

VISUAL BALANCE IN ENGINEERING DESIGN
FOR AESTHETIC VALUE

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ABSTRACT

The aesthetic aspect of a functional product is growing to be an important reason for the consumer's choice to buy the product. Despite this importance, aesthetics has not generally been incorporated into engineering design which makes much sense of functional and ergonomic designs. The study presented in this thesis aims to remedy this observed gap. The study focuses on the integration of aesthetic attributes with functional attributes of a product and on the quantification of the aesthetic principle from fine arts into design variables of the product. In particular, two hypotheses underlie this study: (1) design variables can be classified in terms of their relevance to functional, ergonomic, and aesthetic attributes, and (2) a particular aesthetic principle, namely visual balance, helps to achieve an improved aesthetic product.

The cell phone is used to ground this study. A statistic experiment using the cell phone product positively tests the first hypothesis, resulting in two design variable which are only related to the aesthetic attribute of the cell phone product. The study of the visual balance principle results in a more general formula which relates design variables to visual balance with consideration of both geometry and color of the cell phone product. Finally, another statistic experiment is designed, which positively tests the second hypothesis.

This study concludes: (1) the effective integration of aesthetics with function and ergonomics requires an analysis and classification of design variables, and (2) there is a potential to quantify all aesthetic principles from fine arts into design variables.

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Dedicated to my beautiful daughter

Sara

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LIST OF ABBREVIATIONS

A_c	:	An area (in cm^2) equivalent to the weight of a color
A_g	:	Geometric area (in cm^2)
ANN	:	Artificial Neural Network
$Asym$:	Asymmetric
α	:	The probability of rejecting the statistical hypothesis tested when that hypothesis is true
a_{ij}	:	Area of the component in the sides i and j
BM	:	Total balance measurement
$BM_{horizontal}$:	Balance measurement around horizontal balance
$BM_{vertical}$:	Balance measurement around vertical balance
d_{ij}	:	Distance from the centre of component's area to the balance axis
ϵ	:	Belong to
HSL	:	Hue, Saturation and Luminosity
MATLAB	:	Matrix Laboratory
$N.S.$:	Not significant
O	:	Data observed by the survey
P	:	The probability of obtaining a finding is the result of chance alone
Pr	:	Data predicted by the model
RGB	:	Red, Green and Blue
SD	:	Semantic Differential
SPSS	:	Statistical Package for the Social Sciences
Sym	:	Symmetric

- w_L : Weight of the left side
- w_R : Weight of the right side
- w_T : Weight of the top side
- w_B : Weight of the Bottom side
- Z score : One standard deviation far from the mean of a distribution.

CHAPTER 1

INTRODUCTION

1.1 General Motivation

Traditionally, designs are performed to satisfy the functional requirements of consumers [Reich, 1993]. However, this does not satisfy all desires of consumers as humans have a variety of other needs. Nowadays a product with high functionality but poor aesthetics would not attract much consumer's attention. The final aim of producers would not be accomplished unless all aspects of human desires are considered in design. The more a design satisfies the psychological (emotional and intellectual) needs of consumers, the more it motivates consumers to buy the product. According to Maslow's theory of human motivation, aesthetic values are one of the highest human motives to work and to live [Corsini, 2002]. Although aesthetics plays an important role in product design, it is not generally focused in the human factors research [Liu, 2003] or in the design research [Reich, 1993]. Insufficient scientific understanding of aesthetic design for (functional) products has motivated a recent trend of study in this area. This study was

focus on aesthetic design of functional product. Further, to ground this study, cell phone was taken as a case study throughout.

1.2 Problem Statement

In this study design was categorized into functionality, ergonomics, and aesthetics [Lin and Zhang, 2006]. Functionality refers to the ability of a product to do one of its expected functions/works. Ergonomics is the study of the relationship between humans and machines including such matters as maximum efficiency, safety, comfort, and accuracy [Corsini, 2002]. And finally, aesthetics is the study of quality which gives pleasure to the sense [Oxford dictionary, 2000]. To see differences between ergonomics and aesthetics, it should be mentioned that while the attitudinal component of ergonomics is related to comfort and acceptability of product use [Jordan, 1998], aesthetics is related to pleasure [Oxford dictionary, 2000] in product use, that is, the emotional and hedonic advantages connected with product use [Jordan, 1998].

There are two major problems in the contemporary literature of the aesthetic design of a functional product, i.e.: (1) disconnection of the aesthetic attributes of design with the functional and ergonomic attributes of design, and (2) insufficient understanding of the utilization of aesthetic principles from Fine Arts for the aesthetic design of functional products. This study was focused on providing solutions to these problems.

1.2.1 Integrated approach to design

It is an axiom that different, significant, and almost independent aspects of design should be separated into different categories for consideration in light of a simple

product which is yet functional, usable, and beautiful. Further, such categorization fits well with modular architecture in engineering design and manufacturing, which significantly reduces the design space [Bi and Zhang, 2001] and consequently reduces designer's efforts. As a matter of fact, the general idea of such categorization is also matched well with the Independence Axiom of the Axiomatic Design theory which was proposed by Suh [1990]. The Independence Axiom is one of the basic principles of design and states that functional requirements must be maintained independent of one another in design by choosing appropriate design parameters. Independence Axiom can be applied to the function, ergonomic, and aesthetic attributes of design. Therefore, the attributes of the design should be separable so that changes in one have no effect or as little effect as possible on other attributes. Although different categories of designs are considered separately, the fact that they correspond to a common product requires the integration of these different categories of designs. How to do this integration is the first problem this study was to tackle.

1.2.2 Aesthetics Principle and Design

There are some principles such as Unity, Balance, Variety, and Proportion that have been developed in the field of Fine Art under the name of "principle of design" or "principle of organization". Principles of design (in Fine Art) are the result of some long-term empirical experiment and intuition, and they have been found effective in different places and times of humankind [Feldman, 1971].

Aesthetic principles are known and usable in the field of computer interface design, and some studies such as Bauerly et al. [2003] and Ngo et al. [2003] have been done in

this area. However, there are very few attempts that have been concerned with the critical analysis of aesthetics in engineering design [Pye, 1995], and among them the studies such as Jordan [1998], Yanagisawa and Fukuda [2003], and Yoshimura and Yanagi [2001] can be referred. However, they have not addressed the integration issue; see also the comment made by Lin and Zhang [2006].

1.3 Objectives, Scope, and Method

- *Objective 1:* Integration of aesthetic design with functional and ergonomic designs for a functional product.
- *Objective 2:* Quantification of aesthetic principles from Fine Art in terms of design rules to guide aesthetics design for a functional product.

In objective 1, the hypothesis is that a set of variables is only related to aesthetic design but not to ergonomic and functional designs. The research activity of objective 1 was toward the verification of this hypothesis; as a result, it was expected that a comprehensive classification of design variables for the cell phone product would be determined. Statistical experiment-based methodology was employed for this objective.

In objective 2, visual balance was chosen for study. Through a statistical experiment-based methodology, visual balance was quantified and incorporated into the design methodology for functional products.

Fig. 1.1 provides a general overview of the scope of this thesis using the cell phone product with consideration of all three aspects of design (functional, ergonomic, and aesthetic) with a particular attention to where the visual balance stays. In particular, the

following research activities were carried out. First, cell phone design variables which are highly relevant to aesthetic aspects and irrelevant/slightly relevant to functional and ergonomic aspects of design were identified. Second, a method was developed for quantifying the property of visual balance considering both the area and color of a product. Third, the evaluation of how the visual balance contributes to the aesthetic design in the case of cell phone was carried out.

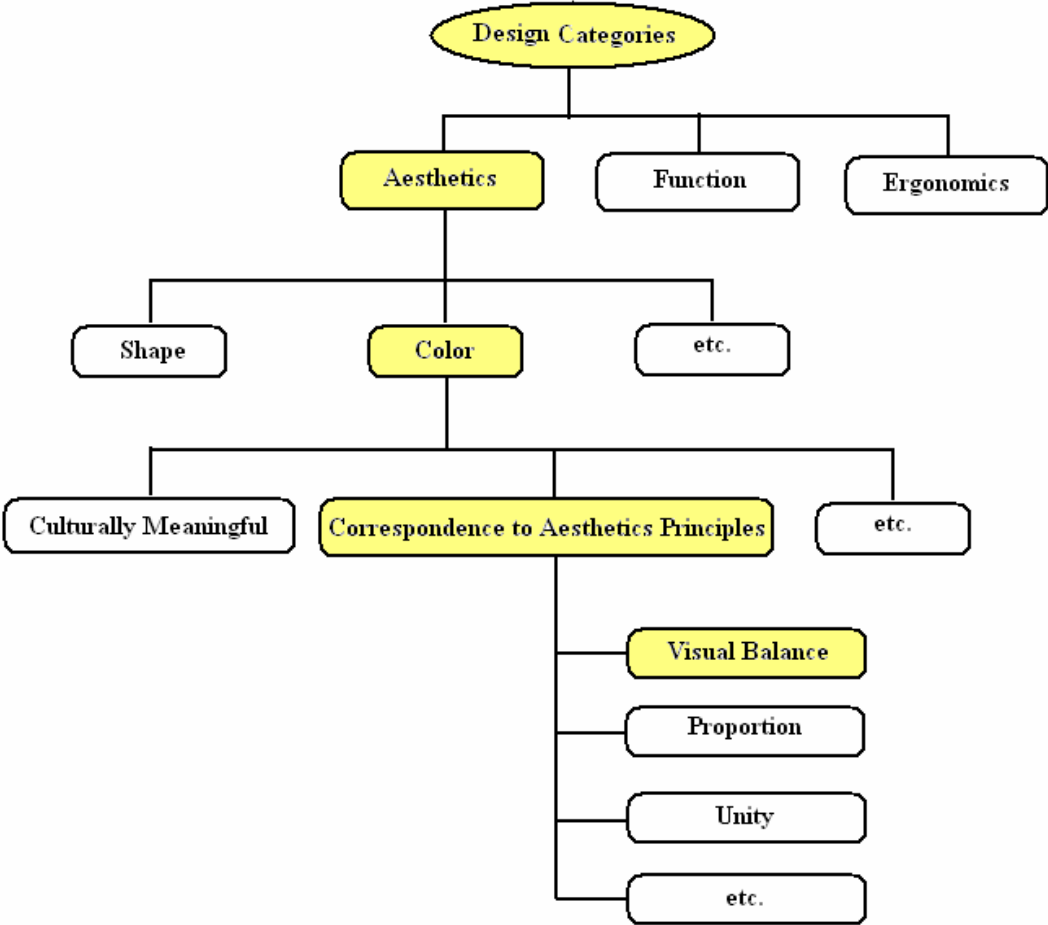


Figure 1.1 Typical scope of a tentative schematic design chart

1.4 Organization of the Thesis

The remainder of the thesis is organized as follows. Chapter 2 includes background information that is necessary for explanations of the subsequent chapters. Particularly, after defining aesthetics, different approaches to aesthetics are reviewed. Then, the importance of aesthetic aspects in design is discussed. Finally, the quantification methods for aesthetics principles in the context of design are described.

In Chapter 3, an experiment will be presented for the classification of design variables in cell phone; in particular the attention will be placed on the design variables that are only related to the aesthetic aspect of cell phone. This chapter will present the way that cell phone samples are collected and results are generated and analyzed.

In Chapter 4, a method is presented to quantify the visual balance principle in the context of designing cell phone. This chapter will present, in particular, how the problem is formulated, how the experiment is designed to prepare a solution to the problem, what is the solution, and the evaluation of the solution.

Chapter 5 presents the evaluation of the aesthetic design based on the methods developed with this research. In particular, this chapter will first present how new designs could be generated using the methods developed, then present the statistic design of an experiment with the result of the experiment, and finally present some new observations.

At last, in Chapter 6, research contributions and limitations are outlined and some suggestions for future work are presented.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

Based on Merriam-Webster's dictionary, aesthetics is "a branch of philosophy dealing with the nature of beauty, art, and taste and also with the creation and appreciation of beauty." And beauty is "the quality or aggregate of qualities in a person or thing that gives pleasure to the senses or pleasurably exalts the mind or spirit" [Merriam-Webster dictionary, 2004]. Cambridge's online dictionary defines aesthetic as "relating to the enjoyment or study of beauty" [Cambridge dictionary, 2004].

In the contemporary art's literature, there are two primary views on beauty. The first view is an intellectual, formal, instrumental, and functional one called the rationalist view; and the second view is a romantic, passionate, intrinsic, fundamental, and sublime view called the romanticist view [Warry, 1962]. Rationalism and Romanticism are two major aesthetic views that seem to contribute in design [Reich, 1993].

In this chapter, these views of beauty are reviewed in detail. In particular, Section 2.2 describes two aesthetic design approaches. A conclusion is found that the rationalism

approach is preferred for this study. In Section 2.3, the rationalism approach is discussed in detail. In Section 2.4, the importance of considering aesthetics in design is discussed. Finally, in Section 2.5 different quantitative methodologies in aesthetic design are described.

2.2 Aesthetics Historical Note

The meaning of aesthetics was separated into isolated categories at least from ancient Greece in philosophy. Greek aesthetics can be understood by elaborating Plato's and Aristotle's views about beauty; the former is romantic and the latter is intellectual [Warry, 1962]. In beauty, Neoplatonic theories place emphasis on its appearance, while Aristotelian theories focus on its harmony [Iannone, 2001].

In Platonic doctrines, the "form" or "idea" is the essential concept [Saatkamp and Holzberger, 1988]. Forms mean eternal, imperceptible, and spiritual entities [Iannone, 2001]. Plato's metaphysical and intuitional point of view about "form" is applicable to beauty as well. Beauty is an immutable and timeless form [Saatkamp and Holzberger, 1988]. Plato believed that beauty was associated with aesthetic forms which are innate in humans [Saatkamp and Holzberger, 1988]. For instance, Plato said that form of a tree literally is a memory of the tree that we have already seen in heaven [Saatkamp and Holzberger, 1988]. In other words, aesthetic forms are hidden structures of beauty. But it seems that at least parts of these forms are made in each culture and, as Reich [1993] pointed out, aesthetic appreciation is predicted on similarity with cultural figures. In other words, the experience of beauty will be realized when a phenomenon is associated with innate forms of beauty *or* meaningful symbols constructed through cultural

practices. According to an interpretive view, culture is a set of shared meanings that are constructed and transmitted by human beings within particular social contexts in their interactions together and with their world, as long as they engage with the world they are interpreting [Crotty, 1998]. According to this view, aesthetic forms can be considered as symbols that are dependant on culture. Considering different meanings of some symbols (such as color) in different cultures, a phenomenon may be perceived beautiful in one culture but plain or even ugly in another culture. Whether aesthetic forms are innate or socially constructed or partially innate and partially constructed inside culture, they must evoke emotional preferences of a person through an associative mechanism.

Aristotle's naturalist view led him to reject Plato's theory of forms [Saatkamp and Holzberger, 1988]. The essence of Aristotle's view on art and beauty is fundamentally rooted in system, classification, and logic [Warry, 1962]. He proclaimed that order, proportion (symmetry), and limit are the basis of beauty [Warry, 1962]. The laws of proportion are the principles that have existed from an ancient time and have been used widely across different fields. For example, Pythagoras used proportion in relation to sound and form perception, and Vitruvius in relation to architecture; and Palladio and Le Corbusier used it in their designs works [Reich, 1993].

Plato associates beauty with love, whereas Aristotle connects it with reason [Warry, 1962]. The Platonist view focuses on the feeling of beauty, while Aristotle's approach concentrates on understanding how human come to feel beauty. Plato's insight eventually led to a romanticist view and Aristotle's opinion was directed to rationalistic views heralded in the 18th-century enlightenment.

There are radical differences between rationalism and romanticism. The ontology embedded in romanticism is idealism. It asserts that beauty solely exists inside the human mind [Reich, 1993]. The epistemology of romanticism is subjectivism. According to subjectivism, beauty is dependent on consciousness. As mentioned, according to holistic approach of romanticism, aesthetics feeling is experienced by overall evaluation of phenomenon through associations with beautiful forms. The ontology embedded in rationalism is realism. It asserts that beauty exists outside of the human mind. The epistemology of rationalism is objectivism. According to objectivism, beauty is a quality of objects [Reich, 1993]. It exists in objects independently of consciousness. Rationalism uses a reductionism (or structuralism) approach. Based on rationalist views, aesthetic experience is constructed out of the combination of elementary sensory pleasures. In this view, by analyzing the properties of object's components and their relations, general rules of aesthetics can be formulated [Reich, 1993]. This formulation gives the rationalist view the power of prediction to generate new aesthetic designs through manipulating the building blocks and their relationships.

The instruments of rationalist and romanticist views on aesthetics are intellect and intuition, respectively. Intellect and intuition, as Arnheim [1986] states, are the double-edge of mind. Intellect analyses the relationships of a chain of logical inferences between standard units of object. The process occurs consciously and sequentially. Intuition perceives the overall structure of each configuration as an integrated whole of a system of interacting forces that strive toward a state of equilibrium for a stable entity. Human knows intuition mostly by its achievement. The intuition process is a field process, rapidly and below the level of consciousness [Arnheim, 1986].

In conclusion, it seems that aesthetics feeling is provoked in human by existed orders in an object as well as by associating a pleasant form (which can be innate or shaped through cultural practices) in the subject. Order, as Aristotle believed, is the aspect of aesthetics which is related to nature [Warry, 1962], and form is the aspect of aesthetics which is related to nurture. The former one is related to the properties of an object (here, the appearances of designs), and the latter one is linked to the interpretation of a subject (here, the pleasant cultural symbols). In this research the rationalism view was followed by employing and examining an aesthetics principle into a design. The rationalist perspective on aesthetics is based on some principles which are explained in the next part.

2.3 Rationalism based Aesthetics Principles

As mentioned before, the principles of rationalism in aesthetics were systematically presented by Aristotle. In the contemporary era, however, these rules have been developed in the field of Fine Art in the name of “principle of design” or “principle of organization”. The followers of this school of thought believe that design grows from our basic need for meaningful order [Preble and Preble, 1994]. In other words, the way that we fulfill our need for order in our thinking is called design [Grieder, 1990]. Different principles have been defined by various authorities. For instance, Preble and Preble [1994] mentioned following seven key terms to represent aesthetics principles of design:

- (1) Unity and variety
- (2) Balance (optical symmetry)

- (3) Emphasis and subordination
- (4) Directional forces
- (5) Contrast
- (6) Repetition and rhythm
- (7) Scale and proportion

Griener [1990] mentioned the following six items as major principles of design:

- (1) Unity
- (2) Variety
- (3) Balance
- (4) Rhythm
- (5) Emphasis
- (6) Proportion

The principles that have been mentioned by almost all artists are:

- (1) Unity
- (2) Balance
- (3) Variety
- (4) Proportion

There is *unity* in a design, when it is understandable as a coherent unit and when the audience can distinguish it from the unrelated environment. *Balance* means that parts of the work should be felt in equilibrium to the viewer's eye. We will enjoy things that are balanced and will not look long at things that are unstable. *Variety* means that design

should have enough variability to maintain the viewer's attention. *Proportion* means that the parts must be related according to a plan which the designer has intended [Grieder, 1990].

Principles of design (in Fine Art) are the result of long-term empirical experiments and intuition and they have been found effective in different places and times [Feldman, 1971]. The approach in this research was rationalistic. In this research, the principle of balance was incorporated to evaluate the aesthetic aspects of design, while two important aspects of balance, color and area, were concentrated on.

2.4 Aesthetics aspect in design

In the ancient world, usefulness and beauty were one and alike. Engineering and aesthetic qualities were separated during and after the industrial revolution, when mass production was governed on aesthetic concerns [Lavie and Tractinsky, 2004]. Petroski cited in Lavie and Tractinsky [2004] argued that in the early of 20th century, Loewy and Dreyfuss, two pioneers in industrial design, introduced aesthetic concerns of design, partly because of its capacity for the promotion of marketing. Currently, Aesthetic aspects are becoming more and more important for consideration in the engineering design process [Lavie and Tractinsky, 2004; Lin and Zhang, 2006; Liu, 2003; Yoshimura and Yangi, 2001]; however, very few attempts have been involved with critical analysis of aesthetics in design [Pye, 1995].

Traditional studies about engineering design and human factors have mostly concentrated on ergonomic aspects of design and have paid less attention to the aesthetic aspects of design [Jordan, 1998; Liu, 2003]. Although considering both functional and

ergonomic features of a product are important in design, the users' interests in and attraction to the product is another determinant for the success of a product. At this point, the "beauty aspect" of a product plays an important role. From the consumer's viewpoint, the beauty value can make engineering products more readily satisfactory and can develop their commercial worthiness [Lavie, 2004].

2.5 Quantification Methods for Aesthetics in Design

Evaluation of aesthetic design has a propensity to be qualitative [Yasuda et al., 1995]; however, the goal of considering aesthetics in engineering design is to utilize scientific, engineering, and mathematical methods to systematically determine and to quantify aesthetic features in design [Liu, 2003].

Liu's [2003] methodology introduced two comprehensive approaches for quantitatively examining aesthetics in design. He proposed a methodology called "dual-process engineering aesthetics research methodology". This methodology consists of two processes and is intended to achieve a comprehensive, precise, and quantitative understanding of aesthetic responses in a design context. The first process, which is called "multivariate psychometric analysis", is for the purpose of creating a scale or questionnaire to measure aesthetic responses from consumers to the questionnaire. For this process, researchers sometimes use attitude scales which have been prepared in psychology. The second process, which is called "psychophysical analysis", is for designing and conducting experiments to measure aesthetic responses to physical stimuli and resulting sensations. One example related to the second process is examining eye movement characteristics of an observer to an object. Liu pointed out that it is important

to integrate the psychometric research process and the psychophysical research process. Liu's methodology has not been mentioned regarding the application of aesthetic principles in design.

Many studies on feelings and designs, such as Chuang [2001], Hsiao [1997], Jindo [1995], Lai [2006], and Nagamach [1995], are based on a Kansei engineering approach. The Kansei engineering method, which is placed into the "multivariate psychometric analysis" of Liu's dual-process methodology, is a popular design method for quantitatively evaluating aesthetic attributes [Yoshimura and Yanagi, 2001]. The Kansei engineering method translates consumer's feeling about a product (such as luxurious, gorgeous and so forth) into design elements [Nagamachi, 1995]. In this approach, some adjective/image words related to feelings of consumers are identified. Then from the identified feelings, design elements of a product are determined and, finally, the product design is adjusted to these feelings.

Studies which use the Kansei engineering approach have two weaknesses: (1) They pay no attention to the aesthetics principles in Art or philosophy, because the Kansei engineering method is just based on statistical results from consumers; and (2) When they focus on the aesthetic aspects of a design, they do not consider the functional and ergonomic aspects of design, because the Kansei engineering method in this regard is not an integrated design approach.

The characteristic of Liu's methodology is measurement-based. Two processes of his methodology are based on psychometric and psychophysical measurement. There is another methodology developed by Breemen et al. [1998] which is called "design for

aesthetics” and is based on the analogy of communication. This method, which associates design variables with aesthetics properties, consists of a loop with a two way process - exploratory process and creative process. In the exploratory process, based on the users’ feelings about a product and in order to identify design variables, experiments with typical products are performed. In the creative process, based on the explored design variables, design features and product images are created and then are controlled through users’ experiments. The essence of this approach, which is based on exploratory and creative processes, is similar to Kansei engineering method. For instance, in the Kansei engineering method, consumer’s feelings about a product are explored and design features are created, or in the method described by Yanagisawa and Fukuda [2003], analysis and synthesis schemes are used instead of exploration and creation.

Nevertheless, in Breemen’s methodology there is a place in which aesthetic principles of Fine Art can be applied in design. As Pham [1999] mentioned, to achieve an effective exploratory process, relevant knowledge (aesthetics principles) from the fields of philosophy of aesthetics and different disciplines in fine arts is utilized. He came up with a list of nine aesthetic principles for analyzing the interactions between aesthetic characteristics and product characteristics. Breemen’s methodology, similar to the Kansei engineering approach, is not an integrated approach in design, because it does not consider the functional and ergonomic aspects of design apart from the aesthetics side.

All studies on the application of aesthetics in design, such as Bauerly et al. [2003], Lavie [2004], and Ngo et al. [2003] in computer interface design, Reich [1993], Yasuda et al. [1995] in bridge design, and Jordan [1998], Yanagisawa and Fukuda [2003],

Yoshimura and Yanagi [2001] in the design of other products, match with the methodologies which are presented by Liu [2003] and/or Breemen et al. [1998]. None of the studies on aesthetics design have integrated the functional or ergonomic aspects of design with the aspect of aesthetic design with the aesthetic principles from Fine Art.

2.6 Conclusion

According to what were discussed in Section 2.4, there is no sufficient study in literature considering the aesthetic aspect of design apart from functional and ergonomic ones. The first objective of this research, which was mentioned in Section 1.3, is for responding to this insufficiency. In addition, based on discussion in Section 2.5, there are only a few studies in literature about quantifying aesthetics principles in the product design. The second objective of this research, which was mentioned in Section 1.3, is established for this need.

CHAPTER 3

CLASSIFICATION OF DESIGN VARIABLES

3.1 Introduction

The purpose of the study presented in this Chapter was to find what design variables in cell phone products that are only related or weakly related to the aesthetic aspect but not to the functional and ergonomics aspects of design. For this purpose, cell phone products in the market as samples need to be selected. This was done by collecting cell phone samples from the Internet. The selection process also considered the coverage of products with respect to the cell phone manufacturers. The collection of cell phone samples was then edited by a program to facilitate the evaluation which is expected to result in a set of design variables which are only related to aesthetics. In this chapter, Section 3.2 will describe the sample selection process. Section 3.3 describes the statistic design of an experiment for the evaluation of sample cell phones. Section 3.4 presents results of the experiment and discussions. A conclusion is presented in Section 3.5.

3.2 Sample Selection Process

Representative cell phone products with a similar configuration from cell phones available in the market were selected. These products were represented by their pictures. It is true that the evaluation based on cell phone pictures may not be the same as the evaluation of a real cell phone; however, it is not practical to access all available cell phones in the market. In the sample selection, this converge issue was addressed.

One hundred and seventy three cell phone pictures from Esato [2004], which is one of the websites with most available cell phone pictures in market, were examined. To confirm that these were indeed representative cell phones, the website of some well known cell phone manufacturers were examined as well, in particular comparing their cell phones with those obtained from Easto [2004]. The comparison confirmed that the level of representativeness of the selected cell phones was more than 95% which is considerably high.

From 173 cell phone pictures, 118 pictures that had visible display and keys and minimum distraction from front view were kept, and others were discarded. In order to minimize the influence of brand names, promotional ads, and sizes of cell phone pictures on the evaluation of beauty, cell phone pictures were edited in the Photoshop environment. The brand names and promotional advertisements on the body and display were removed. To give further a fair ground for a comparative evaluation, each cell phone was modified to have the same height while keeping their height-to-width ratios unchanged; in the modification process, all design features were scaled in consistence with the height-to-width ratio.

118 pictures were reduced to a smaller number of pictures so that the subsequent evaluation process becomes more practical. For this purpose, a cluster analysis method was used which will be explained later in detail. Through this method, similar pictures among the 118 cell phone pictures were put aside, and ultimately, 32 clusters were found. Then one picture was chosen randomly from each cluster. That is to say 118 pictures were reduced to 32 pictures.

In order to do cluster analysis, 9 cell phone design features were selected as variables and quantified. The process for identifying these 9 design features is as follows. According to Han et al. [2004], among 56 extracted design features of cell phone, 43 items are related to hardware and 13 are related to software. Here, the appearance of cell phone pictures in the front view is under consideration. Therefore, software features were discarded. From 43 hardware features, fifteen are hardware critical design features required for the overall satisfaction of users [Han et al., 2004]. Because the perception of beauty is related to the overall satisfaction of a perceiver, it was decided to limit critical design variables to the 15. From the 15 design features, 7 features which were further related to visual evaluation were selected. Two additional features related to the average of and variation in colors, were added. Therefore, in total there were nine features which are listed as follows:

- (1) Ratio of body width to height,
- (2) Frontal shape of body,
- (3) Degree of variations in button size,
- (4) Antenna mechanism,
- (5) Number of exposed buttons (which represents congestion of the picture),

- (6) Layout of components,
- (7) Opening mechanism,
- (8) Average luminosity of the image calculated in Photoshop,
- (9) Standard deviation of the image Luminosity.

The 9 design features mentioned above were quantified and entered in the SPSS program for cluster analysis. A hierarchical cluster analysis method was used. In order to have tight clusters from similar cell phone pictures, a furthest neighbor cluster method was utilized. Further in the cluster analysis, variables were standardized to Z scores, and the squared Euclidean distance measure was used. The cluster analysis led to 32 clusters as mentioned before.

3.3 Statistic Design of an Experiment

The purpose of the experiment was to determine what cell phone design variables are aesthetically uncoupled from the functional and ergonomic aspects of design. The experiment included two factors. The first factor is “Cell Phone Design Variable”, and it has 24 levels:

Design Variable 1: "Number of differently shaped buttons"

Design Variable 2: "Ratio of display width to height"

Design Variable 3: "Ratio of body width to height"

Design Variable 4: "Size of mainly used button"

Design Variable 5: "Color of mainly used button"

Design Variable 6: "Degree of button size variation"

Design Variable 7: "Number of exposed frontal buttons"

Design Variable 8: "Existence of menu navigation buttons"

Design Variable 9: "Shape of mainly used button"

Design Variable 10: "Area of display"

Design Variable 11: "Degree of emphasis on speaker design"

Design Variable 12: "Shape of most salient button"

Design Variable 13: "Horizontal length of body"

Design Variable 14: "Vertical length of body"

Design Variable 15: "Degree of body luster"

Design Variable 16: "Brightness of body color"

Design Variable 17: "Number of colors used in body"

Design Variable 18: "Existence of colorful area"

Design Variable 19: "Decorated area"

Design Variable 20: "Open mechanism"

Design Variable 21: "Layout of components"

Design Variable 22: "Frontal shape of body"

Design Variable 23: "Degree of body roundness"

Design Variable 24: "Color of body"

The 24 design variables were selected from the 56 identified cell phone design features extracted by Han et al. [2004] as critical to user satisfaction. The 24 design features were selected from the hardware class not from the software class such as text, icon, animation, sound, and menu. In addition, the focus was on three major components (button, display, and whole body) and also limited to those appropriate for visual

evaluation. For instance, “material of body” is not a design feature that can be visually evaluated and thus it was not included.

The second factor is “Design Aspect”, and it has three levels: Function, Ergonomics, and Aesthetics.

A computer program was prepared and used in this experiment. Using this program, 6 experts were asked to evaluate the relevance of the 24 levels of the cell phone design variable to the 3 levels of the design aspect factor. The experts did another evaluation for the same experiment one week later. Experts assessed the relevance using Table 3.1.

Table 3.1 Relevance of each design variable to each design aspect

Relevance to Beauty	Relevance to Ergonomics	Relevance to Functionality
Strongly relevant	Strongly relevant	Strongly relevant
Relevant	Relevant	Relevant
Weakly relevant	Weakly relevant	Weakly relevant
Irrelevant	Irrelevant	Irrelevant

The relevance was quantified in a scale from 0 (irrelevant) to 3 (strongly relevant). For each of the 24 levels of the design variable factor, the consensus aggregated from participants’ evaluations for each 3 levels of the design aspect factor was obtained using the approach given in the literature [Liu et al., 2005]. In the next step, this issue was examined that which level of the design variable factor has uncoupled characteristic among the different levels of the design aspects factor. Therefore, a criterion called *Disassociation* was introduced and defined as difference between two levels of the

design aspect factor. The largest disassociation between any two aspects of design means that these two aspects are uncoupled from each other. For instance, if the function aspect of a design variable gets 0 and aesthetics aspect of that design variable gets 3, this means that the design variable is irrelevant to function and strongly relevant to the aesthetics aspect of design, in other words highly uncoupled between the function and aesthetic aspect of design. In the following, the design of this experiment will be explained in detail. Section 3.3.1 is regarding the participants of the experiment. In Section 3.3.2, the procedure of the experiment is described. In Section 3.3.3, the way to measure participants' consensus is explained.

3.3.1 Participants

At first, it was decided to use non-expert participants. Therefore, 20 students were asked to participate in the computer survey. Results showed that non-expert participants were not the proper target for determination of uncoupled design variables. Although before asking questions regarding the design variables, a training session had been prepared for the 20 participants, mixed results were obtained that were close to random data and showed that non-expert participants could not distinguish clearly between the different aspects of design for the design variables (at least with the limited training). Therefore, it was decided to use expert participants. In fact, it also seems to be rather reasonable to consider “experts”, because such an assessment demands much knowledge of design, which requires more training. These expert participants were selected using the criterion of whether they had taken and passed a human factor engineering course, a graduate course in the college of Engineering.

There is no agreement about the sample size and no standards against what a sample size selection could be evaluated [Akins et al., 2005]. Because access to expert subjects is more difficult to achieve than contact with general subjects, the number of expert participants is usually for less than the number of general participants. For instance, in the studies such as Malone et al. [2005], Norman and Olaf [1963], and Strasser et al. [2005] which used expert opinions, only 5, 6, and 7 subjects participated, respectively. Therefore, in this experiment six experts were selected.

3.3.2 Procedure

At first, the age and gender of each participant were asked. Then, 32 cell phone pictures were shown to the participant. The objective of this step was to give the participant a general impression about available pictures in the market so that in the next step of the survey, participants could have less variation in experience of cell phones. In each page 4 pictures were used. The first page of the computer survey and one of the pages with four cell phone pictures can be seen in Figure 3.1 and Figure 3.2, respectively.

The image shows a screenshot of a Windows desktop environment. At the top, a window titled "Form1" is open. The form itself has a light beige background and contains the following elements:

- A title box: "Please enter your gender and age"
- A "Gender" section with two radio buttons: "Male" (selected) and "Female".
- An "Age" section with a text input field containing the number "25".
- A "Continue" button centered below the input fields.

The Windows taskbar at the bottom shows the "start" button, a taskbar with "linking among forms - ..." and "Form1", and a system tray with a clock showing "12:40 PM".

Figure 3.1 The first page of the computer survey



Figure 3.2 Four typical cell phone pictures

There was also a training session conducted before the participants actually did their jobs. Figures 3.3, 3.4, 3.5, 3.6, and 3.7 illustrate computer survey pictures regard to the training session. Figure 3.3 is an introduction and Figures 3.4, 3.5, and 3.6 are some examples to explain the functional, ergonomic, and aesthetic aspects of design. Then, the 24 design variables were explained to the participants using 8 pictures, highlighting 3 design variables on each picture. Pictures of the first 3 design variables can be seen in Figure 3.7.

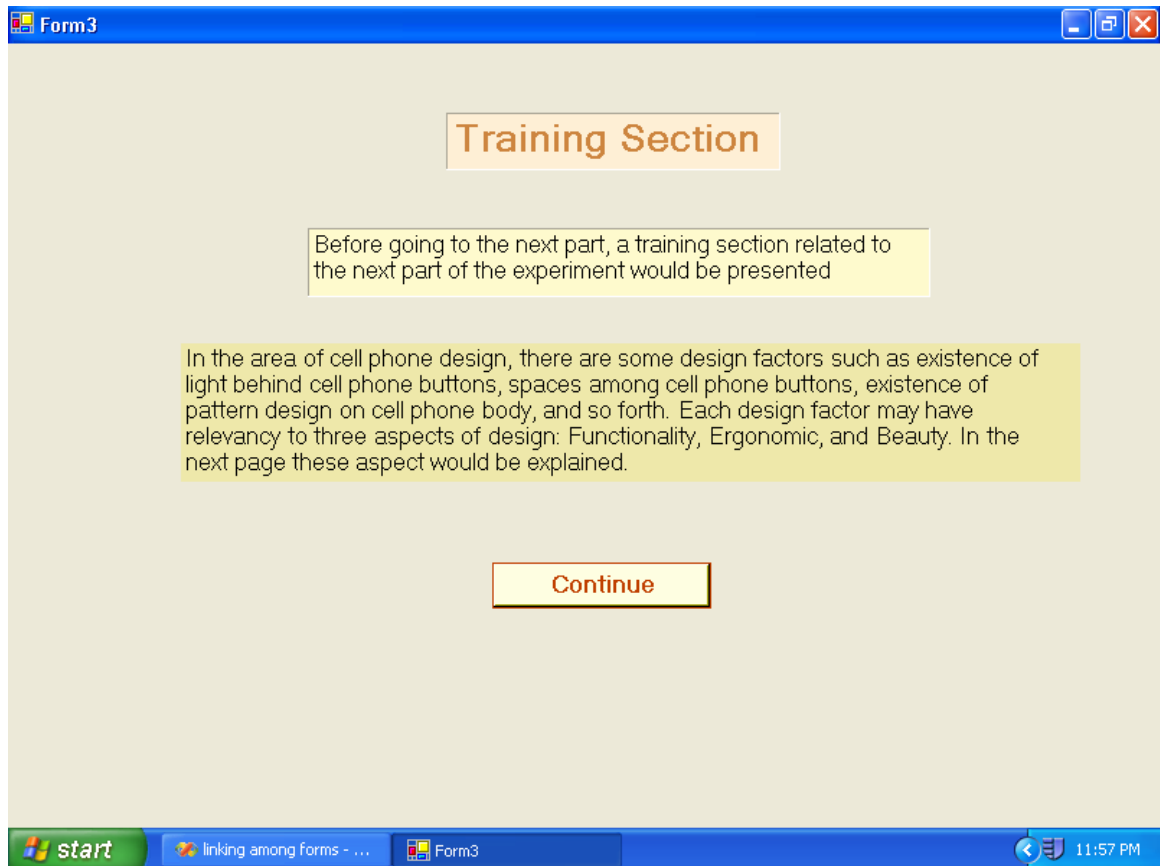



Figure 3.3 Introduction to the training session

3

Function aspect of Design

Cell phone functionality means ability of cell phone to do one of its expected functions/work

For instance in dark condition it is not possible to see cell phone display and to work with buttons. Therefore, the light behind buttons and on the display could be considered as design factors that are relevant to cell phone ability to work/function in the dark situation.



Continue

start linking among forms - ... 3 12:47 PM


Figure 3.4 One example to explain the functional aspect of design

Form6

Ergonomic aspect of Design

A cell phone is ergonomic when user has maximum efficiency, safety, comfort, and accuracy.

For instance in this cell phone picture, spaces among buttons are considered as a design factors. When spaces among buttons are very small, user could not catch a target button without pushing beside buttons and in other word, design with this condition is functionally a poor design. After increasing the space, although user may work with buttons; however, if the space would not be large enough, user would not be comfort to easily use the buttons. Therefore, space among buttons is a design factor that is relevant to the functional aspect of cell phone design and highly relevant to the ergonomic aspect of cell phone design. In this case function and ergonomic aspects of design to some extend are coupled with each other on the "space among cell phone buttons".



Continue

start linking among forms - ... Form6 11:58 PM

Figure 3.5 One example to explain the ergonomic aspect of design

Form7

Beauty aspect of Design

Beauty means quality of being pleasing; especially to look at someone or something that gives great pleasure, especially by being looked at.

In these cell phone pictures, design factor is "picture on the display". Although existing or lacking of picture increases or decreases nothing to the functionality or ergonomic aspects of design; however, it may have influence on the beauty aspects of design. Therefore, the design factor called "picture on the display" is irrelevant to the functional aspect and ergonomic aspect of cell phone design and relevant to the beauty aspect of cell phone design. Regard to mentioned design factor, functional, ergonomic, and beauty aspects of design are uncoupled.

Continue



start | linking among forms - ... | Form7 | 11:59 PM

Figure 3.6 One example to explain the aesthetic aspect of design



Figure 3.7 Illustrations of the first 3 design variables

In the experiment session, the 6 expert participants were requested to judge the relevance of the 24 cell phone design variables to three aspects of design (aesthetics, ergonomics, and function). Following the training session, the experiment session began. Here, each participant was asked for commenting on the level of relevance of each design variable to aesthetics, ergonomics, and function. Figure 3.8 shows an introduction to the experiment session and Figure 3.9 illustrates a picture regarding the first design variable presented to the participants.

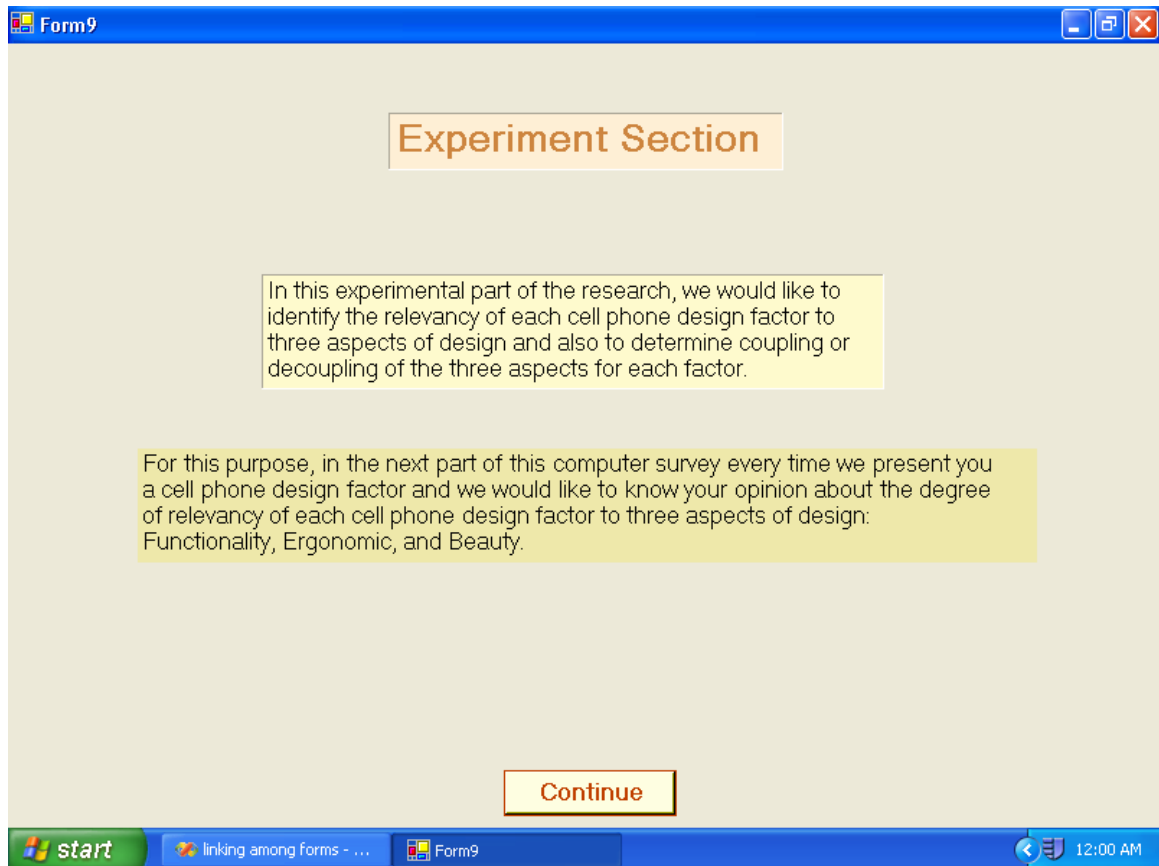


Figure 3.8 Introduction to the experiment session

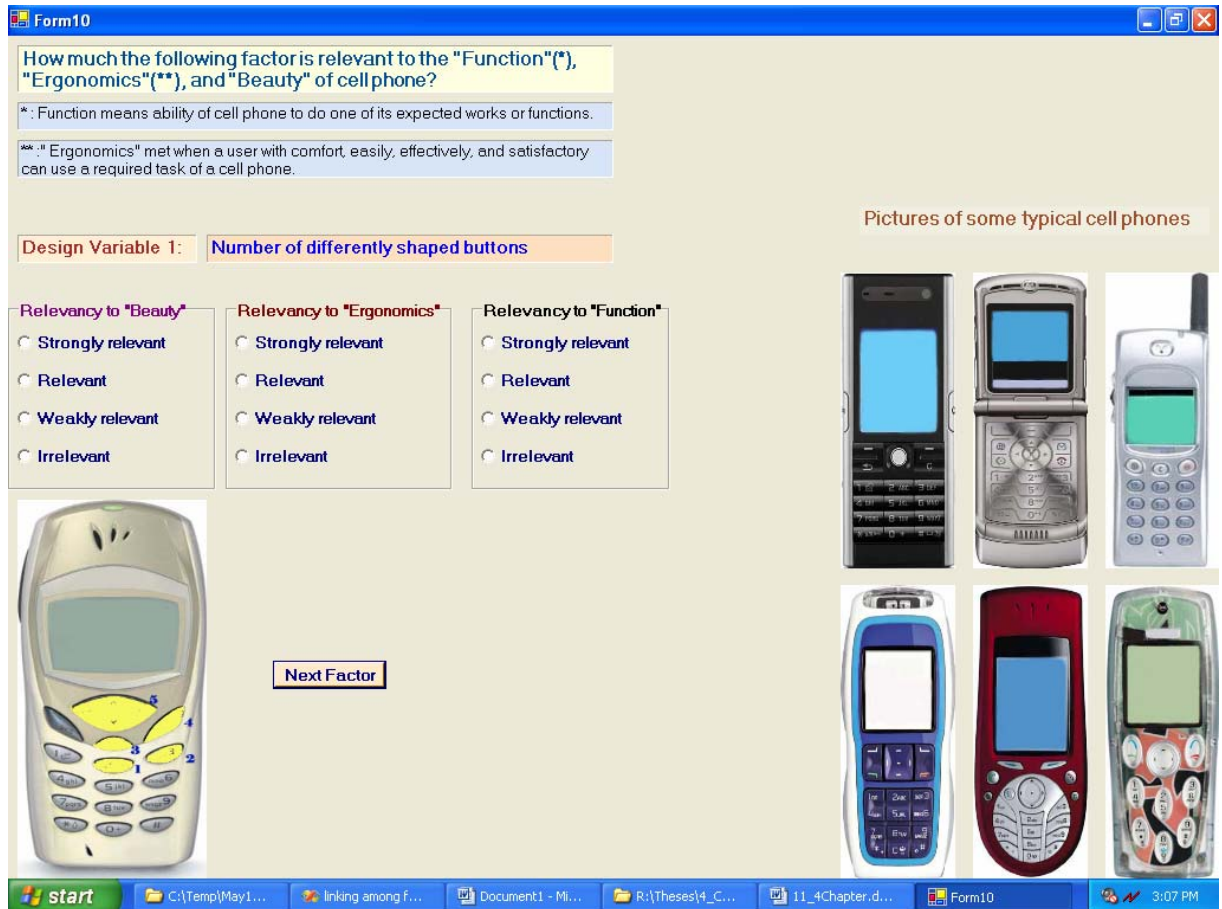


Figure 3.9 Experiment session: the first design variable

As Figure 3.9 shows, after a design variable was defined, its relevance was assessed by each participant through the use of a table like Table 3.1. To help participants refresh their memory regarding each design variable, a picture related to each defined design variable, which had already been presented to the participant in the training session, was again shown to the participants. In addition, pictures of 6 typical cell phone, selected from 6 high rank clusters, were presented beside each question so that participant could think about application of the inquired design variable in other type of cell phones. Therefore, the total number of cell phone pictures presented in this computer survey for each design variable was seven. The reason for choosing seven pictures is because seven,

plus or minus two, is the maximum number of components which can be compared with reasonable psychological assurance of consistency [Miller, 1956].

As already mentioned, six experts used the computer survey and evaluated relevance of the 24 cell phone design variables to the three design aspects. They did the survey one week later again for examining the reliability of the results.

3.3.3 Analysis Method

The evaluation by the participants needed to be analyzed. The traditional approach would be statistical oriented which is basically rooted in the philosophy that a large sample size leads to a more reliable result. However, in this research, only six participants were employed, so those statistic oriented analysis methods are not adequate. A method was employed called aggregation of expert opinions [Lin et al., 2005]. The method gives a consensus among expert judgments. Numbers 0, 1, 2, and 3 were assigned to the expert judgments of being irrelevant, weakly relevant, relevant, and strongly relevant, respectively. Each of the 24 design variables was evaluated by the six experts in the three aspects of the design, and finally, 24(3), or 72 consensus results were obtained from, 72(6), or 432 individual evaluations.

The experiment resulted in 24 consensus results for the aesthetic relevance of 24 design variables, 24 consensus results for the ergonomic relevance of 24 design variables, and 24 consensus results for the functional relevance of 24 design variables. The concern of the study was to find the design variables highly relevant to the aesthetic aspect and only slightly relevant to the ergonomic and functional aspects of design. Therefore, disassociation of participants' judgments between aesthetics and function

along with between aesthetics and ergonomics were used. Design variables with the highest disassociation were considered as design variables for aesthetics uncoupled with function and ergonomics.

3.4 Results and Discussion

Results obtained from the first and the second trial of the participants' evaluations indicated that following two cell phone design variables are highly relevant to aesthetic aspect of design and weakly relevant to functional and ergonomic aspects of design: "*Color of cell phone body*" and "*Decorated area of cell phone body*". The detailed data were presented in Appendix A, and a summary of results for 24 design variables was presented in Table 3.2. The values of the Table 3.2 are average of the values for the first and the second trial. Consistency between the results of the first and second trials was evaluated with Paired-Samples T Test. Both Aesthetics-Function disassociation and Aesthetics-Ergonomics disassociation were significantly ($P < 0.05$) consistent between the two trials.

Table 3.2 Disassociation between Aesthetics with Function and Ergonomics (*: Disassociation (%) between two aspects of design means difference between values of those two aspects divided by maximum potential difference that is 3.)

Cell phone Design Variable	Aesthetics-Function Disassociation (%)*	Aesthetics-Ergonomics Disassociation (%)*
Color of body	94.9	79.2
Decorated area of body	94.9	68.5
Frontal shape of body	87.4	29.5
Ratio of body width to height	79.8	8.6
Number of colors used in body	79.8	37.2
Existence of colorful area	79.8	43.4
Brightness of body color	79.9	47.5
Color of mainly used button	77.7	24.5
Degree of body roundness	77.6	14.1
Degree of body luster	72.3	40.0
Ratio of display width to height	71.1	18.4
Horizontal length of body	69.4	6.0
Shape of most salient button	66.7	3.0
Number of differently shaped buttons	65.2	10.4
Vertical length of body	64.2	9.0
Degree of button size variation	59.6	10.4
Shape of mainly used button	56.8	11.5
Layout of components	52.0	20.8
Area of display	50.1	9.3
Size of mainly used button	26.3	33.3
Number of exposed frontal buttons	24.1	20.4
Degree of emphasis on speaker design	23.4	11.4
Open mechanism	12.5	16.6
Existence of menu navigation buttons	6.0	59.2

3.5 Conclusion

“Color of cell phone body” and *“Decorated area of cell phone body”* were two cell phone variables that were highly relevant to the aesthetic aspect and weakly relevant to the function and ergonomic aspects of design. With the result from this experiment on the cell phone product, it was found that the classification of design variables in terms of their relevance to function, ergonomics and/or aesthetics makes sense to generate an optimal design with consideration of all three aspects of a product: function, ergonomics, and aesthetics.

CHAPTER 4

MEASUREMENT OF VISUAL BALANCE

4.1 Introduction

In order to apply the visual balance principle to the uncoupled design variables which were determined in the last experiment, there was a need to develop a quantitative method for measuring visual balance, in particular measuring the degree of visual balance of a product based on both the color and area of its component. For this purpose, after describing balance and its theoretical views, an existing method for measuring visual balance was reviewed. Then a method was presented for quantifying the equivalent weight of any color. The proposed method was then integrated into the existing method, leading to a new method to measure visual balance given to a component which has both area and color.

4.2 Balance

Balance is the achievement of equilibrium in the overall perceived visual weight of a composition among various parts. The balance is not always achieved symmetrically. There are two general types of balance: Symmetrical and Asymmetrical. In the former,

the left and right sides are mirror images of each other, whereas in the latter the two sides are not the same. To achieve balance, weight distribution should be designed to be pleasing to the eye, and visual weight should be focused around a perceived center of gravity [Preble and Preble, 1994]. Without balance, a composition looks awkward and unstable. Balance evokes a feeling of stability and confidence in a viewer, while an unbalanced display creates a feeling of stress. Feelings about balance are connected to human experience with the actual physical balance [Preble and Preble, 1994; Reilly and Roach, 1984].

There are some rules for visual balance, and they are: (1) a larger form is heavier; (2) an object near the frame of a picture (i.e. product face) is heavier than an object close to a center; (3) a complex form is heavier than a simple one; (4) warm colors such as red and orange are heavier than cold ones such as blue and green; (5) intense colors are heavier than pale/weak colors; (6) the weight of any color increases as the background color approaches to its complementary color [Preble and Preble, 1994]. By controlling the color, size, tone, and shape of components in a design, one could influence the user's perception of balance [Ngo et al., 2000A; Ngo et al., 2000B; Reilly and Roach, 1984].

4.3 Color Models

Before describing background regarding the roles of area and color in balance, important color models need to be clarified. Colors can be presented based on different models including the *HSL* (Hue, Saturation, and Luminosity) model and the *RGB* (Red, Green, and Blue) model.

In the *HSL* model, each color is presented by its Hue, Saturation, and Luminosity. Hue refers to special wavelength of color to which a name is given. Value, also called luminosity, points to relative lightness or darkness of the color and its gradation is between black and white. Intensity, also called saturation and chrome, refers to the purity of a hue at its highest saturation i.e., in its brightest form [Preble and Preble, 1994].

In the *RGB* color model, each color can be defined by appointing how much of each of the red, green and blue color is contained. The variation of each color is between the minimum which is no color and maximum which is full intensity. In the case that all the colors are at minimum the result is black and when all the colors are at maximum, the result is white. These three colors may be numerically written in different ways. One way is in a range between 0.0 (minimum) to 1.0 (maximum). For instance based on this way of formulating, full intensity blue is 0.0, 0.0, 1.0. Another way is to write the color values in terms of percentages, from 0% (minimum) to 100% (maximum). According to this framework, full intensity blue is 0%, 0%, 100%. Another form of appointing values to the colors is by writing numbers in the range 0 to 255. According to this framework, full intensity blue is 0.0, 0.0, 255.0. This range is frequently found in computer science, where programmers have found it convenient to encode each color value in eight bits. This type of encoding would able the programmers to have 2^8 (= 256) different values. A picture on computer screen consists of a set of pixels. The RGB model is applied to each pixel. For 24-bit color, the triplet (0,0,0) represents black, and the triplet (255, 255, 255) represents white. When the three *RGB* values are set to the same value, for example (63, 63, 63), (127, 127, 127), or (191, 191, 191), the resulting color is a shade of gray.

The presence of all basic colors in sufficient amounts creates pure white, and the absence of all basic colors creates pure black [Murray and Van Ryper, 1996]. Because *RGB* is the most widely used additive color model for television and computer screens [Murray and Van Ryper, 1996], for the study of visual balance in this research the *RGB* model was used.

4.4 Role of Area and Color in Balance

Paul Klee, a well known Swiss-German painter (1879-1940), described a model for understanding balance. Based on his model, three formal elements of balance are dimension (area), quality (hue or wavelength of the color), and tone (value or luminosity of the color) [San Lazzaro, 1957]. Based on Klee's model, balance can be valued with area and two dimensions of the *HSL* model, hue and luminosity.

Munsell [1905] presented a principle by which balance can be quantified with the area and two dimensions of the *HSL* model (i.e., luminosity and saturation). Based on Munsell's law, the area of color in a combination is inversely proportional to the product of their luminosity and saturation. Experiments showed that Munsell's formula works quite well [Linnett et al., 1991; Morris and Dunlap, 1987].

Pinkerton and Humphrey [1974] compared the heaviness of 5 colors with constant saturation and luminosity. They found the following order from heaviest to lightest: red, blue, green, orange, and yellow. Locher et al. [2005] compared the perceived weight of 3 colors: red, blue, and yellow. In addition, they examined the size of a colored area. They found the following order from heaviest to lightest: red, blue, and yellow. Also, they

found that the perceived weight of a color varied as a function of the size of the area it occupied (bigger size, more perceived weight).

Klee's model is concerned with the area and only the hue and luminosity aspects of colors in the *HSL* model. Munsell's model is concerned with the area and only the saturation and luminosity aspects of color in the *HSL* model. On the other hand, Pinkerton and Humphrey [1974] considered the hue aspect of only five colors in the *HSL* model. And finally Locher et al. [2005] considered the area and the hue aspect of three colors in the *HSL* model.

In the following, a model which would be able to quantify the balance of a picture based on the area and color of its components was presented, while all three elements of each color in *RGB/HSL* model were considered. It should be noted that with three elements of one model (*RGB/HSL* model), three elements of the other models can be determined. The *RGB* model is more comprehensive than the *HSL* model, for the three attributes in the *HSL* model are not as uniform in semantics and measurements as those in the *RGB* model. This might be the reason that in previous studies by others using the *HSL* model, only two attributes were considered. Additionally, this study was not limited to a few numbers of colors; which others did. Further, in the method that was presented in this study, the influence of background color on the perception of foreground color was considered.

4.5 Balance Measurement

A quantification method for determining the balance of the area was presented by Ngo et al. [2003]. They used the rule that larger objects are perceived heavier, whereas

smaller objects are perceived lighter. They presented Equations 4.1, 4.2, 4.3, and 4.4 for measuring the area balance in a display.

$$BM = 1 - \frac{|BM_{vertical}| + |BM_{horizontal}|}{2} \in [1,0] \quad (4.1)$$

where BM is the total balance. $BM_{vertical}$ and $BM_{horizontal}$ are the vertical and horizontal balances, respectively, with

$$BM_{vertical} = \frac{w_L - w_R}{\max(|w_L|, |w_R|)} \quad (4.2)$$

$$BM_{horizontal} = \frac{w_T - w_B}{\max(|w_T|, |w_B|)} \quad (4.3)$$

when

$$W_j = \sum_i^{n_j} a_{ij} d_{ij} \quad j = L, R, T, B \quad (4.4)$$

Where w , a , d , n , L , R , T , and B stand for weight, area, distance from a central axis, number of components in the j area, left, right, top, and bottom, respectively. The equation developed by Ngo et al. [2003] considered area only for measuring balance.

In this study, Equation 4.4 was extended to include both the geometric area Ag and the equivalent area Ac of the color of a component. Ac of each color is measured with respect to white color. Ac is equivalent to the amount of the white color area which balances a unit area of the color. Equations 4.5 and 4.6 are equations that were proposed in this study. Equation 4.5 is the equation for measuring the weight of each component in a plane, and Equation 4.6 is for measuring the weight of each component.

$$W_j = \sum_i^{n_j} (Ac + Ag)_{ij} d_{ij} \quad j = L, R, T, B \quad (4.5)$$

$$W = (Ac + Ag)d \quad (4.6)$$

As mentioned before, there is a sense of “weight” for each colour; yet the relationship between such a weight and a colour is absent in literature. In other words, there does not exist a first principle from the aesthetic literature regarding the equivalent weight of a colour. The equivalent weight of color may contain non-linear characteristics. Therefore, an artificial neural network (ANN) approach, which is able to model nonlinear features, was used in this study for determination of the equivalent weight of color. This approach is explained in Section 4.6.4.

4.6 Determination of the equivalent weight of color

Perception of the weight of each color is under the influence of its background color as well. As Preble and Preble [1994] mentioned, the weight of any color increases as the background color approaches to its complementary color; therefore here, in determination of the equivalent weight of color, its background color was considered in this study.

The general procedure to develop a model for the equivalent weight of color can be summarized. The first step was to design a code system to represent the structure of color. The second step was to generate a collection of samples that were representative based on the code system. The third step was to conduct the experiment to solicit the human subject perception of the “weight” of the color samples; the solicited information served as so-called training data. The fourth step was to conduct ANN learning to determine the ANN model from the training data, so eventually, given a color and its background color to the ANN model, the equivalent weight can be obtained.

4.6.1 Step One: Design a code system to represent the structure of color

In the first step, the way of representing colors with codes was introduced. According to the *RGB* model, each color can be decomposed to three basic colors (red, green, and blue) in specific ratios. As well, the variation range of each basic color is from 0 to 255 [Murray and Van Ryper, 1996]. Therefore, it can be established a so-called color space which is spanned by three dimensions as shown in Figure 4.1. More specifically, this is a cube space bounded by three points, i.e., $(255, 0, 0)$, $(0, 255, 0)$, $(0, 0, 255)$. The values which vary between 0 and 255 are dimensionless and as mentioned earlier represent the intensity of red, green and blue colors from 0 (no contribution) to 255 (full intensity). Thus, each color in the real-world has a representative point that is on the surface or inside this cube.

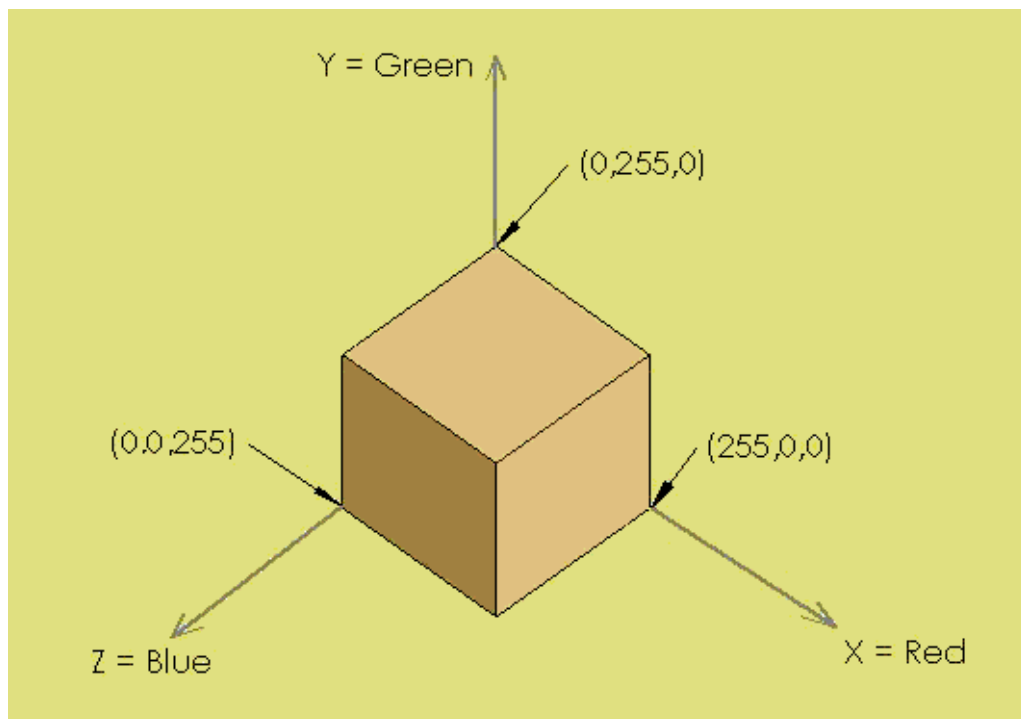


Figure 4.1 Cube of Color (three dimensions representing three basic colors).

4.6.2 Step Two: Preparation of Samples of Pictures with Different Colors

In the second step, using the prepared color code system, a collection of samples was prepared to be used in the third step conducting an experiment to solicit the human subject perception of the “weight” of the color samples. In this connection a reasonable number of pictures with different foreground and background colors was needed to be determined.

At the beginning, it was decided to have three levels of each basic color (0% that is lack of color or black color, 50% or dark level of the color, and 100% or light level of the color) in combination with each other. In that case, 3^3 or 27 colors were produced from a combination of 3 basic colors at 3 levels of percentages. From 27 colors, if one color is used in the foreground and one in the background, the total number of different foreground and background colors would be the combination of 2 on 27 (i.e., $\frac{27 \times 26}{2}$ or 351). Substituting the foreground and background colors to each other would add another 351 cases. Therefore totally, there would be (351 + 351) or 702 modeled colors to show each participant. Showing this huge number of pictures to participants for evaluation was not practically possible. Therefore, a decision was made to use two levels of each basic color (0%, or lacking, and 100%, or existing) in combination with each other. In that case 2^3 or 8 colors were produced from combination of 3 basic colors at 2 levels of percentages. Figure 4.2 shows these 8 colors: Black, Red, Green, Blue, Yellow (mixture of Red and Green), Magenta (mixture of Red and Blue), Cyan (mixture of Green and Blue), and White. R, G, and B in Figure 4.2 stand for red, green, and blue, respectively, and indicate the colors that have been used in each circle. For example,

yellow color is identified with RG, which stands for red and green colors. It is further noted that these eight colors occupy, respectively, eight corners of the color space (Figure 4.1).

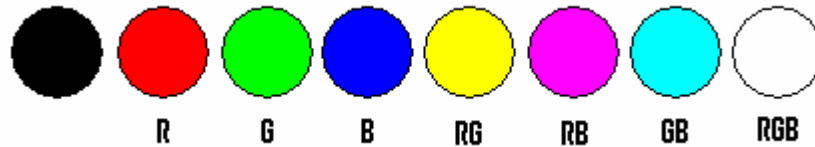


Figure 4.2 Colors produced from combination of 3 basic colors at 2 levels (0% and 100%)

From 8 colors, if one is used in the foreground and one in the background, the total number of different foreground and background colors would be the combination of 2 from 8 (i.e., $\frac{8 \times 7}{2}$ or 28). Substituting the foreground and background colors to each other would add another 28 cases. Therefore, in total there would be (28 + 28) or 56 pictures. The 56 pictures are a practically reasonable number of pictures to be shown to participants in an experiment for evaluating the weights of colors. It is observable that all 56 different foreground and background colors were selected from corners in the cube of color, or in other words, from the boundary of the color space (Figure 4.1). In addition to these 56 pictures from the colors on the edge of the cube of color, a decision was made to use a quarter of 56 (or 14) randomly prepared foreground and background colors from inside of the cube of color (in Figure 4.1). Therefore, finally based on (56 + 14) or 70 proposed combination of foreground and background colors, 70 pictures were modeled. Figure 4.3 shows one instances of the 70 modeled pictures.

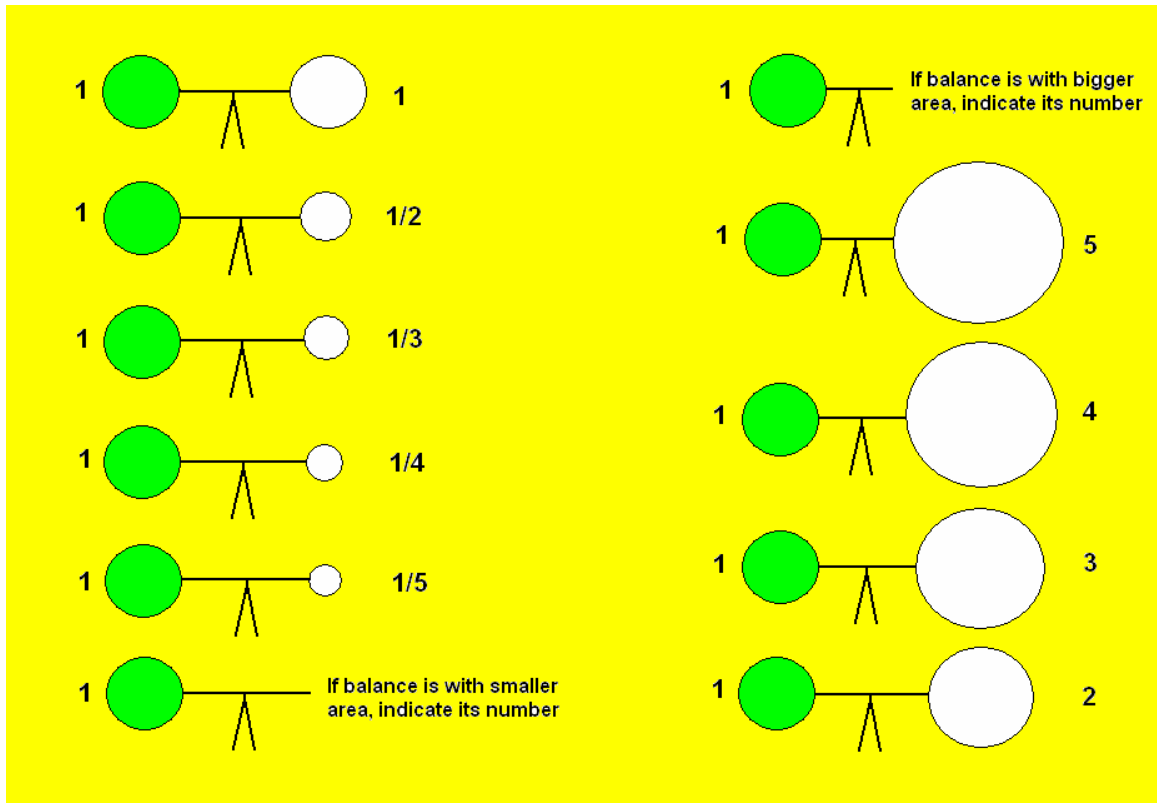


Figure 4.3 One instance from 70 modeled foreground and background colors

On all 70 modeled pictures there were some seesaw scales with two circles at both ends. The area of the left side circles were set to unit area (cm^2). The area of the right side circles varied to the smaller and larger areas than unit. The value beside each right circle represents the area of the right side circle in cm^2 and also is a ratio that the circle has respect to the unit area. The color of the right side circles in the all pictures was white. For the left side circles and background, the 70 proposed combinations of foreground and background colors were used.

4.6.3 Step Three: Statistic Design of an Experiment

In the third step, the 70 modeled pictures were shown to a group of participants twice. The factor of this experiment is “Picture with different Foreground and Background Color” with 70 levels.

4.6.3.1 Participants

One question was to determine how many participants to be recruited for the experiment. As Lin [2003] mentioned, in human factor-related experiments it is hard to determine the sample size according to the standard rules in statistics [Montgomery, 2001]. This may be seen from the published human factor research. As an example, Kotval [1998] did a survey for determining sample sizes of 118 published studies in the area of eye movement in human factor fields of study and found that 13 subjects was the best number. Two instances of slightly larger sample size were Bauerly [2003], who used 16 subjects for research on computer interfaces, and Lin [2003], who conducted a study regarding interface design with 20 subjects.

Therefore, in this experiment 20 students (10 male and 10 female between 20 and 30 years old and with an average age of 26 years old) were asked to do a computer survey and assigned a value to each prepared picture. Participants were selected using a convenience sampling method. It is further noted that two replications of each evaluation were done in order to increase the reliability of the evaluation.

4.6.3.2 Procedure

70(2) or 140 pictures were shown to each participant. Each participant was asked to look at each picture and evaluate that a seesaw scale with what a ratio size of the right circle would give him/her the most feeling of balance or stability. The purpose of this question was to determine what amount of the area of a foreground color (color of the right circle) was perceived equal to one cm^2 of white color in the context of a background color. The experiment length was about 45 minutes and to appreciate participants' time, a \$10 University of Saskatchewan bookstore gift card was given to each of them.

4.6.4 Step Four: Training and Testing a Neural Network Model

Finally in the fourth step, an attempt was made to find a model that would be able to give a weight for each new color after training with color codes and their weights from the third step. For this purpose a neural network model in MatLab 7 was used. The neural network algorithm which was used called, "multi-layer feed-forward neural networks trained by a back propagation algorithm". Back propagation networks are very popular artificial neural networks and are used more than other networks [Lek and Guegan, 1999]. Sigmoid functions were used for the input layer along with two hidden layers, and for the output layer linear functions were considered. Six nodes were used at the input and hidden layers and one node at the output layer.

Data from the experiment was used to train the network model. Six codes that indicated specific ratios of foreground and background color were used as inputs of the network model, and participants' evaluations of the weight of the foreground color were

used as the output, of the model. Therefore, as Figure 4.4 shows, the neural network model had six inputs and one output.

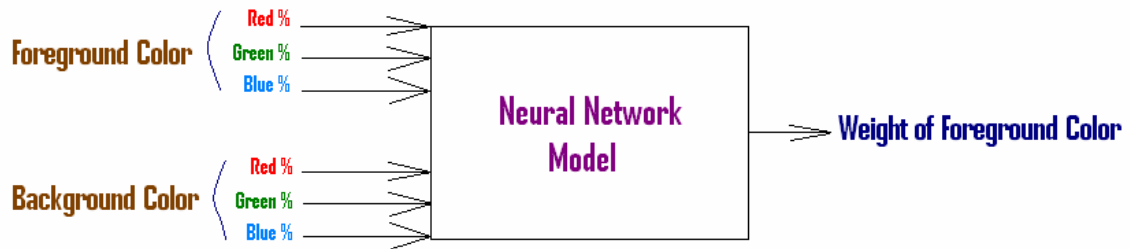


Figure 4.4 Neural Network Schema for measuring color's weight

An average of duplicate data that had been obtained from 20 participants regarding the 70 pictures was taken. Therefore, the total number of data that entered in the network model as input of the model was 1176000 values $\{20 \text{ (number of participants)} \times 2 \text{ (number of replications)} \times 70 \text{ (number of pictures presented to each participant)} \times 6 \text{ (number of codes for two basic colors used as foreground and background)}\}$.

After training, a network model should be tested. There are two main approaches for testing neural network models performance. The first approach is to use an independent data set, called testing data, which compares predicted data with observed data. The second approach use cross-validation, leave-one-out, jackknife, or bootstrapping techniques for testing models performance [Guisan et al., 2000]. The second approach is used when all the data is necessary to train the model and the available data set is small [Spitz and Lek, 1999; Stacy et al., 2006]. In an attempt to separate 70 data elements to training and testing data, it was figured out that all the data elements were needed for training to improve the accuracy of the model. A term was defined in this study, named accuracy error, as an index in the prediction of network

models. Proper accuracy error is met when the average accuracy error of the model for all testing data would be less than 0.05. Accuracy error is defined by Equation 4.7.

$$Accuracy\ error = \frac{(O - Pr)}{O} \quad (4.7)$$

In the Equation 4.7, “*O*” stands for Data observed by the survey, and “*Pr*” stands for Data predicted by the model. In order to decrease the model accuracy error one of the techniques from the second approach was used, called leave-one-out cross validation technique which uses all of the available data elements (except one data element) as training data. Before further explaining regarding leave-one-out cross validation technique, in the following it is explained the reason of reaching to the conclusion that it was necessary to use the most data elements as training data in order to improve the accuracy error of the *ANN* model.

On the first trial, 70 data elements regarding the 70 pictures were separated into two categories: 56 data elements regarding border points in the cube of color, and 14 data elements randomly selected from inside of the cube of color. The network was trained 10 times with 56 data elements and then simulated the network with 14 testing data elements. The purposes were to get to the best accuracy error in network model prediction while network model performance maintain less than 0.05. The best accuracy error achieved by the model after the 10 training runs, was 0.26. Therefore, it was decided to increase the number of training data, which meant decreasing the number of testing data. On the second trial, 70 data elements were separated into 60 training and 10 testing data. Again the network was trained 10 times. In this case, the best accuracy error obtained was 0.19. On the third trial, 70 data elements were separated into 63 training

and 7 testing data and the network again was trained 10 times. In this case the best accuracy error obtained was 0.13. The trend line of decreasing accuracy error showed that all the data are needed to train the network model. It was concluded that having data for training the network from inside of the color's cube, rather than just from the boundary of the color's cube, was a necessity for improving the accuracy error of the network. Based on this conclusion it was decided to use the leave-out cross validation technique.

The leave-one-out cross validation technique should be used when every observation is unique and can be added to the training data. In this technique, only one data need to be retained for testing and all others should be used for training the network [Spitz and Lek, 1999]. Then the testing parameter for the network, here accuracy, should be tested with the one data element left out. Further, another data need to be retained for testing, all others should be used for training the network, and accuracy should be tested with the one data element left out. This process need to be continued until all data once retains for testing. As a result, for a network with "n" data element, "n" accuracy errors should be determined. Final accuracy error of the model would be the average of all "n" accuracy errors. Therefore, ideally, this study needed to have 70 set of 69-1 data and for each one the network should be trained and simulated several times in order to get reasonable performance from the network (less than 0.05) as well as proper accuracy error (less than 0.05).

In the first data assignment, 70 data were separated to a set of 69-1 training-testing data. 70th data were left out, the network was trained with other 69 data, and the accuracy error was calculated. Network performance was less than 0.05; but accuracy

error was not less than 0.05. The network was run for the first set of data with other initial weights. Again accuracy error was poor. This procedure was continued until the 9th run upon which 0.03 network performance and 0.03 accuracy error were reached.

In the second data assignment, another element of data (69th data) was left out as testing data and the network model was trained with the other 69 data (data from 1-68 and 70), and accuracy error was calculated. After the 6th run of this set of data 0.006 network performance and 0.025 accuracy error were reached.

In the third data assignment, another element of the data was set out as testing data (68th data) and the network model was trained with the other 69 data (data from 1-67 and 69 and 70), and accuracy error was calculated. The 9th run of this set of data yielded 0.048 network performance and 0.03 accuracy error.

Just for the first three sets of 69-1 data, the network model was run 24 times and each length of each run was around 5000 epochs. Therefore, it was figured out that the process would be very time consuming if the network wanted to be performed for the remaining 67 sets of 69-1 data considering each set of data needed to run several times (average for three set of 69-1 training testing data was 8 times running).

Therefore, although it was supposed to continue this task to its completion, running the network an average of 8 times for all 70 sets of 69 training and one testing data combinations (altogether 560 times), instead it was decided to stop the procedure and to generalize the information it was obtained from 24 runs done of the first three set of 69-1 data. It was supposed that for each other set of 69-1 data, a performance and accuracy

error less than 0.05 would be arrived, although number necessary for network training for some sets might be high.

Based on this assumption, among the three obtained acceptable networks in each of the three sets of 69-1 training testing data, the one with best accuracy error (least value that is 0.025) and also proper performance (0.006) was selected as the final network model. This selected network model was used for the next experimental work of this study, which was to determine the weight of a new color when compared to a white color based on area ratio. Input and output of training and testing data of the selected network model are in Appendix B. Additionally, the following characteristics of the selected network model are listed in Appendix C: number of layers, number of neurons of each layer, transfer function names of each layer, initial weights, number of epochs, network performance, survey values for simulated data, network values for simulated data, and accuracy error.

4.7 Comparison of the Network Model Prediction with other Studies

The averages of participants' evaluations obtained from the survey regarding the weight of the five following colors with white backgrounds were as follows: black= 3.48, blue= 3.19, red= 3.18, green= 2.47 and yellow= 2.15. Values which the network model suggested for the five colors and the color orange were black= 3.42, blue= 3.19, red= 2.71, green= 2.47, orange= 2.24, and yellow= 2.15. It should be noted that orange color code had not been presented to the network model as training data and its value was predicted by the network model. With the exception of red and blue, these weight rankings of colors from participants and network model are conformable with intuition

and also close to the results of studies done by Locher et al. [2005] and Pinkerton and Humphrey [1974]. Comparison of the rankings of this study with the rankings of Locher's and Pinkerton's studies is shown in Table 4.1. It should be mentioned that Pinkerton's ranking in Table 4.1 is based on the average rank which participants attributed to each color; however, their Wilcoxon matched pairs test showed that yellow was significantly lighter than all other colors and red was significantly heavier than green, orange, and yellow. Therefore, in Pinkerton's study, although red was somewhat heavier than blue, their difference was not significant.

Table 4.1 Comparison of Weight Ranking of Colors among the model with others' (*: Based on average of participants evaluations obtained in the survey; **: Based on output of the neural network model; ***: According to the study of Pinkerton and Humphrey [1974]; ****: According to the study of Locher et al. [2005]; -: Research related to the row did not study weight of the color mentioned on the column)



Colors		Black	Blue	Red	Green	Orange	Yellow
<i>RGB</i> values		(0,0,0)	(255,0,0)	(0,0,255)	(0,255,0)	(255,187,0)	(255,255,0)
Weight Ranking of Colors	Participants*	1	2	3	4	-	5
	Network**	1	2	3	4	5	6
	Pinkerton***	-	2	1	3	4	5
	Locher****	-	2	1	-	-	3

4.8 Conclusion

A network model was obtained with the performance and accuracy error necessary to reliably measure the weight of any color with consideration of its background color. The model was tested for the weight of five colors and found that the hierarchy of color weights proposed by the network model reflects answers from a group of surveyed participants as well as results of other studies. It was concluded that the neural network model is valid and comprehensive in quantifying the weight of colors and the properties of balance in product pictures.

A method was developed for integrating the measured weight of colors with the weight of areas to quantify visual balance. In the method, color's weight is transformed into an equivalent area; therefore, it easily can be added with the weight resulted from area. Therefore, the balance of a picture with respect to color and area of its components can be measured.

CHAPTER 5

Experimental Evaluation

5.1 Introduction

The objective of this chapter is to explain the evaluation of the formula for visual balance and the design rule for the color and decoration. In order to confound other factors related to the function and ergonomics of a product, the design variables which are only associated with aesthetics are considered. In Section 5.2, a model of aesthetic design will be presented. In Section 5.3, the statistic design of an experiment is described. In Section 5.4, the experimental results with discussion are presented. In Section 5.5, some important findings are summarized.

5.2 The Model of Aesthetic Design

5.2.1 Modeling Color

Color, as one of the aesthetic variables, uncoupled with the functional and ergonomics aspects of cell phone, was used as a design feature. General hypothesis was: A visually balanced product is more beautiful than an unbalanced one.

Examining how color may influence the visual balance properties of a design is useful. In this connection, Equation (4.6), i.e., $w = (A_c + A_g) d$, would be referred. In Equation (4.6), (w) indicates the weight of a component, (A_c) the equivalent area which represents the influence of its color and (A_g) its geometric area. In the Equation (4.6), d stands for distance of the geometrical center of a component from vertical axis passing the geometrical center of the cell phone. According to Equation (4.6), if two components with different areas are placed in an equal distance but opposite sides with respect to the balance centre of a product, they would be perceived as balanced if they have the same ($A_c + A_g$). This implies a design rule that a heavy color should be used on a small component and a light color on a large component.

In order to test the general hypothesis that a visually balanced product is more beautiful than an unbalanced one and in order to implement the design rule that a heavy color should be used on a small component and a light color on a large component, a typical cell phone product, seen from Figure 5.1, was modeled in Solidworks with both the symmetric and asymmetric areas and colors.

Figure 5.2 is a front view of the cell phone product with a symmetric geometry and color. Note that the symmetry is with respect to the vertical axis passing through the geometrical center of the cell phone. Figure 5.3 is a front view of the cell phone product with its color being symmetric but its geometry asymmetric; specifically the ellipse area of each of five buttons on the left side is half of the ellipse area of each of five buttons on the right side. In Figures 5.4, different areas and different colors of the buttons on the left and right sides were chosen but they were designed to have an equal $A_c + A_g$. Specifically, background color was shown to be Cream with RGB (235, 235, 150), the

two other colors were, respectively, Brown with its RGB (150, 18, 0) and Pink with its RGB (255, 200, 160). Applying Equation (4.6), the equivalent area of Brown color was 2.7654 cm^2 and that of Pink color was made to be 1.393 cm^2 . To make them have an equal ($A_c + A_g$), the A_c of the Brown colored component was 1.393 cm^2 , while that of the Pink colored component was made to be 2.7654 cm^2 . Therefore, in Figure 5.4, Brown color is used on the larger size buttons on the right side, and Pink color on the smaller size buttons on the left side. This configuration is reversed on Figure 5.5.



Figure 5.1 The 3D picture of a cell phone in SolidWorks



Figure 5.2 Symmetric geometry and symmetric color



Figure 5.3 Asymmetric geometry (left buttons with smaller areas) yet symmetric color

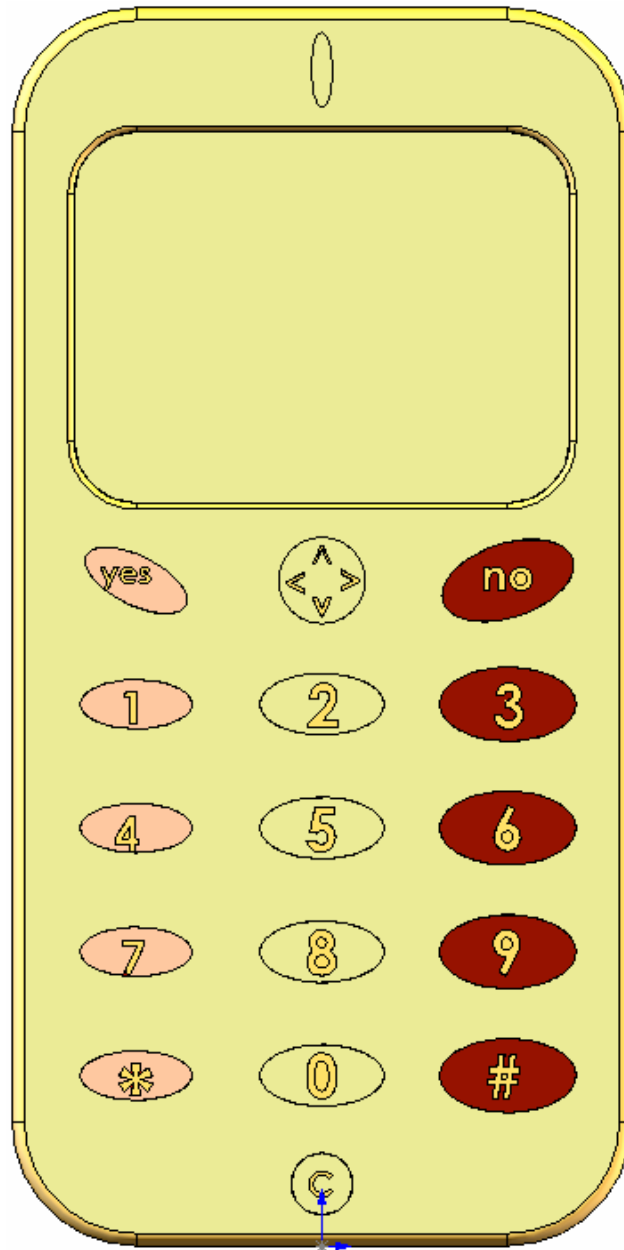


Figure 5.4 Asymmetric geometry (left buttons with smaller areas) and asymmetric color (left buttons with Pink and right buttons with Brown)

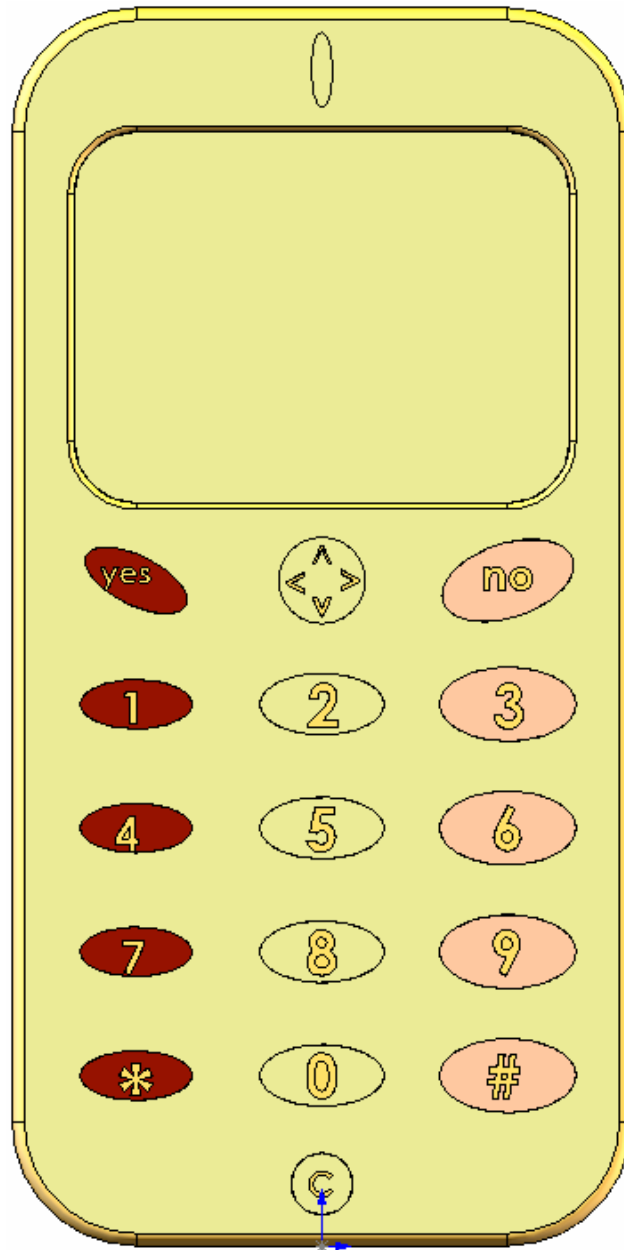


Figure 5.5 Asymmetric geometry (left buttons with smaller areas) and asymmetric color (left buttons with Brown and right buttons with Pink)

Following specific hypotheses were presented: (1) if Brown color is used on the small buttons and Pink on the large buttons, then the product would be visually perceived as balance, though the product is geometrically asymmetric; (2) if the degree

of the visual balance attribute of a product is increased, its overall aesthetics would be increased; (3) a balanced picture would have a higher degree of beauty compared to an unbalanced one; (4) both Figures 5.2 and 5.5 convey more balanced than do Figures 5.3 and 5.4; (5) Figure 5.5 would be perceived as more beautiful than Figure 5.2. Hypothesis (5) was further implies that a mono-color product may be felt less attractive than a product with more colors. Table 5.1 summarizes the preceding discussion of Figures from 5.2 to 5.5. Besides, the general question was: whether proper coloring could lead to improvements in the visual balance property and/or beauty aspect of the design when the geometrical shape of a design is asymmetric?

Table 5.1 Balance characteristics regarding buttons' area and buttons' color

Figure #	Left buttons' areas	Right buttons' areas	Left buttons' colors	Right buttons' colors	Hypothetical Aesthetics Ranking
5.2	Equal		Identical (background color)		2
5.3	Smaller	Larger	Identical (background color)		3
5.4	Smaller	Larger	Lighter	Heavier	4
5.5	Smaller	Larger	Heavier	Lighter	1

5.2.2 Modeling Body Decoration

Body decoration, as one of the aesthetics variables, uncoupled from the functional and ergonomic aspects of a design, is an extensive area which includes patterns drawn

on the body. This study was examining how a smile pattern can influence the beauty and visual balance property of a design. For this purpose, using SolidWorks and Photoshop, four cell phone products were modeled; see Figures 5.6, 5.7, 5.8, and 5.9, respectively. Figure 5.6 is the picture of the original product without the specific decoration and Figures 5.7, 5.8, and 5.9 are those modified from the original ones by adding the specific decorations. Specifically, in Figure 5.7, a cell phone body was decorated with two horizontal lines across its middle, which represents a seriousness pattern; in Figure 5.8, a cell phone body was decorated with two curved lines across the middle, which represents a smile pattern; and in Figure 5.9, instead of one unbalanced antenna at the right side, two half-circles of the antenna were put on the top corners of the cell phone, respectively, to make it more balanced and also to increase the effect of the smile pattern. It is noted that in the design of antenna, the surface area of one antenna must be equal to the sum of the surface areas of the two half sized antennas.



Figure 5.6 Original cell phone picture



Figure 5.7 Cell phone picture with seriousness pattern



Figure 5.8 Cell phone picture with smile pattern



Figure 5.9 Cell phone picture with smile pattern and balance antenna

5.3 Statistic Design of an Experiment

5.3.1 Participants

Forty University of Saskatchewan students participated in this study individually. Among those forty participants twenty were originally from China (ten male and ten female) and twenty were originally from Iran (ten male and ten female).

5.3.2 Measure

The Semantic Differential (*SD*) technique was used. In the *SD* technique, participants were asked to rate a concept/object (here cell phone pictures) according to a bipolar scale. It has been shown that three empirical derived factors (evaluation, potency and activity) are major factors in a wide variety of judgmental situations [Osgood et al., 1969]. Evaluation dimension is associated with the adjective contrasts corresponding to the favorable-unfavorable dimension such as nice-awful, beautiful-ugly, etc. Potency dimension is the perception of the power of the object or concept such as big-little, powerful-powerless, etc. Activity dimension is the perception of the activity of the object or concept such as fast-slow, noisy-quiet, etc.

Appropriate concept/object is the one with high loading on just one dimension of evaluation, potency and activity [Heise, 1970]. On the other hand, the concept of beauty lies on the positive (good) pole of evaluation dimension [Jakobovits, 1966]. Osgood et al. [1955], in their factor analytical work, showed that 0.86 of variation in the beautiful-ugly scale, loaded on the first factor called evaluative factor or evaluation dimension. Therefore, the sense of beauty could be considered as a factor and be evaluated with a beautiful-ugly polar scale.

In this experiment, the beautiful-ugly contrast was used through the *SD* technique as an appropriate scale for determining the holistic/gestalt aesthetic evaluations of the cell phone product. A nine scale *SD* measure was chosen in this study and is shown in Tables 5.2 and 5.3, respectively.

In literature, there is strong evidence that the seven-step scale measure has nearly equal psychological units in the process of judgment when three linguistic quantifiers “extremely”, “quite”, and “slightly” are included in both directions from a neutral origin [Osgood et al., 1969]. Nevertheless, to the participations for in this experiment a nine-step scale was chosen, because there was a need to have a more differentiated evaluation from participants.

Table 5.2 Nine-step scale of *SD* technique used for the beautiful-ugly bipolar

Indicator and bipolar term	Equivalent number
Extremely beautiful	4
Very beautiful	3
Moderately beautiful	2
Slightly beautiful	1
Neutral	0
Slightly ugly	-1
Moderately ugly	-2
Very ugly	-3
Extremely ugly	-4

Table 5.3 Nine-step scale of *SD* technique used for the balanced-unbalanced bipolar

Indicator and bipolar term	Equivalent number
Extremely balanced	4
Very balanced	3
Moderately balanced	2
Slightly balanced	1
Neutral	0
Slightly unbalanced	-1
Moderately unbalanced	-2
Very unbalanced	-3
Extremely unbalance	-4

5.3.3 Procedure

Seven pictures were presented to the participants for ranking from their point of view of beauty and balance. At the beginning, Figures 5.7, 5.8, and 5.9 were presented to the participants, individually. Figures 5.7 and 5.8 were presented to examine their decoration's effect on the level of their beauty, and Figure 5.9 was presented to see what an effect of using a balanced antenna, instead of using an unbalanced one, would be on the beauty. Then, in order to examine how proper use of color may improve the balance property of a picture and how it may have influence on the level of a picture's beauty, Figures 5.2, 5.3, 5.4, and 5.5 were presented to each participant. It is noted that to make

sure participants understand meaning of balance, it was explained them that balance is a feeling of stability that you perceive from a picture. Then, Figure 5.10 was shown to the participants individually and they were asked with the question which color was more beautiful.

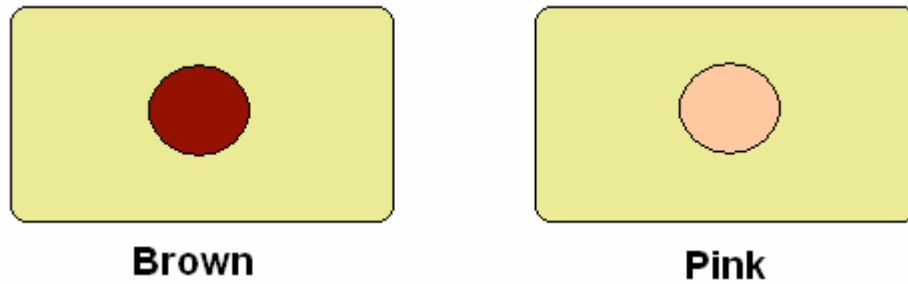


Figure 5.10 Preference to Brown or Pink color

5.4 Results and Discussion

5.4.1 Beauty Analysis

For each of the seven pictures which were presented to participants, 40 ranking data from 10 Chinese female, 10 Chinese male, 10 Iranian female, and 10 Iranian male were recorded. With regard to statistical analysis, participants' evaluations between each two pictures were compared. Therefore, because the 9 step scale, which was discussed in Section 5.3.2, is considered as a ranking scale, for statistical analysis "Wilcoxon's Matched – Pairs test" was used. This test is the most popular nonparametric test for each type of paired scores including the repeated measure [Howell, 2002]. Data was analyzed with the statistical analysis software, SPSS14, considering two-tailed test at $\alpha = 0.05$.

Before the comparison of the participants' evaluations between each two pictures, the effects of culture and gender were analyzed. At the first step of analysis, the responses of Chinese participants were compared with those of Iranian. The result of this comparison is shown in Figure 5.11. Mann-Whitney statistical analysis of data showed that there was not significant difference between participants' evaluation of beauty in terms of cultural background.

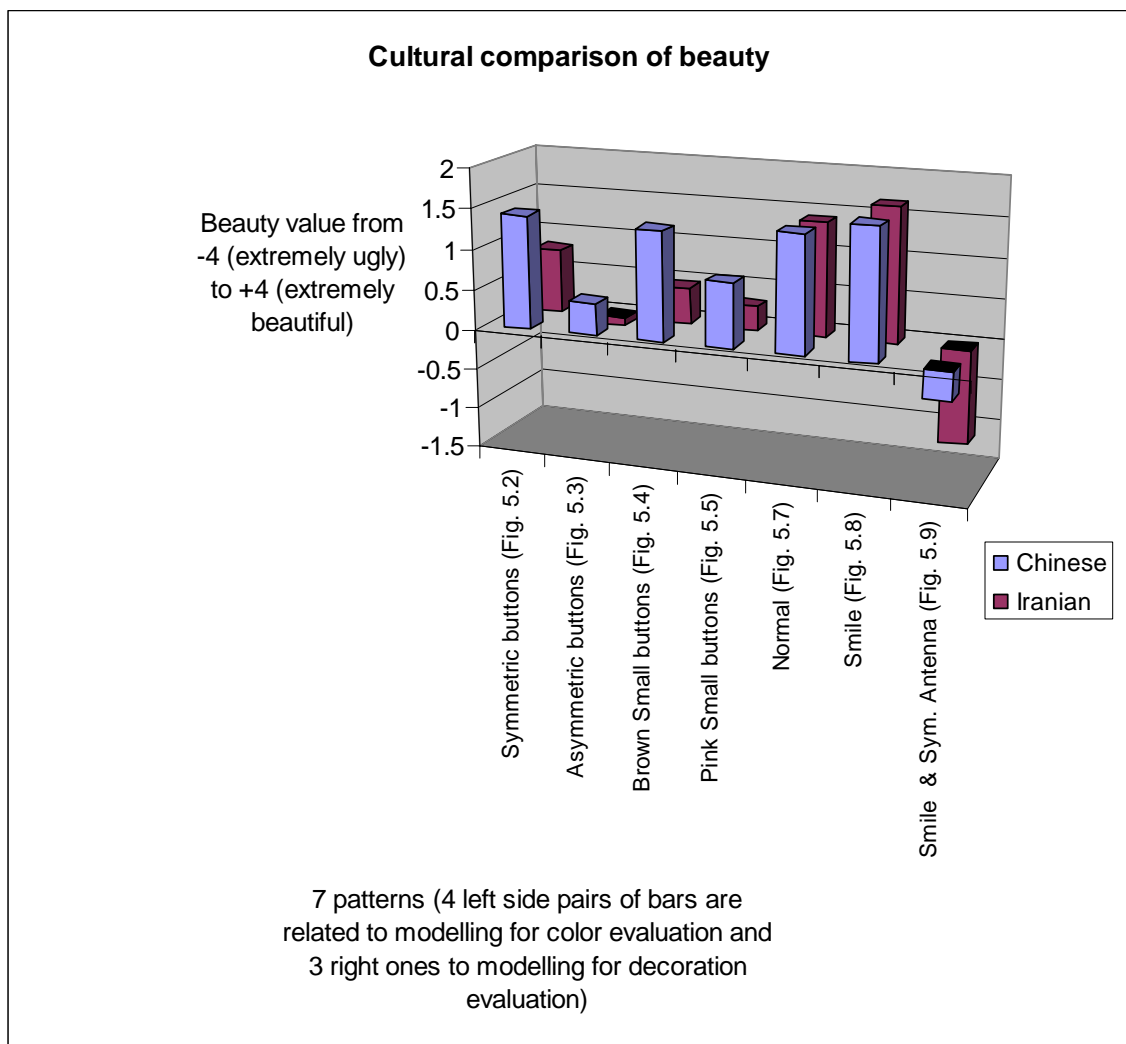


Figure 5.11 Beauty evaluation considering participants' cultural background

At the second step of analysis, the responses of the Male participants were compared to those of the Female participants. The result of this comparison is shown in Figure 5.12. Mann-Whitney statistical analysis of data showed that there was no significant difference between the participants' evaluations of beauty in terms of Gender.

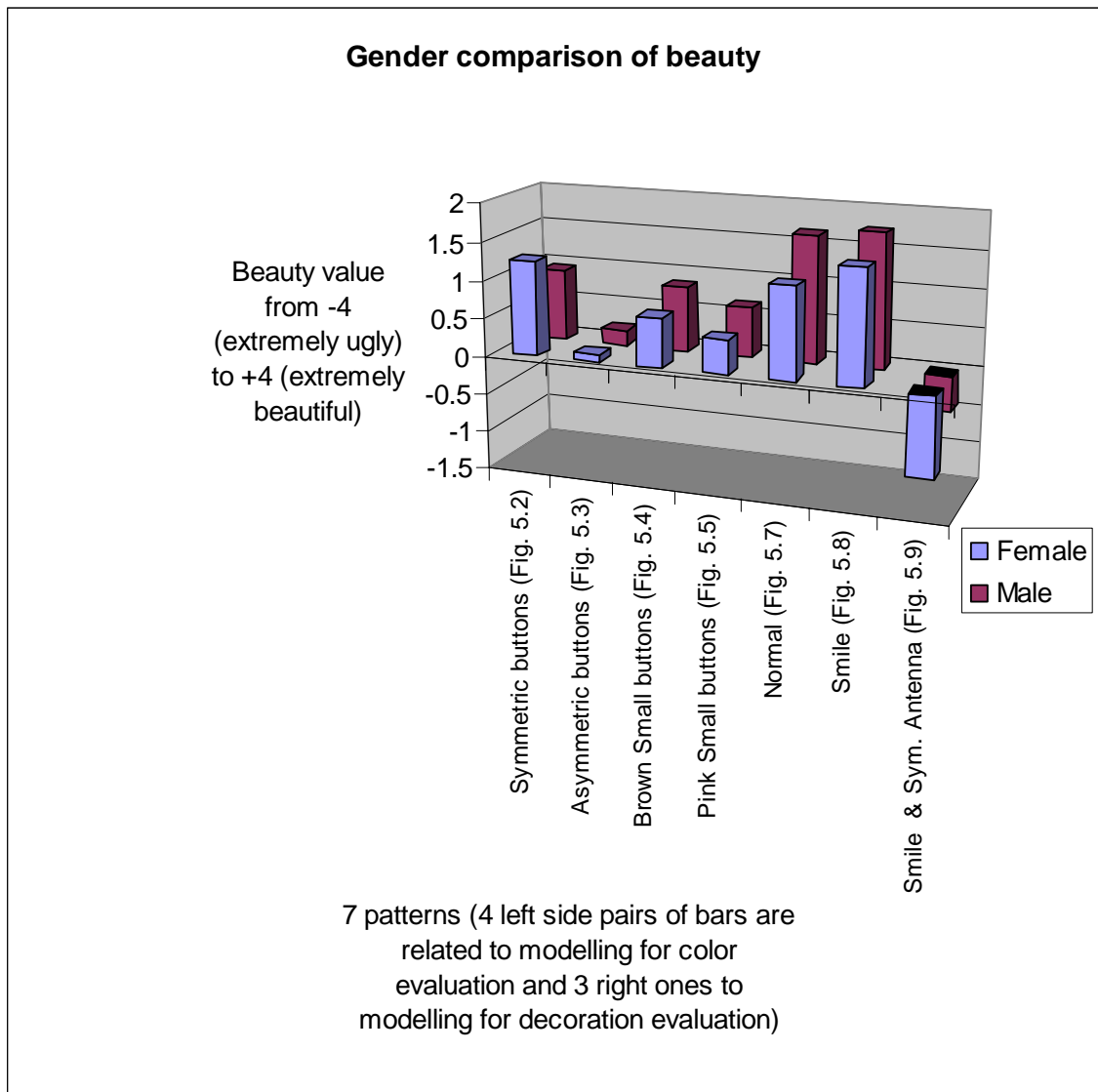


Figure 5.12 Beauty evaluation considering participants' gender

Because the results of the statistical analysis showed that from the point of view of cultural background and gender there were no significant differences between

participants' evaluations, the analysis of data was carried out for all 40 participants. In the following, first the data analysis of color's effect on the beauty of 4 patterns (Figures 5.2, 5.3, 5.4 and 5.5) are studied and then the data analysis of decoration's effect on the beauty of 3 patterns (Figures 5.7, 5.8 and 5.9) are considered. The results of the analysis to examine color's effect on beauty are illustrated in Figures 5.13.

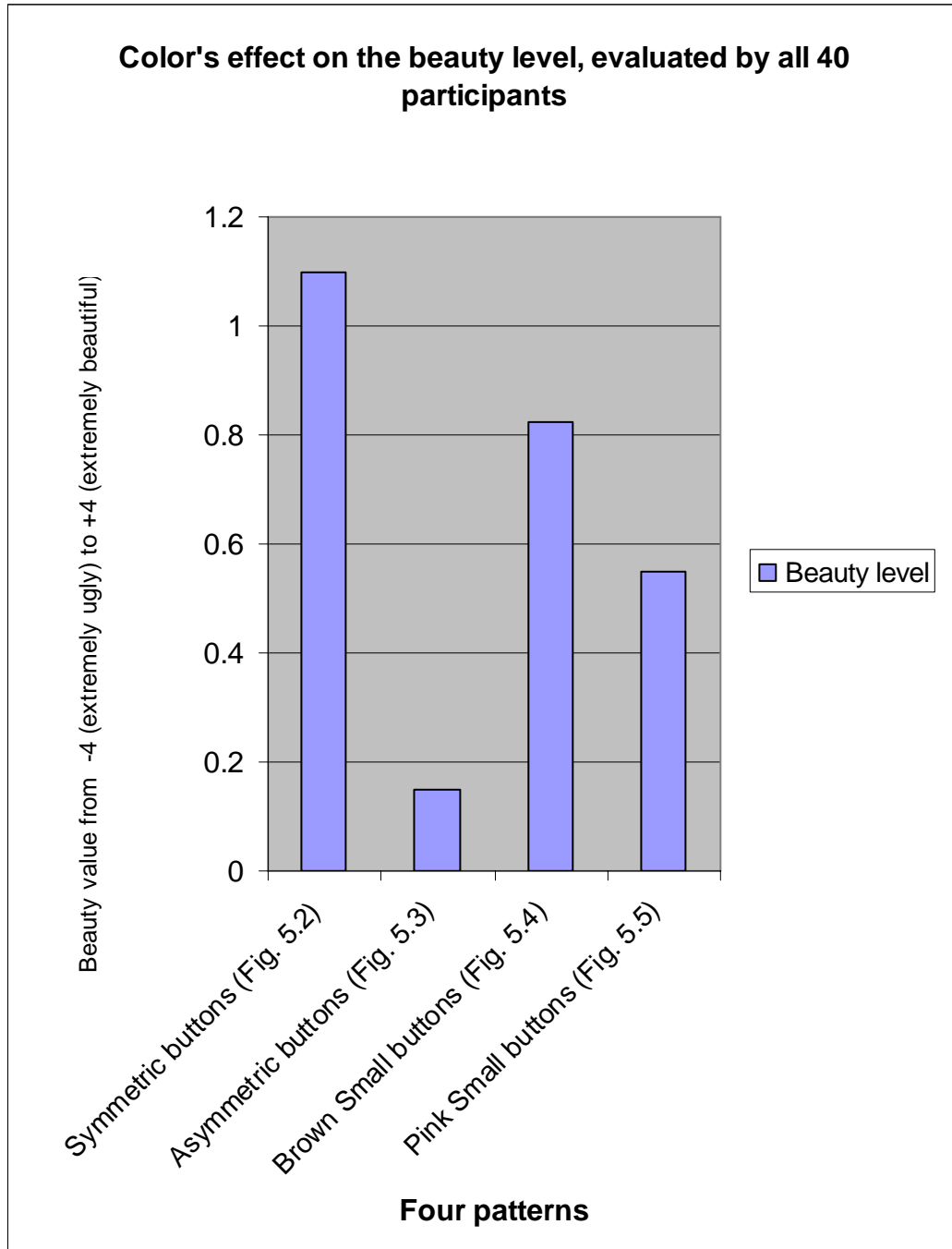


Figure 5.13 Color's effect on beauty

Statistical analysis method “Wilcoxon’s Matched – Pairs test” which was used for the data illustrated on Figure 5.13 showed that there are significant differences (with a P value less than 0.05) between Figure 5.2 and Figure 5.3 and also between Figure 5.3

and Figure 5.4. In addition, there are no significant differences between Figures 5.2 and 5.4, Figures 5.3 and 5.5 and Figure 5.4 and 5.5.

It can be discussed that when the picture with symmetric buttons (Figure 5.2) was changed to the picture with asymmetric buttons (Figure 5.3) the perception of participants on its degree of beauty was significantly decreased. However, when the smaller buttons of the asymmetric picture were colored with heavier color (brown) and the larger buttons were colored with lighter color (pink), participants perceived the picture (Figure 5.5) the same beautiful as the picture with asymmetric buttons (Figure 5.3). When brown and pink colors were reversely used on the small and large size buttons (Figure 5.4), the beauty degree of the picture was not improved. In other words, proper using of color for increasing the balance degree of a geometrically asymmetric picture could increase its degree of beauty. The results of the analysis to investigate decoration's effect on beauty were illustrated in Figures 5.14.

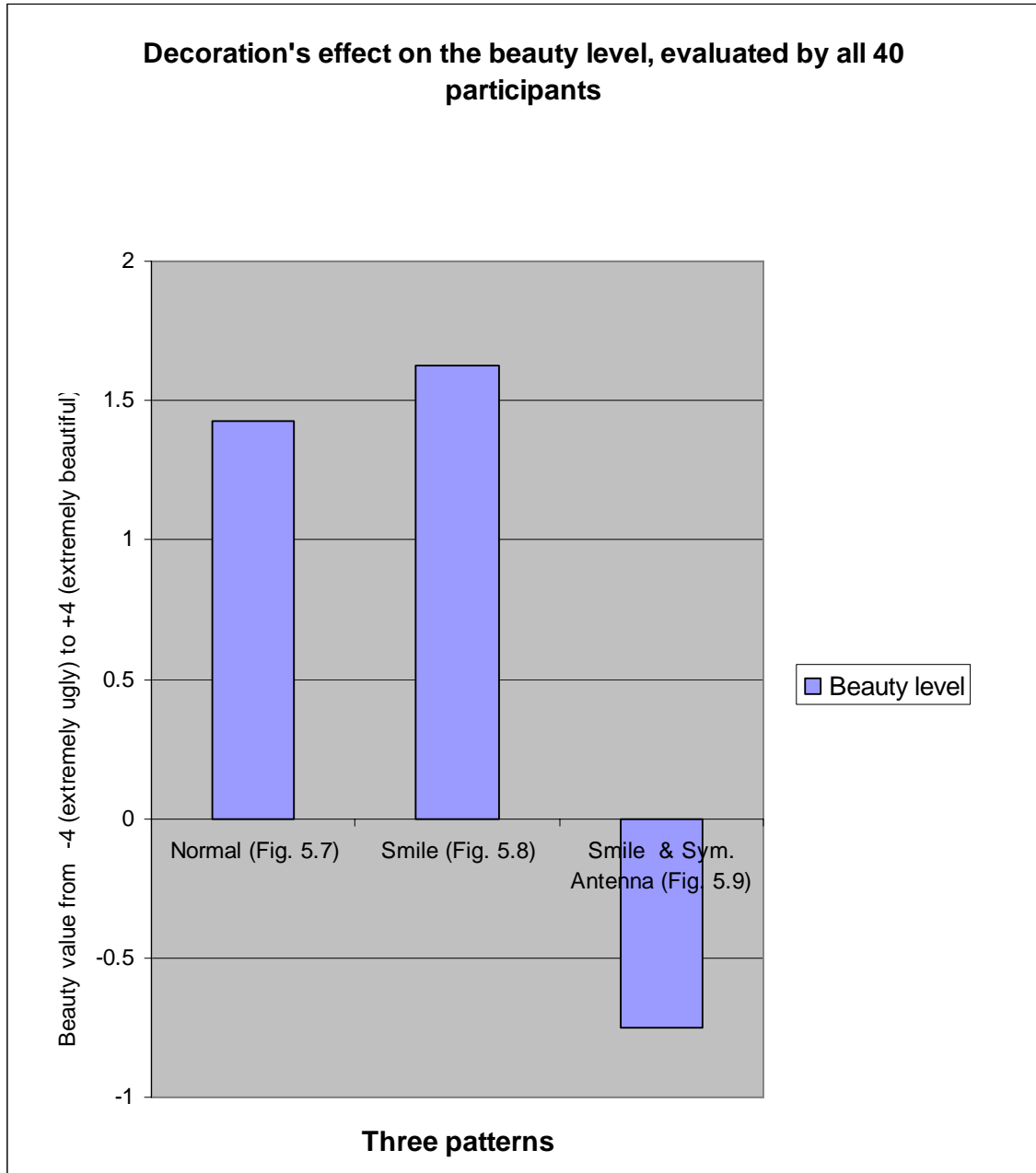


Figure 5.14 Decoration's effect on beauty

Statistical analysis method “Wilcoxon’s Matched – Pairs test” which was used for the data illustrated on Figure 5.14 showed that there are significant differences (with a P value less than 0.0001) between Figure 5.7 and Figure 5.9 and also between Figure 5.8 and Figure 5.9. In addition, there is no significant difference between Figures 5.7 and 5.8.

It can be discussed that the picture with symmetric antenna (Figure 5.9) was significantly evaluated as less beautiful than the other two pictures which had one asymmetric antenna (Figures 5.7 and 5.8); therefore, a qualitative survey was carried out to examine what the reason was. 39 female and male students were asked: 20 Canadian, 10 Chinese, and 9 Iranian, to tell that which picture is the least beautiful one among Figures 5.7, 5.8, and 5.9. The ages of the students were between 20 and 30 years old. Thirty seven of the students answered that the picture with symmetric antenna was the least beautiful one; one student evaluated that picture as the most beautiful one; and one student evaluated it as having a moderate level of beauty. The last two students were female students from China. Most of the participants were asked regarding the reasons behind their evaluations of the picture with symmetric antenna as the least beautiful one. Participants' explanations were recorded and on the recorded data, content analysis was carried out. For this purpose, participants' reasons were analyzed and clustered based on their similarity. Then, a theme was abstracted for the reasons in each cluster. Finally, the importance of each theme was ranked based on the frequency of reasons in each cluster, which is indicated by percentages. Doing this process led to extract following four themes: 1. Style (73%), 2. Ergonomics (12%), 3. Association (9%), 4. Harmony (6%).

The most important theme behind the participants' reasons was the *style* of the design which had made the picture with symmetric antenna the least beautiful one. Some of the most frequent descriptions were: "It has a childish style"; "It is not fit in the male style"; "It's like a toy for children"; "too funny". Another theme was related to poor *ergonomics* which existed because of the shape of the two antennas. Instances of the reasons mentioned under this theme are: "It is not comfort to be held in hand"; "It is

difficult to be put in pocket”; “It sounds physically uncomfortable”. The third theme was *association* because of the shape of two antennas reminded some participants of a mouse and they seemed to have an unpleasing feeling about that. Some examples of the mentioned reasons for this theme are: “It is ugly because it looks like a mouse with two huge ears sticking out his head”; “Circles at the top (it reminds me a mouse!)”. Last extracted theme, *harmony*, was because of the shape of two antennas which would discord with other parts. Examples of this theme are as follows: “Though the ears are round but from this perspective they should match with other curves”; “It seems out-of-shape because of its edges”.

Analysis of the last question of the experiment (this question that Brown is more beautiful or Pink), showed that from 40 participants 26 preferred Brown and 14 preferred Pink.

5.4.2 Balance Analysis

Before the comparison of the participants’ evaluations between each two pictures, the effects of culture and gender were analyzed. At the first step of analysis, the answers of Chinese participants were compared to Iranian. The result of this comparison is shown in Figure 5.15. Mann-Whitney statistical analysis of data showed that there was not significant difference between participants’ evaluation of balance in terms of cultural background.

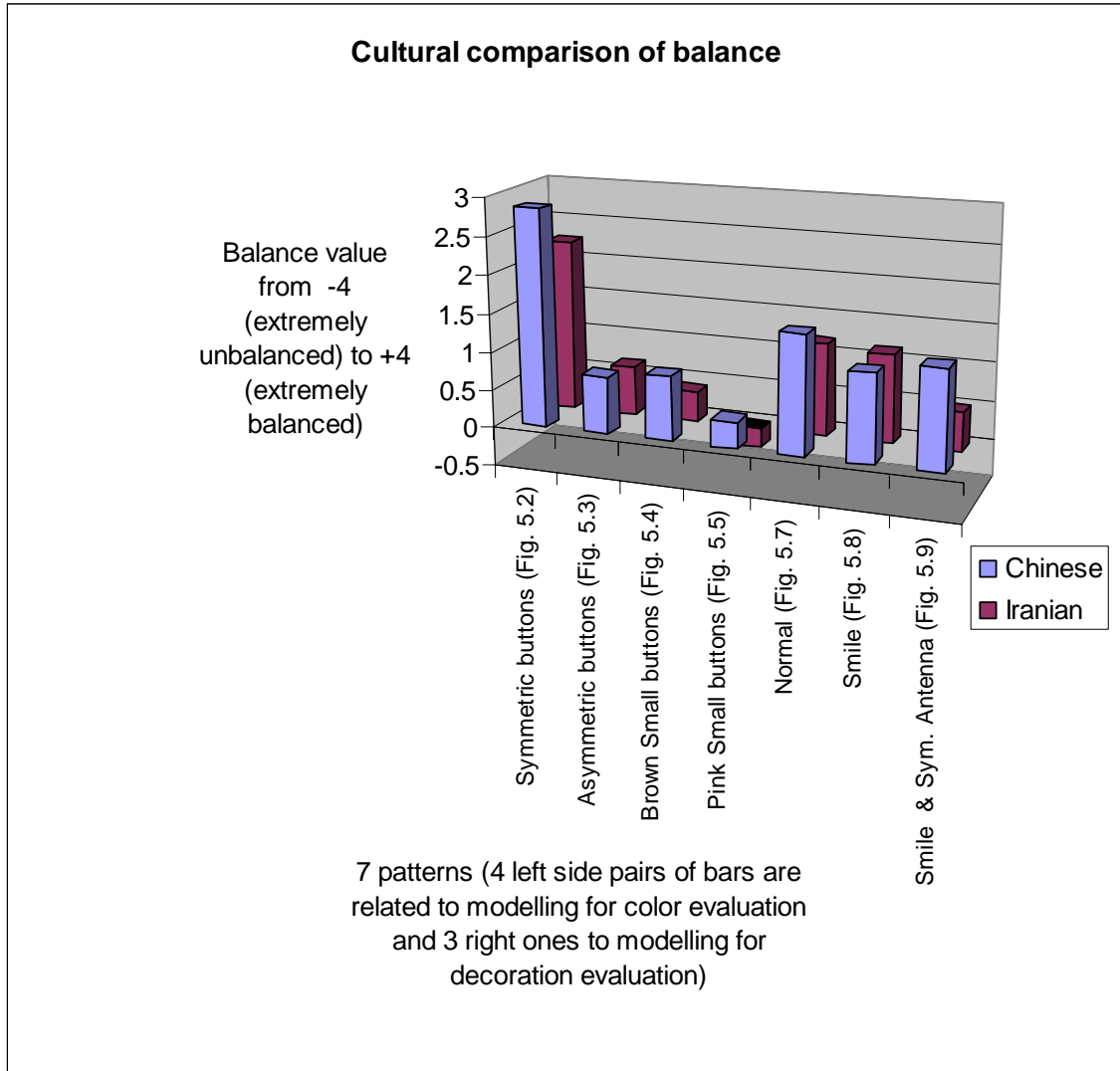


Figure 5.15 Balance evaluation considering participants' cultural background

At the second step of analysis, the responses of the Male participants were compared to those of the Female ones. The result of this comparison is shown in Figure 5.16. Mann-Whitney statistical analysis of data showed that there was no significant difference between participants' evaluations of beauty in terms of Gender.

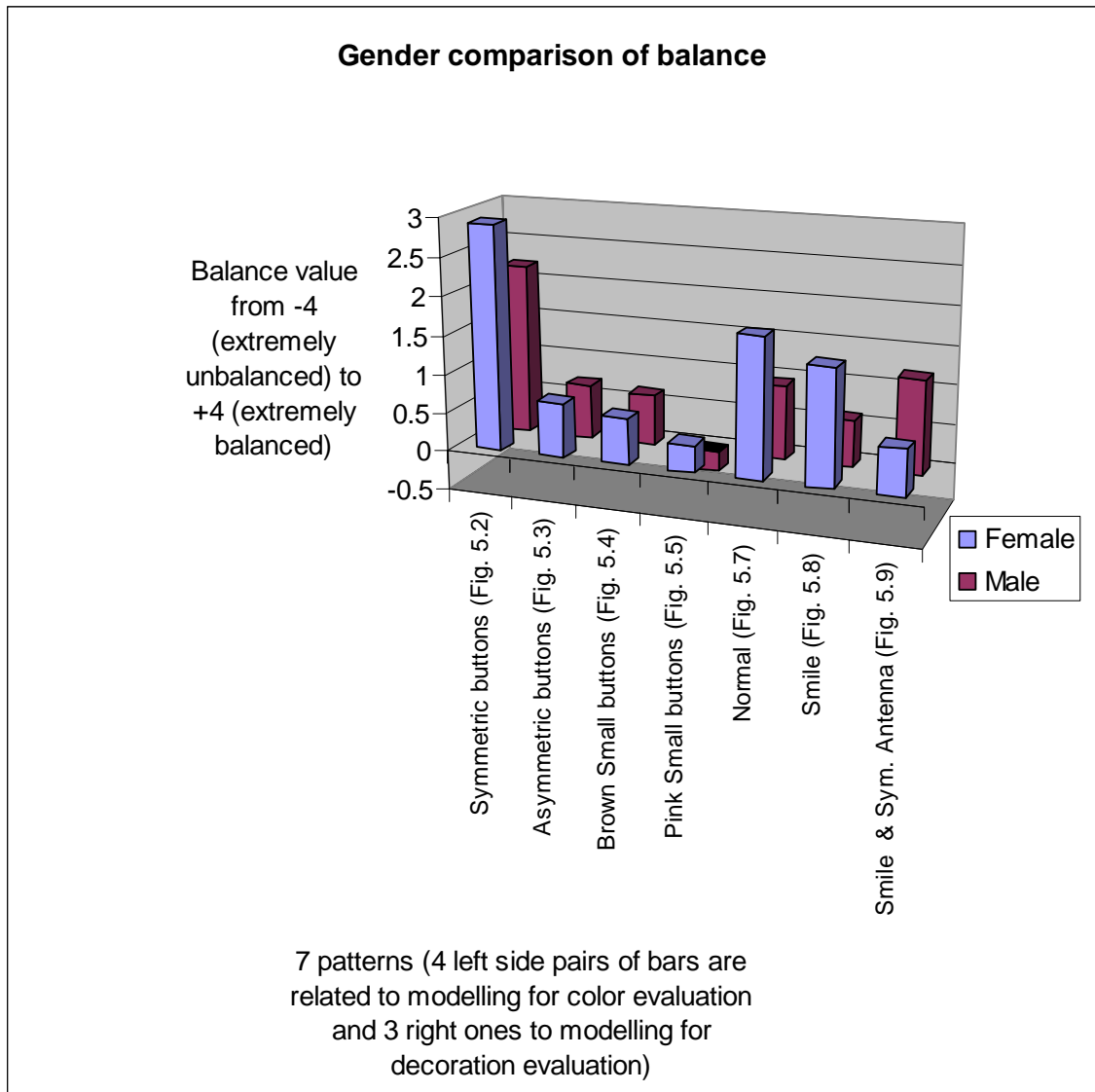


Figure 5.16 Balance evaluation considering participants' gender

Because the results of the statistical analysis showed that from the point of cultural background and gender there were no significant differences between participants' evaluations, the analysis of data was carried out for all 40 participants. In the following, first the data analysis of color's effect on the balance of 4 patterns (Figures 5.2, 5.3, 5.4 and 5.5) are studied and then the data analysis of decoration's effect on the balance of 3

patterns (Figures 5.7, 5.8 and 5.9) are considered. The results of the analysis to examine color's effect on balance are illustrated in Figures 5.17.

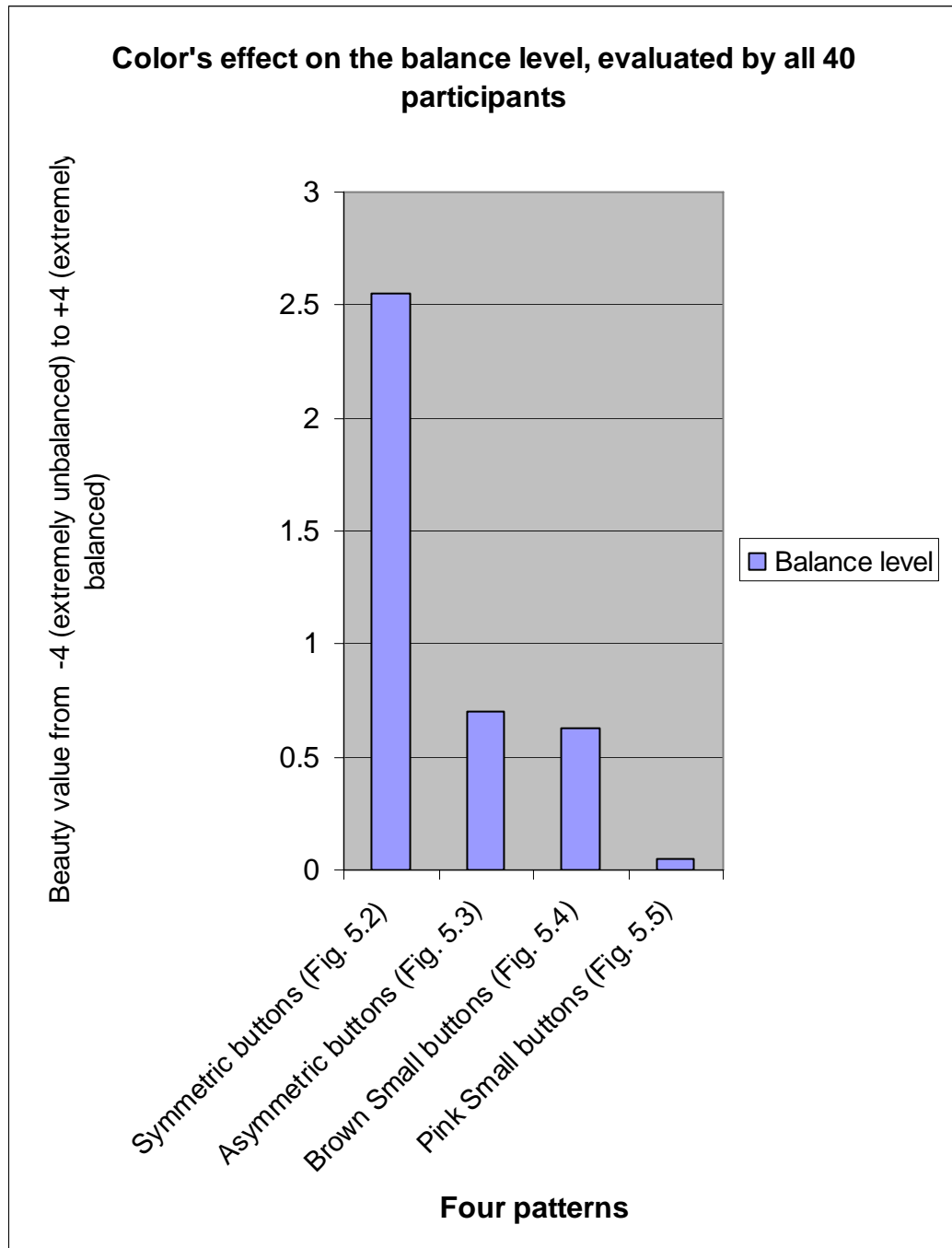


Figure 5.17 Color's effect on balance

Statistical analysis method “Wilcoxon’s Matched – Pairs test” which was used for the data illustrated on Figure 5.17 showed that there are significant differences (with a P value less than 0.05) between Figure 5.2 with each of Figures 5.3, 5.4 and 5.5. Likewise, there is significant difference (with a P value less than 0.05) between Figure 5.4 with Figure 5.5. In addition, there is no significant difference between Figures 5.3 and 5.4.

It can be discussed that when the picture with symmetric buttons (Figure 5.2) was changed to the picture with asymmetric buttons (Figure 5.3) the perception of participants on the picture’s degree of balance was significantly decreased. Also, when the smaller buttons of the asymmetric picture were colored with heavier color (brown) and the larger buttons were colored with lighter color (pink), participant’s perception of the balanced degree of the picture (Figure 5.5) was not improved to the same level of Figure 5.2. The same result obtained when brown and pink colors were used reversely on the small and large size buttons (Figure 5.4).

In the previous section it was discussed that proper using of color for increasing the balance degree of a geometrically asymmetric picture could increase the participants’ evaluation on the picture’s degree of beauty. However this improvement on beauty of the picture that had been obtained because of the balance increasing was not reflected on the evaluation that participants consciously expressed on the balance level of the picture.

The results of the analysis to investigate decoration’s effect on beauty were illustrated in Figures 5.18.

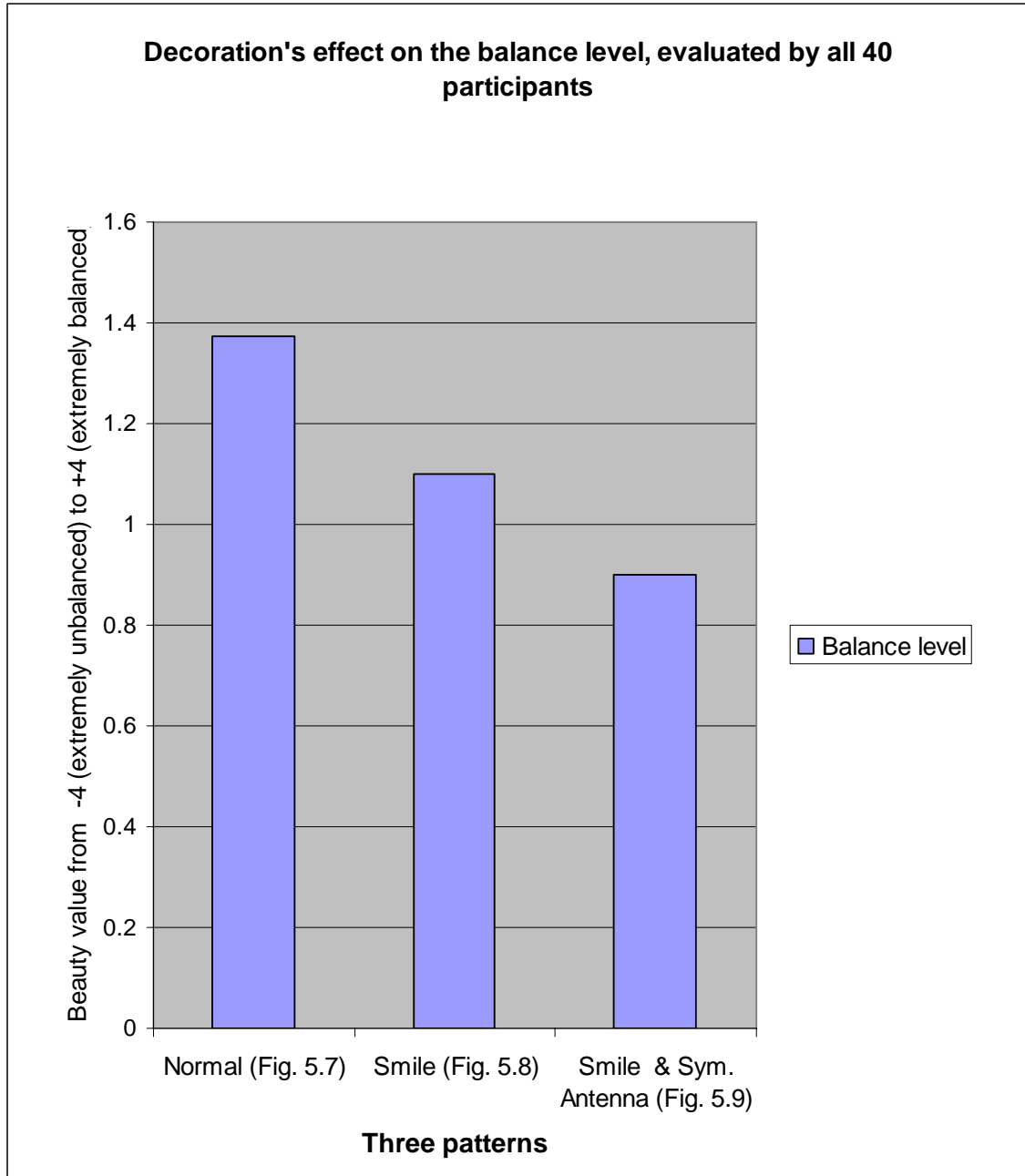


Figure 5.18 Decoration’s effect on balance

Statistical analysis method “Wilcoxon’s Matched – Pairs test” which was used for the data illustrated on Figure 5.18 showed that Figures 5.7, 5.8, and 5.9 had no significant differences with each other.

5.4.3 Beauty and Balance Relation Analysis

In order to see the relationship between beauty and balance, correlation analysis was carried out between the beauty difference and balance difference for each of the two pictures. Table 5.4 shows results of correlation analysis. The second row and columns of the table indicate Figures 5.2, 5.3, 5.4 and 5.5. The star sign in each cell represents a significant relation between beauty difference and balance difference of respected pictures in the entries of row and column.

Table 5.4 Relation between beauty difference and balance difference (*: Correlation is significant at the 0.05 level [2-tailed]; **: Correlation is significant at the 0.01 level [2-tailed]; *N.S.*: Correlation is not significant.)

		Beauty			
		Symmetric (5.2)	Asymmetric (5.3)	Small Brown (5.4)	Small Pink (5.5)
Balance	Symmetric (5.2)		**	*	<i>N.S.</i>
	Asymmetric (5.3)			**	*
	Small Brown (5.4)				<i>N.S.</i>
	Small Pink (5.5)				

5.4.4 Discussion

In Section 5.4.1, it was found that the beauty property of asymmetric Figure 5.3 was significantly improved when in Figure 5.5 the small size buttons were colored Brown (as a heavy color) and the large size buttons were colored Pink (as a light color). This improvement was such that the beauty property of the asymmetric picture reached the same level of beauty as symmetric one (Figure 5.2).

On the other hand, when lighter color (Pink) was used for buttons with smaller area (Figure 5.4), results of analysis showed that there was no significant improvement in the beauty of the asymmetric one (Figure 5.3). Therefore, although in both Figures 5.4 and 5.5, Brown and Pink were added to the buttons of the mono-color asymmetric picture, the beauty only increased when heavier color was applied to smaller area.

To elaborate that the improvement of the beauty was not because of only adding a color to a mono-color design, a question was asked from the participants, that in a non-semantic context (Figure 5.10) which color was more beautiful, Blue or Pink? Sixty five percent of participants preferred the Brown color. However, although in Figure 5.4 bigger size buttons were colored Brown, the beauty of the picture had not been improved.

The balance analysis (in Section 5.4.2) showed that there was no significant change in the balance property of Figure 5.5, compared to 5.3. However, the correlation analysis (in Section 5.4.3) showed that differences of beauty in the two pictures were significantly correlated with differences of balance. It can be resulted that a proper use of colors with compensation purposes for a geometrically unbalanced design could function as expected in that there was an improvement in the level of beauty. However,

participants did not consciously connect these improvements to the pictures' balance improvement.

5.5 Conclusion

(1) One of the hypotheses was that if the area in one geometrically symmetric design is changed to an asymmetric one, which implies that the design geometrically conveys unbalance, the geometrically unbalanced design is also less beautiful than the original one. This hypothesis was positively tested.

(2) Another hypothesis was that given a design that is geometrically unbalanced, its unbalanced property and beauty level would be improved by properly selecting the colors of the areas such that the design is balanced with consideration of both the area and color. This hypothesis was also positively tested.

(3) The beauty of a design is also influenced by style, ergonomics, and resemblance of the shape to an object in the real world. Such influences could overturn the beauty achieved through the balancing principle.

CHAPTER 6

CONCLUSION

6.1 Overview

Contemporary design principles of functional products are short to the consideration of aesthetics of the products. There are well-known aesthetic principles, such as visual balance, in the field of Fine Arts. Despite known subjectivity in aesthetics or beauty, it is worthwhile to study the way of quantifying these principles in guiding the design of aesthetical features into the functional product. The goal of this research was to develop a methodology for incorporating the visual balance principle into the existing function-oriented design process.

To accomplish this goal, two objectives were proposed in this study: (1) integration of aesthetic design with functional and ergonomic designs for a functional product, and (2) quantification of the visual balance principle in terms of the design rules to guide aesthetics design for a functional product.

The first objective of the research was studied in the third chapter, after presenting an introduction and literature review in the first and second chapters. The study on the

first objective was started with the thinking of the independence axiom from Axiomatic Design Theory. According to this axiom, the best design with consideration of aesthetics, ergonomics and function should be such that the attributes of these three aspects must be independent. This further means that design variables should be classified according to their relevance to the three aspects (function, ergonomics, aesthetics). In order to implement the idea of independency among the attributes of aesthetics, ergonomics and function, the study took cell phone as an example throughout. Design variables of cell phone were thus examined for their association with function, ergonomics, and / or aesthetics. An experimental approach was employed to study the classification of the design variables of the cell phone.

The second objective of the research was studied in the fourth chapter, where the study quantified the visual balance principle, resulting in a new formula which considered a full spectrum of colors together with areas. The formula was experimentally determined. In the fifth chapter, the evaluation of the aesthetic design based on the visual balance principle was conducted. The design variables were color and decoration.

The study on the first objective has concluded:

- (1) The classification of design variables with respect to aesthetics, ergonomics, and function is very important to create a design with consideration of all three aspects of a product and with a high degree of integrity in design variables (i.e., satisfying the independence axiom);

- (2) The visual balance principle from fine arts is useful to incorporating the aesthetic attributes into the functional and ergonomic attributes.

The study on the second objective has concluded:

- (1) Visual balance as an aesthetic principle from Fine Art can be quantified into the design variables with consideration of both geometry and color;
- (2) The balanced design with consideration of both area and color is generally more aesthetic than the unbalanced design; and
- (3) The design features such as style, shape, and ergonomics can significantly influence the aesthetic design of a functional product.

6.2 Major Contributions

The following contributions have been made from this study:

- (1) This study presented an idea of classification of design variables of a product in terms of their association with the three aspects: function, ergonomics and aesthetics. This idea is a basis for integration of these three aspects in design yet without producing poor designs; a poor design is the one that violates the axiom design theory, axiom I in particular. The presented idea is an application of one of the design principles, the Independence Axiom of Axiomatic Design that was first presented by Suh [1990], to the design for aesthetics process.
- (2) This study presented a model which measures visual balance with respect to the color and area of its components. This model can determine the weight of any color with

consideration of its background color. In this model, the dimension of the weight of color is the same as the dimension of area. Therefore, the color and area can be “added” to each other. Although, some studies such as Locher et al. [2005] and Pinkerton and Humphrey [1974] studied the weight of colors; yet their works were restricted to a certain degree.

(3) This study added a further verification that a balanced design is perceived more beautiful than an unbalanced design. In addition, if a design has to be asymmetric or unbalanced, its aesthetic value can be improved by selecting colors to achieve visual balance.

(4) This study was the first to show that *style* can be an influential factor than visual balance in the perception of beauty.

6.3 Limitations and Future Work

6.3.1 Limitations

(1) Although this study opened a way for developing a method to quantify weight of colors in terms of values, however transforming human evaluations to crisp values may not be a cautious way for quantifying. A lot of human evaluations are approximate rather than precise in nature [Zadeh, 1976]. Fuzzy theory, which is a method presented by Zadeh [1965] for modeling states with approximate characters, can be appropriate for assigning weight to colors.

(2) As Reich [1993] pointed out, aesthetic appreciation was predicted to have similarity with cultural forms. Aesthetic forms can be considered as symbols that are dependant on

culture; therefore a beautiful creature in one culture may be considered a plain or even ugly entity in another culture. For instance, colors may be loaded with different meanings in different cultures and this cultural dependency may have influence on how colors are perceived. This research was limited to an objectivist epistemology of aesthetics. Therefore, there was not pay attention to the cultural aspects of aesthetics.

(3) In the evaluation of aesthetics of cell phone products the product was reduced to its picture and also the aesthetic term we reduced to the visual aspect of aesthetics.

(4) In order to avoid using small sample sizes, considerations of participants' gender and age was ignored. Therefore, the presented model for measuring the weight of color is a general model and it is not specific to the factors such as gender and age.

(5) In the third experiment for studying decoration, two lines was drawn on the body to represent seriousness and smile patterns and found that there is no significant difference in their level of beauty. This is perhaps because using two lines only on the body as a decoration pattern is not enough to induce any required change in the beauty level.

(6) In the third experiment it was found that the cell phone product with symmetric antenna was perceived as the least beautiful picture. A qualitative survey was carried out to know what reason behind participants' decision was. In the survey, only one question was asked from participants: "Why did you evaluate the picture with symmetric antenna as the least beautiful one?" However, a more solid and informative method could be deployed using a semi-structured interview beginning with the mentioned question but would not be limited to that.

6.3.2 Future Work

The following issues are of interest for future studies.

(1) For the reason that theory of fuzzy logic offer a mathematical support for the perceptual and linguistic features related with human cognition [Gupta, 1998], it is proposed to use Fuzzy-Neural approach, instead of Neural Network method, to add worth to the research.

(2) It is recommended that in future studies on the role of culture in the perception of aesthetics would be considered.

(3) It is suggested that experiments with real products, instead of modeled pictures, to add value to the research.

(4) Regarding the presentation of a model for measuring the weight of color, if the sample size would be significantly increased, demographic factors such as gender and age could be considered, and consequently it would be possible to present specific models.

(5) Participants' evaluation in an aesthetic survey needs further elaboration; it is proposed to use a follow-up interview.

(6) Research should be done for examining whether aesthetic and ergonomic aspects of design are orthogonal or not.

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**APPENDIX A. DISASSOCIATION BETWEEN DESIGN ASPECTS OF
VARIABLES**

Note: The following tables indicate the percentage of relevancy between design attributes (aesthetics with function and aesthetics with ergonomics) of 24 cell phone design variables.

First trial, Aesthetics-Function disassociation:

Rank	Variable	Function-Beauty	Disassociation %	Description
1	19	2.7	89.7	19. "Decorated area"
2	24	2.7	89.7	24. "Color of body"
3	22	2.7	89.7	22. "Frontal shape of body"
4	12	2.2	74.8	12. "Ratio of body width to height"
5	17	2.2	74.8	17. "Number of colors used in body"
6	18	2.2	74.8	18. "Existence of colorful area"
7	15	2.2	74.7	15. "Degree of body luster"
8	16	2.2	74.7	16. "Brightness of body color"
9	5	2.1	70.4	5. "Color of mainly used button"
10	23	2.1	70.4	23. "Degree of body roundness"
11	3	2.0	66.7	3. "Shape of most salient button"
12	13	2.0	66.7	13. "Horizontal length of body"
13	1	1.9	64.0	1. "Number of differently shaped buttons"
14	9	1.9	62.1	9. "Ratio of display width to height"
15	6	1.7	58.1	6. "Degree of button size variation"
16	14	1.7	56.3	14. "Vertical length of body"
17	2	1.6	52.5	2. "Shape of mainly used button"

18	10	1.3	43.7	10. "Area of display"
19	21	1.3	43.7	21. "Layout of components"
20	11	0.9	30.7	11. "Degree of emphasis on speaker design"
21	4	0.4	15.0	4. "Size of mainly used button"
22	8	0.3	10.4	8. "Existence of menu navigation buttons"
23	7	0.3	8.4	7. "Number of exposed frontal buttons"
24	20	0.3	8.3	20. "Open mechanism"

First trial, Aesthetics-Ergonomics disassociation:

Rank	Variable	Ergonomics-Beauty	Disassociation %	Description
1	24	2.3	75.0	24. "Color of body"
2	19	2.0	66.9	19. "Decorated area"
3	15	1.6	51.7	15. "Degree of body luster"
4	8	1.5	51.6	8. "Existence of menu navigation buttons"
5	18	1.1	35.1	18. "Existence of colorful area"
6	17	1.0	33.5	17. "Number of colors used in body"
7	4	1.0	33.2	4. "Size of mainly used button"
8	22	1.0	32.4	22. "Frontal shape of body"
9	16	0.8	26.7	16. "Brightness of body color"
10	9	0.7	22.4	9. "Ratio of display width to height"
11	20	0.7	22.1	20. "Open mechanism"
12	11	0.6	19.1	11. "Degree of emphasis on speaker design"
13	21	0.6	18.5	21. "Layout of components"

14	14	0.4	14.1	14. "Vertical length of body"
15	5	0.4	14.1	5. "Color of mainly used button"
16	6	0.3	11.2	6. "Degree of button size variation"
17	10	0.3	10.4	10. "Area of display"
18	2	0.3	9.3	2. "Shape of mainly used button"
19	13	0.2	8.2	13. "Horizontal length of body"
20	7	0.2	6.0	7. "Number of exposed frontal buttons"
21	1	0.2	5.9	1. "Number of differently shaped buttons"
22	3	0.2	5.9	3. "Shape of most salient button"
23	23	0.1	4.4	23. "Degree of body roundness"
24	12	0.1	1.8	12. "Ratio of body width to height"

Second trial, Aesthetics-Function disassociation:

Rank	Variable	Function-Beauty	Disassociation %	Description
1	19	3.0	100.0	19. "Decorated area"
2	24	3.0	100.0	24. "Color of body"
3	22	2.5	85.0	22. "Frontal shape of body"
4	15	2.5	85.0	16. "Brightness of body color"
5	5	2.5	84.8	5. "Color of mainly used button"
6	14	2.5	84.8	12. "Ratio of body width to height"
7	17	2.5	84.8	17. "Number of colors used in body"
8	18	2.5	84.8	18. "Existence of colorful area"
9	11	2.5	84.8	23. "Degree of body roundness"
10	9	2.4	80.7	9. "Ratio of display width to height"
11	13	2.2	72.1	13. "Horizontal length of body"

12	12	2.2	72.1	14. "Vertical length of body"
13	16	2.1	69.9	15. "Degree of body luster"
14	3	2.0	66.6	3. "Shape of most salient button"
15	1	2.0	66.4	1. "Number of differently shaped buttons"
16	2	1.8	61.1	2. "Shape of mainly used button"
17	6	1.8	61.1	6. "Degree of button size variation"
18	21	1.8	60.2	21. "Layout of components"
19	10	1.7	56.4	10. "Area of display"
20	7	1.2	39.7	7. "Number of exposed frontal buttons"
21	4	1.1	37.6	4. "Size of mainly used button"
22	20	0.5	16.6	20. "Open mechanism"
23	23	0.5	16.1	11. "Degree of emphasis on speaker design"
24	8	0.0	1.5	8. "Existence of menu navigation buttons"

Second trial, Aesthetics-Ergonomics disassociation:

Rank	Variable	Ergonomics-Beauty	Disassociation %	Description
1	24	2.5	83.3	24. "Color of body"
2	19	2.1	70.0	19. "Decorated area"
3	15	2.0	68.3	16. "Brightness of body color"
4	8	2.0	66.7	8. "Existence of menu navigation buttons"
5	18	1.5	51.6	18. "Existence of colorful area"
6	17	1.2	40.8	17. "Number of colors used in body"

7	5	1.0	34.8	5. "Color of mainly used button"
8	7	1.0	34.8	7. "Number of exposed frontal buttons"
9	4	1.0	33.3	4. "Size of mainly used button"
10	16	0.8	28.2	15. "Degree of body luster"
11	22	0.8	26.6	22. "Frontal shape of body"
12	11	0.7	23.7	23. "Degree of body roundness"
13	21	0.7	23.1	21. "Layout of components"
14	14	0.5	15.4	12. "Ratio of body width to height"
15	1	0.4	14.8	1. "Number of differently shaped buttons"
16	9	0.4	14.3	9. "Ratio of display width to height"
17	2	0.4	13.7	2. "Shape of mainly used button"
18	20	0.3	11.0	20. "Open mechanism"
19	6	0.3	9.6	6. "Degree of button size variation"
20	10	0.2	8.2	10. "Area of display"
21	13	0.1	3.8	13. "Horizontal length of body"
22	12	0.1	3.8	14. "Vertical length of body"
23	23	0.1	3.7	11. "Degree of emphasis on speaker design"
24	3	0.0	0.1	3. "Shape of most salient button"

APPENDIX B. INPUT AND OUTPUT OF TRAINING AND TESTING DATA

Note: The following table indicates the input (i.e., the codes connected to foreground and background colors) and the output (i.e., weight of foreground color) of training and testing data of the selected network model. The model enable user to measure weight of a new color considering its background color.

Training Data #	Input						Output
1	255	0	255	255	0	0	2.16125
2	255	255	255	255	0	255	1.19575
3	255	255	255	0	0	0	1.2375
4	255	255	255	0	255	0	1.3425
5	0	0	0	255	0	255	2.94375
6	0	0	255	0	0	0	2.04375
7	0	0	0	0	255	255	2.8
8	0	0	255	0	255	255	2.7875
9	255	255	0	0	255	255	2.04375
10	255	0	0	255	255	255	2.23825
11	255	255	255	255	0	0	1.37075
12	255	255	0	0	255	0	2.14025
13	255	0	255	0	0	0	2.555
14	0	255	255	0	255	0	2.016425
15	255	0	0	255	255	0	2.7375
16	0	255	255	255	255	255	2.4
17	255	255	255	255	255	0	1.4
18	255	0	0	0	0	255	2.7175
19	0	0	255	0	255	0	2.73325

20	255	0	255	0	0	255	2.3665
21	255	0	0	255	0	255	2.5925
22	255	0	255	0	255	0	2.83125
23	255	0	255	255	255	0	2.3125
24	255	0	0	0	0	0	2.76225
25	0	0	255	255	255	0	2.7875
26	0	255	255	255	0	0	2.05275
27	0	255	255	255	255	0	1.9915
28	255	255	0	255	0	255	2.1125
29	0	255	0	0	255	255	2.37075
30	0	0	0	0	255	0	3.61875
31	0	0	255	255	0	255	2.577
32	0	0	255	255	255	255	3.1915
33	0	255	0	255	255	0	2.379
34	0	255	255	0	0	0	1.86725
35	255	255	0	255	0	0	2.255
36	255	0	255	0	255	255	2.64575
37	0	255	0	0	0	0	1.9415
38	0	255	0	255	0	255	2.11875
39	0	0	0	255	255	255	3.4175
40	0	255	0	255	0	0	2.54375
41	0	0	255	255	0	0	2.543675
42	0	255	0	255	255	255	2.471425
43	0	255	255	0	0	255	2.288
44	255	255	0	0	0	255	2.54375
45	255	0	0	255	255	255	3.175
46	0	0	0	255	255	0	3.375

47	255	0	0	0	255	0	2.82075
48	255	0	0	0	255	255	2.925
49	0	0	0	255	0	0	3.1925
50	255	255	255	0	0	255	1.4
51	0	255	255	255	0	255	2.10625
52	255	255	0	255	255	255	2.15
53	255	255	0	0	0	0	2.17375
54	0	0	0	0	0	255	3.21525
55	255	255	255	0	255	255	1.1125
56	0	255	0	0	0	255	2.3645
57	115	10	238	33	167	21	2.331175
58	120	62	211	4	178	111	2.457
59	169	84	81	42	78	218	2.066575
60	222	177	92	244	131	165	2.226875
61	70	2	36	206	133	9	2.706175
62	141	182	79	64	210	185	2.07075
63	16	204	6	168	216	108	2.005
64	106	61	132	30	56	164	1.751625
65	87	153	94	150	155	137	2.02575
66	242	147	1	83	90	128	2.2665
67	60	220	193	86	255	97	2.092625
68	249	17	32	226	52	47	2.007675
70	3	185	55	130	231	170	2.055
Testing Data #	Input						Output
69	159	233	76	110	122	71	1.66325

APPENDIX C. CHARACTERISTICS OF THE NETWORK MODEL

Note: The following information indicates the characteristics of the selected network model. The model enable user to measure weight of a new color considering its background color.

Number of layers= 4

Number of neurons in input layer= 6

Number of neurons in the first hidden layer= 6

Number of neurons in the second hidden layer= 6

Number of neuron in the third hidden layer= 6

Number of neuron in output layer= 1

Transfer function of the first hidden layer= TANSIG

Transfer function of the second hidden layer= TANSIG

Transfer function of the third hidden layer= TANSIG

Transfer function of output layer= PURELIN

Initial Weights (1, 1)= [-0.001936 -0.0017266 -0.00064767 -0.013644 0.004449

0.0024488;

-0.0040904 0.0070168 0.01101 -0.00031899 0.0015415 -0.0054249;

-0.0034381 -0.010491 -0.0045279 -0.00011293 0.003208 0.0081492;

0.0068994 -0.00776 -0.004415 0.0061267 -0.0070876 -0.0020017;

0.0053548 -0.002559 0.0017398 0.0062758 -0.0070031 -0.0096129;

0.010258 -0.0033809 0.00063362 0.009564 -0.0023082 0.0022855]

Initial Weights (2, 1)= [0.15002 -1.1549 -1.1109 0.36296 0.11694 -0.90867;
-0.94129 0.33387 -0.39534 0.93841 -0.67822 -1.033;
-1.1701 0.13145 -0.71155 -0.18427 -0.36641 -1.225;
0.79505 -0.7417 0.77971 0.88297 -0.79886 0.59461;
-0.72466 0.41258 0.39001 -1.2168 0.13495 -1.1024;
-0.79284 -0.1529 1.0139 0.073654 0.90151 1.0312]

Initial Weights (3, 2)= [0.041057 -0.27472 -0.93891 -0.35573 1.3033 -0.88193;
1.4074 -0.23982 0.7548 0.88878 -0.061294 -0.39974;
-1.0632 -0.34471 -0.35281 0.82709 -0.36888 1.1695;
-1.2624 1.1384 -0.12789 -0.32721 0.73938 0.04448;
-0.31977 0.45401 -1.2312 -0.65959 -0.32778 -1.0931;
-0.24133 1.278 0.17277 -0.43466 1.1078 0.65117]

Initial Weights (4, 3)= [-0.99058 0.20625 0.91373 -0.20514 0.4631 0.36928]

Number of epochs= 5824

Network performance= 0.0063587

Survey value for simulated data= 1.66325

Network value for simulated data= 1.6206

Accuracy error= 0.025643