophers and designers understand them. Finally, we have discussed how subjects perceive. Therefore, the explanation consists of the creation of aesthetic perception and how it was analyzed. The above section examines the development of aesthetics as an academic discipline, identifying its central issues and elaborating their relevance to this thesis.

1.3 Morphology of aesthetic experience

The concentrated aesthetic perception is called the aesthetic experience (Berlyne, 1974). According to him, all experience can be assumed as the aesthetic experience with affecting factors like intensity and concentration with the medium of attention. Most of the time, aesthetic experience is considered a delightful and joyful experience, but according to aestheticians, it can also be an undesirable and unpleasing experience.

1.3.1 Structural model

One of Markovic's studies (Marković, 2010b) used factor analysis and determined the different factors of aesthetic experience. In that research, he verified the philosophical definition with the empirical data and confirmed that both subject and object have to be present to have an aesthetic experience. Leder et al., 2004 presented a complete comprehensive model of human affective and cognitive experience. The model has five stages that give two outputs: aesthetic emotion and aesthetic judgment. Their research has validated this model with examples of empirical data available on aesthetics. Multiple feedback systems also back the model within different stages. The factors like knowledge and different style of cognitive processing for different people are also included in this model. Likewise, Nadal et al., 2008 introduced a model with three stages, where they went one step forward and proved with neural correlation. Their model included a reward value system, attentional regulation system, and decision-making system. Marković, 2012 established one model of aesthetic information processing with two parallel levels of visual information processing. The second level has a different hierarchical architecture with two other sub-levels with logical feedback systems. In this model, feedback systems also have an extra level of connection to form multiple loops, which helps iterate the output while reducing the obscurity.

Some earlier research (Winkielman and Cacioppo, 2001) suggested that aesthetic experience can be either a positive emotion or a complete negative emotion. Some of the research proved empirically that aesthetic experience could be both positive as well as a negative term. These outcomes raise the confusion between aesthetic experience and aesthetic feeling. Where aesthetic experience may be a negative factor, the aesthetic feeling is a positive factor (Addison, 2003). We know from the existing literature that aesthetic experience is closely linked to the arousal factor with positive or negative hedonic values. Unconventional and complex stimuli have a higher arousal potential during an aesthetic experience.

1.3.2 Functional model

Evaluation of aesthetics is a multi-phase process with a complex level of layering. In this section, we will be discussing the evolution of aesthetic experience. Most of the model has a common segment like stimulus input and decision-making modules, but several memorial instances influence the aesthetic experience. The person's perception directly influences aesthetic experience, determined by the person's earlier knowledge about the stimuli. For example, red is the colour of danger; at the same time, red is a symbol of love. What makes these same colours convey a different meaning for different instances?

During an aesthetic experience, knowledge (information about an aesthetic object) is a very important factor that is often downplayed (Gombrich, 1961). This means that masking knowledge from all the aesthetic models may provide a window of opportunity for aesthetic standardization. At the same time, the term knowledge is very vast. It includes the observer's syntactic to semantic knowledge, personal to cultural knowledge, etc., and it's easily transformable through different media. Shimamura and Palmer, 2011proposed an aesthetic model named the I-SKE model that represented the componential framework of aesthetic experience. In that model, artists, objects, and subjects are included. Special attention is given to understanding the subject's aesthetic experience, including sensation, knowledge, and emotion. I-SKE model is a good combination of psychological and philosophical approaches.

Interview analysis (Parsons, 1987) introduced a cognitive model of art processing with five stages of aesthetic processing. His work successfully segmented the aesthetic experience, but the linear model failed to link the interaction between different stages. Some models of aesthetic processing got one stimulus input, but evaluating judgment can be derived from in-between any of the stages. The reason might be that human cognitive consciousness is based on a predictive memorial instance guided by its earlier aesthetic experience. Once the brain identifies an aesthetic object, it skips further stages to reduce the cognitive load. The model proposed by Ognjenovic, 1991 was based on a similar strategy. The model contains three stages dealing with aesthetic variables: complexity, symmetry, and semantic characteristics. But in his model, there was no feedback loop presented. The feedback loop helps guide deeper aesthetic processing by checking and measuring its implications in different stages. Human vision is the prime sensor as stimuli input to the cognitive models for aesthetic processing. Most of the models developed are based upon visual information processing. Neuroscientist Chatterjee, 2004 showed the active brain region during visual information processing. He also segmented different brain areas according to their functions. He proved the existence of the feedback system in the brain during an aesthetic experience.

From the existing literature, it is observed that the model got complicated and more refined with time. Some of the essential features include introducing feedback systems; the attentional mechanism with the hierarchy to imitate the actual cognitive process during an aesthetic experience. Most models also support the aesthetic hedonic property as positive and negative moods directly influence the aesthetic experience. Some of the latest aesthetic information processing models (Marković, 2012), (Leder et al., 2004), (Nadal et al., 2008) do support the three stages of information processing (cognitive mechanism, compositional features, and perceptual stage) during an aesthetic experience by bridging the gap between philosophy and psychology during an aesthetic experience. Some models still need empirical evidence to establish all the models to support philosophical arguments. These psychological functions relate directly to the philosophical approaches that we have considered. But in this thesis, we will go a step ahead and try to include all the psychological, philosophical, and scientific approaches.

1.4 Problem statement

Much of the previous research conducted has focused on subjective evaluation. The available objective evaluation progressed in computational aesthetics, but computational aesthetics doesn't recognize the subjective aspects of aesthetic experience. As aesthetic experience is an interaction between subjects and objects, most evaluation procedures do not consider both issues simultaneously. Moreover, from the existing research, it is impossible to identify the key variables of aesthetic measures because philosophers, psychologists, and scientists haven't agreed on the common list of variables required for aesthetic measures. In other words, different researchers have selected different pools of variables during their subjective or objective evaluation of aesthetics. From the literature review, it is evident that most of the reported research deals with the subjective evaluation of aesthetics. Due to that subjective nature, the evaluated aesthetic experience is not persistent and varies with the subjects.

On the contrary, research on objective evaluation is limited and confined to a few fields (e.g., Computer graphics, image processing, etc.). The problem with objective evaluation is that there is no direct human involvement. Hence, there is a need to evaluate aesthetic experience using objective measuring techniques (e.g., eye-tracking, EEG, etc.) with the involvement of human perception.

1.5 Research gap

The classification of aesthetics has been attempted by many researchers (Lavie and Tractinsky, 2004; Nasar and Preiser, 2016; Moshagen & Thielsch, 2010; Tuch et al., 2012b; Sonderegger et al., 2014). Current research acknowledges the contribution of a few research works (Marks, 2014; Lindauer et al., 1986) that classified aesthetics based on human senses: Tactile aesthetics, Visual aesthetics, and Kinaesthetics (Visual + Tactile). Further, this research acknowledges the classification of the visual aesthetics done by Lavie and Tractinsky, 2004. In their research, they have classified aesthetics by their fundamental properties. They have classified aesthetics into Classical aesthetics (visual clarity, simplicity, well organized, clear, clean, symmetrical) and Expressive aesthetics (creativity, originality, fascinating design, and using special effects). Figure 1 shows the classification of the aesthetics along with some cited work in the relevant field. We have also compared the research on fundamental types of aesthetic evaluation techniques (subjective and objective).

From the literature, it was evident that aesthetic perception has a lot of variables (complexity, composition, symmetry, balance, pleasant, interesting, randomness/ order, contrast, and preference). Apart from these variables, many environmental factors (light, noise, temperature, aesthetic attitude, repetition, subject's earlier exposure, etc.) influence aesthetics, as aesthetics depends upon the subject's perception. But it can be observed from Figure 1 that a significant amount of work has been done in Visual aesthetics. Particularly in objective evaluation techniques, a few research studies have used different biometric equipment (EEG, Eye tracking, fMRI, and Facial EMG) for aesthetic research. The same was observed for both classical and expressive aesthetics. Compared to the work carried out in the different countries, the amount of work reported in India is almost negligible. Following the literature review, it has been observed that there are various unexplored areas where further research needs to be carried out to explore the evaluation of aesthetic perception.

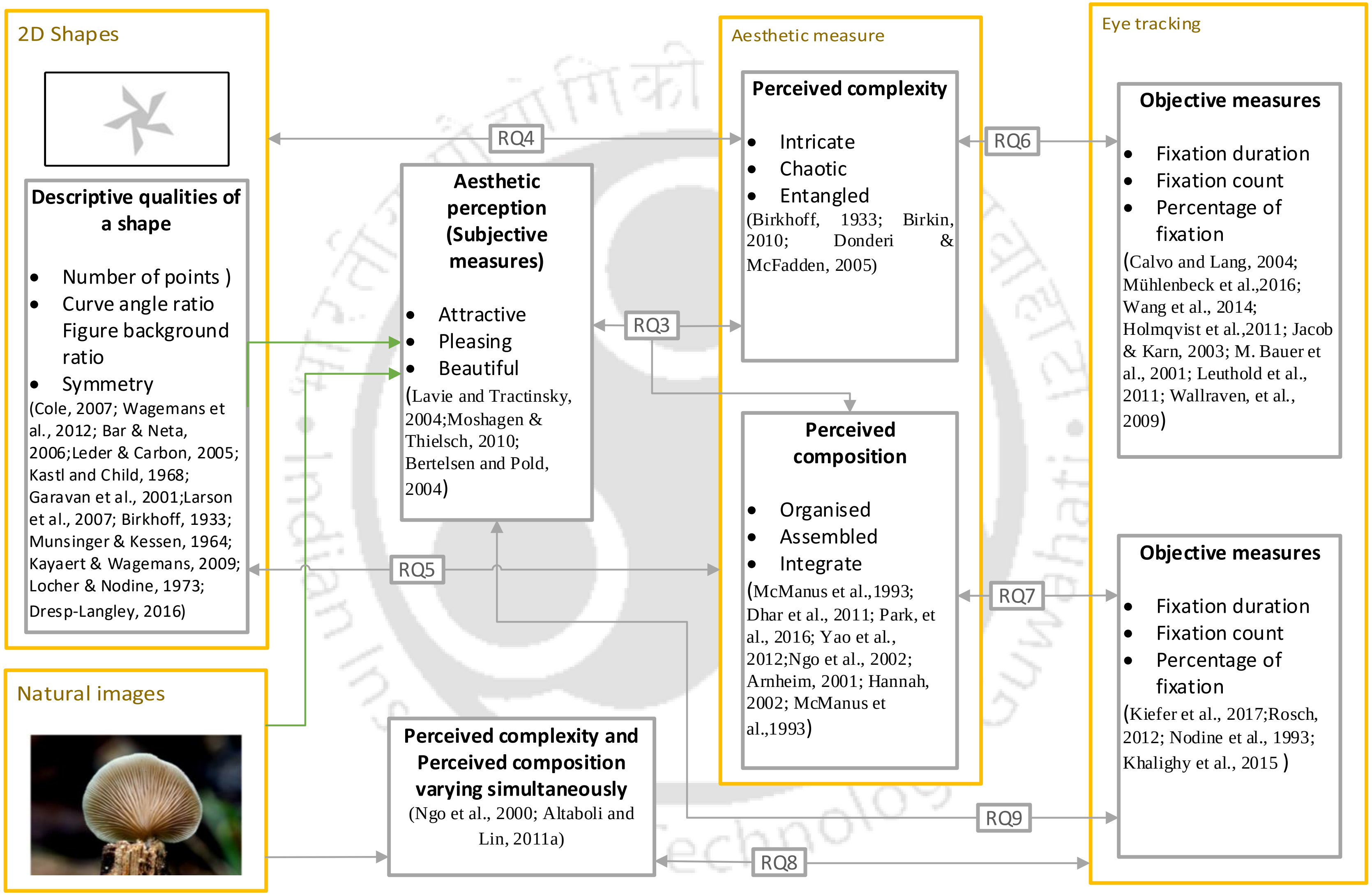


Figure 1. Research gap in the existing research field

1.6 Research questions

Q1: What are the key determinants of visual classical aesthetics?

Q2: What is the current research status in the objective evaluation of visual classical aesthetics?

Q3: Is there any association between the aesthetic perception with perceived complexity and perceived composition during the subjective evaluation?

Q4: Is there any association between perceived complexity and descriptive qualities (number of points, curve angle ratio, figure background ratio, type of symmetry) of a visual?

Q5: Is there any association between perceived composition and descriptive qualities (number of points, curve angle ratio, figure background ratio, type of symmetry) of a visual?

Q6: Is there any association between the perceived complexity of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

Q7: Is there any association between the perceived composition of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

Q8: Is there any association between determinants of classical visual aesthetics (complexity and composition) with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

Q9: Is there any association between aesthetic perception of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?

1.7 Rationale behind the research work

The historical background of science has a lot of reports of distinctive visions that have led to critical discoveries. Visual imagery is almost always a stimulus source for an aesthetic experience. Humans perceive 80% of their input from the eyes only (Douchová, and Nešetřil, 2009). With this, the scientist had a problem measuring aesthetics from visual perception. Research has indicated (Lindgaard, et al., 2011; Ngo, et al., 2000; Moshagen and Thielsch, 2010) that due to aesthetics' plurality and subjectivity in nature, it's not possible to reach a single agreeable conclusion when it comes to determining the variables of visual aesthetics. This is why the present research tried to show different variables and techniques for evaluating visual aesthetics.

1.8 Aim

To establish a correlation between the subjective and objective (eye-tracking) measures during the evaluation of visual classical aesthetics.

1.9 Objectives

- To determine the list of variables that researchers could use as the measures of aesthetic evaluation across diverse fields (e.g., painting, sculpture, product design, film, animation, etc.).
- To assess aesthetics through subjective measures.
- To assess aesthetics through objective measures (eye-tracking).
- To study the correlation between the subjective and objective measures of aesthetics.

1.10 Hypothesis

Ha: Subjective response of the aesthetics perception of a visual is significantly correlated with objective measures (eye-tracking variables: fixation duration, fixation count, percentage of fixation).

H_0: Subjective response of the aesthetics perception of a visual is not significantly correlated with objective measures (eye-tracking variables: fixation duration, fixation count, percentage of fixation).

1.11 Expected outcomes

The outcomes of the research:

- Developed an algorithm in the grasshopper (Rhino)?? (Where is the algorithm or its reference ??) Applied --- algorithm to generate random 2D stimuli by varying the descriptive characteristics of the shapes.
- Reduced and filtered out the number of generated shapes for subjective evaluation. This optimization made determining sub-variables for aesthetic evaluation possible from a large pool of variables. These variables were used to prepare questionnaires.
- Determining the aesthetics variables, which would be flexible and tangible enough to be considered across all the fields of aesthetics.
- An experiment protocol for the eye tracking study of abstract 2D shapes.
- Proposed the variation in eye-tracking variables in different groups of aesthetic levels.

1.12 Organization of the Thesis

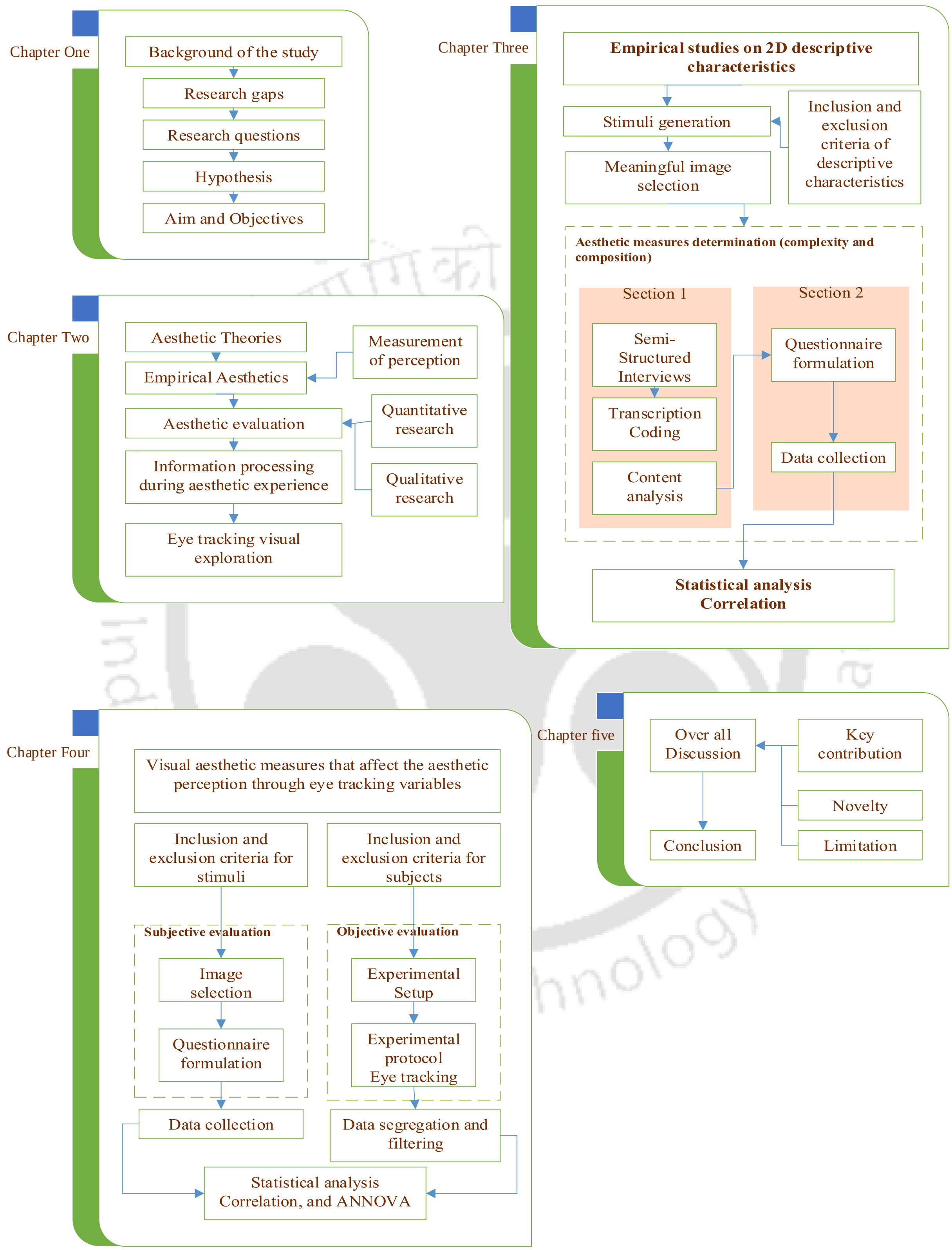


Figure 2. Framework adopted in this research work

1.12.1 Brief description of chapters

The present thesis constitutes five chapters. A short description of these chapters is presented below. Chapter 1 provides the philosophical background of Aesthetic research in its concise form. It helped identify the existing field of studies to better understand aesthetics. From there, the problem statement with the research gaps is identified. The research questions and hypothesis were formulated, and finally, the details of the research framework are represented.

Chapter 2 represents the state-of-the-art literature review containing the previous studies relevant to aesthetic evaluation. This chapter started with mapping existing theories on aesthetic perception and aesthetic objects. After that, the literature moves to the field of empirical aesthetics, with the available type of aesthetic evaluation techniques. Topics like Aesthetic information processing and eye-tracking visual exploration pattern has also been covered here. Finally, the discussion ends with the visual aesthetic measures that affect aesthetic perception through eye-tracking variables.

Chapter 3 provides a qualitative and a quantitative study that helped to derive the stimuli and the variables of aesthetics. Questionnaires are formed utilizing these stimuli and variables, and data were collected to check the correlation between the variables. The whole study was based on content analysis, questionnaire-based, and subjective.

Chapter 4 investigates a quantitative study on the aesthetic perception that involves the subjective rating and eye-tracking study of 2D and natural images. This chapter presents the methodology that helped evaluate 2D shapes. Then the same methodology was followed to evaluate natural images. Finally, correlation, ANOVA, and ordinal logistic regression were done to answer the earlier founded research question.

Chapter 5 summarizes the overall research work in the thesis. This chapter discusses the key contribution (contribution to knowledgebase), novelty, and limitation of the thesis. Furthermore, this chapter also describes the testing of the hypothesis while addressing the various research question.

2

Literature Review

Abstract

The objective of this chapter is to back the advancement of the research through a description of the theoretical and historical contributions to the area of aesthetics. The methodology followed in this chapter covers various forms and phenomena of aesthetics in the domains of both science and philosophy. In which we will cover subjects like Aesthetic theory mapping, Empirical aesthetics, Information processing during the aesthetic experience, aesthetic evaluation, and finally, we will discuss the aesthetic variables. The topic discussed in this chapter would set the context for further investigation on the research topic in the coming chapters of this thesis.

2.1 Introduction

This chapter of the thesis helps map the existing theoretical and practical studies in aesthetics to support the current research keeping in mind the multidisciplinary nature of aesthetics with its variability. This review chapter constrains itself to the studies related to aesthetic visual perception. This means the vast side of the various art-related practices and the philosophical side has not been the focus of this study and are mentioned in a few necessary places. This chapter aims to critically review the existing variables of aesthetics while comprehending the perceived aesthetics. So that broadened understanding of the existing practices on "empirical aesthetics" will provide a rationale for the section of this research methodology. The structure of this chapter is based upon aesthetics and can be articulated with an example of a tree with its parts. For example, where the root of the tree is the aesthetic subjects related to philosophy. The reason for segregating philosophical aesthetics fields as the root of the tree is because the field of aesthetics started in philosophies and evolved from its earliest form. Similarly, the branches and trunk which support the whole tree structure can be compared with the empirical aesthetics. The field of empirical aesthetics depends on scientific studies, where most hypotheses were derived from past philosophical studies. Similarly, the fruit and flowers of the tree are the aesthetic perception or experience. This aesthetic field, in general, deals with human psychology and end output as the aesthetic experience and emotion.

From the previous chapter, this chapter differs in discussing with specificity related to the aesthetics, complexity, and composition. The current chapter is organised and explained so that a sense of direction can be observed from the theories of aesthetics to the practical/ biomechanical analysis of aesthetic variables (complexity and composition). This structure of the study allows setting a narrative for the thesis by focusing on the aesthetic perception of 2D stimuli.

2.2 Aesthetic theory mapping

In chapter 1, we have elaborated the some of the notable core concepts of aesthetics with properties. Section 1 discusses the features and definition of aesthetics. From there, we found those essential properties to have an aesthetic experience according to the philosophical definitions. When we talk about the philosophical stance on aesthetics, this research work follows the modern "analytic philosophy" of aesthetics. In the coming chapter of 3, we have discussed elaborately the methodology adopted. We have learned about the subjective and objective sides of aesthetics. We also learned about various types of aesthetic objects and the difference in aesthetic experience for different types of aesthetic objects. This section of this chapter will clear our stance on the subject-object debate. Jerrold levinson, 2003, said that beauty, ugliness, and sublimity are the aesthetic experience and not the intrinsic properties of aesthetic objects. It also doesn't mean that these aesthetic properties are subjective. These dualities in subjective-objective properties of aesthetics were a long debate in the history of aesthetics and settled in recent history. Our stance on this is accepting the dual distinction of aesthetic perception as the interaction between both subject and object.

2.2.1 Aesthetics theories of aesthetic perception

As discussed earlier, aesthetics has two sides (subjective and objective). In layman's terms, the objective side is the study of art (aesthetic object), and the subjective side is the study of perception. In an essay Monroes beardly (Beardsley, 1982) has defined the difference in the studies while arguing that aesthetic objects/ art is a subset of perceptual aesthetics. Similarly, Richard Lind (Lind, 1992) suggested the difference between perception and motivation. In this research work, we will investigate the same phenomena and examine the difference in human aesthetic perception with the change in aesthetic variables (complexity and composition) for 2D shapes.

Aesthetic perception depends on the earlier aesthetic experience of the subject. So, the question arises; What will happen if the subject has no aesthetic experience related to a particular object? For example, a subject is seeing the ocean for the first time. Does the subject have a higher level of aesthetic perception or lower than normal people who often visit the ocean?So, it is clear that there are factors that influence the aesthetic experience of the subject. When our brain encounters unusual objects for the first time, it tries to extract information by organizing the sense out of it. The reason behind it might be the brain functions, which work on goal-oriented interests. It indicates that there is a subjective side of aesthetics which can be termed as aesthetic perception.

Renowned philosopher on aesthetics, "Kant" gave the theory of disinterestedness. He argued that to have an actual aesthetic experience, the subject shouldn't have any interest in the object. In simpler metaphorical example would be: The referee on a football field should be neutral to all playing teams. Kant further explained that "Taste is the faculty for judging an object or a kind of representation through satisfaction or dissatisfaction without any interest. The object of such satisfaction is beautiful" (Daniels, 2008). Lind, 1992 as a Kantian theorist replaced disinterest with interest in the act of perception itself. Lind also compared this with people's cognitive skills, which can be learned and mastered from previous experience. Later declared, this phenomenon as the "aesthetic attitude" and can be observed in several places of this research work. Aesthetic attitude for a subject depends upon many environmental factors like cultural, social, and ecological factors. It is also called environmental aesthetics.

Similar to Kant's disinterest theory, Gibson, 2014 presented the "theory of affordance." He argued that affordance is a term that describes the relationship between the subject and the perceptual environment of the subject. This means affordance is a dynamic variable with a visual system that optimizes the perceptible properties. Even Dondri, 2006 represented affordance as visual information that allows the perceiver to act. There are some limitations of this theory. One limitation is that it's a non-empirical process while at the same time not supporting some of the basic psychological theories (Bruce et.al., 2003; Norman, 1988). It appears it is a problem of comprehensibility that relates to the role of aesthetic perception in aesthetic experience that needs further investigation.

2.2.2 Aesthetic theories of aesthetic object

In the earlier section of this chapter, we have discussed the subjective side of aesthetics. Similarly, there is the objective side of aesthetics. An aesthetic object can be classified as a natural or man-made object. When we talk about the theory of art, we discuss the man-made aesthetic object that defines art in terms of subjective perception. When it comes to defining art, there are many attempted approaches that try to see aesthetic objects through different lenses. Some of the approaches even justify that there is no definition of art (Donald Judd; Wittgenstein). Similarly, Carroll, 1995 defined art as its value in eliciting the aesthetic experience. The aesthetic philosopher Wittgenstein, 1966 defined that "The problem is not "what is art?", but "what sort of concept is 'art'?". He justified that while defining art, we need to fix the practices and procedures of art production. The practicing art is so diverse that there will always be a gap between the theories and practices. When we call it art practices, it means the physical features upon which art is formed. The characteristics of the practices have overlapping properties and cannot be distinguished and classified separately.

Some objective aesthetic theories define art based on classificatory art practices. The theories like the "concept of the world" are one of the theories where Arther Danto's describe a similar phenomenon through the art practice. He said, "something that the eye cannot describe – an atmosphere of artistic theory, a knowledge of the history of art: an artworld" (Danto, 1964). In simpler terms, he tried to explain that any object in the world can be transformed into an aesthetic object. This doesn't mean that every object is an aesthetic object. But the object needs an art world to understand this. It can be understood from Warhol's work of art brillo boxes when the normal Brill shop pads transformed into the box of art for the art world. Similarly, Gorge dickey, 1974 provided the institutional theory of art. In this aesthetic theory, he opposed the essentialist approach to aesthetics and identified the subject's motivation as the case of aesthetic perception. The theory's structure is based upon a circle, which is also called the "The art circle" (Dickie, 1997). Dickey has separated the subject into two different classes and justified the aesthetic attitude for an art experience. The art circle is flexible enough to consider a newer modified version of art practices with greater precision. The only downside is that this theory might need to be revised when the properties and practices of artwork change. Another aesthetic theory is Relational Aesthetics (Bourriaud et al., 2002), but this art theory only addresses the art objects as art events. The effort focused on the relationship between the different stakeholders like an artist, aesthetic object, and subject. Some of the aesthetic theories are also related to dynamism and environmental interaction, but the focus of the research work is to limit itself to the theories related to visual aesthetic perception and the aesthetic object.

In the quest for a true universal theory of aesthetics, philosophers have tried all possible combinations of aesthetic stakeholders. The major theories emerged based on aesthetics' properties, classification, and relation. The theories related to aesthetics get diverse with time. The theories started with direct questions on the properties of aesthetics and gradually added other possible stakeholders with iterative arguments. It is clear that aesthetics is a complex phenomenon to quantify with time, and the philosophers laid the foundation well. As observed inthe literature, the theories related to the aesthetic object or non-perceptual aesthetics got more popular at the start of the 21st century.

Dickie concluded that aesthetic experience is not a task, thus irrelevant to the empirical studies on aesthetics. Few researchers have contradicted him and explored this area to fill the gaps of non-perceptual art theories. This research also believes the same and has investigated aesthetic objects' perceptual aspects through empirical studies. In the coming section, we will explore the empirical studies related to aesthetics and determine the variables used in perceptual and non-perceptual aesthetics. In chapter one of this thesis, we have discussed some of the variables of aesthetics. It was observed that complexity and composition are two aesthetic variables that exist in both perceptual and non-perceptual theories of aesthetics. In this way, the bridge between perceptual and non-perceptual art can be obtained by carefully implementing biometric technologies. The objective is to understand how descriptive characteristics of aesthetic objects manifest the perceived complexity and perceived composition of the subject. Therefore, in the coming section, the findings of empirical aesthetics will be explored in terms of one of the objectives of the thesis. The objective is to find out the justification for aesthetic variables used in this study.

2.3 Empirical aesthetics

In this section, the historical developments on visual aesthetics perception through the spectacles of science and documented chronologically. The whole documentation narrative has started with a broad topic of visual perception and gradually narrowed down to modern biometric measures to quantify aesthetics. Particularly the scientific studies related to visual aesthetics using eye trackers are a matter of concern for this study. The objects and subjects used in existing studies were not restricted to visual art only.

2.3.1 Establishment of the field

Aesthetics is very broad and used primarily in philosophy, neurology, and design. But the primary concern is what part of visual aesthetics to consider (subject or object) for empirical aesthetics evaluation. The reason might be the approach difference between sociology and science to a particular problem. In empirical aesthetics, quantitative data obtained from the subjects were used to find the result of an experiment, and this is how empirical aesthetics is different from philosophy. In this chapter, these differences in aesthetic perception are discussed. Birkin, 2010 exposed two problems in the empirical studies. He explained, "perception is not directly accessible to the inspection of experimental procedure secondary they are highly variable.".

Controlling variability of perception can be managed by isolating some of the factors of the subject group or by limiting stimulus levels. Before that, we need to learn how to quantify aesthetic perception. Human perception follows the pattern of a scale. That scale is not continuous and can have opposite polarity with the end of the scale. For example, beautiful-ugly, hot-cold, black-white, etc. These perceptual scales need to be verified or compared with the variables of objects or stimuli. Particularly in our case, these variables of objects are called "descriptive characteristics." In psychophysics, this is a common practice, and we have represented this kind of data as "subjective empirical data." Particularly in our study, subjective empirical and objective eye-tracking data were verified by the stimuli and will be compared to conclude the result of the defined hypothesis.

2.3.2 Measurement of perception

Measurement of perception started by taking subjective data in a scaled form. This means linking subjective perception to physiological properties was not possible before Joseph Plateau (1801–1883). The experiment joseph conducted to create the colour grey with different subjects with different viewing conditions. Before introducing a scale for a subjective evaluation, a continuum with a range was needed. Steven,1975 attempted the first work to create a perceptual scale. Although the idea was noble, the idea of a complete perceptual scale was not clear until E.H Weber (1795-1878). Because dividing a perceptual scale to an equal amount was not possible. He introduced " just noticeable difference" or JND. JND was developed as a tool to monitor the minimum noticeable difference in perceptual scale. In JND, the subjects were introduced to a stimulus, and the slow change in stimulus was done until the subjects perceived the difference. For a different kind of perceived scale, different methods were adopted. For example, blindfolded tests were done for developing touch or smell-related perception. Finally, he introduced an equation to establish this theory.

$$\psi = klog\varphi$$

Where sensation = ψ (psi) (psychological measurement), k = constant, φ (phi) = stimulus intensity (physical values). The assumption was that JND forms equal division on a perceptual scale. The relation between the perceptual scale and increased stimulus scale intensity is assumed to be partially proportional. It signifies that the relationship would be a line with logarithmic relation.

Similarly, Stanly steven (Steven, 1975) did an experiment to quantify a perceptual scale. In his experiment, the subjects were asked to rate their sensation. This method was called "Magnitude Estimate Scaling" (MES). In this research, we have used the same techniques to evaluate the subject's perceptual experience. He also suggested that the relation function is not logarithmic in nature. It’s a power function (Steven, 1961) and re-established it as:

$$\psi = k\varphi^{\beta}$$

Where ψ = sensation (psychological measurement), k = constant, φ (phi) = stimulus intensity (physical values), β = value of exponent which may vary from subjects to subjects.

Where in JND, the logarithmic value was linear, in MES the power values were nonlinear. We have use MES in our experiment because it is evident that the value of β behaves like a power function when it comes to the same phenomena in the case of perception measurement. There is some research (Narens, 1996; Birkin, 2010) that confirms the same phenomena in case of perception measurement.

In this section, the history of the perceptual scale has been covered. We have also covered the developmental approach to the perceptual scale with respect to time. It was observed that dealing with quantitative and qualitative data, particularly with multiple variables, is a tedious task. For example, in our experiment, we have determined the perceived complexity and composition as aesthetic variables. As all the variables are subjective, we developed and used separate stimuli for perceived complexity and composition.

2.4 Information processing during aesthetic experience

2.4.1 Top-down and bottom-up approach

Aesthetic experience is a combination of top-down and bottom-up processes as per information processing. Top-down information processes are controlled by the person's perception, which is environmentally influenced. Thus, it is very difficult to control. Contrary to this, the bottom-up information process deals with the structural composition of the aesthetic object (Massaro et al., 2012). Cupchik et al., 2009, proved with a neural correlation that aesthetic experience is a function of the interaction between the top-down orientation of attention and bottom-up perceptual input. Most of the psychological models associated with aesthetic experience are based on the top-down approach, but Leder et al., 2004, proposed an information processing model that holds both approaches. The prerequisite of their proposed model is that subject must view an object as a work of art. This model doesn't hold firm for the aesthetic experience of a natural object.

The bottom-up process of aesthetic information processing is involved with the compositional and complex features of the aesthetic object (Hekkert and Leder, 2008). At the same time, bottom-up aesthetic experiences are independent of the type of emotional, environmental, attentional, and cognitive factors. Many researchers suggest that bottom-up information processing during an aesthetic experience is affected by several variables like symmetry (Berlyne, 1971), balance (Boselie and Leeuwenberg, 1985), (Hekkert and Van Wieringen, 1996), contrast (Ramachandran and Hirstein, 1999; Cupchik et al., 2009). But in actuality, it affects the compositional and complex features of the aesthetic object.

In a bottom-up process, the change in perception is always sensory-driven as humans perceive through their senses. Vision as a human sensor plays a huge role in perceiving day to day work. Other human sensors like audio and touch also have perceiving capability, but the eye as a human sensor dominates all other forms of sensory input. Therefore, eye tracking is a fast and reliable technic among all available biometric techniques, which helps to receive biometric signals from the human eyes to interpret the visual behavior of the subject during an aesthetic experience. It has already been established that an eye tracker is a profound tool for monitoring visual attention (Wallraven et al., 2009; Graham et al., 2010) from the bottom-up aesthetic variables. A few numbers of research have been identified that use eye tracking in behavioral research. When it comes to the field of aesthetic evaluation, research citations drop further. Perhaps interpreting a continuous stream of eye-tracking data to a human behavioral property is a very tedious task.

2.4.2 Cognitive process during aesthetic perception

Previous researchers have indicated that the amount of information directly affects the cognitive load during aesthetic perception. This section will explore the links between the top-down cognitive processes with the bottom-up eye tracking variables during an aesthetic experience. Few numbers of research have identified where eye trackers have been used to study human behavior. During a cognitive process in aesthetic evaluation, different semantics with several compositional elements help the subject to form perception. As we have noticed earlier, perception guides human behavior regarding aesthetic experience. Regarding eye tracking, there is evidence that cognitive load directly affects the eye-tracking variables (Rayner, 1998; Ikehara and Crosby, 2005; Djamasbi et al., 2012). As we know, cognitive load is observed to be high in specific exploration during an aesthetic experience. There are also some loopholes identified in the correlational study, like there has not been any research justifying the amount of cognitive load and its variation with respect to the eye-tracking variable.

An aesthetic object can be perceived differently by different subjects. The literature suggests many possible causes like attention, aesthetic attitude, type of aesthetic object, art training, and ecological factors like cultural and environmental influences on aesthetics. (Gombrich, 1961) believed that "art is incomplete without the perceptual and emotional involvement of the viewer." At this point in philosophy and psychology, both converge on the functioning of aesthetics. When it comes to visual perception, human eyes can scan only 2D images. The rest of the 3D perception of an object happens inside the brane. This reconstruction of the 2D image into a 3D image coined the term "inverse optics". Adelson, 1993, explained about von Helmholtz, who first scientifically supported the fact of two-way information flow (Top-down and bottom-up). Recently a FMRI study (Albright, 2012) suggested the activation of a different set of neurons during the top-down and bottom-up information flow. There are several psychological models along with some neuroimaging correlations of aesthetic information flow. However, still, there is no model that will completely represent the cognitive process during the visual aesthetic experience. This section will review the earlier attempt to establish the relationship between neural activity and cognitive process during an aesthetic experience.

In exiting philosophical, psychological (Lederet al. 2004), and neurological (Chatterjee, 2003) framework, some aspects are common and involve a higher level of attention with emotional output. Though psychological models are good for philosophical thesis, it's very difficult to establish hypotheses for scientific proof. It's a continuous hit and trial process based on logic to establish neural correlation during the aesthetic experience. According to different frameworks on aesthetic processing, the cognitive process is a multi-stage, multi-loop, dual output, a feed-forward system with parallel as well as series processing of information.

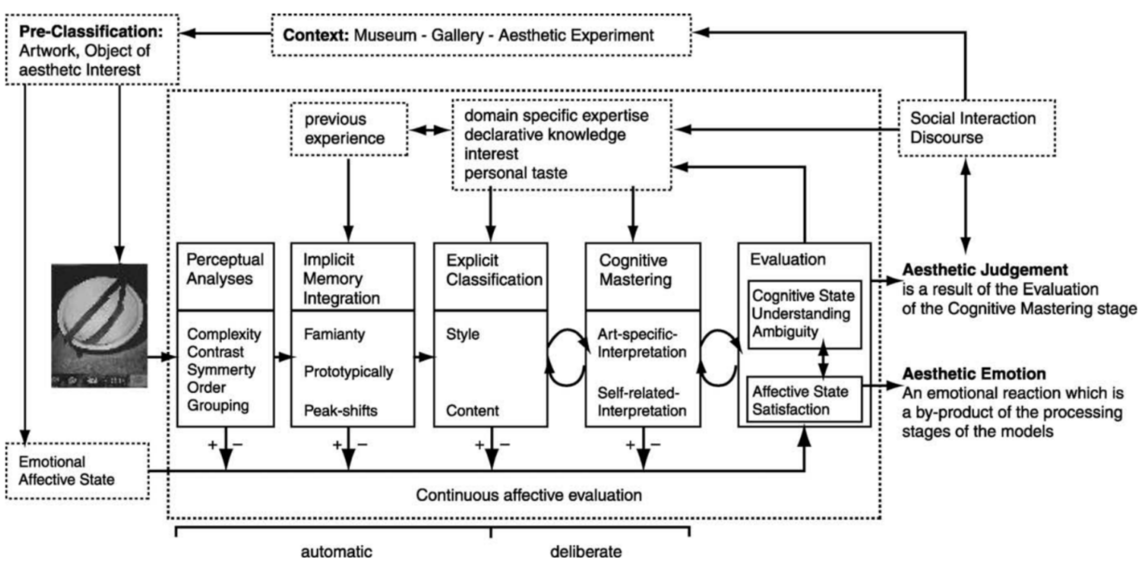


Figure 2.1. Information processing model of aesthetic experience (adopted from Lederet al. 2004)

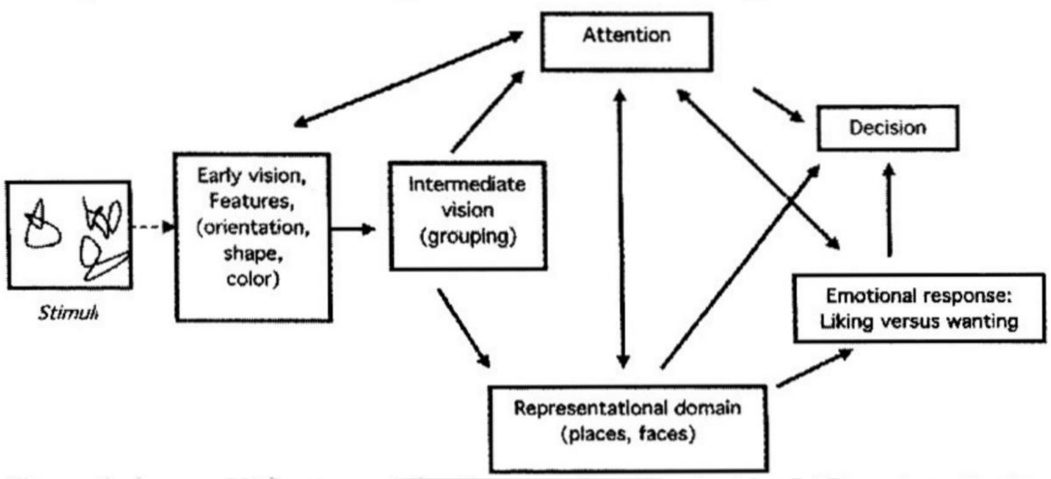


Figure 2.2. A general framework for the neural underpinning of visual aesthetics guided by visual neuroscience

Lederet al., 2004, proposed a psychological, aesthetic information processing model with multiple levels of information processing. From the fig. 2, we can observe that the model consists of five stages: perception, explicit classification, implicit classification, cognitive mastering, and evaluation. The two outputs of the same model are aesthetic judgment and emotion. The proposed model also justifies the cognitive challenges during the positive aesthetic experience. The framework proposed by Chatterjee, 2003 was based upon visual neuroscience. As this review is based on eye-tracking, Anjan Chatterjee's framework is suitable for aesthetic evaluation. The emotional output of the framework with neural correlation is not possible because it's impossible to differentiate two emotional processes in brane (Santayana, 1955). Therefore, it's an assumption that aesthetic emotion is an independent emotion. From fig. 3, we can understand the working model of visual aesthetics. The proposed model was based upon the three levels with two outputs. Where the first level is directly linked to the extraction of simple visual components like shape, colour, texture, and proportion. Second level groups and segregate basic components to analyse visual composition and complexity. And the third level derives semantic meaning from the intermediate vision that is directly linked to memory; as a result, emotion and aesthetic experience are evoked. While doing the neural correlation of the above justified process, it is suggested that stage one or early visual process happens in the occipital region of the brain. Similarly, the second or intermediate level involves the extrastriate cortex with frontal-parietal attentional circuits. As third level or late vision is directly linked to memory can have access to any part of the brain. But the anterior medial temporal lobe is active during the emotional output medial and orbital cortices. Chatterjee, 2003, also justified the universal nature of early, intermediate levels while depriving the late vision of any universal nature due to its link with the subject's memory.

2.5 Aesthetic evaluation

Philosophers and scientists always have a conflict of opinion between subject and object due to their fundamental approach. Both subjective and objective approach has their advantages and disadvantages. Aesthetic research is a mix of both approaches, followed by empirical proof. Specific psychological models (Redies, 2015; Pelowski and Akiba, 2011) determine the information flow from objects to the subject during an aesthetic experience with cognitive processing of the information. A similar model was proposed by (Leder et al., 2004) with five stages and two outputs. Apter, 1984 proposed that aesthetic experience is a self-rewarding cognitive process, not a goal-directed feature. This means when a subject observes the aesthetic properties of an object, a different set of neural operations starts in the brain than when the subject normally observes the same object. Leder supported the same with the information processing model. But the fact was proved scientifically by Cupchik et al., 2009 through neural correlation. In the experiment, the brain parts, like the left and right insula and the left lateral prefrontal cortex, were highly active during the aesthetic experience. Earlier research confirmed that these respective parts were responsible for the emotional and self-referential brain process.

2.5.1 Qualitative research/ Subjective evaluation of aesthetics

Most subjective evaluation of aesthetics is vibrant, problem-oriented, and multidisciplinary. The Aesthetic implications are so diverse it is not possible to cover all aspects of the individual application. Therefore, in this research, efforts are made to present its classification according to the discipline of the application itself. For example, design, computer science, biomechanics, social science, etc. “When people are not prompted specifically about usability, while they may still mention it, it is not the attribute given the highest priority – cost, aesthetics, and features are more important” (Mack and Sharples, 2009). In a subjective evaluation, many variables can be addressed compared to objective research. Subjective evaluation of aesthetics is related to people’s judgment, and its result varies greatly. One way is to do exploratory research by using factor analysis to identify the variables of aesthetics. There is evidence available that the area of human computer interaction has disregarded the area of aesthetic evaluation (Darden and Babin, 1994), (Jordan, 1998), but in the 21st century, the research trend is changing.

Chowdhury, 2015, explored that anthropomorphic aesthetics influences apparent usability, which influences the user’s attention. He measured perceived attractiveness through a standard subjective questionnaire and backed it with eye-tracking research. Kurosu et al., 1995, proved that users are strongly affected by the aesthetics even if they are trying to evaluate the functional aspect of the product usability. They did a subjective evaluation backed by empirical data with the help of a correlational study. They suggested that the aesthetic aspects are equally important as apparent usability. From the literature, it is observed that different aesthetic variables are used in different research (Artacho-Ramírez et al., 2008). Tractinsky, 1997 proved the appearance effect on the user's behaviors while evaluating a product. Tractinsky et al., 2000, did a subjective evaluation to test the relationships between beauty and usability. The experiment was done with a computerized application to replace an Automated Teller Machine. Later multivariate analysis of covariance is done to prove the effect on perceptions due to aesthetics. Lindgaard and Dudek, 2003 found that satisfaction is an experience driven property, and aesthetics, emotion, expectation, and likeability, as well as usability, contribute to the user product experience. Subjective usability testing in design valuation is the most commonly used method to evaluate aesthetics (Lewis, 2006).

Some experiments have established the relation between kinematic parameters and the subjective aesthetic perception of the dance audience in the field of biomechanics. Various dance styles, ranging from bale to contemporary dance, are analyzed to evaluate the viewer’s aesthetic perception. Bronner and Shippen, 2015 introduced a biomechanical model along with some metrics to evaluate the aesthetic perception of the observer in a dance. In this research, the nonlinear principal component analysis is done along with the intra-excursion variability test to calculate dimensionless jerk for the gesture limb. The matrices discovered are backed by empirical data with repeated-measures ANOVA for metric data; Mann–Whitney’s‘U’ and Friedman’s rank tests for nonparametric rank data. Torrents et al., 2013, found a high correlation between higher beauty scores and certain kinematic parameters, especially those related to the amplitude of movement.

Recently the focus of marketing research is shifting to the effect of aesthetics on consumer behavior. Most of the earlier research done in the marketing field were based on consumer responses of retailing stores, but gradually it’s shifting towards internet-based product selection. In marketing research, factors like affective response time are used as the parameter for aesthetic perception. Robert and John, 1982, advised and established the role of aesthetics as a variable in the shopping environment. They studied the effect of arousal and pleasure in the store environment. Russell and Pratt, 1980 presented a unique theoretical structure to represent the perceptual and affective qualities during an aesthetic experience. Lindgaard et al., 2006, conducted three experiments to verify that users can have an immediate aesthetic impression of web pages with high stability to interpret ‘the mere exposure effect. The protocol of the experiment was designed to evaluate aesthetics subjectively, and then inferential statistics were used to evaluate aesthetics first impression. Moshagen and Thielsch, 2010, developed a tool named Visual Aesthetics of Website Inventory (VisAWI) based on subjective evaluation. VisAWI tool explains the domain of interest of visual aesthetics of the websites. Similarly, Artacho-Ramírez et al., 2008, used the differential semantics method and determined the product's subjective symbolic value transmission to the subject through photography, infographic images, and 3D models.

Table 2.1. Examples of subjective evaluation of aesthetics

Subjective evaluation method	Elements evaluated	Tools	Pros	Cons
Classical aesthetic judgment (Lavie and Tractinsky, 2004)	Aesthetic, pleasant, clear, clean, symmetric design.	Questionnaire and evaluation tool for scale evaluation	Important for task-oriented sites, simple and quick, score result	Evaluation of just one kind of aesthetics has to be combined with other method
Expressive aesthetics judgment (Lavie and Tractinsky, 2004)	Creative, using special effects (not evaluated when using screenshots), original, sophisticated, fascinating design.	Questionnaire and evaluation tool for scale evaluation	Important for creative sites, simple and quick, score result	Evaluation of just one kind of aesthetics has to be combined with other method
VisAWI (Moshagen & Thielsch, 2010)	Simplicity, Diversity, Colourfulness, Craftsmanship, (General factor)	Predefined questionnaire and evaluation tool for scale evaluation	Carefully chosen questions based on studies, fast – about 3 minutes for one evaluation, diverse aspects, score result	Time consuming to evaluate quick changes (for this, a short version with four questions can be used)
Interface Criticism (Bertelsen and Pold, 2004)	Whole interface and its parts, associations and communication.	Critique guideline	Concentration on the communicative and associative aspects, deep analysis	Time and knowledge consuming, no score result for comparison

2.5.2 Quantitative research/Objective evaluation of aesthetics

There have been several attempts to have universal design rules that can be backed scientifically with empirical data. Particularly evaluating aesthetics has always been a challenge for researchers due to the high degree of subjectivity. In this section, the attempt will be made to discuss the available research to evaluate aesthetics objectively. Gustav Theodor Fechner is the father of experimental psychophysics. Fecher laid the base of the experimental aesthetics by outlining artistic and architectural objective rules of thumb. There is also a theory available that agrees that dynamic forces drove aesthetic judgments. Considering the observer's individual difference is marginal to drive the universal laws while evaluating aesthetics. An American mathematician Birkhoff (Birkhoff, 1933), introduced the term "aesthetic measure". In his research, he used complexity, balance, symmetry, and balance as variables from polygons. Moles, 1966, proposed an information theory that is based on the philosophy of Max Bense. It also faced some criticism because it was the first computer-generated art. Since then, a lot of theories have been developed to measure aesthetics, like the "semiotics information" theory by Claude Shannon and Charles Sanders Peirce's "semiotic theory," Daniel Berlyne's "perception theory" (Klütsch, 2012). The term "new experimental aesthetics" was coined by Daniel Berlyne, which was based on determining the aesthetic variables of the object and relating them to a subject's aesthetic perception and nonverbal responses. Berlyne also investigated and instigated that it is necessary to consider aesthetic perception with psychological factors. In the field of information technology and graphics screens, Ngo et al., 2000 proposed an approach of using Birkhoff's theory.

The above literature describes the evolution, development, and refinement of objective evaluation of aesthetics. It is observed that the experimental approach with objective evaluation has been scattered throughout all domains. Measuring aesthetics objectively concerns this research much because most of the available subjective methods are questionnaire or survey-based and have no fixed output. Objective evaluation deals with variables that are directly linked to the type of biometric technologies. In the above literature, the evaluation techniques from the philosophical approaches along with the socio-scientific side are explained, but it does not tell anything about the interior functionality and structure of the aesthetics. Therefore, incoming sections will explain the anatomy and physiology of aesthetics and the human behavioral interpretation.

Table 2.2. Examples of objective evaluation of aesthetics

Characteristics/ Name of Method	Elements evaluated	Tools	Pros	Cons
Objective aesthetic measures for graphic screens (Ngo et al., 2000)	Balance, equilibrium, symmetry, sequence and order and complexity, cohesion, unity, proportion, simplicity, density, regularity, economy, homogeneity, rhythm	Mathematical calculations of objects or specific software like AMA (Zain, 2008)	Long-term research-based characteristics of elements, clear comparable score for the result	No access to existing software, calculations are complicated, screen division to objects is complicated, large number of constructs, selection of the most important ones is not clear
Counts-based measure (Altaboli and Lin, 2011)	Number of: constructs or chunks of elements on the screen, number of different sizes of visual objects, number of mages, number of different font types, JPG file size of the screenshot	No special tools	Simple method for the designer to use as the information for counting is well-known and quickly countable, well-suited for informative and task-oriented sites	Can be time consuming with complex and rich designs, complications of division of visual objects
Aesthetic Colouring	Colours of layout areas	Specific software	Offers a selection of aesthetic	Special software needed

System (Zhang *et al.*, 2009)			combinations to specific layout	
Physiological measurements (Tschacher *et al.*, 2012)	Reactions of users to the interface based on eye movement, breathing, heart rate, skin conductance, etc.	Specific software	Real-life results for user reactions	Need for specific technology and knowledge

2.6 Identifying the variables of aesthetics

In the earlier section, we mentioned the different information processing models and visual exploration patterns in the aesthetic experience. Particularly validating the aesthetic information processing model is a tedious task concentrating on philosophical, scientific, and empirical evidence. Locher, 2006 conducted one experiment to determine the top-down visual attributes and validated aesthetic experience as a two-phase processing model with the help of a two-fold eye-tracking experiment. Apart from the top-down validated model, some bottom-up variables like complexity, composition, and contrast contribute to the visual aesthetics (Hekkert and Leder, 2008). From the literature, it seems that these variables are affecting aesthetics in all forms, from nature to art objects. This section tries to discuss the eye tracking objective approach to aesthetic evaluation and combines behavioral studies in psychology with empirical proof to validate aesthetic models. The outcome of this discussion is a unique combination of top-down and bottom-up approaches during aesthetic evaluation while upholding the commonalities of aesthetic evaluation across all domains.

2.6.1 Complexity

The balance between order and chaos is called complexity (Birkin, 2010). Perceived complexity is an important lower-end variable for the aesthetic evaluation that makes inverted U shape with hedonic values of arousal. The curve is called the Wundt curve and is helpful for quantifying the complexity level during the empirical investigation. As we know, fixation and saccade are the two prime variables of eye-tracking, and it doesn't contribute as a direct measure of complexity. But eye tracking can be used to quantify the amount and verity of information in visual stimuli, and those variables are also common in complexity measures.

Mühlenbeck et al., 2016, conducted one cross-cultural eye-tracking study between two human groups ethnically different from one another and compared orangutans' fixation preferences. They found the aesthetic preference of humans for well-structured stimuli with a moderate level of complexity. Similarly, Kocaoğlu and Olguntürk, 2018 establishedan association between color and visual complexity in abstract images. They found that subjects had difficulty finding color harmony in complex abstract images. Though Spinks and Mortimer, 2015 didn't do any experiment on aesthetic evaluation they did an eye-tracking experiment on human behaviour in decision making during complex information processing. They have verified the importance of complexity and proved it with a correlational study with eye-tracking data. Henderson et al., 1999, did two experiments to determine eye movement behaviour while participants viewed different complex pictures to find the targeted object. Their research concluded that attention is initially driven by cognitive, semantic factors driven by complexity, and the eye tends to return to semantically inconsistent objects. Wallraven et al., 2009, also conducted two experiments to determine the relationship between the subjective complexity rating and computational analysis of eye tracking data while viewing the paintings across all timelines. Like actual aesthetic experience, both high and low-level information processing model is used. They concluded that certain artistic styles of paintings show the same amount of preference for aesthetic and complexity ratings.

Computer interface in all forms is a very application oriented domain, and aesthetic along with complexity evaluation has a deep implication in the field of HCI. Wang et al., 2014 did an experiment to study complexity to influence the behavior of the online shopper. In that study, they proved that due to cognitive load complexity in stimuli affects attention. In a moderate amount of complexity value, fixation duration, fixation count, and task completion time were observed as the highest. (Goldberg, 2014; Leuthold et al., 2011) Eye tracking ware used to compare the different navigation designs and task complexity and found out that vertical menus were faster and needed fewer eye fixations.

2.6.2 Composition

The inclusion of semantic information and balance between the elements is an example of aesthetic composition. It is impossible to differentiate the reason for the fixation between semantic meaning and aesthetic elements. We have known from the study that the subject's perception drives the aesthetic experience. Compositional structure in stimuli establishes different relationships among the different elements present and affects a subject's perception. Different elements together form a relationship with content and covey semantic meaning. As per literature, familiar perception of stimuli tends to have higher preferential value both consciously and unconsciously. The literature and empirical evidence confirmed that some of the compositional features could be calculated through an eye tracker.

The human eye favors balanced stimuli and searches for informative elements in aesthetic stimuli. In the process of identifying the compositional elements of visual aesthetics, fixation data can play a reliable role. Locher, 2006, proved that the centre of the composition of paintings was fixed more compared to other outer grid locations. The experiments are conducted two-fold with two types of groups, with and without knowledge of art. They found that aesthetic experience is a top-down process, and in general, fixation count increases with an increase in time, like the given task in free viewing. Kapoula et al., 2009 verified the dominance of the central area with higher fixation during the aesthetic experience of the stimuli. The reason suggested that initial fixation starting from the compositional axis of the painting help to focus their gaze for visual exploration. Their experiment tried to address the eye-tracking interaction during the stimuli judgment of abstract cubist painting with the cognitive task of naming the painting.

In another eye-tracking experiment (Molnar, 1981), only two subjects are selected, and only initial 60 fixations are considered during painting viewing. One subject is told to explore the aesthetic of the painting, and another one is guided to explore the semantic meaning. From the result, the two subject's fixations are significantly correlated, and most of the fixations are concentrated on the semantically informative area with a high fixation concentration at the centre. Kaufman and Richards, 1969 did a series of experiments to determine the fixation tendency of the basic visual forms. One of their conclusions was drawn on the basis of cortical representation that drives fixation on the basis of the compositional balance of the painting.

Table 2.3. Research work identified with different variables of aesthetics

List of variables	Research topic	Reference
Complexity	Aesthetics, Neuroscience, Fashion, Computation, psychology, Architecture	Locher and Dolese, 2004; Martindale et al., 1990; Bies et al., 2016; Birkhoff, 1933; Cox and Cox, 2002; Galanter, 2010; Güçlütürket. al., 2016; Reinecke et al., 2013; Sun et al., 2014; Tuch, et al., 2012; Mühlenbeck, et al., 2016; Calvoet al., 2004; Megahed and Gabr, 2010; Hekkert and van Wieringen, 1996.
Composition	Aesthetics, psychology, cognition, HCI, image processing	Locher and Dolese, 2004; Swamiand Furnham, 2012; Oliviaet al., 2004; Dresp-Langley, 2016; Locher and Nodine, 1989; Hekkert and van Wieringen, 1996; Palmer et al., 2008; Nodine and McGinnis, 1983; Bauerly, and Liu., 2006; Obrador et al., 2012; Obrador et al., 2010; Locher, et al., 1998; Chatterjee and Vartanian, 2014.
Symmetry	Aesthetics, Neuroaesthetics, Psychology, Architecture, HCI,	Locherand Dolese, 2004; Bieset al., 2016, Swamiand Furnham, 2012; Megahed and Gabr, 2010; Olivia et al., 2004; Dresp-Langley, 2016; Locher and Nodine, 1989; Bauerly and Liu., 2006.
Balance	Aesthetics, Psychology	Hekkert and van Wieringen, 1996; Nodine and McGinnis, 1983; Locher et al., 1998; Chatterjee and Vartanian, 2014.
Pleasant	Aesthetics	Locher and Dolese, 2004; Tuch et al., 2012; Calvo et. al., 2004.
Interesting	Aesthetics	Locher and Dolese, 2004.
Randomness/ order	Aesthetics	Locherand Dolese, 2004; Martindale et al., 1990.
Contrast	Aesthetics, Architecture, cognition	Locher and Dolese, 2004; Reinecke et al., 2013; Megahedand Gabr, 2010; Olivia et al., 2004.
Preference	Aesthetics, Neuroscience, Fashion, Psychology	Martindale et al., 1990; Bies et al., 2016; Cox and Cox, 2002; Güçlütürket al., 2016; Tuch et al., 2012; Mühlenbeck et al., 2016; Swami and Furnham, 2012.

2.7 Summary of the literature survey

The review of literature on different theories and approaches for aesthetic perception has been presented in four topics. (a) Aesthetic theory mapping, (b) Empirical aesthetics, (c) Information processing during the aesthetic experience, (d) Aesthetic evaluation, and finally, (e) Identifying the variables of aesthetics. In this review, the exploration of literature is based upon the existing theories on empirical aesthetics. The literature survey started with the philosophical stance of aesthetic theory. Then it gradually moves to the theories related to aesthetic perception and theories of the aesthetic object. The second topic we have covered is the information process in the brain during the aesthetic experience. In that, we have discussed the top-down and bottom-up information processing along with the cognitive process during aesthetic perception. Finally, the topic reviews the types of research approaches to the problem, including quantitative and qualitative evaluations of aesthetics. We have also explained visual aesthetic measures that affect aesthetic perception, and that was one of the objectives of this research work.

Summary of observations from the literature review:

- In the quest for a truly universal theory of aesthetics, the philosophers have tried all possible combinations of aesthetic stakeholders. The major theories that emerged were based upon the properties, classification, and relation of aesthetics. The theories related to aesthetics get diverse with time. The theories started with direct questions on the properties of aesthetics and gradually added other possible stakeholders with iterative arguments. With time it is clear that aesthetics is a complex phenomenon to quantify, and the foundation was well laid by the philosophers. As observed in literature, the theories related to the aesthetic object or non-perceptual aesthetics gained more popularity at the start of the 21st century.

- Some philosophers believe that aesthetic experience is not a task, thus irrelevant to the empirical studies on aesthetics. Few researchers have contradicted this belief and have explored this area to fill the gaps in non-perceptual art theories. This research also believes the same and will investigate the perceptual aspects of aesthetic objects through empirical studies.

- We have also explored the empirical studies related to aesthetics and found out the variables used in both perceptual and non-perceptual aesthetics. In chapter two of this thesis, we have discussed some of the variables of aesthetics. It was observed that complexity and composition are two variables of aesthetics that exist in both perceptual and non-perceptual theories of aesthetics.

- In this way, the bridge between the perceptual and non-perceptual object can be obtained through the careful implementation of biometric technologies. The objective is to understand how descriptive characteristics of aesthetic objects manifest the perceived complexity and perceived composition of the subject. The intention is to find out the justification for aesthetic variables used in this study.

3

Subjective Perception of Aesthetics Based on Complexity and Composition of 2D Shapes

Abstract

An object's descriptive/physical characteristics act as semantic attributes and influence the volunteer's visual perception. Variables for evaluating aesthetics are diverse and vary across the fields of research. Literature indicates that researchers attempted to evaluate aesthetics and considered many variables in an unstructured manner. Moreover, the evaluation of aesthetics of 2D shapes is rarely reported by earlier researchers. Therefore, the objective of the current study is to explore the relationship of descriptive characteristics with the variables defining aesthetics. A total of 60 random 2D shapes were shown to participants (n=85) to filter out the meaningful shapes based on their perceptions. Their subjective response of synonyms of aesthetics variables were also collected. Thereafter, the identified meaningful shapes were rated based on various aesthetic variables using questionnaires. Finally, a correlation between descriptive characteristics of 2D shapes was established with the level of perceived complexity, composition, and perception of aesthetics. Results showed that some of the attributes of descriptive characteristics were highly correlated with the quality of composition and level of complexity. It can be concluded that individuals' perception of aesthetics is associated with their perceived complexity and composition of the 2D shapes.

3.1 Introduction

Different schools of thought premeditated Aesthetics from different viewpoints. With time, the concept of aesthetics evolved, refined, and classified. The word beauty is commonly applied to pleasing things, either to the senses, to the imagination, or to our understanding. Initially, the study of aesthetics had started in philosophy, but in recent times, in the early 19th century, its focus shifted towards experimental aesthetics backed by empirical data. The concept developed by philosophers was slowly tested and refined by scientists to reach a common conclusion.

Though the concept of beauty existed before, the first inclusion of aesthetic criteria came in the stream of architecture around the 1st century BC. The inclusion criteria came around the mid-18th century by Gustav Theodor Fechner (Fechner, 1876) in experimental aesthetics. Later on, the field of experimental aesthetics emerged from that. In experimental aesthetics, both subjects' perceptions and objects' properties were considered to design methodology and conduct experiments. Therefore, the variables of aesthetics vary in different fields of study. Over the years, the application of aesthetics has evolved into many branches—computational aesthetics, visual aesthetics, product aesthetics, etc. The analysis method to determine variables and relationships also got sophisticated. In some forms of research, the objects used for aesthetic evaluation were computer-generated art. Similarly, algorithms were used to determine a visual characteristic of the aesthetic object (Amirshahi et al., 2012; Datta et al., 2006). Most of the research in this field has focused on finding new methods to evaluate different aesthetic properties (Hayn-Leichsenring et al., 2017; Mallon et al., 2014; Amirshahi et al., 2012; Yanulevskaya et al., 2012). The problem comes from the lack of a common variable that prevented different methods and approaches from being comparable.

To parameterise aesthetics, the subject's type and amount of perceptual output are considered intricate factors for the experiment. An aesthetics model (Leder et al., 2004) explained that the aesthetic experience time could be short or long and depend upon various controlling factors. Therefore, in this research, we will consider aesthetic appraisal whenever a subject has an aesthetic experience, which is a quick positive, pleasurable experience for the subject. Another reason is that here we are using random 2D shapes as stimuli. In the experimental condition, subjects won't get much time; hence won't have any reference to have an aesthetic judgment, which will result in standardizing the function of motor control in human perception.

In subjective aesthetic evaluation, taking visual and perform rating scores is a common practice for aesthetic evaluation (Amirshahi et al., 2014). Where individual images were rated accordingly to the defined variables to conclude hypothesis. The defined variables change across all fields of aesthetics. There are some major concerns related to the definition and understanding of aesthetics. Some of them are subject vs. object, the reaction output of the aesthetic experience, the aesthetic attitude of the subject, etc.

Apart from exploring aesthetic variables, another interesting matter is identifying the descriptive characteristics of 2D shapes. To understand the physiognomic factors and aesthetic preference of random shapes, the existing stand of the current research has to be clear. Through visual stimulation, human perceives a stimulus. The brain understands the details of information in descriptive characteristics (physical properties) to develop a preference for a visual stimulus. Research starts with the statement that "optimised visual stimuli have higher preferential value for different subjects." Breaking a visual stimulus into small elements leads to shapes that consist of curves and angles. The perceptual part of the curves and angles is also related to attention. Research suggests that (Cole, 2007) attention of the subject is greater in the informative parts of the stimuli, and corners seek most attention in a 2D shape. There is a contradiction from the existing empirical studies that "if attention is higher in angular shapes then why the aesthetic preference is less compared to curved shapes". The possible reason might be one element of the Gestalt principle (proximity), which helps the human brain to simplify information in visuals (Wagemans et al., 2012).

The field of aesthetic preference is subjective and trend-based. Research suggests that People's preferences in any stimuli rating can vary with time. Then the main question stands, "does human has a permanent inclination towards curved shapes over angular ones across culture, age, and type of stimuli." Bar & Neta, 2006, confirmed with a cross-cultural study that angularity of the shapes in products has a critical influence on the subject's attitude, and curved edges were preferred more. But in both cases, aesthetic awareness of the subject produced different results. However, research indicates that angularity can be associated with both positive and negative notions. The preference for angularity application can be seen in the field of car designing (Leder & Carbon, 2005), toy design (Jadva et al., 2010) to typography (Kastl and Child, 1968).

As aesthetic objects are classified into two types, man-made and natural. Both of these objects are a combination of angular and curve profiles. Many other factors kick in when it comes to aesthetic preference because getting empirical proof in simulating conditions with a forced-choice task can be a delicate matter. The factors like aesthetic attitude, repetition of the elements, semantic meaning, etc., have a distinctive effect on the subject's preference. Silvia & Barona, 2009 performed their experiment with random polygons and found that art expertly has an interaction with the angularity of the random polygon, which affects the affective rating.

Some of the research suggests that angularity relates to primitive human psychology to stay away from sharp objects. One FMRI research, Bar & Neta, 2006 discovered that the "amygdala" part of the brain was active during the visualization of the sharp object, which resonates fear generation in the human mind.

But the same "amygdala" is also involved in positive affective experience (Garavan et al., 2001). Apart from the argument of fear generation, some research work reflects that angular shape's position and orientation also control the attention of the subject. Through visual search, Larson et al., 2007 identified that compared to the up pointing "V" down pointing "V" symbol was faster and more accurately perceived. Later on, Larson et al., 2009 did a neural correlation study with confirmation of activation of the same amygdala region of the brain. Leder et al., 2011 went one step ahead and used stimuli, which are hedonic (positive and negative) in the emotional valance. They discovered that subjects prefer curved objects over sharp objects for positive and neutrally emotional valance objects. Still, the critical finding was that negative emotionally valance objects (e.g., snakes) were not preferred irrespective of their curvature. The alternative evidence says that (Friedenberg & Bertamini, 2015; Phillips et al., 2011) angularity is preferred more than curved lines, but the object used in these experiments doesn’t carry semantic meaning compared to earlier experiments. It was expected that random polygons or shapes without semantic meaning don’t have emotion as output and may play a role. We can conclude that aesthetic experience is more emotion and semantic dependent compared to the physical characteristics of an object, and descriptive qualities of the stimuli are subjective, context-specific, and semantic in nature. This section has verified that the optimum amount of descriptive qualities influence visual perception. Some of the patterns were noticed, but all of the examples are context-specific and subjective. We also found that to have an aesthetic experience, the attention has to be higher, but it doesn’t mean that greater attention always means higher subjective preference.

Researchers have explored the visual properties of images and established relationships between them. Some researchers have explored the descriptive qualities that provide objective criteria to assess the aesthetic quality of 2D shapes. Apart from the motivational factors, aesthetics is affected by different environmental noises. Therefore, while doing an empirical study on aesthetics, it is challenging to control all the environmental noises, particularly for 2D shapes. To control this, a few researchers (Gulhan, et al., 2021) have done experiments on VR environments and compared them with the actual environment.

Particularly in visual aesthetics, the subject's perceptual variable doesn't change much but the object's property changes even for every experiment. To counter this, the aim of this experiment is: (a) to determine aesthetic variable and descriptive characteristics of 2D shape from the subjective interview, (b) to run the analysis for a better understanding of trend in subjective rating and descriptive characteristics, and (c) to draw a relationship between the aesthetic variable and descriptive characteristics. If we can establish a relationship with 2D shapes, then the aesthetic perception of higher and complex 3D forms can be determined through visual properties. This paper takes advantage of the computer-generated random 2D monochromatic shapes to perform the subjective test. These shapes are used to evaluate different properties of descriptive characteristics with respect to aesthetic perception.

In this study, we measured the following descriptive characteristics for the stimuli: Number of points, Angle curve ratio, figure background ratio, symmetry, and the number of symmetrical sides. In the coming section, the exact definition of these measures can be explored in detail. For subjective rating, we include only single images that were defined by the descriptive characteristics to form a shape. The exclusion criteria were further explained in the methodology section. Though, it is evident that classical paintings can be connected with more positive aesthetic judgments than abstract paintings (Markovic, 2010a). The reason for taking abstract shapes was to eliminate the universal meaning of the shapes so that the subject's perception could be monitored uniformly across all stimuli.

This article provides the research data that connects existing subjective aesthetic studies and visuals. Therefore, till now, the effort was to draw attention to the visual aesthetics and subjective rating. In this article, we have tried to focus on research done on 2D shapes, but unfortunately, there was not much research done in this area. We found that no work deals with the subjective aesthetic perception of random 2D descriptive characteristics of the shapes.

3.2 Empirical studies on 2D descriptive characteristics

The studies related to aesthetics are broadly classified into two types, exploratory and experimental. In this study, we have included both kinds of studies. In section 1, we have done exploratory research with the interview of different subjects by showing them 2D shapes and asking them specific questions. Similarly, in section 2, we have done an experimental study to derive the relation between the aesthetic variable and descriptive properties of 2D shapes. Both exploratory and experimental studies have their advantages and disadvantages.

Earlier exploratory studies, in general, deal with natural stimuli. But with time, computer or algorithm-generated shapes have been used as stimulus. We have used artificially generated 2D shapes for aesthetic perception evaluation. An exploratory study is generally relevant to the subject's opinion and doesn't focus much on the object's properties. In our work have done content analysis through transcription coding. (Birkin, 2010) did an exploratory study on complexity. We have incorporated a similar evaluation technique in our research. Similarly, in the field of architecture, researchers used the exploratory study to evaluate the aesthetics of the buildings differently (e.g., Hershberger & Clements, 1973).

There is an age-old debate among researchers that aesthetics is subjective or objective. Experimental aesthetics promote the objective view of aesthetics, and the objective view promotes aesthetics as a function of certain features of an object. Our experiment also focused on the objective view of aesthetics. Berlyne, 1971 conveyed that an object's physical properties are identical for all subjects. But, the same physical characteristic may result in varying arousals in the different subjects due to different environmental factors. This means the same descriptive characteristics of an object may result in different levels of aesthetic experience. The popular theories on the perception of aesthetics like Gestalt and Pragnaz claimed the same. Visuals that are perceived as aesthetically pleasant follow the principle of Pragnanz and considered as good Gestalten. Particularly, Pragnanz's theories focus on an object's physical properties/ descriptive characteristics, whereas Gestalt's theory was concerned with its psychological and perceptual representation. These theories' implications on descriptive characteristics are that stimuli with the right complexity and composition promote Pragnaz's theory for fast and efficient information transfer. Similarly, the stimuli which follow less gestalt principle follow more perceiving time (Sharps & Nunes, 2002).

To determine the aesthetic variables, an object's complexity and composition are found to be two prominent variables. All the variables identified from the available literature are either complexity and composition itself or the sub-variables of complexity and composition. For example, Balance and proportion (Arnheim, 1974; Birkhoff, 1933; Fechner, 1876; Gombrich, 1995), novelty and prototypicality (Hekkert and van Wieringen, 1990; Hekkert et al., 2003), as well as contrast and clarity (Gombrich, 1995; Solso, 2003)) all are the variable of composition. Similarly, complexity is reported by (Birkhoff, 1933; and Eysenck 1941) for the aesthetic study.

We used a computer program to generate 2D shapes to prepare the stimuli for the experiment. Using computer-generated images as stimuli has considerable benefits. Some of them are: Computer-generated stimuli provide a platform to edit the stimuli by varying the variables. Once the program is ready, it’s straightforward to modify or generate new stimuli. The variety of images produced can be high compared to the conventional method. The random shapes were chosen as stimuli to receive the dissimilar meaning of the object so that the familiarity function of the stimuli for the subject could be eliminated (Forsythe, 2008).

Currently, no methodological guidelines exist to generate 2D shapes that accommodate psychological parameters. It’s even more difficult to quantify based on available descriptive qualities for the aesthetic measures. The available techniques also have to deploy some set of rules that would be evaluable through the statistical parameters. D'Arcy Thompson's (Thompson & Bonner, 2014) book is one of the few works incorporating psychological measures relevant to form analysis and providing guidelines for random shape-generating techniques. In the coming section, the descriptive characteristics that affect perceptual parameters have been identified and explained.

3.2.1 Symmetry vs. asymmetry

The topology of a 2D form can be governed by many descriptive characteristics. Symmetry as a variable is a common and well-understood descriptive characteristic for 2D shapes. Birkhoff, 1933 started the research on quantifying aesthetics through a mathematical formula, though later, a lot of criticism was shown on his work. But he gave the idea that if a basic 2D polygon or a shape can be aesthetically evaluable, then there is a possibility to evaluate a higher form of art. But sadly, since then, a lot of work has been done in this area, but the objective is not completely achieved. From the aesthetic point of view, Birkhoff stated the importance of symmetry of 2D polygons. Munsinger & Kessen, 1964 did a series of experiments to find the relationship between the different amounts of the variability of 2D shapes the expressive preference. They started with random letters and performed experiments with symmetric and asymmetric 2D shapes. Kayaert & Wagemans, 2009, did research on shape recognition of unfamiliar random 2D shapes. At the same time, presenting shapes to subjects, symmetrical and asymmetrical shapes mixed to measure the influence of complexity. In an experiment, (Locher & Nodine, 1973) examined the symmetry and structural angularity, the number of turns of 2D shapes to measure the perceived complexity. Their experiment also studied the effect of perceived complexity on eye-tracking variables like the number of fixation and fixation duration. Dresp-Langley, 2016, researched to identify symmetry's role while developing nature-inspired fractals. The review of that article involved finding the role of two-dimensional design.

3.2.2 Closed Contours vs. open contours

Contours may or may not be a bounded region of interest and have high information content. Contours are classified as closed and open contours. Contours are used together to transform the pattern while introducing systematic variations in shapes. The abstraction of the contours is the first step before the analysis of the contour. The contours are directly drawn from images, therefore very suitable for semantic and perceptual analysis. The article is limiting itself to the single contour abstraction techniques because this article aims to target the smallest complete element of an image, which is a shape. Another reason is that abstractism plays a huge role in modern art, which means it starts with the idea that "every random shape can have a semantic meaning," thus making it eligible for the perceptual study. Analysis of a contour deals with the information accruing to the abstract shape. Contours are generally described with their place, size, orientation, etc. Without comparative analysis, it is not possible to exactly evaluate random shapes objectively. A comparative study has a problem like part to part and part to the whole comparison. Arnoult & Attneave, 1956, compared different contour analysis techniques and explained the benefit of analyzing contour in parts. He explained that there could be a few standardized dimensions that can control and measured simultaneously while maintaining individual homogeneity. His proposed method had an advantage: there is no effect of size and orientation, no use of normalizing factor, etc. Similarly, Fehrer, 2006, inferred from descriptive characters like the number of homogeneous lines on perceptual complexity. Attneave, 1957, proposed the number of sides of the polygon and repetitious sequence of elements as descriptive characteristics for judging complexity.

3.2.3 Curved vs. angular

There is evidence that curved shapes are preferred over angular shapes and vice versa. This section of the article reports that human preferences favor random shapes in the context of angularity of the stimuli. Curved as well as angular shapes together define a shape. Most of the shapes in nature or manmade are a mixture of both, apart from some deliberately made artworks which separate both types (e.g., Starry Night by Vincent Van Gogh). William Hogarth first started the debate of curve and angularity in the context of aesthetics. The first attempt of classification of lines is made by (Hogarth, 1753) in his book "The Analysis of Beauty." In the context of physiognomic perception of angularity (Makovac and Gerbino, 2010); (Gómez-Puerto et al., 2013) Gómez-Puerto and his team did research related to the synthesis of sound and vision while linking with the various semantic attributes.

In the quest to find the descriptive characteristics for 2D shapes, the literature suggests that symmetry, type of contour, and angularity are very important variables. These descriptive characteristics also significantly affect the subject's perception, which we will discuss in this article's coming section. Literature also suggests (Zhou et al., 2021) that the 2D descriptive character-like angularity has a lot of implications. Even it increases consumer preference for certain kinds of products.It is also observed that different available analytical techniques that tried to address the descriptive characteristics of 2D shapes are failed to address the perceptual side.

However, studies determine the relationship between the subject's aesthetic perception and the aesthetic variable. No study was found to be relevant concerning an aesthetic variable and descriptive stats of 2D shape. Therefore, the result of the coming experiment will determine whether aesthetic variables and descriptive characteristics have a relationship.

3.3 Methodology

This methodology acknowledges the aesthetic interactions between 2D stimuli and subjects. The purpose is to identify the aesthetic variables and find the relation between them. The aim is to study the correlation between all these variables over a range of perceived complexity and composition. Therefore, the research employs qualitative data collection and analysis. The entire experiment is conducted in two sections. In the first section, we aim to establish the variables of aesthetics, complexity, and composition through interviews. In the second section, we have used these selected variables from the first section of the experiment and employed them to evaluate subjective complexity, composition, and aesthetic judgment through scoring. The following sections explain each of these experiments in detail.

From the research on the aesthetic perception of 2D shapes, a few of the research questions arise. In this part, those research questions are answered: (a) How do descriptive characteristics vary in controlled monochromatic 2D shapes as stimuli? (b) Do 2D shapes have a level of complexity and composition with subjects that can influence aesthetic perception? (c)What is the relationship between measures of objective descriptive characteristics and subjective perceived Aesthetics? (d) Can we conclude that there is a preference for a certain level of complexity and composition in 2D shapes? This study considers a methodology while integrating subjective and empirical data to answer these research questions. The subjective study explores descriptive characteristics and subjective perception by filtering out meaningful shapes for objective study. Finally, the working model of this methodology is illustrated in Figure 3.2.

3.3.1 Research plan

There have been few attempts to study both subjective and objective aesthetics. Particularly for the objective part of the study, a range of aesthetic objects is required, and creating or defining such a range of stimuli is challenging. Another problem is that analysis requires a gradual increase in the variable (complexity, composition, and aesthetics). Therefore, this is the first intention of section 1 of this study: to generate a series of images representing equidistant samples along a scale of perceived complexity, composition, and aesthetics by varying descriptive characteristics of 2D stimuli. A separate set of stimuli was developed for perceived complexity and perceived composition.

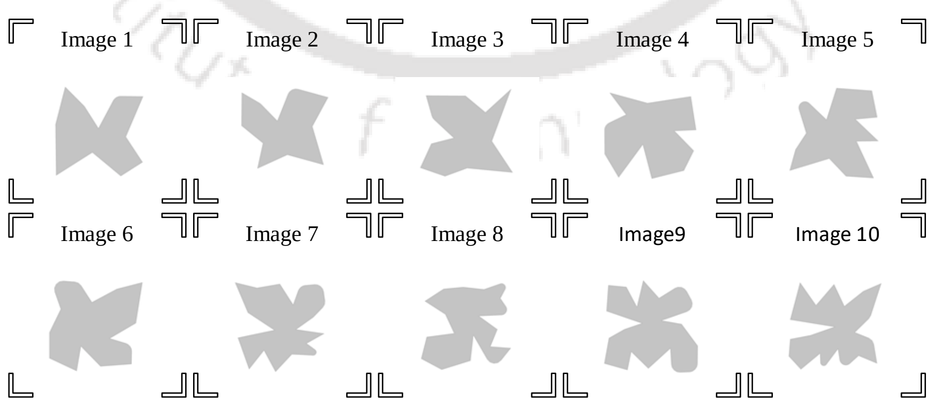


Figure 3.1a: Ten filtered images of complexity stimuli for subjective rating

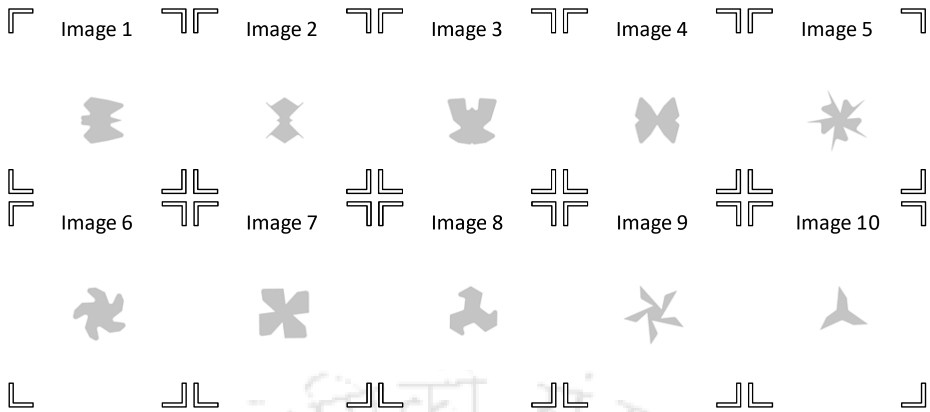


Figure 3.1b: Ten filtered images of composition stimuli for subjective rating

The plan is to start with a limited number of visuals and maintain relationships between them while arranging them with gradually increased positions. Finally, show all stimuli to subjects and documenting the most meaningful shapes with their semantic meaning. The objective is to select the ten most meaningful shapes from complexity and composition stimuli (Figure 3.1a and Figure 3.1b). For complex stimuli, section 1 begins with 2D shapes with minimum descriptive characteristics like the low number of points, curve angle ratio, figure background ratio, etc. Similarly, section 1 begins with 2D shapes with less symmetry, figure background ratio, and curve angle ratio for composed stimuli. The random 2D stimuli are generated from regenerative programming in grasshopper rhino software. For complexity stimuli: The number of points controlled while keeping the symmetrical elements constant. At the same time, variable like figure background ratio and curve angle ratio were constant. For the first batch of stimuli, the quantity of points is fixed at a fairly low value (10 number of points) and for most complex stimuli, the quantity of points was very high (60 number of points), and all shapes were asymmetrical. For composition stimuli: Similarly, the number of points were remained constant for one symmetrical side of a shape while varying the symmetrical sides of 2D shapes (vertical, horizontal, rotational, etc.,) of the shapes. At the same time, variables like figure background ratio and curve angle ratio were randomly kept. For the initial batch of composed stimuli, the quantity of points is fixed at a fairly low value (10 number of points) with a lower level of symmetry (vertical and horizontal symmetry). Similarly, for most composed stimuli, the higher number of points is considered (20 number of points) with higher level of symmetry (rotational symmetry with the higher number of sides).

Section 2 is all about collecting empirical data of perceived aesthetics, perceived complexity, and perceived composition. The output of section 1 goes as the input of section 2. Therefore, the whole experiment is conducted in two sessions. As a result of section 1, 10 most meaningful images were selected to be presented in section 2. The reason for selecting meaningful images lies in philosophy. Marković, 2012, argued that for aesthetic evaluation, an object must contain semantic meaning for the subject.

Similarly, a total of 9 sub-variables (Entangle, Intricate, Chaotic, Organise, Assemble, Integrate, Attractive, Pleasing, Beautiful) are also selected as the output of 1 section for perceived complexity, perceived composition, and perceived aesthetics, respectively. All these sub-variables were identified from the transcription coding of a structured interview. Subjects were asked questions like What made one image more aesthetic than another? The purpose of taking sub variable is for better parameterization during the empirical evaluation of 2D shapes. In section 2, the selected 2D images and sub-variables were combined to make questionnaires on a 7-point Likert scale to measure perceived aesthetics, perceived complexity, and perceived composition.

To determine the relationship between the aesthetic variables and descriptive characteristics, the chosen methodology is represented in figure 3.2. The model acknowledges the concept of subject and object along with the meaningfulness of the object. It also considers some of the important parameters like experimenting with two sessions so that repeated exposure of the stimuli can be controlled, which influences the aesthetic evaluation. In this study, the stimuli generated are of two types and generated by controlling the descriptive characteristics of the shape. It can be noticed that both types of stimuli were treated separately in section 1. During the interview, the subjective questions were asked as an output of section 1. The most meaningful shapes and sub-variables of aesthetics were filtered out. Those outputs were used as input to put up questionnaires for section 2. It can be observed from figure 3.2 that section 2 has three types of data and two types of output. Three types of data were data of complexity analysis, data of composition analysis, and data of aesthetic perception on the 2D stimuli. The two outputs of section 2 combined the data between perceived aesthetics and perceived composition, and the other output is the data between perceived aesthetics and perceived complexity. Simultaneously, the relation between the aesthetic variables, complexity, and composition is done with a correlation study, and the result has reported in the coming section.

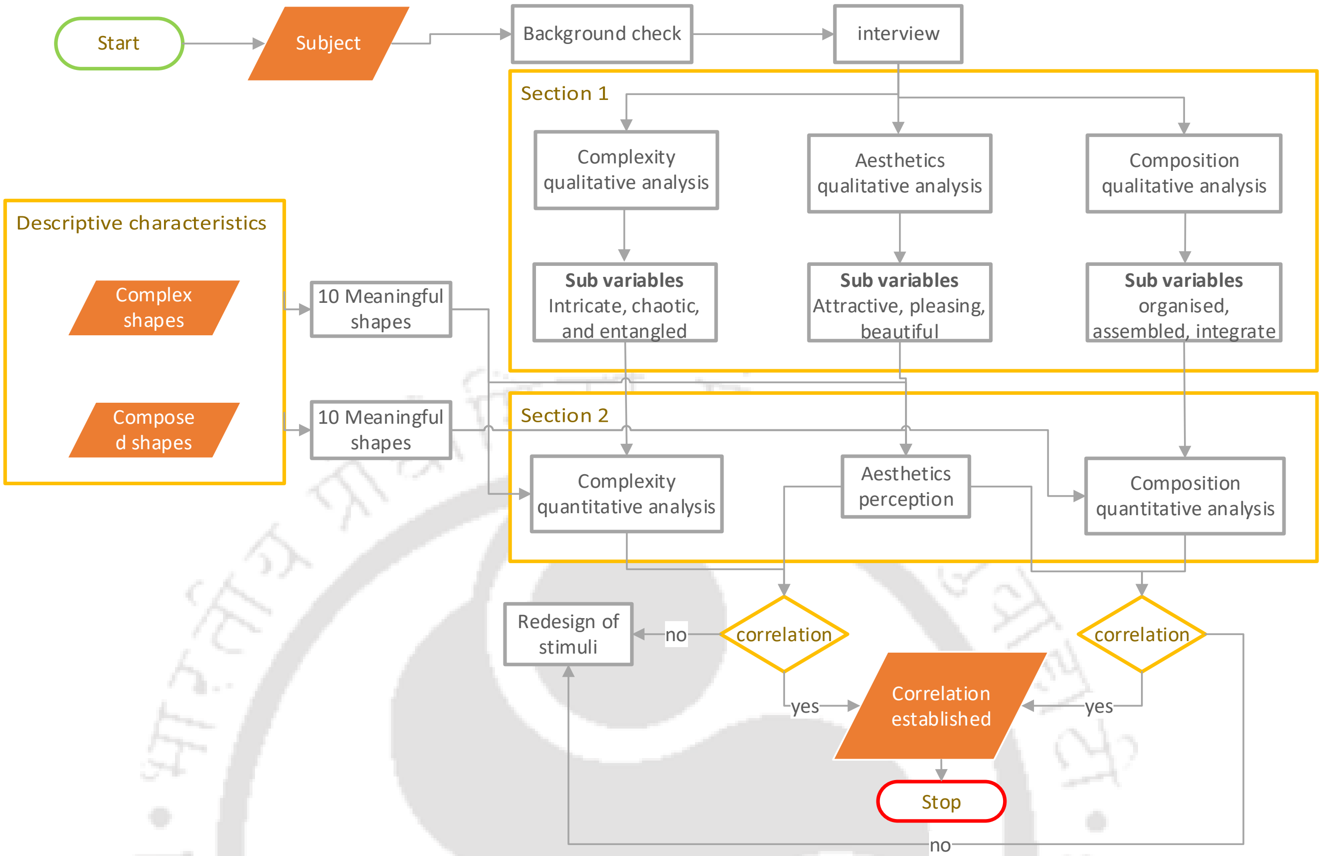


Figure 3.2. Methodology followed for subjective evaluation (Study 1)

3.3.2 Qualitative aesthetic variable determination (Section 1)

For this study, students from the Indian Institute of Technology, Guwahati, principally from the department of design are recruited. To maintain the difference in aesthetic attitude (Stolnitz, 1978), similar student with equivalent study background were chosen. During the selection of stimuli, a set of questionnaires also floated among the subjects to select the most understandable synonym words for further subjective evaluation.

Figure 3.3. Subject participating in image selection

3.3.2.1 Semi-Structured Interviews

To see whether we can establish the criteria or determine the variables of aesthetic perception with parameterization, we planned to conduct semi-structured interviews with participants. These interviews are conducted for the last part of the first section of the experiment. The main objective is to determine the criteria for judging aesthetics, complexity, composition, and sub-variables. The subjects were asked a question like, "What made one image more aesthetic than another"? Simultaneously they were asked about the synonyms of these verbs. After the frequency count of these selected verbs, we conducted a ranking test. As an output, we find out the suitable sub-variables used for parameterizing the aesthetics variables. The task performance of the subjects was observed with the question-answer session at the end. The interviews also allow us to see how the participants coped with the task and offer them an opportunity to ask questions and comment on the experience. This data is documented as written documents. Later converted into excel files and transcribed for qualitative analysis, as described in the following section.

3.3.2.2 Transcription Coding and Analysis

This analysis identified and categorized the various responses to the interview questions and the significance of their interpreted data. There are some differences between the qualitative and quantitative data. Quantitative data depends upon the rating of the physical object and interpreted statistically. This experiment used quantitative data to determine the variables like aesthetic perception, meaningfulness, and preference of 2D shapes. Similarly, qualitative data usually interpreted through the written or recorded data and deals with the semantic information of the object. Our objective is to determine aesthetics, complexity, and composition, excluding their semantic information. Thus, we required a different approach like the content analysis. During the semi-structured interviews, we were simultaneously converting and constructing the content of the subject's answer. The process is called transcription (Krippendorff, 2018), which is one of the methods of content analysis. Saldaña, 2021, defined that reading, leveling, and decoding are the primary way to create a database for subjective analysis: "coding is the transitional process between data collection and more extensive data analysis." Amongst the various methods of content analysis, this section of study focuses on transcription coding to analyze the qualitative data gathered via semi-structured interviews.

Since the nature of subjective data to be collected is quantitative, it is appropriate to use statistical data analysis methods. Because in section one, we have done frequency count to find out the sub-variables (helped for parameterization only) of complexity and composition. Later on, in the second section, we are looking for a correlation between perceived complexity and subjective aesthetic perception.

3.3.3 Quantitative aesthetic variable determination (Section 2)

As the independent variables of aesthetics, perceived complexity and perceived composition are the primary subjective measure. The other subjective measurements in this study are aesthetic preference (how much a shape is liked) and meaningfulness. This evaluation is done particularly in the second section of the experiment. Only the selected 20 meaningful images from the first section of the experiment were chosen for aesthetic evaluation. In this study, we abbreviate aesthetics to three measures as preference, meaningfulness, and perception. Philosophical aesthetics classifies aesthetic preference as a judgment of agreeableness (Birkin, 2010).

After the 20 filtered out, meaning full shapes in section 1. To represent data in section 2, there is a hierarchy needed for complex and composed stimuli. Since there is no method to determine the hierarchical arrangements for stimulus for understanding perceived variables. There a different strategy is employed to find out the hierarchy among stimuli. Here the stimuli were 1st arranged based on their symmetrical types. Then rearrangement was done between the group, based on the figure background and curve angle ratio. Similarly, selected images were ranked for complex stimuli based on the number of points they have formed upon. The method requires the participation of volunteers to engage in tasks, which for this study are recruited from students at the Indian Institute of Technology, Guwahati, principally from the department of design.

3.3.3.1 Protocol

In this section of the experiment, magnitude estimate scaling (MES) technique is used to collect the empirical data of the perceived aesthetics, perceived complexity and perceived composition. In this field, this technique was employed by Donderi & McFadden, 2005. To achieve this, first, we have collected a whole spectrum of stimuli. However, complexity varies from simplest to complex stimuli and composition varying from unorganized shape to most organized shape. All of the stimuli were made from varying descriptive characteristics. A pilot study was run to prepare the information scale of complexity and composition measurement. The subjects were informed about the lowest and highest scale of the subjective rating before the experiment to have an idea about rating scale during the rating. After collecting empirical data, we have done correlation separately between the composed and complex variables with perceived aesthetics.

3.3.3.2 Participants

A total of 85 students participated in the experiment voluntarily. Participated students are of a mixture of South Asian ethnic groups from the Indian Institute of Technology Guwahati. As the study is a perceptual experiment, subjects were kept naïve and uninformed on the purpose of the study, but the experimental procedure is informed briefly. After the experiment, the rest of the information on the purpose of the experiment were informed to the subjects on the basis of their interest. All subjects gave written informed consent through a consent form approved by the ethics committee at the Indian Institute of Technology while compiling international and national guidelines for humans as subjects (Declaration of Helsinki, 1964). Subjects were also informed about the right to withdraw from the experiment according to their will. Communication language for the experiment is limited to English or Hindi, and subjects without understandability of these languages were excluded from this experiment to avoid communication problems. Participants were undergraduate, master, and Ph.D. students with familiarity with elements of design. They were 69.4% males and 30.6% female students. The exclusion criteria for age was considered from 18 to 40 with an average age of 23. All subjects' vision were normal or used external goggles to normalise vision.

3.3.3.3 Materials/ Stimuli

Two sets of Ten monochromatic 2D random shapes, all printed in A4 papers, were used as visual stimuli. A different set of stimuli were used for the variable of complexity and composition to check the relation between the descriptive qualities with aesthetic variables (perceived complexity and perceived composition). Each shape was made by varying the descriptive qualities of shapes in a controlled manner through grasshopper programming (no of points, curve angle ratio, object background ratio, symmetry). For section 1, 60 random images were generated with each set to access the perceived complexity and the perceived composition of the visuals. As mentioned in section 2, only 20 images were filtered out based on their meaningfulness. For set 1 stimulus, the number of points of the stimulus is controlled, and other descriptive quality of the shapes remained constant to observe perceived complexity. Similarly, for set 2, stimuli were generated varying variables like symmetry, curve angle proportion, figure background proportion to evaluate perceived composition.

3.3.3.4 Stimulus presentation

The experiment was designed to detect complexity and composition dependent aesthetic arousal. Therefore, all the information related to descriptive qualities of shape, that the prior knowledge or memory could influence had to be considered. To ensure this, the abstract shapes were selected so that the exact meaning could not be expected and easy to interpret to the subjects. During the questionnaire and briefing session, subjects were seated in a normally illuminated room. In the 2nd section of experiment 85, selected participants rated perceived complexity and perceived composition respectively for two sets of selected stimuli. The presented monochromatic shapes were grey with a maintained value for all stimuli. The whole stimuli were presented on a white background to maintain a uniform contrast level. The order of the images was random and presented at once, where subjects has to rate the stimulus according to the magnitude estimate scaling. Visuals are projected on a screen while maintaining the uniformity of the shapes.

3.3.3.5 Apparatus

All of the stimuli were created using Rhino 5 version and displayed using google form on an intel I5 Pc on OS window 10. All stimuli were displayed in a 42- Inch LCD monitor (1024 X 786 resolution, SAMSUNG, Model No. PS42A410C1) which is connected to a I5 intel pc through local network in a darkened room. The background colour and contrast of the stimuli kept constant for the whole experiment.

3.3.3.6 Task

In section 2, subjects were asked to sit in a calming posture for 5 minutes for better acclimatisation of the environment. Then the affect evaluation task was given to subjects and asked to rate each stimulus for aesthetic preference, meaningfulness, complexity, composition, etc. (Friedenberg & Bertamini, 2015). All the images appeared on the monitor at a time. The subjects were asked to rate all the stimuli on a 7-point Likert scale, where `lowest' is levelled at 1 and reflect "not pleasing at all". Similarly, `highest' rating of 7 reflect `extremely pleasing' and number 4 reflect "neutral". To get the better accuracy in the subjective rating, magnitude estimate scaling (MES) is used. The subjects were shown the previously generated scale so that they will have an idea of uniformity while rating. During the experiment, the subjects were encouraged to use the full scale.

3.4 Result and discussion

The present section focuses on determining the comprehensibility and understanding of aesthetics variables of a 2D shape and check the relationship among them. To validate the followed methodology of the experiment, the obtained data are analyzed, and the results are interpreted. The result is divided into two parts as per the output of the section of the experiment.

3.4.1 Result of qualitative aesthetic variable determination (Section 1)

In section 1, the data of 37 participants are shown in table 3.1. The table explains the output of the conducted experiment. From the table, some of the concepts related to aesthetics which are very similar in the available literature, can be concluded from the transcription analysis. The numerical data are shown in the table fulfill the objective of the experiment. There is a total of six questions asked. Three questions are asked to determine the properties of aesthetics, complexity, and composition from the six questions. The remaining three questions are asked to finalize the sub variables of aesthetics, complexity, and composition. The result of the asked questions was coded first. Then sub variable for complexity, composition and aesthetics were determined from the rating of 100 subjects using google forms. Then frequency count of the subsequent data was done. Later ranking was done to understand the codes that influence variables. The obtained result can be interpreted with the section 2 result to conclude the output of this study. The finalized sub variables are later used in section 2 of the experiment to determine the correlation between the descriptive characteristics of 2D shape and aesthetics, complexity, and composition.

Table 3.1. Result of the analyzed data of the interviews and synonyms selection.

Q1. Criteria for judging Aesthetics (20) (37 Participants)	**Code**	**Count**	**%**	**Rank**
Complexity	1			
Quantity of object’s elements (shapes/ lines/colour/texture)	1I	7	18.9	4
Variety of object’s elements (shapes/ lines/colour/texture)	1II	3	8.1	9
Amount of variation (order)	1IIb	1	2.7	13
Composition	2			
Ratio of variation (composition element) (figure background ratio	2a	12	32.4	1
Symmetry	2b	8	21.6	3
Position	2c	5	13.5	6
Contrast	2e	4	10.8	7
Hierarchy	2g	2	5.4	11
Sequence	2i	1	2.7	12
Repetition/ Redundancy	3	4	10.8	8
Invested in forming object	4a	1	2.7	14
Understanding the object	4b	2	5.4	10
Personal attachment/memory	5	12	32.4	2
Amount of Semantic information	6	6	16.2	5
Q2 Synonyms for word Aesthetics (For 100 Participants)	**Code**	**Count**	**%**	**Rank**
Attractive	1	79	79	1
Pleasing	2	74	74	3
Composed	3	26	25	9
Understandable	4	20	20	10
Appealing	5	69	69	4
Beautiful	6	77	77	2
Q3. Criteria for complexity (20) (37 Participants)	**Code**	**Count**	**%**	**Rank**
Complexity	1			
Quantity of object’s elements (shapes/ lines/colour/texture)	1I	27	72.9	1
Variety of object’s elements (shapes/ lines/colour/texture)	1II	7	18.9	2
Number of varieties	1IIa	5	13.5	3
Amount of variation (order)	1IIb	2	5.4	4
Composition	2			
Contrast	2e	1	2.7	6
Size	2f	2	5.4	5
Repetition/ Redundancy	3	1	2.7	7
Q4 Synonyms for word Complexity (For 100 Participants)	**Code**	**Count**	**%**	**Rank**

Order	1	5	5	9
Understandability	2	3	3	10
Intricate	3	67	67	2
Chaotic	4	64	64	3
Confusing	5	61	61	4
Hard	6	51	51	7
Critical	7	59	59	6
Tough	8	61	61	5
Compound	9	31	31	8
Entangled	10	79	79	1
Q5. Criteria for composition (20) (37 Participants)	**Code**	**Count**	**%**	**Rank**
Complexity	1		2	
Quantity of object’s elements (shapes/ lines/colour/texture)	1I	1	2.7	8
Composition	2			
Ratio of variation (composition element) (figure background ratio,	2a	4	10.8	3
Symmetry	2b	11	29.7	1
Position	2c	7	18.9	2
Orientation	2d	1	2.7	9
Contrast	2e	3	8.1	4
Hierarchy	2g	1	2.7	10
Grouping	2h	2	5.4	6
Sequence	2i	2	5.4	7
Repetition/ Redundancy	3	1	2.7	11
Personal attachment/memory	5	3	8.1	5
Amount of Semantic information	6	1	2.7	12
Q6 Synonyms for word Composition (For 100 Participants)	**Code**	**Count**	**%**	**Rank**
Assembled	1	67	67	1
Organised	2	56	56	3
Balanced	3	26	26	7
Harmony	4	46	46	6
Combination	5	54	54	4
Integration	6	64	64	2
Arrangement	7	54	54	5
Mixing	8	8	8	8
Consolidation	9	3	3	9
Balanced	10	3	3	10

In section 1, separately developed random 2D shapes were shown to subjects during the interview. A total 60 number of shapes were shown to subjects, and most meaningful images were asked to filter out. We found out that for both complex and composed stimuli, the images were filtered out were made out from 10 to 20 points. Figure 3.1a and 3.1b have shown the most meaningful filtered images.

To check whether random 2D images are feasible to use as test stimuli for section 2 evaluation, the current test was done. Twenty monochromatic 2D shapes, 10 in each set, were chosen from the set of 60 stimuli representing the range of complexity and composition in stimuli. The images were printed on A4 paper and pined on two pinboards (Figure 3.3). The purpose was to show all 60 stimuli at a time to have a comparative idea regarding shapes. All 37 subjects were given task to filter out meaningful perceived images as the shapes were abstract in form.

The demographic profile of the questionnaire sample (n = 37) indicates a there were 62.2% male and 37.8% female. The age cap was restricted to 18 to 40. The highest group of age were from 24 age group with 7 number participant and contributed to 18.9% of the total group. Participants were drawn from various professions, but most of the subjects were design students contributing 48.6% of the total participant. All the participants showed interest in the interview.

From the transcription coding of the questionnaire, total 20 components extracted for evaluation. The three components relevant to this study were interpretable as aesthetic perception, perceived complexity, and perceived composition. Individual questionnaires, along with their coding, are indicated in table 3.1. In the interviews for evaluation, the aesthetic perception topmost five components were Ratio of variation (32%), Personal attachment/memory (32.4%), Symmetry (21.6%), Quantity of object's elements (18.9%), Amount of Semantic information (16.2%) that justified the criteria for judging aesthetics. Similarly, for perceived complexity, the top most five components were Quantity of object's elements (72.9%), Variety of object's elements (18.9%), Number of varieties (13.5%), Amount of variation (order) (5.4%), Size (5.4%). The top five criteria for judging perceived composition were Symmetry (29.7%), Position (18.9%), Ratio of variation (10.8%), Contrast (8.1%), Personal attachment/memory (8%).

Therefore, from the interview, it's clear that complexity and composition both contribute to the cause of aesthetic arousal. It also confirms the role of personal attachment and semantic information of the object to influence the aesthetic perception. One of the outputs of the interview was that 2D shapes could be used to evaluate aesthetics. The overall results of the coded data of interviews are encouraging as the available literature's outcome matches subjects' perceptions. The proposed variables were influenced by the descriptive characteristics of shape and its matching with the interview result. One drawback of measuring perceived aesthetics, complexity, and composition by interviewing subjects was the type of output. The data provided the rank and frequency count of the asked questionnaires, which provides the idea of subjects' perceptions. Simultaneously, it doesn't give any idea about the quantity as the obtained comparative data as the obtained data was not a scaled data. Although this content analysis methods trial is an informal test procedure and lacks a thorough statistical analysis, the results are promising. They provide a basis for continuing the study towards a correlational analysis in section 2.

3.4.2 Result of quantitative aesthetic variable determination (Section 2)

In section 2, the data of 85 participants are shown in table 2 and table 3. The table provides the correlation data between aesthetics variables with the descriptive variable of 2D shapes. From the correlated data, some the concept related to aesthetics that is very similar to the available literature can be concluded. The output of numerical data shown in the table fulfills the experiment's objective to establish the relationship between the descriptive qualities of 2D shape with aesthetics variables. There is a total of two sets of questions with different set 2D shapes for complexity and composition. In each set, there are ten images to rate with magnitude estimation scaling using the Likert scale.

In this section, the correlation has been performed to check the relationship of aesthetic variables with descriptive characteristics and observe their closeness with subjective data in section 1. the analysis section is divided into two parts and separately explained the relation with the complexity and composition variable. Even separate stimuli and separate questionnaires were used for individual variables during the experiment. After the collection of the data first, the normality test was planned as per the analysis procedure. Both subjectively scored data sets of complexity and composed stimuli came as non-parametric as the data type is not a scaled data.

3.4.2.1 Inter correlations of Perceived Aesthetics for composition stimuli

a. Correlation between Aesthetic variables for composition stimuli:

The measured aesthetic variables correlate with each other (Table 3.2a for a detailed analysis of correlations of aesthetics variables) to obtain the relationship between them. However, it is established in the previous research that meaningfulness is essential to have an aesthetic experience. Our result in correlated data reflected similarity. There is a high positive correlation between perceived aesthetics and meaningfulness ($r = .655$, $p < .001$). Apart from that, several high inter-correlation data can be noted from the table 3.2a between perceived aesthetics and its variable. Particularly the correlation data of perceived composition showed a high positive correlation (r =.631, p < .001) and a matter of investigation for further analysis to find out the relation between aesthetics and descriptive qualities of shape.

Table 3.2a: Inter correlation Coefficients (Spearman's r) of Perceived Aesthetics for composition stimuli

	Aesthetics			
Perceived Aesthetics	**Preference**	**Meaningfulness**	**Perceived composition**	**Perceived aesthetics**
Preference	1.000	.670**	.627**	.705**
Meaningfulness		1.000	.627**	.655**
Perceived composition			1.000	.631**
Perceived aesthetics				1.000

*p <0.05, **p <0.01

b. Intra correlation of Perceived aesthetics and descriptive statistics:

In all the subjects, obtained subjective data indicated significant correlations between the variables of perceived aesthetics and descriptive characteristics of 2D shapes. Particularly, for perceived composition, out of five variables of descriptive characteristics, three variables showed high correlation (Table 3.2b). Angle curve ratio and symmetry shown a positive correlation number of points in a 2D shape showed a negative correlation. There was no correlation found between the number of symmetrical sides and perceived composition. Similarly, figure background ratio showed a low significant correlation with perceived composition.

In section 1 of the experiment, 29.7% of the subjects confirmed that symmetry is a part of perceived composition that contribute to the aesthetics of the object. Similarly, 10.8% subjects confirmed that ratio and proportions are also the variable of composition. It is observed same from the table below and confirms that the count, angularity, and symmetry affect the perception of the composition, which influence the aesthetics of the object directly.

Table 3.2b: Intra Correlations (Spearman's r) of Perceived Aesthetics and Descriptive qualities for composition stimuli

	Descriptive qualities				
Perceived aesthetics	**Number of Points**	**Angle curve ratio**	**Figure background ratio**	**Symmetry**	**Symmetrical sides**
Preference	-.107**	.042	-.044	.051	.073*
Meaningfulness	-.091**	.009	-.023	-.051	-.026
Perceived composition	-.159**	.101**	-.088*	.092**	.038
Perceived aesthetics	-.095**	.017	-.070*	.033	.094**

*p <0.05, **p <0.01

Bold values represent p <.05 and are additionally marked with one or two asterisks, respectively

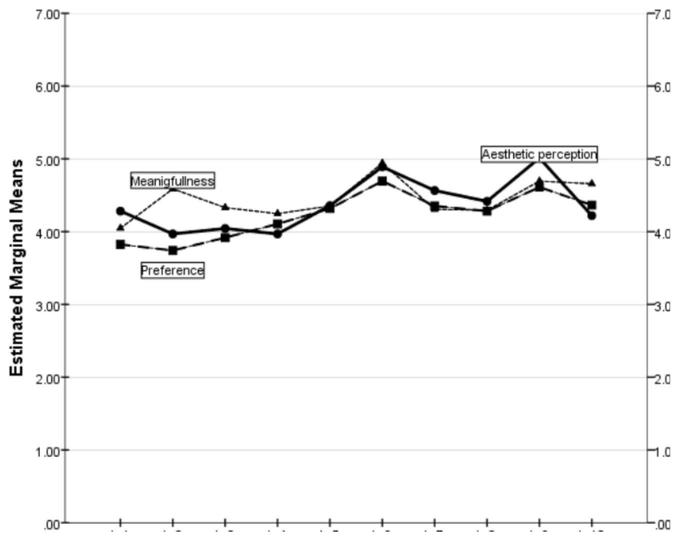


Figure 3.4a: Plot of Aesthetic preference, perceived meaningfulness and perceived aesthetics

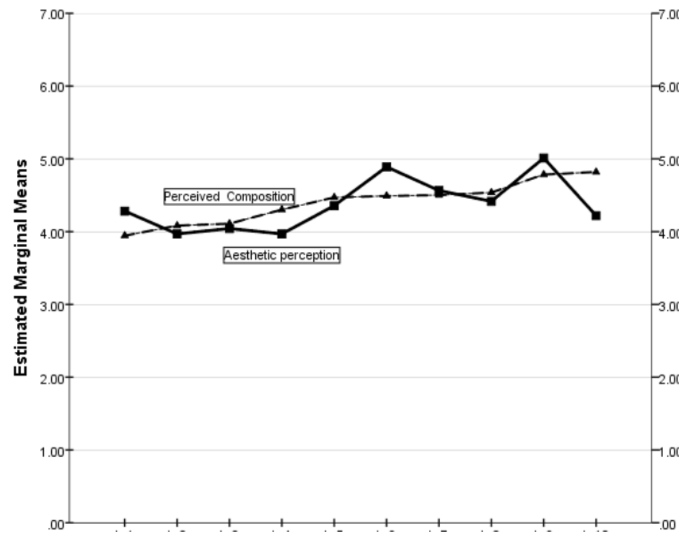


Figure 3.4b: Shows the plot of perceived aesthetics, perceived composition

[Note Figure: Type of symmetry is varying from image 1 to 10. Starting from horizontal symmetry to rotational symmetry]

Figure 3.4a shows the averages (mean) of all participants for the subjective ratings of Aesthetic preference, perceived meaningfulness, and perceived aesthetics. Here X-axis represents the ten most composed images shown to the subjects. The images were arranged in a way that the types of symmetrical category the shape fall into. In Y-axis, the mean of the subjective scale is represented. In the graph, the preference is represented by a dashed line, and the meaningfulness of the images were rated as dotted line. The continuous line is represented by the aesthetic perception. Similarly, for Figure 3.4b, two subjective variables, aesthetic perception and perceived composition were compared. All of the scales, both X and Y axis, were similar to the Figure 3.4a. Here the perceived composition is represented by a dotted line, and aesthetic perception is represented by a continuous line.

From Figure 3.4a it can be observed that the 2D shapes with a lower or higher level of symmetry doesn’t show the much-perceived difference between the variables. This may signify that the amount of information increase in the stimuli may not influence the perceived subjective data in composition. The overall perceived aesthetics line rated higher than the preference and meaningfulness line. The whole trend of the graph is wavy and progressive in a horizontal line that varies equally for all three variables and signifies that there is not much difference in subjective perception for all variables. Unlike Figure 3.4a, Figure 3.4b line graph trends for both variables are different. Where the perceived composition line increased in higher symmetrical shapes. The whole trend of aesthetic perception line was overall wavy and parallel.

3.4.2.2 Inter correlations of Perceived Aesthetics for complexity stimuli

a. Correlation between Aesthetic variables for complexity stimuli:

The complexity stimuli measured aesthetic variables correlate with each other to obtain the relationship between them. Similar to the composition stimuli, a high positive correlation was observed between perceived aesthetics and meaningfulness ($r = 0.707$, $p < .001$). Other aesthetic variables showed a strong intra correlation with meaningfulness and can be observed in table 3.3a. Further, the correlation data of perceived complexity showed a high positive correlation $r = .333$, $p < .001$) and a matter of investigation for further analysis to find out the relation between aesthetics and descriptive qualities of shape.

Table 3.3a: Inter correlation Coefficients (Spearman's r) of Perceived Aesthetics for complexity stimuli

	Perceived Aesthetics			
Perceived Aesthetics	**Preference**	**Meaningfulness**	**Perceived complexity**	**Perceived aesthetics**
Preference	1.000	.726**	.314**	.664**
Meaningfulness		1.000	.347**	.707**
Perceived complexity			1.000	.333**
Perceived aesthetics				1.000

*p <0.05, **p <0.01

b. Intra correlation of Perceived aesthetics and descriptive statistics

After finding out the relation between the aesthetic variables, we investigated whether the aesthetic variables are related tothe descriptive characteristics of a 2D shape. Therefore, intra correlation was done to observe the relationship between the stimuli's aesthetic variable and perceived complexity. In all the subjects, obtained subjective data indicated significant correlations between the variables of perceived aesthetics and descriptive characteristics of 2D shapes. Particularly, for perceived complexity, out of 4 variables of descriptive characteristics, two variables showed high correlation (Table 3.3b). The number of points showed a positive correlation, and the angle curve ratio in a 2D shape showed a negative correlation. There was no correlation found in the figure background ratio. The symmetry as a variable is not used as a descriptive variable because we have used asymmetrical shapes as stimuli to determine the perceived complexity of the shapes.

In section 1 of the experiment, out of the total subjects, 72.9% of the subjects confirmed that quantity is a part of perceived complexity. Similarly, 18.9% of subjects confirmed that verity is also a complexity variable. It is observed from the table below and confirms that count and angularity affect the perception of the complexity, which directly influences the aesthetics of the object.

Table 3.3b: Intra correlation Coefficients (Spearman's r) of Perceived Aesthetics for complexity stimuli

	Descriptive qualities		
Perceived Aesthetics	**Number of Points**	**Angle curve ratio**	**Figure background ratio**
Preference	-.031	.022	.092**
Meaningfulness	.015	.013	.085*
Perceived complexity	.174**	-.096**	-.019
Perceived aesthetics	-.056	.051	.063

*p <0.05, **p <0.01

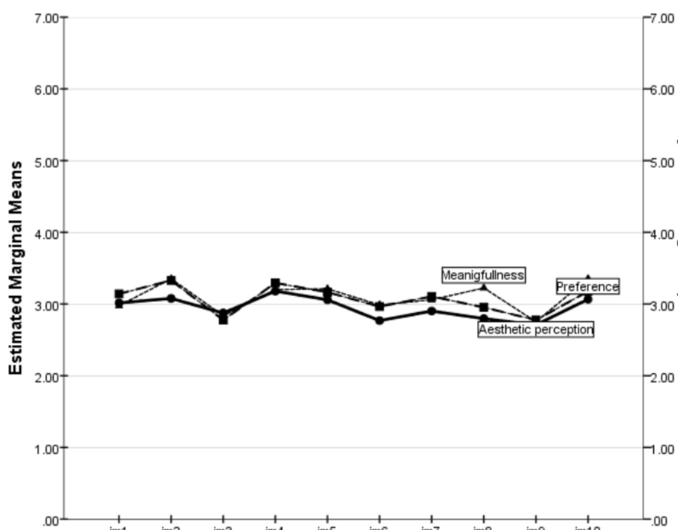


Figure 3.5a: Plot of Aesthetic preference, perceived meaningfulness and perceived aesthetics

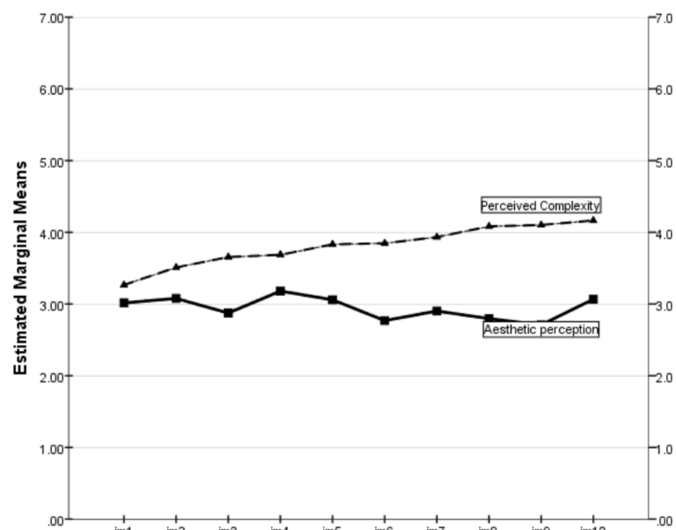


Figure 3.5b: Shows the plot of perceived aesthetics, perceived complexity

[Note Figure: Type of symmetry is varying from image 1 to 10. Starting from horizontal symmetry to rotational symmetry]

Figure 3.5a shows the averages (mean) of all participants for the subjective ratings of Aesthetic preference, perceived meaningfulness, and perceived aesthetics. Here X-axis represents the ten images shown to the subjects. The images were arranged in a way that the number of points increases in each image from left to right. In the Y axis, the mean of the subjective scale is represented. In the graph, the preference is represented by a dashed line, and the meaningfulness of the images is represented as the dotted line. The aesthetic perception represents the continuous line. Similarly, for Figure 3.5b, two subjective variables, aesthetic perception and perceived complexity, were compared. All of the scales, both the X and Y axis, were similar to Figure 3.5a. Here perceived complexity is represented by a dotted dash line, and a continuous line represents aesthetic perception.

Figure 3.5a shows that the 2D shapes with a smaller number of points have a similar subjective score average for preference, meaningfulness, and aesthetics. The subjective score varies in shape with a higher number of points. This may signify that the amount of information increased in the stimuli may influence the perceived subjective data. The whole trend of the graph is wavy and progressive in a horizontal line that varies equally for all three variables. Unlike Figure 3.5a, Figure 3.5b line graph trends for both variables are different. Where the perceived complexity plot increased with the number points in the shapes. The whole trend of the aesthetic perception line was overall wavy and parallel.

While exploring the relationship between aesthetic variables and descriptive measures of 2D shapes, it is clear that dealing with 2D shapes increases perceptual difficulties for the subjects. Particularly higher complex and lower composed shapes were difficult to perceive. The reason might be that many variables influence aesthetics, and limiting those variables to 2D shapes that to only one object per image influenced perception. Therefore, descriptive qualities showed a significant correlation with the aesthetic variables but on a lower side. The result of section 1 interview and section 2 subjective rating on the 2D shape and its variable reflected similar results. For example: in both experiments, the role of meaning as a variable is clear for the aesthetic experience.

3.4.3 Discussion

The experiment results indicate that the aesthetic variable has a strong relationship with the descriptive qualities of a shape. In this article, the subjective aesthetic rating of the 2D shape is done, and its relation with descriptive properties was highlighted. From this point, future studies can go in two directions. In one direction, a higher level of forms with variables like color and texture analysis can be included in the aesthetic studies. Similarly, the same phenomenon can be studied with the use of biometric equipment. Except for these, environmental aspects like gender, cultural influence, aesthetic attitude, and age can be explored. There are few numbers of study available that is done on the aesthetic subjective rating of 2D shapes.

The research questions were addressed by identifying the variable of perceived aesthetics and descriptive characteristics from the interview and coding. Then followed by a rating task of the selected images from section 1. The subjective data we collected are in two ways, both by interview and rating. Both sections of the experiment have a similar output and show the strong relationship between an aesthetic variable and descriptive characteristics of the 2D shape.

While in section one, 37 subjects participated, in section two, 85 subjects have participated. The result in section 1 confirmed that the composition and complexity are the two reliable variables for observing subjects' perception. Also, 20 meaningful images were filtered out for the experiment in section two. A strong correlation is observed between several descriptive characteristics and aesthetic variables. This finding shows that having a high descriptive characteristic does not necessarily mean that the subjective aesthetic ratings are also high for the same object. Many correlational researches confirmed the same findings from previous studies (Datta et al., 2006; Karvonen, 2002; Palmer & Schloss, 2010; Amirshahi et al., 2014). Additional studies are needed further to understand the influence of trendiness on aesthetic preference. Finally, in this experiment, 2D shapes have a wider range of different subject matters, as an abstract shape can be interpreted and perceived in several ways.

We found no inverted 'U' relation between descriptive characteristics and perceived complexity. Instead, the perceived complexity plot continuously increased. One of the reasons might be not hitting the threshold of visual complexity (Wolfram, 2002) during stimuli selection in section 1. The higher complex images (which are controlled by descriptive characteristics) are rated higher in perceived complexity than other images with lower descriptive values. Besides ratings of complexity and composition of the shapes, a further rating task is added in the form of preference and meaningfulness. So that the whole spectrum of the variables can be covered from physiological to psychological.

3.5 Conclusion

The results indicate that aesthetic perception is exceedingly inconstant to human experience and tough to limit to a simple function of complexity and composition alone. One exciting outcome was that perceived complexity was found to be significantly correlated with the number of points, curve angle ratio, and perceived aesthetics. Similarly, the perceived composition was significantly correlated with the number of points, curve angle ratio, figure background ratio, symmetry, and perceived aesthetics. It indicated that descriptive characteristics would directly influence the perception of complexity and composition during the aesthetic perception of 2D shapes. In experiment 1, semi-structured interviews with participants suggest that most of the factors that influence aesthetic perception are directly or indirectly part of perceived complexity or composition. The result of the literature study in chapter 2 and the subjective study was done in this chapter resembled the same output and put a direction to the research while selecting the variables of aesthetics.

4

The Relation Between the Aesthetics perception and Eye-tracking Data of 2D and Natural Stimuli

Abstract

The previous chapter confirmed the global variables of aesthetics through qualitative analysis while showing the feasibility of the empirical evaluation of the abstract 2D shapes. The current chapter explores the possibility for the quantitative assessment of the aesthetic perception of filtered abstract 2D shapes. Using different 2D stimuli was mandatory for complexity and composition evaluation because the methodology demands the separate control of complexity and composition in the stimuli. The methodology also incorporates all the aesthetic perception requirements like availability of both subject and object, repetition, cultural and environmental factors, etc. Further, in section two of this chapter, we have explored whether a similar aesthetic phenomenon can be observed with natural images. The primary objective of this chapter is to document the analysis of the solutions to define the relation between the subjective and objective data. The plan is to measure the perceived composition and perceived complexity to see how it corresponds with aesthetic perceptions of visual objects through an eye tracker. The eye-tracking test was done separately to collect 2D and natural stimuli data. Aesthetic perception is quantified by questioning participants to rate the stimuli, and a statistical analysis determines how these ratings correlate with eye-tracking data. Finally, the subjective rating and the objective eye-tracking data were correlated along with the ANOVA to find out the relation between the aesthetics and eye-tracking variables.

4.1 Introduction

William Shakespeare once said, “The Eyes are the window to your soul.”. The quote's actual interpretation may not directly relate to this research work. Still, it is quite conclusive that the human eyes are the sensory organ with many facets other than viewing. The neurological studies suggest that when we see objects for visual identification, they rely primarily on sensory information. The information about the object instantly affects different parts of the brain that influence eye movements (Stroop, 1935) for psychological motor control. Those eye movements can be monitored and utilised by the researchers as subjects look at what subjects are thinking about. Therefore, it can be said that "eyes are the window to the subject's soul" and has a greater application in monitoring human affect.

There is a constant argument between formalists and sentimentalists over aesthetic evaluation. When formalist justifies the objective approach to the aesthetic evaluation, sentimentalist doesn't support that. Moreover, there is no consensus regarding the advantage of one technique over another (subjective vs. objective evaluation) when evaluating the aesthetic experience. Bottom-up information processing is influenced by individual graphical elements (position, color, size, shape, orientation, etc.) that interact to create compositional and complex features of the aesthetic object. The visual composition and complexity directly affect the aesthetic perception. The eye movement behavior has been studied by various researchers (Wallraven et al., 2009; Graham et al.,2010; Mould et al., 2012; Birkin, 2010; Mühlenbeck et al., 2016; Wang et al., 2014; Nodine et al., 1993) in the context of aesthetic decision making, varied attention level, the role of art training, repetition of visual information, visual interest and different cultural factors along with the cognitive functioning of bottom-up processes.

An eye tracker also provides information accessibility of visual search. We ask people to view a visual/stimulus for a limited amount of time (6 sec) during an eye-tracking experiment. The researchers do not understand the subject's aesthetic sense and how visual exploration differs in aesthetic experience from normal information search. Another problem with eye-tracking research was that subject's state of mind. Subjects with lower aesthetic attitude can view differently and may lead to constant distraction in eye movements even when stimuli remain the same. It means stimuli may be functionally same, but perceptual levels differ.

Earlier researchers have explored the visual properties of images and established relationships between them. But very few numbers of researchers (Guo et al., 2019; Ho and Lu, 2014; Shi et al., 2021; Gu et al., 2021; Liu et al., 2020; Guo et al., 2016) have explored the aesthetic measures through objective means (eye-tracking variables). Apart from the motivational factors, aesthetics is affected by different environmental noises. Therefore, while doing an empirical study on aesthetics, it is challenging to control all the environmental noises, particularly for 2D shapes.

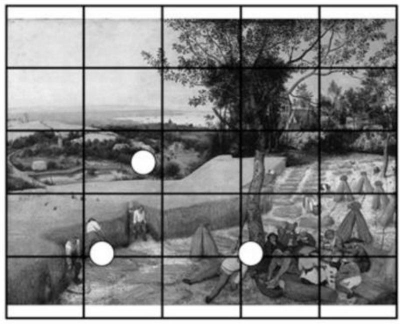
The psychological motor control during the aesthetic viewing, consists of some basic reflexes of human eye movement like fast information search and getting a whole narrative before assembling the collected information. The details of the cognitive functioning of aesthetic viewing have been explained in chapter 2 of this thesis. This study has tried to identify eye movements while organizing a quantitative study to determine the correlation between aesthetic measures and eye-tracking variables. We have constituted the visual aesthetic measures that affect aesthetic perception from the literature. Finally, a methodological approach is followed that examines the association between aesthetic variables and eye-tracking variables. We have also conveyed the importance of the role of eye movements along with the human behavioral interpretation of the varied attention level. Therefore, this chapter started with the justification of the eye tracker as a tool to quantify human attention levels. Later on, we have investigated and represented the mapping of visual complexity and composition through eye-tracking. To answer the derived research questions from this research, a suitable methodology is designed, and analysis was done. Finally, in the result section of this chapter, the correlation, and association among the dependent and independent variables were explained.

4.2 Eye tracking visual exploration pattern, and Human behavioral interpretation

The top-down and bottom-up processes can contribute to a better understanding of the functionalities of aesthetic experience with the multiple stages of operation. During the aesthetic experience, the visual exploratory pattern with human behavioral interpretation can elaborate the reasoning behind the functioning of the cognitive processes. Once information is provided to the brain, the cognitive and perceptual process starts in the brain that gives output as emotion and aesthetic judgment. To monitor different semantic information and its perceptual interpretation, eye tracking proved to be a very effective medium. In visual aesthetics, several image perception models are there based on the eye movements. From the literature, it's obtained that visual composition and complexity affect the viewing pattern. First (Mackworth and Morandi, 1967) represented a framework for visual attention based on information theory. Later the same method was used by Antes, 1974 to record eye movements to study visual perception. The above method provided a platform to guide visual exploration through eye movements. (Goller et al., 2019) studied visual attention between the face and paintings and established the relation between liking and visual Attention. There are two major parameters for the visual exploration exit (duration of the fixation and length of the saccade). Though it appears that the eye moves fluently in its sockets, research showed while watching the eye make continuous jumps. The pauses between the jumps are called fixations, and the jumps itself are called saccades. Apart from saccade and fixation, other eye tracking variables are present that determine the visual behavior of the observer.

Earlier Berlyne, 1973 classified two types (specific and diversive) of visual exploration with different motives. He found that initial eye moments saccades were long, and the fixations were short. After a few seconds, longer fixation and smaller saccades were observed. In actual we can say that first eye tries to have a random analysis on the content in diversive exploration. And in specific exploration, the eye concentrates on the specific region of interest to understand the semantic meaning of the object. In general, diversive exploration is considered short, and its fixation duration is considered to be under 300 milliseconds.

Similarly, the nature of the specific exploration is long, and the fixation duration is considered to be over 400 milliseconds. Few researchers have verified how fixation gets longer in duration and shorter by the length of fixation with time. These phenomena are observed at the start of the visual exploration. The main purpose of random exploration might be the search for the information content in the stimuli. This type of visual exploration is called as "diversive" visual exploration. Similarly, after some time, the gaze becomes shorter with a local overview of the stimuli, that type of exploration is called "specific" visual exploration. (Molnar, 1981) did an experiment and recorded thousand eye movements during 5 minutes of painting viewing and studied fixation duration and saccadic length. In that research, they have created two groups of subjects, a) Aesthetic group, b) Semantic group, and asked questions while viewing eight classical paintings. They verified the result with earlier findings. The transition period of the visual exploration from diversive to specific can be observed. The transition fixation number is between 5 to 9. The result suggested a significant difference in fixation duration in viewing patterns between the two groups. The semantic group recorded a significantly higher fixation rate when asked about what they had observed in that picture. Nodine et al., 1993 conducted an experiment between trained and untrained subjects for viewing aesthetic objects to test the effect of the formal art training. In that research, the similar properties of eye exploration like specific exploration and diversive exploration are verified with pictorial composition's significant effect on art training. Some researchers (Locher et al., 2008) performed two experiments to determine the subject’s behavioral interest in aesthetic experience. From figure 4.1 the average dwell time spent in each grid can be noted by 3 points on the picture.



		9,7,9	11,14,9	0,9,0
	9,10,0		11,0,8	
0,0,7	0,5,9	17,7,6	0,0,6	
0,9,0	0,8,7	0,0,7	0,0,8	

Figure 4.1. The percent viewing times (dwell times) for grid locations for the first 3s of viewing (first value), period 3–7s (second value), and 7s to total viewing time (third value) for each art work. The art works are: (a) Bruegel's The Harvester, (Adopted from Locher et al., 2008).

They found out that free viewing can also play a vital effect on aesthetic experience than time-bounded viewing. This experiment proved that in specific exploration, semantic and compositional element process cognitively in the brain during an aesthetic experience. Kapoula et al., 2009 proved that cognitive activity also affects the fixation duration with eye-tracking study while naming the unknown paintings.

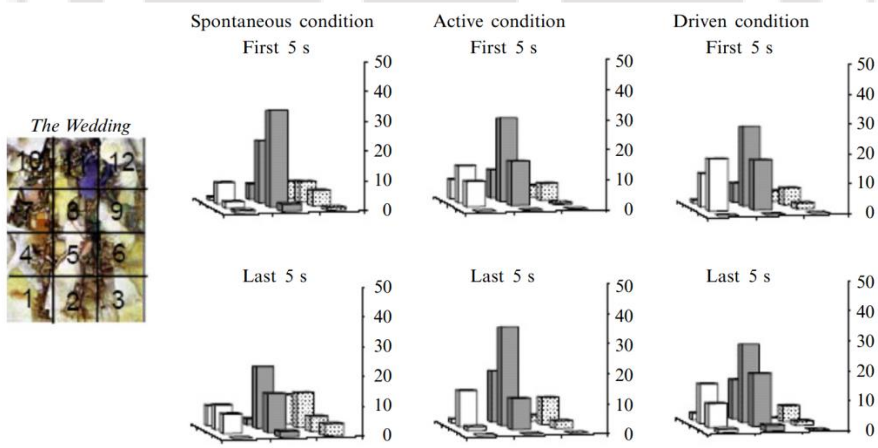


Figure 4.2. Distribution of fixation time over different areas during the first 5 s and last 5 s of exploration (adopted from Kapoula et al., 2009).

In fig. 4.2 the distribution of fixation time during the first 5 s and during the last 5 s of exploration for each condition were plotted. Inspection of the distributions shows that in most cases, the distribution of fixation time during the first 5 s is more concentrated on a few selected areas than during the last 5 s. The suggested reason was given for deeper semantic analysis during the experimental procedure. (Yarbus, 1967) reported some of the universal eye movement strategies. He reported that the fixation is high in the semantic rich area of the stimuli, not in the high-density area. The experimental output of the yarbus proved that the eye fixated in the semantic reach area. But they cannot justify whether higher fixation is due to semantic-rich information or due to compositional variables of the image. (Kaufman and Richards, 1969) proved that due to the physiological constitution, the center of gravity of the image is explored more. Yarbus also proved that the eye focuses on the center of the stimuli.

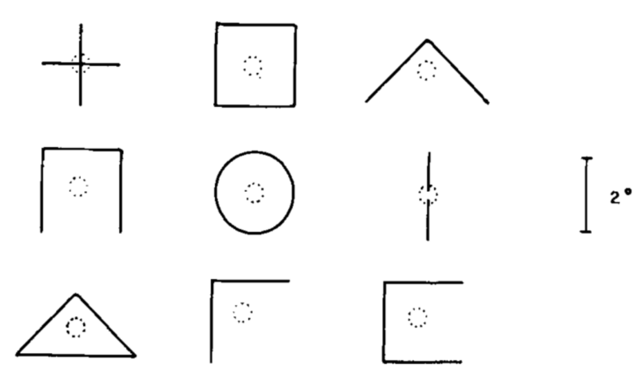


Figure 4.3. Mean spontaneous fixation positions (dotted circles) for various figures. Note approximate equivalence between open and enclosed forms (adopted from Kaufman and Richards, 1969).

Figure 4.3 shows a collection of nine figures, each subtending about a 2-degree visual angle. The small, dotted circles on the forms indicate the region where 86% of the fixations occurred. They also proved that the eye concentrates on the same local points after fully exploring (diversive and specific) stimuli. He described some of the difficulties in aesthetic visual exploration. Those are reliability of the aesthetic attitude of a subject and real aesthetic attitude in laboratory conditions. Molnar, 1981 did an experiment on two groups classified with semantic and aesthetic viewing.

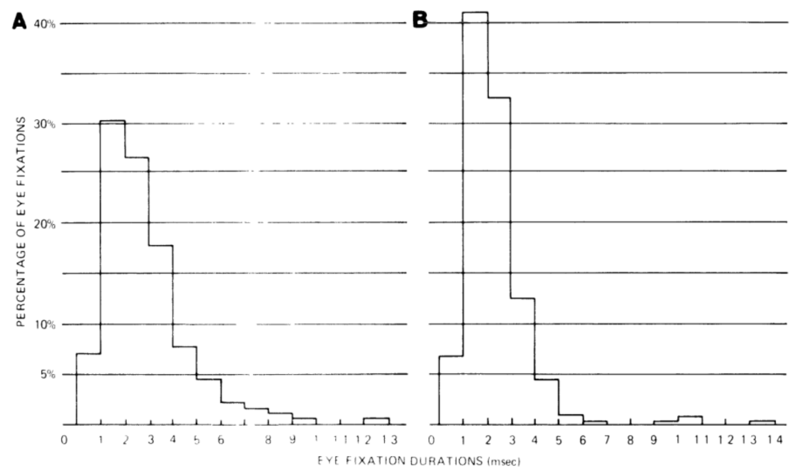


Figure 4.4. Distribution of durations of fixations grouped in classes of 100 msec: (A) Aesthetic group; (B) Semantic group (Adopted from Molnar, 1981).

They found that the aesthetic group explored the stimuli slower than the semantic group. Perhaps the reason might be aesthetic exploration is a higher cognitive task. The duration of fixation in the "aesthetic" situation (Figure 4.4A) has an outline radically different than the outline of the semantic group (Figure 4.4B). In particular, we find a greater number of fixations longer than 300 ms in the aesthetic group.

There are several types of approaches to the eye-tracking study. Different types of eye-tracking tests are there, for example, free viewing, guided viewing, content awareness task, information search task, object recognition, etc. As we know, aesthetic evaluation involves both top-down and bottom-up approaches. Task requirement is a top-down approach, and free viewing is considered as a bottom-up cognitive approach to evaluate aesthetics. Because during task requirement viewing, cognitive tasks affect the pattern of eye movements (Locher, 1996). (Wallraven et al., 2009) did an eye-tracking experiment to rate the visual complexity or aesthetic appeal of the paintings. Global search patterns are observed with lower local fixation in aesthetic appeal, and wider fixations were observed compared to visual complexity viewing. Some visual aesthetic objects can influence visual exploration in a top-down manner (Massaro et al., 2012). The aesthetic experience of the natural object, along with human-centric visuals, can have a top-down information flow due to the higher level of intimacy attached to the visual object (Nodine, 1982).

Till now, we learned that eye-tracking variables like fixation and saccades have a correlational relationship with aesthetic experience and cognitive load. It has been proved experimentally that semantic information in the aesthetic object drives attention, which drives the eye to seek information (Yarbus, 1967) and (Buswell, 1935). Information and the interpretation of information are two different things, and it's easy to get confused due to its vastness. While analysing eye-tracking data during visual exploration, if a region is full of fixation, it doesn't mean that the region is full of semantic information. It’s a combinational effect of the different variables that determine the perception of an aesthetic experience. There have been both sides to the story that some researchers have suggested that it is not possible to perceive aesthetic experience through eye movement alone (Gibson, 1950). There are other factors like subjective psychology that contribute to the cause. One of the essential reasons might be that it is not possible to explore the same object twice by the same person in a similar manner. But at the same time, there is also some similarity in the exploratory pattern of the same object by the same person (Noton and Stark, 1971) even if the subjectsees it several days apart. They have also confirmed that viewing pattern is different for different people. Some researchers also empirically proved that amount of information with its composition guides the exploration (Mackworth and Morandi, 1967).

Table 4.1. Research work identified with aesthetic variables and eye-tracking

Variables of aesthetics	Influencing sub-variables	Objective evaluation of aesthetics	Eye-tracking	Subjective evaluation
Complexity (Birkhoff, 1933; Birkin, 2010; Donderi & McFadden, 2005)	**Quantity**	Oliva *et al.*, 2004; Xing, 2007	Calvo and Lang, 2004; Mühlenbeck et al.,2016; Wang et al., 2014; Holmqvist et al.,2011; Jacob & Karn, 2003; M. Bauer et al., 2001; Leuthold et al., 2011; Wallraven, et al., 2009	Birkin, 2010; Donderi & McFadden, 2005; Olivia, et al., 2004; Xing, 2007; Megahed and Gabr,2010
	Variety	Heylighen, 1992; Heylighen, 1999; Ashby, 1991; Olivia, et al., 2004; Leeuwenberg and van der Helm, 1991; Xing, 2007		
	Order	Waldrop, 1993; Arnheim, 1974; Megahed and Gabr,2010; Arnheim, 1977; Staudek, 1999		
Composition (McManus et al.,1993; Dhar et al., 2011; Park, et al., 2016; Yao et al., 2012)	**Symmetry**	Ngo et al., 2000; Bouleau, 2014; Locher et al., 1998; Bouleau, 2014; Bauerly and Liu, 2006	Kiefer et al., 2017	McManus et al.,1993; Altaboli and Lin, 2011b; Locher et al., 1998; Bauerly and Liu, 2006
	Balance	Altaboli and Lin, 2011b; Ngo et al., 2002; Zhang et al., 2017; Arnheim, 2001; Bouleau, 2014; McManus et al., 1993; Locher et al., 1998; Bauerly and Liu, 2006		
	Proportion	Ngo et al., 2002; Arnheim, 2001; Hannah, 2002; McManus et al.,1993		

4.3 Visual aesthetic measures that affect the aesthetic perception through eye tracking variables

The bottom-up approach can measure attention during the aesthetic experience (Wallraven et al., 2009). There is also evidence that increased visual complexity in the stimuli changes the compositional value of the stimuli during the aesthetic experience and vice versa. Complexity and composition are the variables that affect aesthetic experience with the emotional output. From several psychological and neurological models, it is obtained that the attention of the subject is a crucial factor to have an aesthetic experience. Attention gets affected by the visual complexity and composition of the stimuli, but attention also affects composition in return. In the coming section, we will discuss the review work on visual complexity and composition and how these variables can be controlled by eye-tracking technology.

4.3.1 Mapping of visual complexity through eye-tracking

The balance between order and chaos defines complexity. The term complexity was coined in psychology by (Hochberg and McAlister, 1953). The introduction of complexity started with the objective evaluation of the aesthetics. There were earlier attempts to evaluate aesthetic measures through objective evaluation of complexity (Birkhoff, 1933), but they were criticised for non-consideration of the semantic aspect. There are empirical evidence that perceptual complexity exhibits an inverted U shape (wound curve) relation with visual complexity. Visual complexity affects the subject's attention, and it also helps to identify the compositional patterns in an aesthetic object. Patterns help understand and process the semantic meaning of the visual stimuli (Birkin, 2010).

Berlyne, 1978 in his book, discussed the variables of the perceived complexity. He said that "Rated complexity has been found to increase with the number of independently chosen elements in a pattern, the number of attributes distinguishing elements, the number of forms that each attribute can take and the number of attributes distinguishing elements". Martindale et al., 1990; Silvia and Barona, 2009; Güçlütürk, et al., 2016 worked on berlyne's theory and made a series of experiments to measure visual complexity. It was observed that less complex polygons were more preferred, whereas for smaller sizes the reverse was the case. The complexity of the stimuli was measured by the no curves present in the random polygons to complex abstract visuals. They discovered that semantic information is a good predictor of aesthetic experience compared to the complexity, and he also found that art training didn't affect the result in his experiment. It's proved that visual complexity only affects the attention of the subject. (Roberts, 2007) did an experiment on visual complexity by taking 7 variables of the complexity and found that aesthetic preference is mainly governed by the three variables of complexity: amount and variety of elements, recognition and scene organization, and asymmetry. The only problem is that the above studies are based on the subjective rating and don't have consistent output. In earlier experiments, the objective complexity measurement has applied to simple visuals like primitive shapes. But it's not possible to measure complex paintings with deep semantic meaning. There is one computational method called the "chessboard method" to evaluate the complexity of the paintings. In this method, a visual has to be divided with a large no of squares. Then those squares are analysed with the different level of greys as per their color tone. This discretization of visual elements is quite common in the image processing field. Several computational aesthetic studies are observed in the luminous and color study using the same method. The demerit of this computational process is that it doesn't consider subject's perception, which presence is a must for an aesthetic experience. Therefore, the eye-tracking technique is suitable for both formal and semantic information for aesthetic experience.

From the literature study on eye tracking, we observed that perceptual complexity cannot be measured directly from eye tracking variables. As perceptual complexity affects attention and attention can be measured from eye-tracking. From the pattern of eye fixation, it is observed that complexity is directly proportional to visual exploration. (Mühlenbeck et al., 2016) conducted one cross-cultural eye-tracking study between the two human groups, ethnically different from one another, and compared orangutans' fixation preferences.

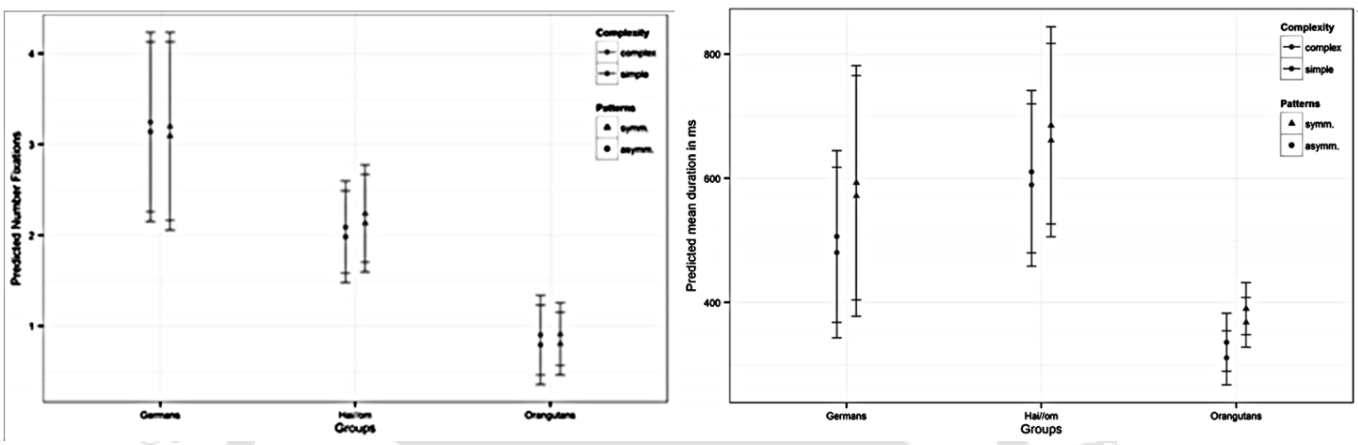


Figure 4.5. The number of fixations for symmetry, mean fixation duration for the three groups. The colors indicate the complexity of the patterns, and the different symbols represent symmetry and asymmetry with the standard deviation of the error bars (adopted from Mühlenbeck et al., 2016).

Figure 4.5 reflects that Germans had the highest number of fixations, Orangutans had the lowest. Similarly, the same graph shows that gaze points across the three groups were longer on symmetric patterns than asymmetric patterns and longer on simple patterns than complex ones. They have studied symmetry with different levels of complexity while recording the aesthetic evaluation of the pattern from human groups. They found out the aesthetic preference of humans for well-structured stimuli with a moderate level of complexity.

In web design, Leuthold et al., 2011measured the effect of task complexity on the different web navigation systems and found the higher perceptual value in the case of vertical menus. Similarly, Goldberg, 2014 studied the effect of several page design factors through eye-tracking and measured the screen complexity. In another eye-tracking experiment users' attention and behavior are studied in the cognitive loads. As per the result, visual attention effected moderately by task complexity (Wang et al., 2014). (Henderson et al., 1999) did an eye-tracking memory test to measure the effect of semantic consistency while participants viewed different complex pictures to find the targeted object. Their research concluded that attention is initially driven by cognitive and semantic factors that drive by complexity, and the eye tends to return to semantically inconsistent objects. He also compared the result with other fixation-based studies of complex stimuli. Wallraven et al., 2009 analyzed both perceptual and eye-tracking data of different paintings of different timelines and defined some of the properties of bottom-up aesthetic experience. They concluded that certain artistic styles of paintings show the same amount of preference for aesthetic and complexity rating. They also found out that aesthetic viewing and complexity determination followed the global search strategy.

4.3.2 Mapping of visual Composition through eye-tracking

Molnar, 1981, explained that a good composition consists of a combination of formal qualities and semantic information. Several models provide the effect of image composition on aesthetic experience. From the time of the Greeks, geometric compositional rules existed and thrived during the time of Renessa (golden ratio, golden rectangle). Studying visual exploration through eye tracking can reveal the perception of compositional features of the stimuli during an aesthetic experience. In this section, we will be explaining the effect on eye movements due to compositional features in visual stimuli.

In a good composition, visual elements organized in a way that their perceptual forces interact with each other to evoke semantic as well as attentional values to the subject. dos Reis and Merino, 2021 did the research on mood board composition designs and evaluated through the eye tracking. They found out that the visual reading of a mood board offered a different pattern than visual reading of websites. Therefore, image’s composition influenced the viewer's perception and is a very important for visual exploration. Similarly, Nojo, 2014, conduct the experiment to examine the association between painting compositions and gaze movements collected by an eye-tracker. During the initial visual exploration of the stimuli, the viewer uses short fixations to identify the structural features of the composition. After that, during the detailed analysis of compositional structure longer fixation duration was observed. During the diversive exploration semantic meaning of the compositional structures are interpreted. Nodine and Mcginnis, 1983 did an eye-tracking experiment on a compositional balance of the painting.

Figure. 4.6 shows that the balance line of the left painting composition is slightly steeper than that of the right painting, even though the perceptual centers are almost identical. They have deliberately made some structural changes with the original painting and recorded fixation. They found that a change in composition clearly changes the viewing time of the painting which is related to the attention hence affects the perception of the subject. Nodine and Mcginnis, 1983 studied the perception of paintings while doing the variation with the compositional balance of the stimuli. They found that starting fixations successfully guided attention, while fixation distribution of both the visual exploratory patterns followed the balance line providing the directionality to the visual exploration. Locher and Nodine, 1989 carried a similar experiment, to study the different types of exploratory behavior to measure the symmetry effect. In that experiment, visual samples were prepared with a different compositional feature by varying the symmetrical level of the same paintings.

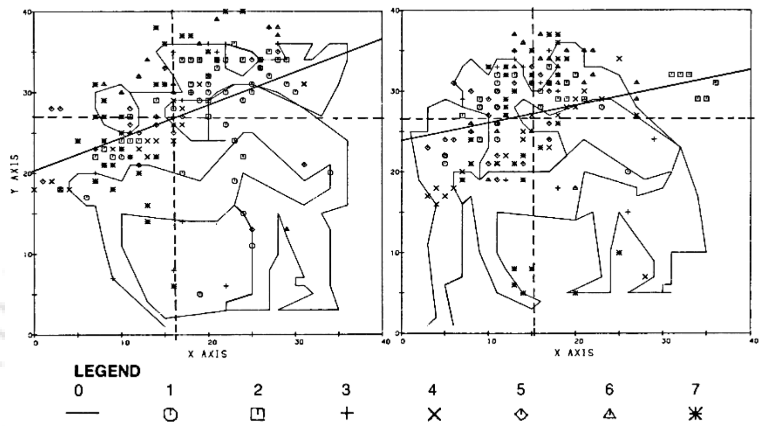


Figure 4.6. Fixation distributions, perceptual centers, and balance lines for Outline of Caravaggio's version of the Entombment (left) and Rubens's version (right) (Adopted from Nodine and Mcginnis, 1983).

There are also eye-tracking studies that would define the perceptual difference of visual composition between the art trained and untrained persons. Nodine et al., 1993 studied the subject's visual exploration pattern while executing composition judgment. They found that composition affects the attention of the trained viewer, but the untrained viewer's attention was significantly less due to the less understanding of compositional symmetry in the stimuli. Some research analysed fixation patterns to monitor the compositional symmetry of stimuli and proved that specific exploration doesn’t affect perception. Locher, 1996 has discussed the effect of the center in a composition of stimuli. They have classified the center of the stimuli into three types perceived balance center (compositional center), geometrical center, and visual gaze center. He explained that none of the centers are the actual center of the stimuli. To test this central compositional exploration (Nodine, 1982), subjects were told to stare at the extreme left corner of the stimuli. Still, when the experiment started within three seconds, subjects’ vision came to the center of the stimuli. There is evidence that the central area of visual stimuli involves perception attraction because gaze density is densely distributed in the central region. Similarly, Serrano et al., 2017did experiment on visual composition of and set guidelines for designing visual content for non-rectangular displays.

Table 4.2. Eye-tracking behavioral interpretation during aesthetic perception

Variables	Eye-tracking variables	Behavioral interpretation Aesthetic perception
Composition	**Fixation duration**	• The increased perceptual load resulted in approximately 8-10% higher fixation durations for all display settings and a similar low in the number of saccades, but only when motion blur reduction was used. (Rosch, 2012). • Art-trained viewers generated proportionally more long-to-short gazes (specific-to-diversive exploration) for the less formal (less predictable) than, the more formal (more predictable) compositional designs, while untrained viewers generated the inverse patterns. (Nodine et al., 1993). • A higher standard deviation of the duration of the fixations indicates a lower proportion because elements with optimum proportion attract eyes for the same amount of time because of similarity in visual. (Khalighy et al., 2015).
	No of fixation	• The number of fixations in eye-tracking data represents the number of elements because viewers are likely to look at each element. Therefore, as the number of fixations increases, the more elements there are. (Khalighy et al., 2015).
	First fixation point	-
	Scan path	-
Complexity	**Fixation duration**	• Viewing timeproportion during the first 500 ms was higher for both pleasant and unpleasant pictures than for neutral pictures (Calvo and Lang, 2004) • Subjects preferred symmetric over asymmetric patterns in their fixation duration (Mühlenbeck et al., 2016). • Fixation duration was not significantly dissimilar on the websites with different complexity levels (Wang et al., 2014). • Fixation duration is sensitive to cognitive state, mental workload, and fatigue (Holmqvist et al., 2011). • Increse in fixation duration could be due to the user's difficulty to lure information or the user drawing a significant amount of information, representing an increase in image complexity (Jacob and Karn, 2003).

		• There is a positive relationship between fixation duration and background complexity.
	No of fixation	• Balanced pictorial arrangements attract more fixation on the surface than unbalanced arrangements. (Locher, 2008) • Subject preferred symmetric over asymmetric patterns in their number of fixation (Mühlenbeck et al., 2016). • Task completion and fixation count time were at the highest level on the website with high complexity (Wang et al., 2014). • vertical menus, users needed fewer eye fixations, were faster and more successful (Leuthold *et al.*, 2011)
	First fixation	• Placement of the first fixation was higher for both pleasant and unpleasant pictures than for neutral pictures (Calvo and Lang, 2004). • The first fixation on abstract paintings took longer. (Wallraven *et al.*, 2009). • The first fixation is sensitive to the size of AOIs, clarity of tasks, foreground/background contrast of visual targets (Holmqvist and Andersson, 2011).
	Scan path	-

4.4 Methodology

Current methodology deals with the aesthetic interactions between visual stimuli and subjects through eye-tracking biometric equipment. This experiment is designed in two sections to answer the research questions. The stimuli used in both experiments were different, but the methodology to execute the experiment was the same for both section A and section B. The methodology followed in this study is quantitative in nature. In section, A 2D stimuli were used, and in section B, natural images were used. The study aims to find the relation between the founded aesthetic variables in previous chapters with eye-tracking variables. Tacking two types of stimuli is to observe the same perceptual phenomena in sections A and B. The aim of the study is to determine the correlation and association between the eye-tracking variable and over a range of perceived complexity and composition which was selected from the previous chapter. For section A, only three 2D stimuli were chosen simultaneously; for section B, six natural stimuli were chosen for the eye-tracking study. The following sections explain each of these experiments in detail with reasoning.

A few of the research questions arise from the aesthetic perception of 2D shapes and natural stimuli. In this part, those research questions are: Q6: Is there any association between the perceived complexity of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?; Q7: Is there any association between the perceived composition of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?; Q8: Is there any association between determinants of classical visual aesthetics (complexity and composition) with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)?; Q9: Is there any association between aesthetic perception of a visual with the eye-tracking variables (Fixation duration, fixation count, saccade, scan path, first fixation point)? This study considers a methodology while integrating both subjective empirical data and objective eye tracking data to answer these research questions. The subjective study explores the perceptual level of complexity and composition from the rating scale. Similarly, the eye-tracking test was done following the protocols (Figure 4.10) and the working model is illustrated in Figure 4.7 and Figure 4.8.

4.4.1 Research plan

To execute the research methodology, we need a range of aesthetic objects, and it is challenging to create or define such a range of stimuli. For section A, the experiment used 2D stimulus from chapter 3. It can be observed (Figure 4.7) that for perceived complexity and perceived composition two different sets of stimuli are selected. The reason for taking separate stimulus was that we wanted to monitor perceived complexity without affecting the composition of the stimuli and vice versa. To evaluate visual aesthetics objectively, we need to know the correlation between the subjective and objective measures. To prove the methodologies of this thesis, the objective of this research is presented in the form of research questions. In the research question [RQ9], subjective empirical data of the aesthetic perception of a stimulus is compared with the objective eye-tracking data. But, to draw meaningful conclusions, some other research questions must be explored. For example, the expected relation between the determinants of aesthetics (complexity and composition) with the eye-tracking variable [RQ6] and [RQ7]. Both aesthetics variables derived from the shape's descriptive characteristics, which are tested by [RQ4] and [RQ5].

Similarly, the relation between the experimental variables and the subjective response must be explored before [RQ3]. Figure 4.7 and Figure 4.8. explain the stepwise procedure to archive the defined research questions in the flow chart. We can observe that different types of stimuli are needed to accommodate and explore the above research question. Therefore, the first step is to develop 2D random shapes using descriptive qualities of shapes that influence experimental variables. The justification of selecting the experimental variables from 2D descriptive characteristics and the tool used to generate shapes have been given in the coming section. We can note that random shapes have been modeled using non-parametric modeling. Once the stimuli are generated, we can proceed to the evaluation of the generated stimuli. From the diagram, we can see that evaluation can be done in a two-way eye-tracking and subjective.

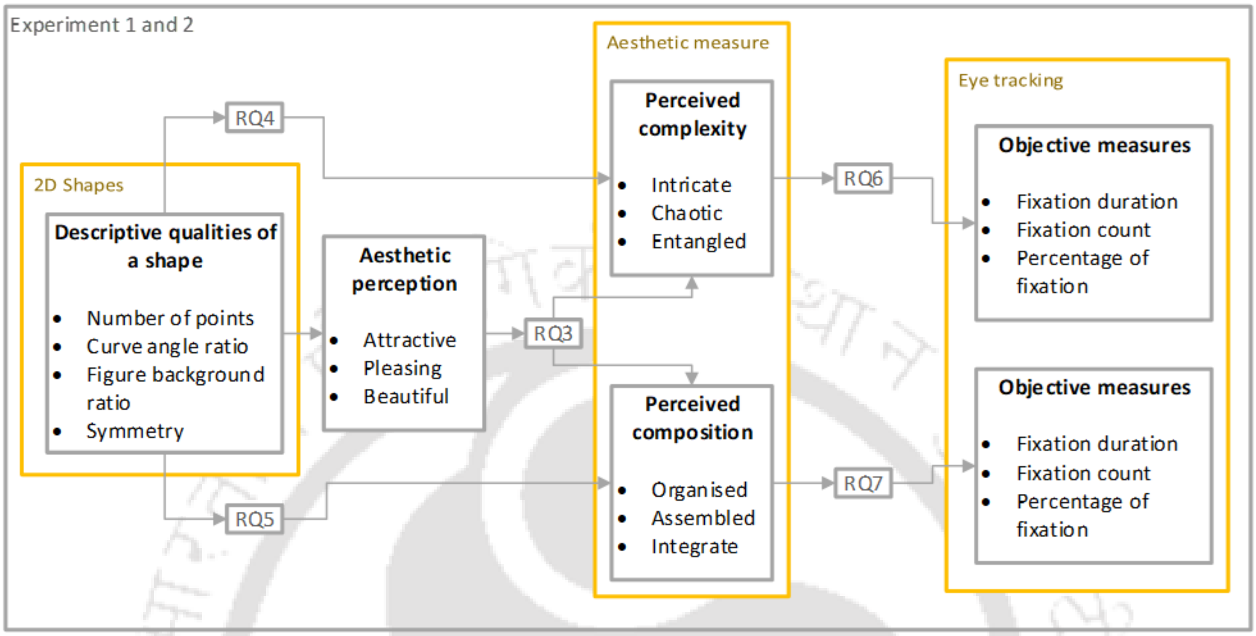


Figure 4.7. Schematic diagram for evaluation of visual classical aesthetics of 2D shapes using both subjective and objective measures

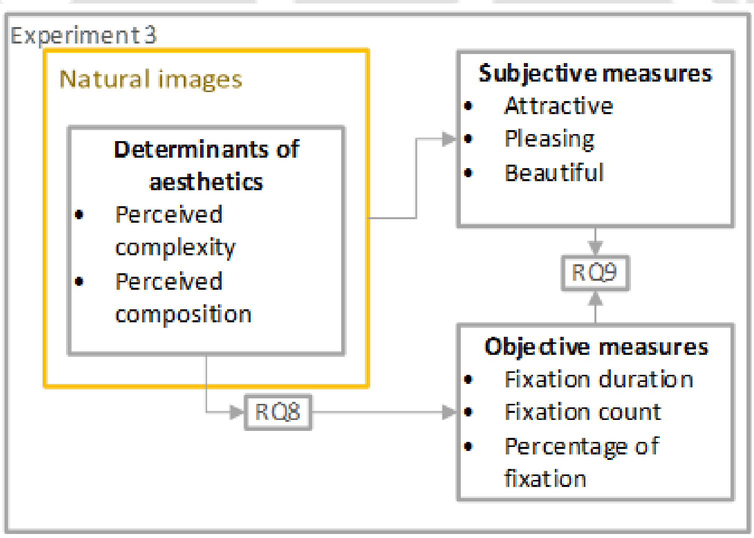


Figure 4.8. Schematic diagram for evaluation of visual classical aesthetics of 2D natural stimuli. Using both subjective and objective measures.

Before exploring the relationship between subjective and objective methods, we need to establish a correlation between aesthetic measures and descriptive characteristics that helped generate random shapes. After that only, we will be able to establish a relation between the eye-tracking variables and subjective response. The methodological process will go through an eye-tracking experiment and a represented research question. We can notice that we must reconsider the experimental variables if we fail to establish the relationship through this methodology. Once all the above-proposed research questions are explored through this methodology, we can find an alternative way to evaluate aesthetics through eye-tracking.

4.4.1.1 Checking relationship between quantitative and eye tracking data for 2D shapes (Section A)

We did both eye-tracking tests and quantitative evaluation of subjective data to determine the relationship between the aesthetic variables and eye-tracking. Both data were compared statistically to answer the above research questions. The eye-tracking methodology is represented in Figure 4.7. The methodology acknowledges all the desirability for aesthetics evaluation like the concept of subject and object, the meaningfulness of the object, repetition of stimuli, etc. In this study, the stimuli used are the output of experiment 1. From the previous experiment total of 6 stimuli were selected for further perceived complexity and perceived composition evaluation. First, after the throw examination of the subject eye-tracking test was done.

Figure 4.8 explains the experimental procedure followed to prove [RQ6] and [RQ7]. An eye tracker is used as an experimental apparatus to explore the following research questions. Once the subject reached the lab, the subjects had to sit for 5 minutes. During those 5 minutes, the briefing of the entire experiment was done. After that, a consent form is signed by the subject. In the next step subject's vision test was done. The prerequisites for the experiment were that subjects must have 20/20 vision. Other vision tests like Ishihara color blind test were avoided because the stimuli are monochromatic in color. If the subject passes the test, then a single-point calibration is done. In some cases, when the eyes are not in good condition, calibration is not possible. In that case, the subject is rejected. Once the calibration is done, the experiment gets started.

The presentation is prepared with all the ten selected stimuli with 6 sec time intervals. A dot appears at the center to counter drift correction between each stimulus. The participant needs to view that dot for stable eye fixation continuously. In case of an eye deviation, the recalibration is done. All the experimental procedure is explained in detail in the methodology of research question exploration. Similar to experiment 1 the subjective evaluation of the proposed 2D shapes was recorded through the questionnaires. Similar to experiment 1, the subjective rating has three types of data and two types of output. Three types of data were extracted (data of complexity analysis, data of composition analysis, and data of aesthetic perception) from the 2D stimuli. Simultaneously, the relation between the aesthetic variables and eye-tracking variable is done with a correlation study, and the result has been reported.

4.4.1.2 Checking relationship between quantitative and eye tracking data for Natural stimuli (Section B)

The methodology followed to prove the research question [RQ8] and [RQ9] is very similar to the methodology of the [RQ 6], [RQ7]. The only difference in this experiment is the use of natural stimuli instead of 2D shapes. In this experiment, perceived complexity, perceived composition, and aesthetic perception were evaluated from a pool of stimulus. The motive is to observe the difference in phenomena on natural stimuli than 2D shapes.

4.4.2 Eye-tracking method

In this section of the experiment, the magnitude estimate scaling (MES) technique is used to collect subjective empirical data on perceived aesthetics, complexity, and composition. To achieve this, we first collected the high, moderate, and low complex and composed stimuli from experiment 1 in chapter 3. The reason for taking three stimuli each for complexity and composition evaluation was for difficulty in eye-tracking data evaluation. The whole spectrum of stimuli was chosen because we wanted to record the high differences in eye movements during the experiment. All of the stimuli were made from varying descriptive characteristics. A pilot study was run to prepare the information scale of complexity and composition measurement. The subjects were informed about the lowest and highest subjective rating scale before the experiment. After collecting empirical data, we correlated separately between the composed and complex variables with the eye-tracking variable.

4.4.2.1 Materials

Two sets of Three monochromatic 2D random shapes were used as visual stimuli (Figure 4.9). Each shape was made by varying the descriptive qualities of shapes in a controlled manner through the grasshopper programming (no of points, curve angle ratio, object background ratio, symmetry). The abstract shapes were chosen because selecting a non-abstract visual may convey a specific meaning for the subjects that may influence the eye movements. Therefore, the motive is subjects should not be able to exact the meaning of the stimuli. For section A, six random images were selected from experiment 1, chapter 3. For complexity stimuli, the number of points of the stimulus is controlled, and other descriptive qualities of the shapes remain constant. Similarly, composition stimuli were generated varying variables like symmetry, curve angle proportion, figure background proportion to evaluate perceived composition.

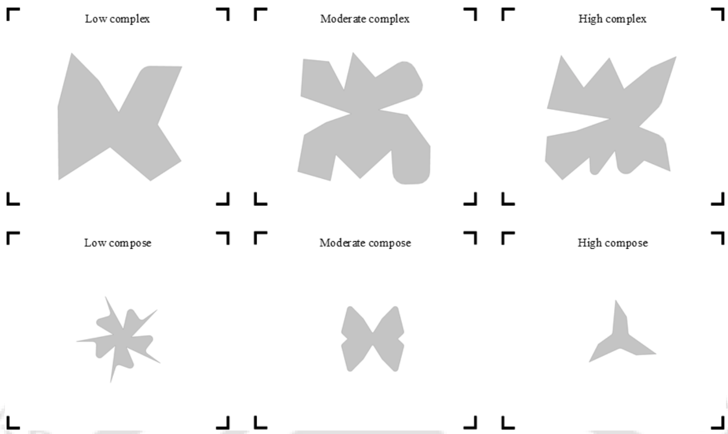


Figure 4.9. Six filtered images of complexity and composition stimuli for objective rating

4.4.2.2 Protocol

The experiment was designed to collect the complexity and composition dependent aesthetic arousal. Once the subject reached the lab, the subjects had to sit for 5 minutes. During those 5 minutes, the briefing of the entire experiment was done. After that, a consent form is signed by the subject. In the next step subject's vision test was done. The prerequisites for the experiment were that subjects must have 20/20 vision. Other vision tests like Ishihara color blind test were avoided because the stimuli are monochromatic in color. If the subject passes the test, then a single-point calibration is done. The overall protocol of the eye-tracking experiment can be understood from Figure 4.10. In some cases, when the eyes are not in good condition, calibration is not possible. In that case, the subject is rejected. Once the calibration is done, the experiment gets started.

The whole experiment is done in a controlled dark room. The presentation is prepared with all the six selected stimuli with 6 sec time intervals. A dot appears at the centre to counter drift correction between each stimulus. In between, the experimenter needs to continuously monitor the eye fixation. In case of an eye deviation, the recalibration is done. At a time, only two stimuli had appeared on the screen. A program is written in the macro to randomise the combination of the stimuli in real time. All the different combinations of the stimuli were chosen and presented as per the protocol. From figure 4.11, the presentation of the stimulus can be observed. The arrow mark below represents the direction of the timeline.

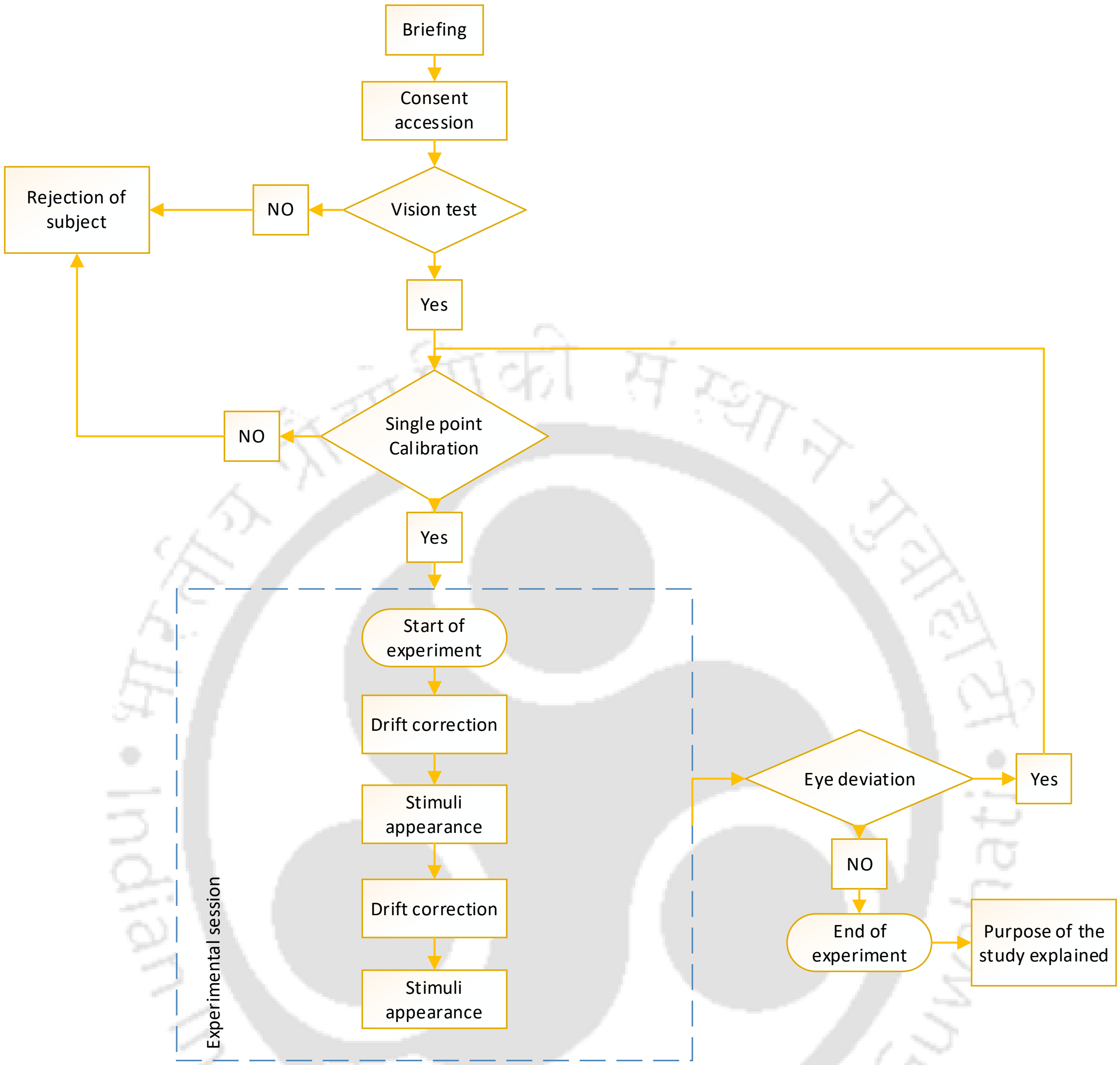


Figure 4.10. Protocol for eye tracking test

A total of 26 students participated in the experiment voluntarily. Participated students are of a mixture of South Asian ethnic groups from the Indian Institute of Technology Guwahati. All subjects gave written informed consent through a consent form approved by the ethics committee at the Indian Institute of Technology while compiling international and national guidelines for humans as subjects (Declaration of Helsinki, 1964). Subjects were also informed about the right to withdraw from the experiment according to their will. Participants were undergraduate, master, and Ph.D. students with familiarity with elements of design. The exclusion criteria for age was considered from 18 to 40 with an average age of 23. All subjects' vision were normal or used external goggles to normalise vision.

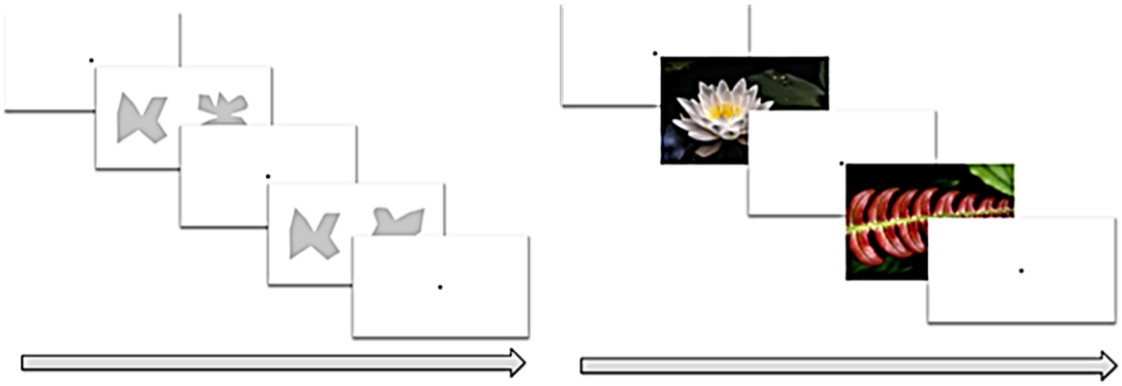


Figure 4.11. Stimuli appearance protocol for the eye-tracking experiment

After the eye-tracking experiment, subjects were asked to rate perceived complexity and perceived composition respectively for two sets of stimuli. The presented monochromatic shapes were grey with a maintained value for all stimuli. The whole stimuli were presented on a white background to maintain a uniform contrast level. The order of the images was random and presented at once, where subjects had to rate the stimulus according to the magnitude estimate scaling. Visuals are projected on a screen while maintaining the uniformity of the shapes.

4.4.2.3 Apparatus

All of the stimuli were created using Rhino 5 version and displayed using google form on an intel I5 Pc on OS window 10. All stimuli were displayed in a 42- Inch LCD monitor (1024X786 resolution, SAMSUNG, Model No. PS42A410C1) connected to an I5 intel pc through a local network in a darkened room. The background color, the contrast of the stimuli, drift correction, and calibration screen was filled with 1/f noise at dark luminance level and kept constant for the whole experiment. The apparatus used in this experiment include an eye-tracking system. An SMI iView X, the binocular eye-tracking system was used. The device was calibrated with a one-point technique for each participant.

4.4.2.4 Task

In sections A and B, participants were asked to view the stimuli with no specific instructions. Subjects were informed just to "explore and observe the stimuli" in stipulated time. To draw out free view observation, the viewing behaviour must be self-determined. The purpose was to motivate subjects unbiasedly, entirely depending upon the object's perception. In the eye-tracking study, the subjects were instructed to remain still in a chair with soft head resistance as the movement in eyesight may affect the data acquisition. For safety, an additional chin guard is used to ensure the alignment of the midsagittal plane and the eyes within the center of the screen. Before the experiment, a 1-point calibration method was used to reduce the mean and redone separately for every subject.

To avoid the drifting of eye movement, a black dot appeared in the center of the screen in between each stimulus. Recalibration was done in case of a higher degree of error. This period is called the inter-stimulus interval (ISI), and in this experiment, it was kept constant for 2 secs. Analysis data of each trial during the ISI were excluded as it doesn't contribute to the aim of the experiment. Similarly, the first fixation is also avoided in the analysis as localization was determined by the preceding fixation spot used for drift correction. The images ware appeared after the black dot position in the center and inside 6 degrees of the vertical median. The stimulus appeared for 6 secs for free viewing tasks. During this time, the eye movement data were recorded. This process continued until all the images were viewed, and the average time taken for one experiment was around 25 min.

In sections A and B, subjects were asked to sit in a calming posture for 5 minutes for better acclimatization of the environment. Then the affect evaluation task was given to subjects and asked to rate each stimulus for aesthetic preference, meaningfulness, complexity, composition, etc. (Friedenberg & Bertamini, 2015). All the images appeared on the monitor at a time. The subjects were asked to rate all the stimuli on a 7-point Likert scale, where `lowest' is levelled at 1 and reflect "not pleasing at all". Similarly, `highest' rating of 7 reflect `extremely pleasing' and the number 4 reflect "neutral". The subjects were shown the previously generated scale to have an idea of uniformity while rating. The subjects were encouraged to use the full scale during the experiment and rate all the stimuli independently.

4.5 Result

The present section focuses on understanding the aesthetics variables of 2D and natural visuals and checking the relationship among them with the eye-tracking variables. To validate the followed methodology of the experiment, the obtained data are analyzed, and the results are interpreted. The result is divided into two parts as per the output of the experiment section. In section A and section B, the same 26 subject's data were collected after doing the eye-tracking experiment. We first segregated the eye tracking data as per different stimuli to analyze the collected data. All eye-tracking data were generated using the SMI BeGaze (v 3.7) eye-tracking software. BeGaze software helps structure the information recorded through gaze plots, attention maps etc. We have extracted the event statistic data for each subject and segregated them as per the eye tracking variables. The data then moved to the IBM SPSS (25) software for statistical analysis.

4.5.1 Correlation Result of 2D shape (Section A)

For complexity stimuli, the data of 26 participants are shown in Table 4.3.B and Table 4.4.B. The table provided the correlation data between eye-tracking variables with the aesthetic measures of 2D shapes. From the correlated data, some concept related to aesthetics that is very similar to the available literature can be concluded. The output of numerical data shown in the table fulfills the experiment's objective to establish the relationship between the eye-tracking variables and the aesthetic experience of the 2D shape. There are two sets of questionnaires with different sets of 2D shapes for complexity and composition for the experiment. The first eye-tracking test was done after testing the subject’s eye requirements. Then, the same images were used to rate with magnitude estimation scaling using the Likert scale.

In this section, the correlation has been performed to check the relationship of eye-tracking variables with subjective data. So that the legitimacy of the eye-tracking variables can be explained for aesthetics evaluation. The analysis section is divided into two parts and separately explained the relation with the complexity and composition variable. Even separate stimuli and questionnaires were used for individual variables during the experiment. After the collection of the data first, the normality test was planned as per the analysis procedure. Both subjectively scored data sets of complexity and composed stimuli came as non-parametric as the data type is not scaled data.

4.5.1.1 Correlation of eye-tracking variables and descriptive characteristics for 2D complexity stimuli

In this section, we investigated whether the eye tracking variables have any relationship with the descriptive characteristics of a 2D shape. Therefore, a correlation was done to observe the relationship between the subject's eye-tracking data with stimuli's descriptive characteristics. In all the subjects, obtained eye-tracking data indicated significant correlations with descriptive characteristics of 2D shapes.

Particularly, eye tracking variables like (fixation duration, fixation count, and percentage of fixation) all showed a highly significant correlation (Table 4.3.A) with all three variables of descriptive characteristics. Descriptive variables like the number of points and figure background ratio showed a positive correlation, and the angle curve ratio in a 2D shape showed a negative correlation. The symmetry as a variable is not used as a descriptive variable because we have used asymmetrical shapes as stimuli to determine the perceived complexity of the shapes.

In section 1 of the experiment, 72.9% of the subjects confirmed that quantity is a part of perceived complexity. Similarly, 18.9% of subjects confirmed that verity is also a complexity variable. It is observed the same from the table below and confirms that count and angularity affect the perception of the complexity, which directly influences the object's aesthetics.

Table 4.3.A. Correlation coefficients (Spearman's r) of eye-tracking variables with descriptive variables for complexity stimuli

	Fixation duration	**Fixation count**	**Percentage of fixation**
Number of points	.332**	.316**	.340**
Angle curve ratio	-.332**	-.316**	-.340**
Figure background ratio	.268**	.261**	.277**
*p <0.05, **p <0.01			

4.5.1.2 Correlation between Aesthetic variables and eye-tracking variables for 2D complexity stimuli

To achieve some of the objective of the experiment, the subjects were shown the complex stimuli, and the eye-tracking test was done, followed by the subjective rating of that shape. Later on, eye-tracking variables and subjective data were correlated to analyze their relationship. All the correlated data were positive in nature. A significant positive correlation was observed between perceived aesthetics and fixation duration and percentage of fixation. The correlation obtained was not so strong, but it was significant, which may lead to further analysis.

Other aesthetic variables like perceived complexity, preference, meaningfulness showed strong correlation with eye-tracking variables. And can be observed from Table 4.3.B. Further, the correlation data of perceived complexity showed a high positive correlation with the fixation duration, fixation count, and percentage of fixation.

Similarly, the preference as the aesthetics variable showed a positive correlation with fixation duration, average fixation, and percentage of fixation. Preference didn’t show any correlation with fixation count. One of the aesthetic variable meaningfulness showed a positive correlation with fixation duration and percentage of fixation. At the same time, the image’s meaningfulness didn’t show any correlation with the fixation count.

Table 4.3.B. Inter correlation coefficients (Spearman's r) of perceived aesthetics for complexity stimuli

	Fixation duration	Fixation count	Percentage of fixation
Perceived complexity	.308**	.287**	.313**
Preference	.174**	.053	.182**
Meaningfulness	.151**	.030	.146**
Perceived aesthetics	.161**	.037	.158**
*p <0.05, **p <0.01			

4.5.1.3 Correlation of eye-tracking variables and descriptive characteristics for composition stimuli

In all the subjects, subjective data indicated significant correlations between the eye-tracking variables and descriptive characteristics of 2D shapes. Some of the eye-tracking variables (fixation duration, fixation count, and percentage of fixation) showed a significant correlation (Table 4.4) with all five variables of descriptive characteristics. The number of points and symmetrical sides showed a high positive correlation with all variables of eye-tracking. Similarly, the angle curve and figure background ratios didn't correlate with eye-tracking variables. Only angularity showed a negative correlation with the eye-tracking variables. The type of symmetry as a variable showed a low positive significant correlation with eye-tracking variables. It is observed from the table below that the count, angularity, and symmetry affect the perception of the composition, which influences the eye-tracking variables during free viewing of the object. The correlation result suggests that composition variables like proportion and symmetry of the elements present in stimuli can be predicted through the eye-tracking variables and a matter of further investigation.

Table 4.4.A Intra Correlations (Spearman's r) of Perceived Aesthetics and Descriptive qualities for composition stimuli.

	Fixation duration	Fixation count	Percentage of fixation
Number of points	.355**	.345**	.354**
Angle curve ratio	-.071	-.084	-.071
Figure background ratio	.071	.084	.071
Type of symmetry	.123*	.102	.123*
Type symmetrical side	.355**	.345**	.354**
*p <0.05, **p <0.01			

4.5.1.4 Correlation between Aesthetic variables and eye-tracking variables for composition stimuli

Similar to the complexity images study, the subjects were shown the composed stimuli, and the eye-tracking test was done, followed by the subjective rating of that shape. Later on, eye-tracking variables and subjective data were correlated to analyze the relationship between them. All the correlated data were positive, except the perceived composition. The correlation data of perceived composition showed a strong negative correlation with the fixation duration, fixation count, and percentage of fixation. It proves that the well-composed images were easier to perceive, thus negatively correlated with eye-tracking variables. A significant positive correlation was observed between perceived aesthetics and fixation duration, fixation count, and percentage of fixation. Other aesthetic variables like preference showed a strong significant correlation with fixation duration and percentage of fixation. Similarly, meaningfulness showed no correlation with various eye-tracking variables and can be observed from Table 4.4.B.

Table 4.4.B Inter correlation Coefficients (Spearman's r) of Perceived Aesthetics for composition stimuli

	Fixation duration	**Fixation count**	**Percentage of fixation**
Perceived composition	-.355**	-.345**	-.354**
Preference	.230**	.111	.224**
Meaningfulness	.048	.013	.033
Perceived aesthetics	.260**	.193**	.272**
*p <0.05, **p <0.01			

While exploring the relationship between aesthetic variables and eye-tracking variables of 2D shapes, it is clear that dealing with 2D shapes significantly affects perceptual difficulties for the subjects. Therefore, from the experiment, it's clear that complexity and composition both contribute to the cause of aesthetic arousal and can be monitored from the eye tracker. It also confirms the role of eye tracking variables of a visual to influence aesthetic perception. Notably, higher complex and lower composed shapes were difficult to perceive. The reason might be that many variables influence aesthetics, and limiting those variables to 2D shapes that to only one object per image influenced perception. Therefore, eye tracking variables showed a significant correlation with the aesthetic variables but on a lower side.

4.5.2 Differences in eye tracking data for different level of aesthetic visuals (ANOVA)

To understand the perceptual difference among different groups of stimuli, collected data were analysed with respect to the eye-tracking variables (fixation count, fixation duration, and percentage of fixation).

The literature shows that the visual exploration of the subject controls fixation duration and the number of fixations. According to (Berlyne, 1971) there are two types of visual exploration processes (specific and diversive). In his experiment, Kotval, and Goldberg, 1998, verified these same phenomena through the eye-tracking matrices. Later on, Plumhoff and schirillo, 2009 proved the relationship between the change in fixation duration with respect to the saccade extent. Therefore, it is evident that a high value of fixation duration and longer scan path means difficulty in perceptual information. Higher fixation duration signifies a higher level of attention, and greater attention leads to an aesthetically pleasing experience. We can also verify the same with the previously represented correlation data of complex and composed stimuli. For the analysis of gaze data, SMI, BeGaze 3.7 software (Senso Motoric Instruments) is used. It uses dispersion threshold algorithms that analyze the default values of 50 pixels and a minimum length of 80 ms. The eye-tracking data were segregated and calculated manually by fixing the Area of Interest for different stimuli. The statistical analysis of the measured data was done with the help of IBM SPSS 20 (windows 64 bit).

We conducted statistical analysis on the measured dependent variables (perceived complexity and perceived composition). Before inferential statistics, we tested the data for normality with the Shapiro-Wilk test (Shapiro and Wilk, 1965). Results showed that on the significance level alfa=0.05 none of matrices were normally distributed: For complexity stimuli fixation count W=0.976, p=0.000; fixation duration W = 0.989, p = 0.023; percentage of fixation W=0.990, p=0.000. Similarly, for composition stimuli fixation count W=0.960, p=0.000; fixation duration W = 0.987, p = 0.007; percentage of fixation W = 0.992, p = 0.088. As none of the data are normally distributed except the composition of percentage of fixation, data does not meet the assumption of parametric statistics. Therefore, only non-parametric statistics have been used to do the analysis.

4.5.2.1 Result of differences in eye tracking data for different level of Perceived Complexity of 2D shapes (ANOVA of section A)

The perceptual examination was conducted as an overall statistical analysis between the tested groups of complex stimuli, regardless of their complexity level. For this purpose, the visual viewing strategy for selected three groups of stimuli was compared by applying the Kruskal Wallis test of the eye-tracking variables for complexity stimuli to capitulate statistically significant results. Kruskal-Wallis Test similarly showed (Table 4.5) that there is a significant difference in the distribution of the eye-tracking variables in a different group of complexity stimuli (fixation count H = 31.298, p = 0.000; fixation duration H = 34.849, p = 0.000; percentage of fixation H = 36.408, p = 0.000).

Table 4.5. Result of the Kruskal-Wallis Test for complexity stimuli

For perceived complexity	Total N	Test statistics	Degree of Freedom	Asymptotic Sig.(2-sided test)
fixation count	312	31.298	2	.000***
fixation duration	312	34.849	2	.000***
percentage of fixation	312	36.408	2	.000***
ANOVA for ranks. *p<.05, **p<.01, ***p< .001				

While our overall findings suggested that the groups of complex stimuli perform somewhat similar in terms of visual exploration and confirm the results of Berlyne, 1971. We found that the lower complex stimulus facilitated a lower fixation duration than the others. This may signify the effect on eye-tracking variables due to variation of perceived complexity in visuals. A lower fixation duration means participants can comprehend the quantity and quality of information as descriptive qualities in 2D shape. In the next step, we analysed the main effects for the different levels of complexity stimuli using Kruskal–Wallis test.

Kruskal-Wallis pairwise group comparison test was done for the same gaze behaviors of subjects' total Fixation duration (Table 4.6, Figure 4.12). Post hoc analysis revealed a significant difference in fixation duration between the Low complex and neutral complex stimuli (p=0.000). Similarly, a significant difference was observed between the low complex and High complex stimuli group (p=0.000). But the fixation duration difference between the neutral complex and high complex stimuli is insignificant (p= 0.487).

At this point, to study the attention that users paid during the free viewing of different complex stimuli, we performed an analysis of gaze data in specified AOIs. To collect eye-tracking data, we constructed regions around each stimulus to include all gaze points closer to that stimuli than to any other. For all subjects, the area of AOI was made constant for every class of stimulus.

Based on the AOI analysis, we observe a vast difference between the fixation count on the task-relevant AOIs. Similarly, Kruskal-Wallis pairwise group comparison test was done for the same gaze behaviors of subjects' Fixation count (Table 4.6, Figure 4.12). Post hoc analysis found a significant difference in fixation duration between the Low complex and neutral complex stimuli (p=0.000). Similarly, a significant difference was observed between the low complex and High complex stimuli group (p=0.000). But the fixation duration difference between the neutral complex and high complex stimuli is insignificant (p= 0.652).

Analysing the percentage of fixation in the AOI's; our observations confirmed that when there is a more significant complexity level in stimuli due to more information, people explore more in the provided AOI. For the percentage of fixation, Kruskal-Wallis pairwise group comparison test was done (Table 4.6, Figure 4.12). Post hoc analysis found a significant difference in the percentage of fixation between the Low complex and neutral complex stimuli (p=0.000). Similarly, a significant difference was observed between the groups of low complex and high complex stimuli (p=0.000). But the fixation duration difference between the neutral complex and high complex stimuli is insignificant (p= 0.524).

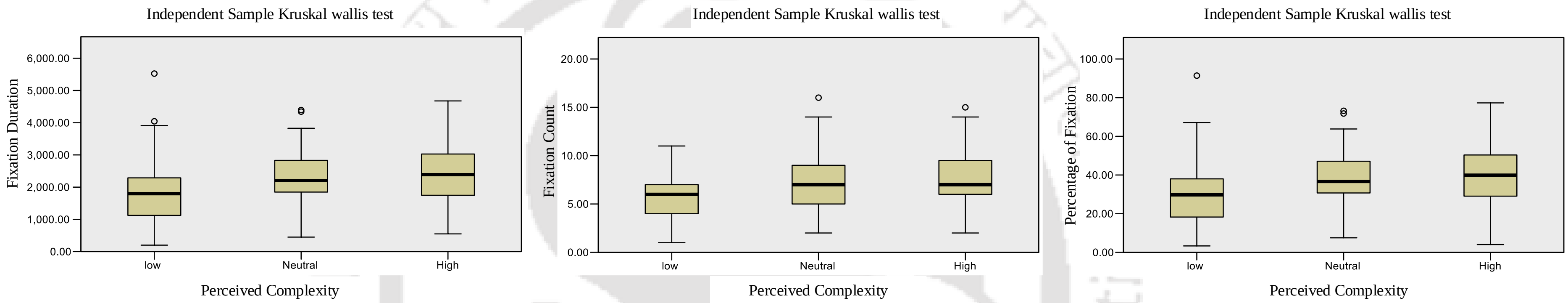


Figure 4.12. Fixation duration, fixation count, and percentage of fixation of the three groups for complexity. The box plots indicate the eye-tracking pattern with the standard deviation of the estimates in the error bars.

Table 4.6. Post hoc analysis of between the groups of complexity stimuli

For complexity stimuli	Group 1-Group 2	T-test	Std. Error	Std. Test Statistic(t)	Sig.	Adj. Sig
Fixation duration	Low complex- Neutral complex	-59.168	12.510	-4.730	.000***	.000***
	Low complex- High complex	-67.856	12.510	-5.424	.000***	.000***
	Neutral complex- High complex	-8.688	12.510	-6.94	.487	1.000
Fixation count	Low complex- Neutral complex	-57.279	12.443	-4.603	.000***	.000***
	Low complex- High complex	-62.894	12.443	-5.055	.000***	.000***
	Neutral complex- High complex	-5.612	12.443	-.451	.652	1.000
Percentage of fixation	Low complex- Neutral complex	-61.019	12.510	-4.878	.000***	.000***
	Low complex- High complex	-68.990	12.510	-5.515	.000***	.000***
	Neutral complex- High complex	-7.971	12.510	-.637	.524	1.000
Note. Adj. sig = multiple comparison corrected p-value (Bonferroni correction). *p<.05, **p<.01, ***p< .001						

4.5.2.2 Result of differences in eye tracking data for different level of Perceived Composition of 2D shapes (ANOVA of section A)

The perceptual examination was conducted as an overall statistical analysis between the tested groups of composed stimuli, regardless of their composition level. For this purpose, the visual viewing strategy for selected three groups of stimuli was compared by applying the Kruskal Wallis test of the eye-tracking variables for composed stimuli to capitulate statistically significant results. Kruskal-Wallis Test similarly showed (Table 4.7) that there is a significant difference in the distribution of the eye-tracking variables in a different group of composition stimuli (fixation count $H = 40.231$, $p = 0.000$; fixation duration $H = 43.915$, $p = 0.000$; percentage of fixation $H = 43.610$, $p = 0.000$).

Table 4.7. Result of Kruskal-Wallis Test for complexity and composition stimuli

For perceived composition	Total N	Test statistics	Degree of Freedom	Asymptotic Sig. (2-sided test)
fixation count	312	40.231	2	.000***
fixation duration	312	43.915	2	.000***
percentage of fixation	312	43.610	2	.000***
ANOVA for ranks, *p<.05, **p<.01, ***p< .001				

While our overall findings suggested that the groups of composed stimuli perform somewhat similar in terms of visual exploration and confirm the results of (Berlyne, 1971). At this point, we found that the lower composed stimulus facilitated a high fixation duration compared to the others. This may signify the effect on eye-tracking variables due to variation of perceived composition in visuals. A higher fixation duration means participants cannot comprehend the arrangement of the information as descriptive qualities in 2D shape. In the next step, we analysed the main effects for the different levels of composition stimuli using Kruskal–Wallis test.

Kruskal-Wallis pairwise group comparison test was done for the same gaze behaviors of subjects' total Fixation duration (Table 4.8, Figure 4.13). With post hoc analysis, we observed a significant difference of fixation duration between the Low composed and neutral composed stimuli ($p = 0.000$). Similarly, a significant difference was observed between the low composed and high composed stimuli group ($p = 0.000$). But the fixation duration difference between the neutral composed and high composed stimuli is insignificant ($p = 0.631$).

At this point, to study the attention that users paid during the free viewing of different composed stimuli, we performed an analysis of gaze data in specified AOIs. We constructed regions around each stimulus to include all gaze points closer to that stimuli to counter the possible registration issues with the eye-tracking data. For all of the subjects, the area of AOI was made constant for a specific group of stimuli. We observe a vast difference between the Fixation count data based on the AOI analysis. Similarly, Kruskal-Wallis pairwise group comparison test was done for the same gaze behaviors of subjects' Fixation count (Table 4.8, Figure 4.13). With post hoc analysis, we found a significant difference of fixation duration between the Low composed and neutral composed stimuli ($p = 0.000$). Similarly, a significant difference was observed between the low composed and high composed stimuli group ($p = 0.000$). But the fixation duration difference between the neutral composed and high composed stimuli is insignificant ($p = 0.652$).

Analysing the percentage of fixation in the AOI's; our observations confirmed that when there is a larger composed level in stimuli due to the better arrangement of information level. For the percentage of fixation, Kruskal-Wallis pairwise group comparison test was done (Table 4.8, Figure 4.13). With post hoc analysis, we found a significant difference of the percentage of fixation between the Low composed and neutral-composed stimuli (p=0.000). Similarly, there is a significant difference observed between low-composed and high-composed stimuli groups (p=0.000). But the fixation duration difference between the neutral composed and high composed stimuli is found to be insignificant (p= 0.524).

Table 4.8 Ordinal Logistic Regression for Perceived Complexity and Perceived Composition

	Perceived complexity		**Perceived composition**	
Eye tracking Variables	**Odds ratio**	**95% CI**	**Odds ratio**	**95% CI**
Fixation duration	1.000	0.998, 1.002	1.000	0.999, 1.001
Fixation count	**1.222***	**1.034, 1.444**	**0.862***	**0.784, 0.947**
Percentage of fixation	1.033	0.932, 1.144	0.980	0.935, 1.038
***= significant**				

To examine the influence of eye tracking variables on ratings, the OLR model was fitted with a rating as the dependent variable (perceived complexity and perceived composition), fixation duration, fixation count, and average fixation as predictor or independent variables. From table 4.8, it can be observed that both perceived complexity and composition could be predicted using fixation count but not other eye tracking variables. The value of the odds ratio for the perceived complexity is found to be 1.22 and significant. At the same time, the fixation duration for the percentage of fixation and odds ratio for perceived complexity were found to be insignificant. Similarly, for composition variable odds ratio of fixation count was 0.862 and significant.

In both of the dependent variables, a similar result was observed. The OLR result suggested that fixation count contributes significantly to predicting perceived complexity and composition. The confidence intervals of two predictors (fixation duration and Percentage of fixation) contain the approximate value of 1, suggesting no variables significantly contribute to the prediction of the perceived complexity ratings. Thus, it can be concluded that it is very difficult to judge the perceived complexity and composition based only on eye tracking variables, as the prediction capability of eye tracking variable (except fixation count) are very low in determining perceived complexity and composition.

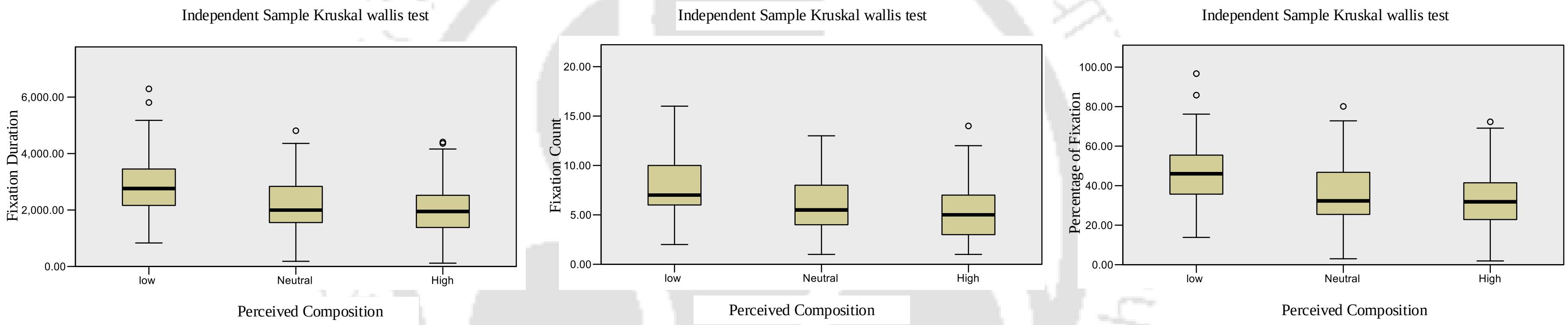


Figure 4.13. Fixation duration, fixation count, and percentage of fixation of the three groups for composition. The box plots indicate the eye-tracking pattern with the standard deviation of the estimates in the error bars.

Table 4.9. Post hoc analysis of between the groups of composition stimuli

For composition stimuli	Group Details	T-test	Std. Error	Std. Test Statistic(t)	Sig.	Adj. Sig
Fixation duration	High composed - Neutral composed	15.673	12.510	1.253	.210	.613
	High composed - Low composed	78.337	12.510	6.262	.000***	.000***
	Neutral composed - Low composed	62.663	12.510	5.009	.000***	.000***
Fixation count	Low composed - Neutral composed	18.361	12.432	1.477	.140	.419
	Low composed - High composed	75.591	12.432	6.080	.000***	.000***
	Neutral composed - High composed	57.231	12.432	4.604	.000***	.000***
Percentage of fixation	Low composed - Neutral composed	15.615	12.510	1.248	.212	.636
	Low composed- High composed	78.062	12.510	6.240	.000***	.000***
	Neutral composed - High composed	62.447	12.510	4.992	.000***	.000***
Note. Adj. sig = multiple comparison corrected p-value (Bonferroni correction). *p<.05, **p<.01, ***p< .001						

4.5.2.3 Summary of differences in eye tracking data for different level of aesthetic variables of 2D shapes (ANOVA of section A)

The results show that both for complexity and composed stimuli groups, the eye-tracking distribution fount is significantly different (Table 4.9.). Further post hoc analysis was done to moniter the difference between the specific groups. It was found that the difference between Low complex- Neutral complex and Low complex- High complex is found to be significant for complexity stimuli. Similarly, for composition stimuli, the difference between Low composed- High composed and Neutral composed - High composed are significant. For the testing of hypothesis to determine the ANOVA for the complexity stimuli, the null hypothesis is fixed that the eye-tracking variables are the same across categories of perceived complexity. Similarly, for the testing of hypothesis to determine the ANOVA for the composition stimuli, the null hypothesis is fixed that the eye-tracking variables are the same across categories of perceived composition.

Table 4.10. ANOVA Hypothesis Test Summary for complexity and composition stimuli

ANOVA Hypothesis Test Summary				
Complexity	**Null Hypothesis**	**Test**	**Sig.**	**Decision**
1	The distribution of fixation duration is the same across categories of Complexity.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
2	The distribution of fixation count is the same across categories of Complexity.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of the percentage of fixation is the same across categories of Complexity.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
Composition	**Null Hypothesis**	**Test**	**Sig.**	**Decision**
1	The distribution of fixation duration is the same across categories of Composition.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
2	The distribution of fixation count is the same across categories of Composition.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of the percentage of fixation is the same across categories of Composition.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
Asymptotic significances are displayed. The significance level is .05.				

4.5.2.4 Discussion of differences in eye tracking data for different level of aesthetic variables of 2D shapes (ANOVA of section A)

In this experiment, the subjective aesthetic rating of the 2D shape is done, and its relation with eye-tracking data was highlighted. The correlation between the variables was found to be significant. The research questions were addressed by doing a correlational study. Later on, the Kruskal Wallis test was also done to explore the difference between the type of stimulus followed by the postdoc analysis. Finally, the ordinal logistic regression was done to map the model of aesthetic experience. For both complexity and composed stimuli, the subjective data were collected by rating. Both sections of the experiment have a similar output and show the strong relationship between an aesthetic variable and eye-tracking data.

In the eye-tracking experiment, the same 26 subjects participated. The result of the eye-tracking experiment confirmed that the composition and complexity are the two reliable variables to observe subjects' perception. A strong correlation is observed between several eye-tracking variables and aesthetic variables. This finding shows that having a higher value of eye-tracking variables like fixation duration, fixation count, and percentage of fixation does not necessarily mean that the subjective aesthetic ratings are also high for the same object. Particularly for a high level of composition, the value of aesthetic variables is observed to be low. But for a high level of complexity stimuli, the eye-tracking variable's value increased with an increase in complexity level. Additional studies are needed further to understand the influence of visual affect on aesthetic preference. Finally, we found that 2D shapes have a wider range of different subject matters, as an abstract shape can be interpreted and perceived in several ways.

We found no inverted 'U' (Berlyne, 1971) relation between eye-tracking variables and perceived complexity. Instead, the perceived complexity plot continuously increased. The higher complex images are rated higher in the perceived complexity scale than other images. The same phenomena were observed in the eye-tracking variables. But opposite to complexity, the well-composed image has a significant negative correlation with eye-tracking variables. We find that a high level of composition reduces the value of eye fixations.

4.5.2.5 Result of differences in eye tracking data for different level of aesthetics in natural stimuli (ANOVA of section B)

The perceptual examination was conducted as an overall statistical analysis between the tested groups of natural stimuli, regardless of their aesthetics level. For this purpose, the visual viewing strategy for selected six groups of stimuli ware compared by applying the Kruskal Wallis test of the eye-tracking variables for natural stimuli to capitulate statistically significant results. Kruskal-Wallis Test similarly showed (Table 4.10) a significant difference in the distribution of the eye-tracking variables in a different group of natural stimuli (fixation duration H=17.226, p = 0.004; fixation count H=5.578, p = 0.349; percentage of fixation H=17.247, p = 0.004).

Table 4.11. Result of Kruskal-Wallis Test for aesthetic stimuli

For perceived complexity	Total N	Test statistics	Degree of Freedom	Asymptotic Sig. (2-sided test)
fixation duration	156	17.226	5	.004***
fixation count	156	5.578	5	.349
percentage of fixation	156	17.247	5	.004***
Note. F test was used because we applied ANOVA for ranks. *p<.05, **p<.01, ***p< .001				

From literature, it is observed that lower total fixation duration means difficulties in perceiving. Therefore, we analysed the main effects for the different levels of aesthetic perception for natural stimuli using the Kruskal–Wallis test and simultaneously extracted eye tracking data. Kruskal-Wallis pairwise group comparison test was done for the same gaze behaviours of subjects' total Fixation duration (Table 4.10, Figure 4.14). Post hoc analysis revealed a significant difference in fixation duration between the Low – Highest rated aesthetic natural stimuli (p=0.002). Similarly, a significant difference was observed between the Low – lowest rated aesthetic stimuli (p=0.001). Other than these two posts hoc analyses, all fixation duration results were insignificant.

At this point, to study the attention that users paid during the free viewing of different natural stimuli, we performed an analysis of gaze data in specified AOIs. To collect eye-tracking data, we constructed regions around each stimulus to include all gaze points closer to that stimuli than to any other. For all subjects, the area of AOI was made constant for every class of stimulus. Based on the AOI analysis, we observe a similar value of the fixation count on the task-relevant AOIs. Therefore, no significant difference was observed (Table 4.10, Figure 4.14).

Analysing the percentage of fixation in the AOI's; our observations confirmed that when there is a significant difference in aesthetic perception level in stimuli. For the percentage of fixation, Kruskal-Wallis pairwise group comparison test was done (Table 4.10, Figure 4.14). Post hoc analysis found a significant difference (p=0.002) in the percentage of fixation between the Low – Highest rated natural stimuli. Similarly, a significant difference was observed between the groups of Low – lowest rated natural stimuli (p=0.001). Other than these two posts hoc analysis all of the percentage of fixation results came insignificant.

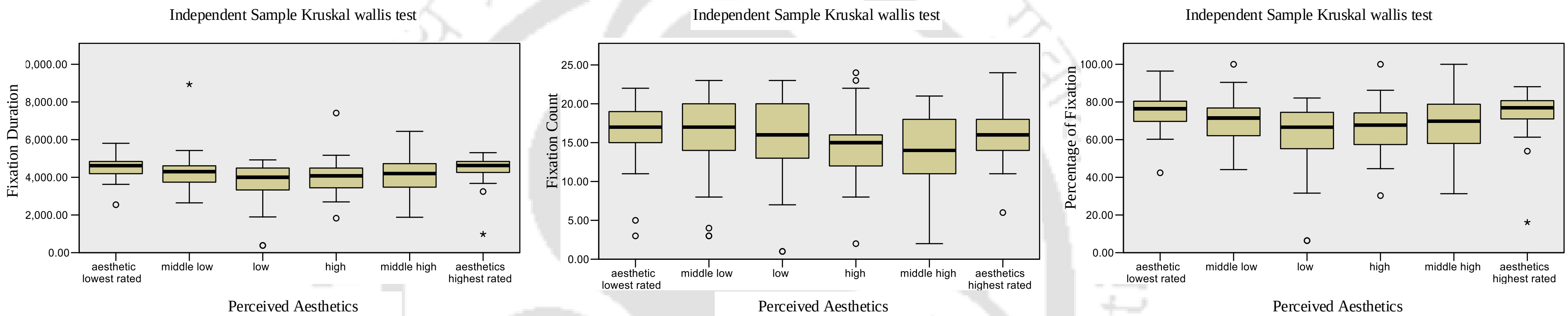


Figure 4.14. Fixation duration, fixation count, and percentage of fixation of the six groups for aesthetic stimuli. The box plots indicate the eye-tracking pattern with the standard deviation of the estimates in the error bars

Table 4.12. Post hoc analysis of between the groups of aesthetic stimuli

For aesthetics stimuli	Group Details	T-test	Std. Error	Std. Test Statistic(t)	Sig.	Adj. Sig
Fixation duration	Low–Highest rated	-38.538	12.530	-3.076	.002**	.031**
	Low – lowest rated	40.481	12.530	3.231	.001***	.019***
Percentage of fixation	Low–Highest rated	-38.673	12.529	-3.087	.002**	.030**
	Low – lowest rated	40.308	12.529	3.217	.001***	.019**
Note. Adj. sig = multiple comparison corrected p-value (Bonferroni correction). *p<.05, **p<.01, ***p< .001						

4.5.2.6 Discussion of differences in eye tracking data for different level of aesthetic variables of natural images (ANOVA of section B)

The results show that the eye-tracking distribution was significantly different for different aesthetic levels of stimuli groups (Table 4.11). Further post hoc analysis was done to monitor the difference between the specific groups. It was found that the difference between the Low – Highest rated and Low – lowest rated are found to be significant for different natural stimuli. Similarly, for composition stimuli, the difference between Low composed- High composed and Neutral composed - High composed are significant (p = 0.004). For the hypothesis testing to determine the ANOVA for the natural stimuli, the null hypothesis is fixed that the eye-tracking variables are the same across categories of perceived aesthetics.

Table 4.13. ANOVA Hypothesis Test Summary for natural stimuli

Complexity	Null Hypothesis	Test	Sig.	Decision
1	The distribution of fixation duration is the same across categories of Perceived aesthetics.	Independent-Samples Kruskal-Wallis Test	.004	Reject the null hypothesis.
2	The distribution of fixation count is the same across categories of Perceived aesthetics.	Independent-Samples Kruskal-Wallis Test	.349	Retain the null hypothesis.
3	The distribution of the percentage of fixation is the same across categories of Perceived aesthetics.	Independent-Samples Kruskal-Wallis Test	.004	Reject the null hypothesis.
Asymptotic significances are displayed. The significance level is .05.				

4.5.2.7 Discussion of differences in eye tracking data for different level of aesthetic variables of natural images (ANOVA of section B)

In this experiment, the subjective aesthetic rating with perceived complexity and perceived composition of the natural images is done, and its relation with eye-tracking data was highlighted. The correlation between the variables was found to be significant. The research questions were addressed by doing a correlational study. Later on, the Kruskal Wallis test was also done to explore the difference between the type of stimulus followed by the postdoc analysis. Finally, the ordinal logistic regression was done to map the model of aesthetic experience. For both complexity and composed stimuli, we collected subjective data at a time by rating. Both sections of the experiment have a similar output and show the strong relationship between an aesthetic variable and eye-tracking data.

In the eye-tracking experiment and subjective rating, the same 26 subjects have participated. The result in the eye-tracking experiment confirmed that the composition and complexity are the two reliable variables to observe subjects' perception. A strong correlation is observed between several eye-tracking variables and aesthetic variables. This finding shows that having a higher value of eye-tracking variables like fixation duration, fixation count, and percentage of fixation does not necessarily mean that the subjective aesthetic ratings are also high for the same object. Particularly for a high level of composition, the value of aesthetic variables is observed to be low. But for a high level of complexity stimuli, the value of the eye-tracking variable increased with an increase in complexity level.

We found a 'U' relation between eye-tracking variables and aesthetic variables. The eye-tracking data decreased in the middle and increased again. It means in a moderate amount of aesthetics level, the eye-tracking variables are observed to be lowest. The higher and lower aesthetics stimuli are observed higher eye-tracking values than other images.

5

General Discussion and Conclusion

Abstract

In this chapter, the observation and result of the experiment from all the chapters have been summarized briefly in the form of research outcomes, addressing the research questions and fulfillment of the objectives. The testing of the hypothesis is explained following the key contributions of the present research. The present chapter clarifies how the subjective and objective evaluation of aesthetics has been performed with the derived variables from the literature survey and gives meaning to the entire thesis where research fragments have been joined from different chapters to understand the complete scenario of the entire research. Apart from that, the novelty of the present research is discussed at the end, along with the limitations.

5.1 Discussion

The current research tried to observe the relation between aesthetic perception with eye-tracking variables. To find the relationship between the variables of aesthetics, we need to control the level of variability in independent variables (complexity and composition). For that reason, 2D shapes were chosen as stimuli, and complexity and composition were controlled through the coding. After carefully generating, segregating, and evaluating these stimuli, the analysis was done to answer the research question. The outline of the current research was divided into six phases: problem identification through literature survey; qualitative assessment of the aesthetic perception; development of a novel regenerative program to generate 2D shapes; subjective evaluation of the quantitative data through a questionnaire; objective evaluation of the quantitative data through eye tracker; and empirical evaluation of the different aesthetic variables.

In the first phase, the problem identification was made, where a review of literature related to the study of this thesis was carried out in the different fields. Then gradually, the literature survey was narrowed down to the research gap. To accommodate the identified research gap, multiple research questions were formulated. Also, in this section, the hypothesis of the research was formulated after setting the aim and objectives.

Similarly, in the second phase, a qualitative assessment of the aesthetic perception was conducted. The objective of this phase of research was to tally the result of the literature with our quantitative data. The result found from the contest analysis of the interview were very encouraging for the further study on the topic. It also helped finalize the 2D stimuli and the other variables we are trying to control.

In the third phase, we developed the 2D stimuli through the grasshopper regenerative coding. As explained in chapter 3, the two types of stimuli were developed and tested for further evaluation. These stimuli were developed using the descriptive properties of a shape as one of our research questions is to find out the relation between the descriptive qualities with aesthetic measures.

The 20 (10 for perceived complexity and 10 for perceived composition) most meaningful stimuli were selected from the 60 stimuli in phase four. The questionnaires were prepared using each of the stimuli. A total of 85 subjects participated in the data collection. The objective of this phase of the study is to select the six visuals (3 for perceived complexity and 3 for perceived composition) based on the most, moderate, and least rating of the stimuli. The correlation was drawn in the experiment, and a high correlation was observed between the descriptive qualities and aesthetic measures.

This section of the research aimed to systematically examine the role of perceived complexity and perceived composition correspondences to aesthetic perception of abstract 2D shapes. Apart from that, the individual differences in the meaningfulness of the 2D visual with preference level were also explored. The correlation demonstrated the relation between perceived aesthetics and its variables (complexity and composition) through visual senses. The found association was highly consistent across the studies. Our correlation findings are partially consistent with previous research that demonstrated a relation between descriptive characteristics of 2D shapes and aesthetic variables (Blazhenkova and Kumar, 2018, Fryer et al., 2014; Hanson-Vaux et al., 2013; Spence, 2011; Dreksler and Spence, 2019, Velasco et al., 2015).

However, this is the first study to demonstrate the global variables of aesthetics on abstract shapes systematically. At the same time, the variables of aesthetics were defined when attributes were presented as verbal labels in the qualitative study, and the relationship was established when attributes were presented as real experiences in the quantitative study of 2D shapes. The current findings cover the previous research on the restraining role of individual differences in descriptive characteristics shape processing (Cotter et al., 2017, Zhang et al., 2006). In addition, correlational analyses of the shape indicate that rating on perceived scores were generally interconnected across multiple attributes, particularly in the form of descriptive qualities of shape.

After that, in phase 5, those selected stimuli were evaluated through an eye-tracking free viewing experiment. The protocol of the investigation is explained in chapter 4. Then the eye-tracking data were extracted and segregated according to the respective visuals. The result of the correlation study was found to be strong between the aesthetic variable and eye-tracking data. When the complexity showed a positive correlation, composition negatively correlated with the eye-tracking variables. After that, the Kruskal Wallis one-way ANOVA was done separately to see the difference between the complexity and composition stimuli. There is a significant difference noticed in the eye-tracking variables for both complexity and composition stimuli.

The principal objective of this phase of the research to develop a methodology to acquire visual exploration of abstract 2D shapes. Particularly to understand the effect of different level of complex and composed stimuli on visual exploration. In this experiment a limited 26 subjects have participated and generated a large data set (cumulatively 10300 fixations). Each of fixation point embodied a single, relatively unconscious decision about the 2D stimuli. As the result the methodology successfully demonstrate the empirical evidence to understand the relation between the subject and object. To our knowledge this is the first eye tracking experiment to compare the aesthetic perception with controlled abstract 2D shapes backed by qualitative data. The justification of the research can be linked to existing aesthetic studies (Bertamini, et al., 2016; Silvia and Barona, 2009; Zhang et al., 2006; Vessel and Rubin, 2010; Bies et al., 2016; Friedenberg and Bertamini, 2015; Martindale et al., 1990; Jacobsen and Höfel, 2002; Friedenberg, 2018) on 2D shapes. Apart from that eye tracking as a tool is delicate tool for aesthetic research and concluding a phenomenon in human behavioural gaze pattern is very difficult to handle in multiple class of stimuli.

As the conclusion of the research we found out that the subject engaging with 2D shapes shows different viewing results (eye tracking data) for complexity and composed stimuli. Where aesthetic perception of the complex stimuli reduces with increase in complexity level, at the same time the aesthetic perception increases with the increased in composed level. The details of the experimental results are explained in the chapter 4 of the thesis. The preliminary evidence suggests the need of further research and congregating results with varity of other stimuli in natural environment.

Similarly, for phase 6, the methodology followed was very similar to phase 5, but here, the stimuli used were natural stimuli. The results of Kruskal Wallis one-way ANOVA indicated that the difference of aesthetic perception was significant between the stimuli. The fixation count particularly is a significant predictor of aesthetic perception.

In the future, studies can be made to explore the higher level of forms with variables like color and texture analysis in aesthetic studies. Apart from that both general and specific emotional abilities (e.g., discriminating between different emotions and emotional recognition) can also be studied. Similarly, the same phenomenon can be investigated while using biometric instruments to study perceived aesthetics to observe neurological side of the aesthetic perception. Later the environmental aspects like gender, cultural influence, aesthetic attitude, age can be explored.

5.1.1 Outcomes of the research

The outcomes that come up with a unique methodology for aesthetic evaluation through subjective and objective means are listed as below:

- Developed an algorithm in the grasshopper (Rhino) to generate random 2D stimuli by varying the descriptive characteristics of the shapes.
- Reduced and filter out the number of generated shapes for subjective evaluation. This determination of the sub-variables for aesthetic evaluation from a large pool of variables is possible, which will be used to prepare questionnaires.
- Determination of the tangible variables of aesthetics across all the field of aesthetics.
- An experiment protocol for the eye tracking study of abstract 2D shapes.
- Proposing the variation in eye tracking variables in different groups of aesthetic level.
- Establishment of design philosophy for the quantitative evaluation through the eye tracker.

5.1.2 Addressing the research questions

The current research findings were highlighted and documented following points.

- This study includes qualitative data analysis to determine the variables of aesthetics collecting data from 37 subjects. From the interview, it’s clear that complexity and composition both contribute to the cause of aesthetic arousal. The data provided the rank and frequency count of the asked questionnaires, which provides the idea of subjects’ perceptions. From the qualitative data analysis, we have addressed the research question (RQ-1) and (RQ-2).

- While exploring the relationship between aesthetic variables and descriptive measures of 2D shapes, it is clear that dealing with 2D shapes increases perceptual difficulties for the subjects. Particularly higher complex and lower composed shapes were difficult to perceive. Therefore, descriptive qualities significantly correlated with the aesthetic variables but on a lower side. The result of experiment 1 interview and subjective rating on the 2D shape and its variable reflected similar results (RQ-3, RQ-4, and RQ-5).
- While exploring the relationship between aesthetic variables and eye-tracking variables, it is clear that dealing with 2D shapes increases perceptual difficulties for the subjects. Particularly higher complex and lower composed shapes were difficult to perceive. Therefore, the eye-tracking variable significantly correlated with the perceived complexity. Similarly, the perceived composition showed a negative correlation with the eye-tracking variables. The result of experiment 2 eye-tracking experiment and aesthetics subjective rating on the 2D shape reflected similar results (RQ-6 and RQ-7).
- In natural stimuli, the relationship between aesthetic variables and eye-tracking variables are perceptual soothing for the subjects. We did find a U relationship between the eye-tracking and aesthetic variables. Particularly higher aesthetics and lower aesthetics stimuli were difficult to perceive. Therefore, the eye-tracking variable showed a significant association with aesthetic perception (RQ-8 and RQ-9).

5.1.3 Fulfilment of the objectives

Objective 1. To determine the list of variables that could be used by researchers as the measures of aesthetic evaluation across the diverse fields (e.g., painting, sculpture, product design, film, animation, etc.).

Total nine major variables from the various field of application (Aesthetics, Ergonomics, Neuroscience, Neuroaesthetics, Fashion, HCI, Computation, Psychology, Architecture) were identified using a semi-structured literature review. This literature helped investigate the effectiveness of the variables (Complexity, Composition, Symmetry, Balance, Pleasant, Interesting, Randomness/ order, Contrast, Preference) across all disciplines. Thus, objective 1 of the research was fulfilled. Detail description of the variables used in the aesthetic evaluation and the evaluation techniques are explained in chapter 2.

Objective 2. To assess aesthetics through subjective measures.

A semi-structed interview with transcription coding was administered to identify the usefulness of variables. To verify the efficacy of the subjective data, a set of questionnaires were prepared, and a correlation study was done. Thus, objective 2 of the research was fulfilled. Detail description of the subjective measures along the methodology followed can be accessed through chapter 3.

Objective 3. To assess aesthetics through objective measures (eye-tracking).

An eye-tracking experiment was administered with a limited number of stimuli and subjects. The variables of aesthetics (complexity and composition) were controlled through these stimuli, and the eye-tracking parameters were studied. Finally, a questionnaire is filled to draw a correlation between the eye-tracking data and subjective empirical data. Thus, objective 3 of the research was fulfilled. Detail description of the objective measures along the methodology followed can be accessed through chapter 4.

Objective 4. To study the level correlation between the subjective and objective measures of aesthetics.

To empirically examine the effectiveness of the objective measures, a correlation has to be done between the objective and subjective measures. In chapter 4 of this thesis, two correlational studies and the methodologies were drawn and explained. In two different studies, two different types of stimuli were used. In both studies, the relation and association between the subjective data (questionnaires) and objective data (eye-tracking) are found to be strong. Thus, research objective 4 of the study was fulfilled.

5.1.4 Testing of hypothesis

Null Hypothesis (H0): Subjective response of the aesthetics perception of a visual is not significantly correlated with objective measures (like eye-tracking variables: fixation duration, fixation count, percentage of fixation).

Alternative Hypothesis (Ha): Subjective response of the aesthetics perception of a visual is significantly correlated with objective measures (eye-tracking variables: fixation duration, fixation count, percentage of fixation).

To test the hypothesis, first subjective and objective data of the aesthetic perception of subjects from the same set of stimuli were collected. The subjective questionnaires were prepared from the qualitative study done in chapter 3. Transcription coding and content analysis are performed to form the questionnaire based on the finalised variables. Similarly, the stimuli for the hypothesis testing were selected from the experimental output of section 2 of chapter 3. In the eye-tracking experiment of chapter 4, the data were first recorded and then segregated into eye-tracking variables (Fixation duration, Fixation count, and percentage of fixation). The Spearman correlation was drawn between the objective and subjective data. The result of the correlation can be observed from the table (Table 4.3.B and Table 4.4.B). It can be observed that a significant correlation ($p < 0.01$) was observed between the subjective and objective data. Thus, the Alternative Hypothesis (Ha) is accepted, and the Null Hypothesis (H0) is rejected.

5.1.5 Key contributions of the present research

The present research works enrich the knowledge of cognitive ergonomics in aesthetics evaluation by utilizing eye-tracking data and subjective ratings. The novel contribution of the current research is explained below:

a. Contribution to knowledge-base

The evaluation medium for most aesthetics studies starts with the collection of subjective data. Then the data is analyzed to conclude certain hypotheses. As discussed in the research problem, the variables differed in different studies. Therefore, to identify aesthetic variables that can be considered in all fields is helpful for researchers to acquire basic knowledge in the process of data collection, analysis, and interpretation. Those aesthetics variables can be used and referred by designers and researchers for the aesthetics evaluation of specific user populations for any visuals. Biometric technology like eye tracker is used to very the same result objectively. This enables researchers and ergonomists to find an alternative way to identify the aesthetic experience, which may lead to improvement in an aesthetic object. The protocol followed in the experiment can be utilized to design studies in a similar kind of research. Hence, the establishment of design philosophy for developments of new methodology in ergonomic design considerations and enhancement the evaluation technique is used as knowledgebases.

b. Contribution towards methodological perspective

The methodological protocols that can provide visible contributions for researchers in evaluating aesthetics consist of doing a content analysis of the qualitative data, developing the 2D stimuli with regenerative coding, intra and inter-correlation of aesthetic variables, and operating and analyzing an eye-tracking experiment. From the methodological aspects of data analysis, the statistical analysis of the aesthetic evaluation consists of normality testing using skewness and kurtosis. Then, Spearman correlation, Kruskal Wallis test for one-way ANOVA followed by the post hoc analysis, ordinal logistic regression to determine the significant predictor. It determines the aesthetics variables that can be evaluated through an eye tracker, which will make an important methodological contribution for the variable identification in a diverse aesthetic field. The analysis of existing subjective aesthetics evaluation techniques compared to the presented objective evaluation technique through the eye tracker is considered the novel methodological contribution of its kind. The proposed methodology can be used as an alternative to the unreliable subjective rating, which can be adopted globally as a design evaluation technique.

5.2 Novelty

- This is the first kind of study that tried to find a correlation between subjective measures (in terms of complexity and composition) of visual classical aesthetics and objective measure of aesthetics (eye-tracking variables).
- The current study established a correlation between descriptive characteristics of the visual stimuli and subjective perception of complexity and composition in the case of random 2D monochromatic shape. This type of study involving 2D shapes is unique as most earlier studies related to aesthetic evaluation deal with complex images.
- The methodology (regenerative programming) adopted for generating visual stimuli for evaluation of complexity and composition by manipulating various descriptive qualities (number of points, curve angle ratio, variation of symmetry, figure background relation) is novel and can be followed by future researchers for their stimuli preparation.

5.3 Limitations

Even if how much a researcher tried to track down the finest conceivable experimental protocol and execute the experiment accordingly. The probability of having a limitation less research work is never possible. The foreseeable limitations of the present research could be considered for further exploration of the future research scope.

- Current research deals with an eye-tracking study. Collecting a large sample size of subjects is not possible with the eye-tracking experiment, as manual data extraction and segregation of eye-tracking data is a tedious and time-consuming task. Therefore, limited sources and time constraints forced to limit the sample size to 26. Similarly, only 100 persons were considered and analyzed for the interview, as doing content analysis and transcription coding for all persons was a resource-consuming task.
- This research did not explore the different socio-demographic details of the subjects. All the participated subjects are of a mixture of south Asian ethnic groups from the Indian Institute of

Technology Guwahati and are students. Apart from the demography, the gender-based aesthetic evaluation was not performed.

- In this study, only monochromatic 2D visuals were used as the stimuli. The other elements of visuals like color, form, and texture were not explored.
- There are many environmental factors that control aesthetics and kind of impossible to address all. Even one of the most challenging tasks in aesthetic research to control those environmental factors like, light, noise, temperature, aesthetic attitude, repetition, subject's earlier exposer etc.
- This research used eye-tracking data for objective evaluation. Other biometric techniques like EEG, facial EMG are not explored to follow the same methodology.
- The current experiment is conducted in a lab set in environment. Particularly, the eye-tracking experiment was a planned simulation of the actual aesthetic experience. As the experiment was conducted in the lab with a controlled environment, it is impossible to compare the artificial simulation with the natural environment. Further studies can be planned in natural environmental conditions.
- This study only explored classical aesthetics in terms of complexity and composition. The other class of aesthetics, like expressive aesthetics, is not explored. The scope of this study was limited to visuals only. The other field of aesthetics like poetry, dance, art, music was not explored in this study due to the limited amount of time.

5.4 Conclusions

The results indicate that aesthetic perception is highly variable and difficult to narrow down to a simple function of complexity and composition alone. One of the interesting outcome was that perceived complexity was found significantly correlated with the number of points, curve angle ratio, and perceived aesthetics. Similarly, the perceived composition was significantly correlated with the number of points, curve angle ratio, figure background ratio, symmetry, and perceived aesthetics. It indicated if descriptive characteristics (number of points, curve angle ratio, figure background ratio, type of symmetry) of2D shapes are altered, it would directly impact the perception of complexity and composition, thereby influencing aesthetic perception. In experiment 1, interviews with participants suggest that most of the factors that influence aesthetic perception are directly or indirectly part of perceived complexity or composition.

Following experiment 2, using three stimuli of different perceived aesthetic levels, it was noticed that perceived complexity was significantly correlated (positive) with a few eye tracking variables, namely fixation duration, fixation count, and percentage of fixation. It means an increase in complexity level contributes to a high value of aforesaid eye tracking variables. In case of composition, eye tracking variables like fixation duration, fixation count, and percentage of fixation were found to be significantly correlated (negative). It can be stated that better composition of the stimuli leads to a reduction of values of earlier mentioned eye tracking variables. Independent sample Kruskal-Wallis test expressed that fixation count, fixation duration, and fixation percent varied significantly across three different levels of complexity of the stimuli. Similar observations were also noticed for three different stimuli composition levels. Out of various eye tracking variables in current research, only Fixation duration, Fixation count, and Percentage of fixation have been directly impacted by the change in the perceived level of complexity and composition.

To examine the influence of perceived complexity and composition (independent variables) on eye tracking variables (dependent variables), an Ordinal Logistic regression analysis was conducted. The OLR result observed that both perceived complexity and composition could be predicted using fixation count but not other eye tracking variables. Thus, it can be concluded that it is very difficult to judge the perceived complexity and composition based on eye tracking variables, as the prediction capability of eye tracking variable (except fixation count) are very low in determining perceived complexity and composition.

The Study with natural stimuli where both levels of complexity and composition vary simultaneously showed that fixation duration and percentage of fixation varied significantly across stimuli of different levels of perceived aesthetics. It was noticed that the stimuli with lower and high level of perceived aesthetics have a higher level of fixation duration and percentage of fixation. Thus it can be concluded that the level of perceived aesthetics could be identified from the eye tracking by measuring the variables like fixation duration and percentage of fixation.

The present study with 2D monochromatic shapes is a stepping stone for the objective evaluation of aesthetics based on eye tracking variables. It was successful to a great extent to establish an experimental protocol for evaluating aesthetics involving both subjective and objective measures and thereafter, their correlation. Moreover, the current study disclosed the correlation between descriptive characteristics of a visual (Number of points, curve angle ratio, figure background ratio, and symmetry) with perceived complexity or composition and association with perceived aesthetics. Further research as the extension of current research by involving different influencing factors (Color, Form, Texture, etc.) will provide detailed information regarding objective measures of aesthetics.

The resulting plots didn't follow the inverted Bel curve theory, but it did offer a convenient method to evaluate the relationship between the aesthetic and eye tracking variables. These findings constitute empirical evidence for the relation between aesthetic perception and eye tracking variables. Therefore, contribute to knowledge in the field of visual classical aesthetics. The results of experiments conveyed that to achieve higher aesthetic perception, there should be a balance between complexity and composition.

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