ABSTRACT

Puhalla, Dennis M. Color as Cognitive Artifact: *A Means of Communication – Language and Message*. (Under the direction of Professor Meredith Davis.)

Color is an intrinsic visual attribute of form that functions as language and message. The purpose of this study was to investigate objectively structured color combinations as a means to communicate visual order for the purpose reinforcing information hierarchy. Controlling the visual relationships of hue, value and chroma contrast can significantly assist a person's cognitive ability to assign importance and dominance to a controlled color structure.

This research study provided significant findings supporting the hypothesis that intrinsic color structures can be formulated objectively; represent a visual hierarchy; and be perceived in an understandable order. The documented findings of this study presented explicit evidence that addresses specific mechanisms for objective color ordering.

The independent variables in the study were the attributes of color that form a color combination within each of the three attributes of color. The interconnection of these attributes was compared by contrast and similarity through a grouping of colors in derivative structured patterns. Variables of size, shape, space, position, signs, symbols and motion were constrained. Facilitating color representation and presentation, text and type were utilized as controlled variables.

In order to determine if color combinations could be identified and objectively qualified and quantified, an experimental research design strategy was operationalized. Six hue, value and chroma configurations produced eighteen color structures. To determine the predominant tendency in viewers'

perception of color organization a statistical analysis was calculated. For task effectiveness, statistical analysis was computed in ordinal scale measurements and Chi-Square analysis for 99 participants. For task efficiency, minimum, maximum, mean and median scores were calculated. To analyze task efficiency, three distinct ANOVA calculations were made for time variations within the value, hue and chroma structures. Chi-Square and ANOVA analyses verified *significant* probability results in each hue, value and chroma structure.

The natural inferences of the study support the proposition that there is a natural relationship between objective color ordering principles and human comprehension. The study offers an alternative to current methods and techniques for color selection anchored in subjective psychological intentions and marketing tactics. Color can be assembled according to objective rules or “codes.”

COLOR AS COGNITIVE ARTIFACT:
A Means of Communication – Language and Message

by

DENNIS M. PUHALLA

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Approved by:

Professor Martha Scotford	Professor Anne L. Schiller
Associate Professor Bryan Laffitte	Professor Meredith J. Davis *Chair of Advisory Committee*

dedicated to:

D. Matthew

Melissa Lauren

Kurt A.

and Lillian Katherine

my family

and to:

my parents

BIOGRAPHY

Dennis Puhalla is Professor of Design in the College of Design, Architecture, Art and Planning at the University of Cincinnati in Ohio. At the conclusion of the 2000-2001 academic year, Puhalla completed ten years of administrative service as Director of the School of Design and twenty-five years of teaching in the School of Design. While on academic leave from the University of Cincinnati in the August 2002, Puhalla entered into full-time doctoral studies at North Carolina State University, College of Design in Information Design.

During his tenure as Director of the School of Design, significant initiatives came to fruition. The following examples demonstrate accomplishments:

- Established a new degree program in Digital Design.
- Integrated new technology into the Foundation Studies: Design curriculum.
- Integrated digital rapid prototyping into the industrial design curriculum.
- Established video conferencing and distance learning program in transportation design.
- Established a transportation design track in industrial design.
- Co-authored an interdisciplinary medical instrument design curriculum with the Department of Bio-Medical Engineering, College of Engineering at the University of Cincinnati.

Puhalla's teaching career continues to be principally devoted to first year foundation design education. In addition, he teaches courses in the School of Design graduate program and industrial design. In 1991, he was awarded the College of Design, Architecture, Art and Planning, *Professor of the Year Award* and in 2001 was included in *Who's Who Among American Teachers,* sixth edition. Puhalla's professional work has been exhibited nationally and internationally. Works are included in private and corporate collections throughout the United States. He has also served as a consultant to design literature publications. Puhalla is a recipient of numerous University of Cincinnati research and faculty development grants. In 2004, he was honored as a *University of Cincinnati Brodie Fellow*. Prior to his appointment at the University of Cincinnati, Puhalla was an assistant professor at Miami University, Oxford, Ohio. He received a BS in Design and an MFA from the University of Cincinnati.

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It is with a deep heartfelt appreciation that I express my gratitude to those who have taken part in my academic journey. My gratitude may be best expressed through a Chinese proverb: *When you drink from a stream, remember the spring.* During my studies at North Carolina State University, I drank from the *stream*. Now, the time has come to recognize and acknowledge the *spring*. It is those who have generously given their time, fostered growth and stimulated intellectual curiosity.

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I also wish to express my gratitude to my wife, Diana Puhalla. She granted and empowered me with the time and space to pursue a dream. Her trust and faith in me are unwavering and loyal. She often reminded me of a quote from the Victorian writer George Eliot – *pseudonym for Mary Ann Evans,* "It is never too late to be what we might have been."

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CHAPTER 1

INTRODUCTION: FOCUS OF STUDY AND CONTEXT

1. Introduction: Focus of Study and Context

The introduction identifies the focus and context of the research. It includes topics related to the following: statement of study; hypothesis and variables; study delimitation and limitations (proposed assumptions); importance of the study in design research.

1.1 Study Statement

The study of color represents an array of perspectives on the topic spanning centuries. A bibliographic review of literature related to color reveals a chronology of investigations dating back to Plato's (427–347 B.C.) work *Timaeus.* Plato claims the basic ingredients of the universes are not earth, air, fire, and water. Rather, these elements are comprised of planes, which are, in turn, made out of elementary triangular shapes. "The *Timaeus* is an attempt to show that although many other types of objects besides the "Theory of Forms" must be invoked in order to understand the orderly nature of the changing universe – souls, triangles, space – the best scientific explanations will portray the physical world as a purposeful and very good approximation to a perfect pattern inherent in these unchanging and eternal objects" (Audi, 1999, p.713). Various journals chronicle numerous studies documenting research questions, methodologies and findings. From this extensive archive of resources, much can be gleaned about color history, color theory, color perception and color application.

Color is an intrinsic visual attribute of form. “Color has immediate perceptual and cognitive significance in human experience” (Varela, Thompson, and Rosch, 1991, p.157). It serves as an activating stimulus that intensifies visual consciousness and responsiveness. “Since perception of color is the single most strongly emotional part of the visual process, it has great force and can be utilized to express and reinforce visual information to a great advantage” (Dondis, 1973, p.55). A less than exhaustive list of color topics includes the areas of philosophy, anthropology, psychology, aesthetics, chemistry, painting, photography, architecture, design, and communication. Molecular biologists research colors in the living world and mineralogists focus on color in the inorganic world. The collaborative research of physiologists, neuroscientists, and ophthalmologists is attempting to unravel the sensation of color vision. Their collective research concentrates on the processing of color stimuli in the eye and in the brain, as well as the human psychological reaction to color stimuli. “Culturally conditioned behavioral patterns, such as color naming, are of great interest to linguists, psychologists, anthropologists, artists and designers” (Zollinger, 1999, p.1). Color representation and symbolic meaning are integral to culture. However, the symbolic meaning of color is not universal among cultures. According to Henry Dreyfuss, “… many authoritative studies have been published but no single source explained the traditional and contemporary meanings of specific colors in specific contexts – and these vary widely in different cultures” (Dreyfuss, 1984, p.232). Apparently, the lack of comprehensive facts regarding color representation and symbolism continues to be the case.

Color is used as a coded information system in design, architecture, cartography, science, medicine, industry and government. However, principles for the application of color in these systems have little documented research as their basis. Most studies involving visual communication and color combinations have been criticized as having a weak theoretical base and poor predictive value. Some researchers doubt the existence of a simple law of color structuring, suggesting that color factors are skewed by human subjective responsiveness. Since the time of Galileo, theorists have come to reject the claim that colors are physical properties of physical objects (Ross, 2004). Rather, they hold that color is a subjective mental construct of physical objects or physical objects that produce visual states of color.

Persons with a normally functioning visual system obtain a rather large amount of information about their surroundings from the visual sense and color plays a most important part in this sensory interpretation (Kuehni, 1983). Color configuration for functional communication has been addressed in works related to information design, color theory and color application. Authors Favre and November contend color substantially improves efficacy of the message transmission (Favre and November, 1979). Assertions are made about the appropriateness of color contrast and perceived order within an image application, which makes concepts understandable for the end user. However, little credible empirical evidence to support these assertions is cited. In the book *Experiences in Visual Thinking*, McKim provides seven visual elements to clarify the use of color graphics (McKim, 1972). He does not mention color ordering principles or references to studies that confirm the assumptions. Conversely, Tufte (2001) affirms, "Color often generates graphical puzzles. Despite our experiences with the spectrum in science textbooks and rainbows, the mind's eye does not readily give a visual ordering to colors, except possibly for red to reflect higher levels than other colors" (p.154). On the other hand, these works are non-scientifically based and are not intended to advocate a scientific argument. This study presents credible empirical evidence that the mind's eye does "readily give a visual ordering of color."

Some social scientists believe that perceived color order and harmony may be related to a common, residual evolutionary human trait. In ancient times, people needed to receive clear and certain messages in order to survive (Byrne, 1997). Uncertainty and ambiguity of received messages might result in instability, discomfort, even death. The ordering of information is as critical to understanding as the mere presence of information. Thus, uncertain or random color ordering communicates ambiguous messages evoking inaction, wrong action or tardy action. Lakoff and Johnson (1999) contend that "Our preponderance of commonplace basic experiences—that include basic-level objects, basic spatial relations, basic colors, and basic actions—lead to a commonsense theory of meaning and truth, that the world really, objectively is as we experience it and conceptualize it to be" (p.509).

Critical to the interpretation of meaning is syntax, as well as semantics. Syntax is the study of the order and relationship between words or other structural elements that form grammatical sentences and phrases. This could also include the study of relationships between signs and symbols and what they represent. Semantics addresses meaning or the interpretation of a word or sentence. Thus, interpretation is dependent upon a systematic, orderly construction and arrangement of parts, as well as the relationships between signs/symbols and what they represent. According to Lakoff (1990), "Semantics is a technical way to 'give meaning' to the uninterrupted symbols of the syntax" (p.222). To some degree, the interpretation of meaning is therefore a hierarchical conceptual structure found in language and visual representation. Hierarchical structuring is a graded or ranked factor, which determines importance. Since hierarchy is a stratified organization of parts, it is fundamental to the principles of ordering and to comprehensibility. Assisting our ability to interpret and analyze words, sentences and symbols is the orderly representation of color structures. A color study can be useful if it describes the rationale on which color relationships are based and suggests ways in which this rationale can help us to think structurally about color (Libby, 1974).

A hierarchical structuring of parts follows particular conventions found in a variety of media, including software created for visual communication. One such software application is Microsoft *PowerPoint*. The application accommodates a variety of templates with type/text styles and color combinations configured to represent order, sequence and importance. The templates found within software applications raise questions regarding usefulness and meaningful communication. Upon examination, the color application within these templates appears to be arbitrary and superficial. The rationale for color organization does not emerge from logical inherent color categorization and structure.

The purpose of this study is to investigate structured color combinations as a means to communicate visual order for the purpose of meaningful information transmission. The application of objective color ordering is critical to making information understandable. Since the study is focused on communication within the digital environment, the vehicle for color experiment was limited to projected digital media. The use of the new visual communication media has proliferated significantly. Consequently, it has become a popular method of presentation within many disciplines including business, government and education organizations. The findings of this research could impact color selection options in graphic and presentation software applications.

1.2 Hypotheses and Variables

Color functions as language and message. Color combinations can be defined and formulated objectively leading to visual order of importance (hierarchy) and sequence in a visual digital communication environment. Controlling the visual relationships of hue, value and chroma contrast can significantly assist the perception of importance and dominance within a prescribed color combination. The perception of color dominance is constructed by the viewer and not necessarily inherent in the artifact itself.

The variables in the study were the attributes of color that form a color combination within each of its three attributes: hue, value and chroma. The dependency of these attributes was compared visually in terms of contrast and similarity through a grouping of colors in derivative structured patterns. Derivative color combinations were formulated by each hue, value and chroma category. Extraneous variables of size, shape, space, position, signs, symbols and motion were constrained. To facilitate color representation and presentation, text and type were utilized but were controlled variables.

It was hypothesized that the intrinsic attributes of color form specific categories that generate visual hierarchical structures. These hierarchical color structures within a category are comprised of inherent contrasting relationships. Therefore intrinsic color structures can establish a visual hierarchy, which influence perceived order and importance. The primary focus of the study was to find empirical evidence that color combinations can be categorized according to variables defined by three attributes: hue, value and chroma. Furthermore, the study sought to establish whether color categories could be manipulated in an order of importance that assists the cognitive ability to understand and comprehend specific systems of color contrast.

1.3 Delimitation and Limitations of the Study (proposed assumptions)

The study's focal point centered on derivative color combinations constructed in Adobe *Illustrator* and projected color observed in Microsoft *PowerPoint*. Subsequently, there can be no assurance that similar findings will necessarily be present in printed matter or in product instrumentation. The emphasis of the study was placed on the visual characteristics of color contrast and color similarity displayed in each of the hue, value and chroma categories. The inherent compositional structures of the three attributes were identified and arranged in a system of visual hierarchy according to their discrete properties.

However, this study does raise questions about the generalizability to wider uses of color construction methodology in other communication media. Considering the principles of color organization were explored along the lines of the three attributes of color – hue, value and chroma – findings from the study suggest that the methodology of color selection and organization may have further applicability. Fundamentally, color attributes do not change; only the reflective surface and medium change. Color and communication are inseparable in designed systems and applications.

It has been theorized by some design practitioners that people make judgments of importance primarily on the basis of relative value contrast and that chroma and hue are defined by the specific nature of those value relationships. This research study hypothesized that each color attribute intrinsically constituted a system of color contrast within itself, thereby producing a hierarchical order of color dominance. It was assumed that viewers would be able to discern hierarchical color structures in a digital representation of a text based communication system. The focus here is on two main aspects: the differing emphases in the structure of the color combinations and the manner in which people perceive color order and hierarchy. The tacit implication of the experiment advances a proposition that color structure is a visual language mediating the interplay among the form, the message and interpretation. In this study, message and interpretation are directly related to an organizational color structure that is concerned with the perceived and assigned importance of color within that system. Consequently, it is not the intent to focus on color naming, color symbolism or cultural preferences and differences.

1.4 Importance of the Study in Design Research

Generally, designers intuitively agree on the most pleasing color combinations, though established theories about the specific nature of color composition have no basis in empirical research. In short, there are no rules. The importance of this study was to find guiding principles of fact. It was, therefore, necessary to statistically determine the predominant trend or tendency in viewers' perception of color organization. The documented findings of this study presented explicit evidence that addresses specific mechanisms for objective color ordering phenomena within a dynamic environment.

Dynamic environments are associated with a wide range of digital communication media, including software applications designed for large and small-scale digital projection used for demonstrations, presentations, exhibitions, narratives and lectures. Adobe *Photoshop*, Macromedia *Flash* and Macromedia *Director* are multifaceted, highly developed, and complex software applications requiring dedicated user-learning time. Software applications of those types necessitate accomplished, computer-literate expertise. In contrast, the digital communication application created by Microsoft *PowerPoint* does not require the same degree of astute computer proficiency.

In most cases, computer science engineers determine what types of configurations and templates reside within a software application. With its ready-made templates, *PowerPoint* is the standard method of making presentations in corporate, government and education establishments. This method of communication has become so popular that it has replaced the high-resolution found in the projection of 35mm slides. In an article appearing in *AV Video Multimedia Producer*, Debra Kaufman reported Kodak discontinued production of the 35mm Carousel slide projector in 2004. It is likely that the use of digital projectors and *PowerPoint*, especially in business and industry, is to blame for the demise of slide presentation media (Kaufman, 2004). However, issues related to graphic format and color application templates lack articulation within *PowerPoint's* application system. These templates and other operations embedded in the software are marginally sensitive to meaningful hierarchical color combinations and extraneous to effective visual communication. Of course, these templates include a vast array of ingredients, among which color is just one component. Edward Tufte argues assuredly that *PowerPoint* templates usually "weaken verbal and spatial reasoning, and almost always corrupt the statistical analysis." Edward Tufte is Professor Emeritus at Yale University where he taught courses in statistical evidence, information design and interface design. Tufte continues his argument, the *PowerPoint* method of presentation employs "rigid slide-by-slide hierarchies" that are "indifferent to content" accompanied by "arbitrary compartments producing an anti-narrative with choppy continuity" reducing "analytical quality" (Tufte, 2003, p.3).

PowerPoint does offer the ability to customize a template in color, text and form. The color selection system interface employs hue, value and chroma manipulation capabilities. Since most *PowerPoint* users are uneducated in design and color application, the method for color selection in the applications interface design is complex and arbitrary. For this segment of the population, color selection should be made simple and transparent. A definitive hierarchical color structure interface formulated in hue, value and chroma structures facilitates a systematic, orderly organization and method for appropriate color selection.

It is an observable fact that color plays an influential role in the interpretation of a message. One scientific study conducted by the Xerox Corporation and the *International Communications* shows 90% *(within a margin of error +/- 3.1%)* of the people responding confirmed color increases memory retention (Research, 2003). A second laboratory experiment studied the effects of color on a person's ability to extract information from different graphical tables (Hoadley, 1990). Results from this study indicate color improves a person's time and accuracy in performance. This study also acknowledged that preliminary guidelines for the use of color have been established based on limited research. "These guidelines should be qualified since the empirical literature on the effects of color is troubled by poor research designs and is lacking in consistent and conclusive findings" (Hoadley, 1990, p.135). Neither of these studies makes a case for color selection methodology based on hierarchical color relationships. Both studies offer an argument for continued research on objective color ordering.

Color should function as a code for transmitting a message, making things easy to understand and to assimilate. Effective color assembly strategies produce strong visual impact, improve legibility and define product identity. Meaningful color communication should improve the efficiency and efficacy of the message perceived by the end-user. Simultaneously, color must function successfully on several levels. Color must serve as a primary structural element in the organization of print, digital and product design. In this capacity, color must create appropriate spatial and navigational effects that are specific to the operational tasks. The designer must identify ideal and normal sequences: what the user should see first; where the eye should move next; and how much time the viewer's attention should be held within each area.

Among designers, it is a generally accepted notion that it is best to keep color combinations to a minimum number of components. Perceptual psychologists refer to this notion as “signal detection theory.” Signal detection theory provides a precise language and graphic notation for analyzing decision-making. When a minimum of colors and shapes exists within the visual field, the brain is able to understand and to organize information. Multiple colors of too many unrestrained contrast constructions create *visual noise* making it impossible to focus and find anything. Lev Grossman discloses, “The unconscious mind is astonishingly good at filtering out superfluous data and seizing on essential truth, but too much time or information can confuse and blind it” (Grossman, 2005, p.57).

In this study, the strategy for color selection, categorization and coding is based upon the contrasting relationships of hue, value and chroma inherent in the Munsell Notation System of color organization. The color selection strategy employs a method that transcends the selection of conventional color categories. Conventional color categories (harmonies) are known to be primary, secondary and tertiary triad schemes; as well as complementary, analogous and monochromatic schemes. However, within these schemes or categories hierarchical structuring is not inherent. Therefore, hierarchical structuring within these schemes must be constructed. By evaluating and addressing the ordinary relationships found within these color schemes in relationship to Munsell's hue, value and chroma organizational structure, hierarchical color categorization is realized.

The purpose of this study was to investigate which derivative color combinations in hue, value or chroma communicate visual order for the purpose of meaningful information transmission. The principles of color selection and organization are founded upon objective criteria originating from derivative color combinations. Derivatives were obtained from the context within each of the three attributes of color. The derivative color combinations can establish visual order of importance and contribute to the human ability to understand a message. Color can be assembled according to certain rules or "codes." Color and communication represent the intentions and purposes of the initiator. If users do not have a clear understanding of color codes, translation is more than likely invalid. Without intelligible visual recognition of color pattern in design application, interpretation and purpose are lost.

Derivative and objective color selection methodology is not a strategy found in the literature related to color theory and application. The application of objective color selection and ordering is crucial to making information understandable. In this study, the vehicle for color presentation was limited to projected digital media. The inferences, implications and analysis of the *Intrinsic Structures Research* study as described above are probable and credible empirical findings that need to be moved forward, exploring this fertile ground of color application and interpretation. The study offers an alternative to current methods and techniques for color selection methodology anchored in subjective psychological intentions and marketing tactics. Therefore, the mechanism for studying color hierarchy acknowledges and supports findings that can influence design research, design practice and design education.

Philosophy, social science and design have generated a considerable amount of published material on the subject of color. Berlin, Kay, Hardin, Rosch, Munsell, Albers and Tufte are a few among the notable references on the topic of color. However, little has been made available that identifies objective guiding principles related to color selection and organization.

Color is a variable that can increase clarity and significance. "Colors trigger very specific responses in the central nervous system and the cerebral cortex. Once they affect the cerebral cortex, colors can activate thoughts, memories, and particular modes of perception" (Gobé, 2001, p.77). As C. L. Hardin explains, "Color comes into its own in recognition of objects and in conveying specific biological information" (Hardin, 1992, p.376). Hardin also points out that among the operative principles in human factors research, color contrast shortens recognition tasks and improves task accuracy. "Color is a powerful aid to object recognition, and categorical color difference seems particularly helpful" (Hardin, 1992, p.376). The research results presented in this dissertation offer empirical evidence that objective guiding principles related to color selection and organization can be identified and strengthen a person's cognitive ability to extract information, increase retention and assist comprehension.

CHAPTER 2

LITERATURE REVIEW

The literature review is an account of that which has been published on the topic of color. Scholarly books and articles convey what knowledge and ideas have been established on the study of color. This literature review offers an overview of significant literature published on the topic of color.

2.1 Literature Review Narrative

The existence of color hierarchy and order within visual communication is a topic that is overlooked in contemporary research. Visual designers and researchers generally agree that color is a powerful non-verbal communication means of conveying messages with clarity. While much is known regarding color, it appears that little is currently known regarding the application of color ordering, sequence and hierarchy and how they assist in visual recognition tasks. Information design and color imaging research draw upon content connections in domains of knowledge associated with anthropology, philosophy, psychology, cognitive science and color imaging application. Physics questions how color is caused, leaving to philosophy and psychology to inquire whether color is delusive and how we interpret what we see (Sloane, 1989). These domains of knowledge, to varying degrees, speak to the study of color and can contribute to information design research (Figure 2.1). As Sloane (1989) maintains, the study of color is relevant and applicable to many disciplines.

This research study is focused on color ordering and importance in a digital communication environment by means of a projected digital display. Visual recognition tasks are simply those in which someone looks at the context of color organization as a means of ordering information to determine importance. Real world applications of these tasks include: searching for information on an x-ray; locating the correct key on a keyboard; finding a car in a parking lot; or finding a specific word in text

(Palmer, 1995). Understanding how color recognition relates to perceived order and importance will, therefore, have useful applications to the naturalistic, real world display of visual information systems based upon objective color selection strategy.

	COLOR APPLICATION	INFORMATION DESIGN	PHILOSOPHY	PSYCHOLOGY	ANTHROPOLOGY	COGNITIVE SCIENCE	HUMAN FACTORS	
Albers	●							The Interaction of Color
Carter	●							Digital Color and Type
Itten	●							The Art of Color
McKim	●							Experiences in Visual Thinking
Munsell	●							Notation System
Favre	●				○			Color and und et Communication
Sidelinger	●							Color Manual
Dreyfuss	○	●			○			Symbol Sourcebook
Tufte		●						Visual Display of Quantitative Information
Tufte		●						Envisioning Information
Tufte		●						Visual Explanations
Jacobson		●						Information Design
Wurman		●						Information Anxiety
Hackos and Redish				○			●	User and Task Analysis for Interface Design
Turner			○	○	●			The Forest of Symbols
Solso			○	●				Cognition and the Visual Arts
Arnheim			○	●				Visual Thinking
Norman	○	○	○	○		●		The Psychology of Everyday Things
Kosslyn			○	○		●		Image and Mind
Kosslyn			○	○		●		Image and Brain
Kosslyn			○	○		●		Elements of Graph Design
Johnson			○	○		●		The Body in the Mind
Lakeoff and Johnson			○	○		●		Philosophy in the Flesh
Varela, Thompson and Rosch			○	○		●		The Embodied Mind
Hardin			●	○		○		Color for Philosophers
Hardin and Maffi			●	○		○		Color Categories in Thought and Language
Berlin and Kay			●	○		○		Basic Color Terms
Davis			●	○		○		Color Perception
Byrne			●	○		○		Readings on Color

● primary domain ○ secondary domains

Figure 2.1: Literature Review – Domain of Knowledge Matrix.

2.2 Epistemological Orientation

> *Color is a peculiarly striking aspect of the world as it appears to us. It is therefore a natural starting point for any investigation into appearance and reality. No surprise then, that philosophy has always taken an interest in color* (Byrne and Hilbert, 1997, p.xi).

Empirical knowledge is central to perception. Perception is the process by which we acquire information about the world around us using our five senses (Burnham, 2004). Sight, sound, touch, smell and taste are ways of representing and thinking about the world. From this epistemological orientation, Immanuel Kant is the foremost figure. From a Kantian philosophical tradition, it is representation that makes the object possible, rather than the object that makes the representation possible. Therefore, experiencing the world is dependent on a conceptual structure providing representational properties of experience. Reasoning connects the world we experience through structure. The rational structure of the mind reflects the rational structure of the world and of things-in-themselves. The human mind is an active originator of experience, rather than just a passive recipient of perception. As Kelly Ross explains, the human mind is a 'blank tablet,' perceptual input must be *processed* to be *recognized* or it would just be noise (Ross, 2004).

Karl Reinhold advanced Kantian philosophy. Reinhold's effort to construct *Elementary Philosophy*, led him to become one of the founders of "post-Kantian idealism." The principles of the *Elementary Philosophy* include the "Principle of Consciousness," the "Theory of the Power of Cognition" and the "Theory of the Power of Representation" which closely follow Kant's proposition. In the "Theory of the Power of Representation," the term "representation" designates whatever we are directly conscious of whenever we are conscious of anything whatsoever (Breazeale, 2003).

Rohmann explains *causal* and *representative* theories of perception are a mental representation of an object, but that the object must be real to cause genuine perception. "Other theories insist that objective knowledge of the world is impossible and only the mental perception can be confidently regarded as real" (Rohmann, 1999, p.300). In addition, Rohmann continues, "A long-standing convention in philosophy and psychology distinguishes between *sensation* and *perception*, that is, between the raw data of color, shape, sound and other sensory stimuli and the mind's interpretation of the data into recognizable objects of experience" (Rohmann, 1999, p.300).

Another orientation to understanding the processing of information is associated with structuralism. It embraces the idea that individual phenomena can be understood only within the context of overall structures and that these structures represent universal sets of relations driving meaning within specific contexts. Structuralism developed from the early 20th Century work of Swiss linguist Ferdinand de Saussure who saw language as a system within which words act as arbitrary signs. Language systems employ a syntax, which governs the rules of order in which words or other elements of structure are combined to form grammatical sentences. Language construction is also dependent upon hierarchical structuring. Implicit hierarchical structuring increases the human ability to perceive similarities and differences among things. Hierarchical structuring preserves meaning in writing, speaking and visual representation. The basis of hierarchical structuring in this dissertation refers to the observed degree of color contrast within each category of hue, value and chroma. Each attribute of color intrinsically "governs the rules of order" in which the elements of those structures formulate a perceived visual hierarchy.

Stuart Hall maintains that *meaning* relies on representation through language. Language is the medium in which, thoughts, ideas and feelings are represented. Language is any system of representation including representations found in written words, signs, symbols, electronically produced images and musical notes. According to Hall (1997), "Things don't mean: we construct meaning using representational systems – concepts and signs" (p.5). Communication through signs and symbols as they relate to constructed meaning is defined by semiotics. Semiotics encompasses syntactics – the formal properties of signs and symbols and pragmatics – actual or practical occurrences. The formal properties of color are its three attributes that are comprised of inherent actual and practical structures. These color structural systems provide a meaning that is associated with the order in which things are seen and interpreted.

Visual language responds to the need to deal with the complexities of metaphorical and factual representation. Visual language is an inextricable interlocking arrangement of words and visual ingredients. Jacques Bertin (1983) asserts, “Graphic representation constitutes one of the basic sign-systems conceived by the human mind for the purposes of storing, understanding, and communicating essential information. As a ‘language’ for the eye, graphics benefit from the ubiquitous properties of visual perception” (p.4.). Thoughts are expressed in systems of coding that include verbal language, written language and representational visual language. Therefore, representational visual language can be approached by the science which deals with all sign-systems—semiology (Bertin, 1983).

Color is a system of representation that relates to our cultural and psychological experiences. Hence, color has emotional and symbolic meanings. Color also functions as a non-verbal visual communication system that strengthens visual and conceptual awareness. Effective color application possesses inherent attributes that accentuate visual and conceptual awareness. Herein, reside two propositions: (1) color is subjective as it is associated with our psychological state-of-mind; and (2) color is objective as it has inherent hue, value and chroma characteristics that intensify perception and communication.

Human reaction to color communication is created by a combination of biological, physiological, psychological, social and cultural factors. The core of this research is not intended to examine these factors. The foundation of this color research is rooted in the construction of meaning (the order in which things are perceived) in non-verbal communication that transcends psychological and cultural conditions. The focus is specifically related to the visual representation of hue, value and chroma structures. When individuals respond to visual stimuli coded by the categorical representation of hue, value and chroma, meaning is constructed on the basis of perceived order and color contrast within a structure. These categorical representations are a means of objective visual communication contributing to the syntactics of a visual language and the delivery of a message. The language establishes a visual hierarchy, assisting a person's ability to assign a prescribed order of dominance and importance to information. Hue, value and chroma structures play an important role in bringing visual relevance and purpose to an object or grouping of objects. Color exists exclusively as a sensory perception on the part of the viewer (Küppers, 1982). The structure of the color assembly invokes an image of the object that is constructed by human perception. The perceived interpretation of order within a color structure constitutes the colored object as a cognitive artifact.

Much of the literature on color focuses on whether color is objective as a "real property of objects around us" or subjective as a "property of conscious phenomenal episodes" (Kraut, 1992). Many philosophers conclude that color is subjective. According to subjectivism, colors attributed to objects are mental colors, which are cognitive qualitative properties of visual states. Therefore, subjectivism claims that physical objects are colorless (Hardin, 1988). However, the philosophy of color holds competing positions. "As between those who say that the external world is colored and those who say that the external world is not colored, the judicious choice is to agree with both. Ever 'so inclusively speaking' the external world is not colored. 'More or less inclusively speaking' the external world is colored" (Lakoff and Johnston, 1999, p.25).

C. L. Hardin claims, "We are to be eliminativists with respect to color as a property of objects, but reductivists with respect to color experiences" (Hardin, 1988). According to the *Stanford Encyclopedia of Philosophy*, "*Eliminativism* is the radical claim that our ordinary, commonsense understanding of the mind is deeply wrong and that some or all of the mental states posited by common-sense do not actually exist" (Ramsey, 2003). According to Byrne and Hilbert, "Eliminativism about color is the thesis that no physical objects are colored. Since physical objects certainly look to be colored, Eliminativism charges experience with widespread misrepresentation" (Byrne and Hilbert, 1997, p.xi). While this proposition may appear unreasonable, it is a proposition that dates back at least to the ancient Greek philosopher Democritus' *atomism theory* (Byrne and Hilbert, 1997). The controversial philosophical orientation of *reductionism* is characterized by several separate but related positions: principles of one theory can be explained in terms of another, more inclusive or fundamental. From a reductionist perspective, psychology could be reduced to physiology and chemistry could be reduced to physics (Audi, 1999). In the case of color, reductive dispositionalism calls upon our visual experience representing the world as containing a colored (red) object. "If reductive dispositionalsim is to be an option, there must be some way of picking out the visual experiences in question without recourse to their color contents" (Byrne and Hilbert, 1997, p.xii). Correspondingly, Byrne and Hilbert affirm experiences may be classified by their distinctive phenomenology, as well as by their contents. Accordingly, Hardin stipulates contrasting philosophical orientations with respect to color as a property of objects and to color as a human perceptual experience. In the book *Color for Philosophers: Unweaving the Rainbow*, Hardin finds fault with the evolution of color categories, referring to the work of Berlin and Kay, Rosch, and others (Hardin, 1988). However, in his article "The Virtues of Illusion" Hardin now regards his discussion of color categories and basic terms to be flawed (Hardin, 1992). Furthermore, he contends, the perceptual structure of colors has no "… counterpart in the domain of wavelengths of light, even though we normally see those colors because we are stimulated by light that has an appropriate wavelength configuration" (Hardin, 1992, p.371).

The study of color provides a microcosm of cognitive science for disciplines of neuroscience, psychology, artificial intelligence, linguistics, philosophy, anthropology and genetics. Each discipline has made important contributions to our understanding of color (Rosch, 1991). Ethnoscience derives research methodology from linguistic analysis, the focus of which studies the domains that form the patterns of object classification (schema) in a society. Science, linguistics and anthropology have frequently provided evidence that supports the proposition that color perception is basically identical across societies. Conklin explains "Under laboratory conditions, *color discrimination* is probably the same for all human populations, irrespective of language; but the manner in which different languages classify the millions of 'colors', which every normal individual can discriminate, *differ*" (McGee and Warms, 1996). It stands to reason then, that ethnoscientists who conduct research where color identification is important to their findings should use appropriate color matching systems rather than color name identification.

Linguistics and anthropology contend that each language and culture expresses a unique view of the world through a particular way of slicing reality into named categories. Consequently, visible color wavelengths are seen through a definitive cultural lens. C. L. Hardin and Luisa Maffi discuss the history of color naming, research methods and standards in the book *Color Categories in Thought and Language.* Because of unique linguistic classification systems, colors are recognized and identified differently from one culture to another. Within a given culture, color vocabularies influence color classification, which, in turn, prescribes meaning for that particular culture. Harold C. Conklin used linguistic methods for the reason that a vocabulary strongly influences the classification of colors. Conklin studied the Hanunóo, a Mangyan tribe from southeastern Mindoro, the seventh largest island in the Philippines. Conklin focused his attention on the Hanunóo Tribe system of color categorization. Showing the Hanunóo painted cards, dyed fabrics and many other colored materials, Conklin recorded how the Hanunóo describe the colors of their natural and artificial surroundings. Employing a representation system, Conklin analyzed the Hanunóo color criteria and compared their classification system with the American classification system (McGee and Warms, 1996).

As a result, he found that the Hanunóo make color distinctions by grouping colors at two levels of contrast. The four terms, which constitute the first level, are identified as general: relative darkness; relative lightness; relative presence of redness; and relative presence of greenness. These colors are distinct from each other and people always used the same color name to describe a certain color sample. The second level is specific and includes several sublevels with hundreds of color names. While many color names overlap, people did not necessarily agree with each other when they classified colors in this level. In addition to actual colors, Conklin also discovered that the Hanunóo pay attention to moisture, texture and shine of objects and give different color names according to these criteria.

Conklin concluded that the Hanunóo color classification system was based on lightness, darkness, wetness and dryness. These color criteria are different from the American color classification system, where moisture, texture and shine of objects are not considered. Prior to Conklin's findings, researchers assumed that the Hanunóo confused colors because the people seemed to call the same color by different terms. However, Conklin showed these seeming contradictions stemmed from the researchers' lack of understanding of the Hanunóo's color criteria. His linguistic analysis facilitated a means by which anthropologists could see how people in different cultures conceptualize their world in their own ways (McGee and Warms, 1999).

By contrast, Victor Turner, the British Structuralist, argued that symbols are verifiable units with laws determining their use. Observed data, informants, interpretations and the anthropologist's analysis are verifiable and therefore legitimate. Victor Turner lived among the Ndembu, a central African tribe from 1950 to 1954, studying their behavior and religious practices. Even though the Ndembu allowed him to participate in their society, as an anthropologist he was still considered to be an "outsider." Turner studied the meaning the rituals had to insiders, that is, to the members of the society the anthropologist was studying. For Turner, this was an important dimension of the meaning of a ritual. In the book *The Forest of Symbols*, Turner described ritual as "a prescribed formal behavior of occasions not given over to technological routine, having reference to beliefs in mystical beings or powers. The symbol is the smallest unit of ritual which still retains the specific properties of ritual behavior; it is the ultimate unit of specific structure in a ritual context" (Turner, 1989, p.19).

Differing from the color categorization of the Hanunóo tribe studied by Conklin, the Ndembu color categorization is a three-part system of classification. The colors of white, red and black are the only colors for which the Ndembu have primary terms. Turner discovered that in many Ndembu rituals the colors red, white and black are represented in symbolic objects – red or white found in clay, black found in charcoal. Through dialogue, Turner learned that the relationship between the three colors refers to the mystery of the three rivers: the rivers of whiteness, redness and blackness. These rivers represented a power flowing from a common source in the high god, Nzambi. An interpretation of the meanings of the red and white symbols in Ndembu rituals indicated that white symbols are associated with goodness, health, power, visibility and life; ritual whiteness refers to harmony, continuity, purity, the manifest and the legitimate. Red symbols are associated with different kinds of blood; redness represents both good and ill, of good blood (animal blood shed by the hunters) and bad blood (blood of menstruation and murder). Black symbols are associated with evil, disease and witchcraft; black is often ritually neglected because it does not make things visible and is associated with death and impurity. Red and white are associated with life: white stands for the preservation of life, while red refers to the taking of life, or bloodshed for the communal good. This binary structure between red and white is captured within a wider tripartite mode of classification of which black, referring to death, is the third element. The supreme antithetical pair of the triad is the white/black (life/death) contrast.

Victor Turner's symbolic analysis of the Ndembu color classification offers a comparison with French Structuralist anthropology. Within the framework of French Structuralism, Lévi-Strauss defines his *nature-culture binary opposition* classification system. The poles of meaning that Turner labels ideological and sensory could almost as easily be labeled culture and nature (McGee and Warms, 1996, p.448). Lévi-Strauss' departure from the ethnoscientists lies in his analysis of classification and meaning systems in terms of universal principles. He identifies two layers of meaning, a superficial one, which is observed and recorded from the native's perspective, and a *deep structure* that reflects a universal principle of opposition or duality. This constant feature is engendered by the basic human dilemma of imposing a rigid cultural construction on an ambiguous and ambivalent natural world. Basic cultural institutions, such as rituals, myths, marriage arrangements and economic exchanges, represent the expression and mediation of intellectual contradictions and oppositions. However some structuralists believe a symbolic object, gesture or word carries no meaning. Symbols become meaningful only in opposition to each other. The relationship between different ritual symbols corresponds with the relationship between different categories of human thought – the symbolic objects, gestures and words. Qualities of red, white and black, and their symbolic representations in various forms, can be understood only when put (as they are in the structure of human thought) in relation to one another.

The evolution of descriptive and communicative color terminology is central to the work of anthropologist Brent Berlin and linguist Paul Kay. Their research findings support the notion that several different and unrelated languages encode a *universal* inventory of exactly eleven basic color categories: *white, black, red, green, yellow, blue, brown, purple, pink, orange* and *gray* (Berlin and Kay, 1991). However, both researchers concede that some languages encode fewer than eleven categories. The speakers of those languages impose strict limitations on those categories. According to Berlin and Kay, the *distributional restrictions of color terms across languages* are:

1. *All languages contain terms for white and black.*
2. *If a language contains three terms, then it contains a term for red.*
3. *If a language contains four terms, then it contains a term for either green or yellow (but not both).*
4. *If a language contains five terms, then it contains terms for both green and yellow.*
5. *If a language contains six terms, then it contains a term for blue.*
6. *If a language contains seven terms, then it contains a term for brown.*
7. *If a language contains eight or more terms, then it contains a term for purple, pink, orange, grey or some combination of these* (Berlin and Kay, 1991, p.2).

Berlin and Kay concluded, "… there appears to be a fixed sequence of evolutionary stages through which language must pass as its basic color vocabulary increases" (p.14). Berlin and Kay believed language encodes categories that formed six equivalency classes. On the basis of this rationale, Berlin and Kay reasoned there were at least *seven evolutionary stages*. "A given language at a given point of time can be assigned to one and only one state; and that a language currently in a given stage must historically have passed through all prior states in appropriate order" (Berlin and Kay, 1969). The seven stages are recognized as the evolution of basic color terms. Berlin and Kay summarized the *seven evolutionary stages* as follows:

Stage 1 ...... BLACK, WHITE (two terms).

Stage 2 ...... BLACK, WHITE, RED (three terms)

Stage 3a .... BLACK, WHITE, RED, GREEN–extending into blues (four terms)

Stage 3b .... BLACK, WHITE, RED, YELLOW (four terms)

Stage 4 ...... BLACK, WHITE, RED, GREEN, YELLOW (five terms)

Stage 5 ...... black, white, RED, green, YELLOW, blue (six terms)

Stage 6 ...... black, white, RED, green, YELLOW, blue, brown (seven terms)

Stage 7 ...... black, white, red, green, yellow, blue, brown, purple, pink, orange, grey (eight, nine, ten or eleven terms) (Berlin and Kay, 1991, p.23).

According to Berlin and Kay, "Increase in the number of basic color terms may be seen as part of a general increase in vocabulary, a response to an *informationally* richer cultural environment about which speakers must communicate effectively" (p.23).

Berlin and Kay's research findings created a controversy that continues to this day. At the heart of that controversy is the claim that some color categories are *basic* in the sense of being cultural universals. According to Berlin and Kay, a color word such as *pink* is universal but there are many languages that do not have a comparable word. Questions and controversy arise from Berlin and Kay's *universality* proposition.

Since *color naming* was assumed to be "culturally relative," it was argued that *cognition* had been demonstrated to be "culturally relative." Eleanor Rosch (Varela, Thompson and Roach, 1991) propositioned color language and color cognition were functions of some third underlying factor. Testing her hypothesis, a series of color experiments was conducted with the Dani of New Guinea since their language lacked virtually all color vocabulary. Color research studies conducted by Rosch in the late 1960's compared linguistic color discernment by Americans to that by Dani of New Guinea. While the Dani people use only two words for color identification, Rosch found that English-speaking people commonly use 11 separate "elemental" color words that include: white, black and gray. Rosch tested the color memory of the two groups' members by first showing them a color, and after a short delay asking them to find that color in a separate group of similar colors. Despite the groups' significant differences in color taxonomy, she found that each of the two groups perceived colors in the same way. Rosch's findings concluded that "color categories are entirely determined by emergent patterns of neuronal activity in the human visual system" and "color categories depend on culture-specific cognitive processes" (Varela, Thompson and Roach, 1991, p.170). Rosch advances the proposition that *terminology* does not affect perception and meaning. Advocates of the universality proposition embraced the findings of Rosch. The research of I. R. Davies offers new evidence supporting universal perceptual-cognitive color categories. "The same data also support language modulating color-cognition: Universal structures are fine-tuned by language" (Davies, 1997, p.186). Davies argues, "color-cognition is more universal than color-language."

The work of Eleanor Rosch postulates yet another position on color perception and meaning. Rosch discusses color in three different stages: the *structure of color appearance; color as a perceived attribute of things in the world;* and *color as an experiential category* (Rosch, 1993). The *structure of color appearance* is defined by *hue* referring to the degree of colorfulness. According to Rosch, there are eleven prototype-centered categories. Black, white and gray reside in an achromatic region. Eight chromatic clusters cover limited regions of color space. Brown and pink are centered in regions of high saturation. Rosch identifies red, yellow, green, blue, orange and purple as "focal colors." Low-lightness focal red appears pink and high-lightness orange when darkened appears brown. Red, yellow, green and blue are salient chromatic focal colors. Orange and purple are identified as high-saturated focal colors. She acknowledges chromatic colors differ in strength or saturation of their hue. "Saturated colors have a greater degree of hue, whereas desaturated colors are closer to gray" (Rosch, 1993, p.158). This is incongruent with theoretical color structures, defining hue as a family of color within the visible spectrum. Colorfulness (chroma or saturation) is typically identified within a hue category as a separate structural category. Supporting the assertion *color as a perceived attribute of things in the world,* Rosch contends that visual perception is an "active exchange with other sensory modalities" as well as "varieties of cognitive expectancies and memories" (p.160). Rosch claims that focal colors red, yellow, green and blue are more salient and therefore easier to remember, whatever the color's name.

After many years of color research on the topic of color naming, categorization and language, the extent to which language might influence perception and meaning is still ardently argued. Davidoff explains color categorization as the *internal space* meaning that many different *shades* of color are associated with the same color name (Davidoff, 1991). According to Davidoff's colleague Debi Roberson, categorical perception occurs, but only for speakers of the language that marks the categorical distinction. "Many languages have been documented to use additional 'borrowed' terms from other languages and all may rapidly expand their color vocabulary when first they come into contact with more technologically advanced cultures" (Roberson, 2005, p.58). Assuming that human color vision is relatively fixed to the visible spectrum, there may also be optimal numbers of linguistic categories for different levels of description. Roberson contends that the "… speakers of any language can have more (and different) cognitive color categories than they have linguistic ones." For the speakers of a common language, categorical perception and distinction occur. Davidoff and Roberson doubt Rosch's findings regarding the pivotal role of focal colors, suggesting further experimentation (Davidoff and Roberson, 1997).

George Lakoff and Mark Johnson (1999) maintain, "Color is a function of the world and our biology interacting" (p.25). In *Philosophy in the Flesh*, Lakoff and Johnson explain that most of our thought is unconscious, in the sense that it operates beneath the level of cognitive awareness, inaccessible to consciousness and operating at a rapid pace preventing mindful consciousness. Three major findings of cognitive science include that “The mind is inherently embodied; thought is mostly unconscious; abstract concepts are largely metaphorical” (Lakoff and Johnson, 1999, p.3).

Meaning, understanding and rationality are conditioned by the patterns of our bodily experiences. Abstract meaning and rational connections are linked to cognitive and bodily structures emerging from physical experiences that can be interpreted metaphorically. Colors, in themselves, do not literally have weight, force or hierarchy. As Johnson describes in The *Body in the Mind* (1987), color forces exist as a perceptual image through particular bodily encounters and cognitive engagement. The psychological patterns called *schemata* make it possible to structure color in a sensible coherent experience.

Extensive research into how the brain perceives and processes visual information demonstrated a definitive resolution to the nature of the internal representation of visual mental imagery. Connections between the eye and mind have been studied extensively. As Stephen Kosslyn relates, documented studies demonstrate that visual encounters can be interpreted through the mechanics of perception, memory and cognition. The nature of visual mental imagery and high-level color perception are interrelated with applications of psychological principles in visual display design. Color imagery in cognition is different for individual type and group type (Kosslyn, 1980). Insights and empirical results from computer vision, neuroscience and cognitive science have generated a general *theory of visual mental imagery, visual perception and cognitive performance* (Kosslyn, 1996).

Gestalt theories acknowledged the holistic aspects of perception. These holistic aspects of perception are evident in the world of visual design. Systematic study of the connection between cognitive psychology and its relevance to art includes: brain and vision; figure and form perception; visual cognition; context; cognition; and art. The collection of data on how humans perceive, process and store information is sizable (Solso, 1996). Perceptual response to the world is the basic means from which we structure events, derive ideas and delineate language. The sense of sight has been described as the "most efficient organ of human cognition." Images of thought and perception as cognition are apparent in symbols, signs, pictures and selective vision. Arnheim upholds, "Thinking calls for images and images contain thought" (Arnheim, 1974, p.100). However, Richard Saul Wurman warns, we have limited capacity to transmit and process images, and that we cannot assimilate everything. "The more images with which we are confronted the more our view of the world is likely to be distorted" (Wurman, 2001, p.18).

Visual imaging and application design strategies for enhancing the rate of information transfer in print, presentations and computer screens are founded on fundamental principles of color and information (Tufte, 1990). A synthesized list of the principles can be viewed as an hypothesi for "quality" in graphical displays. Carter has argued persuasively, "The most important thing you can do to achieve optimum legibility when working with color and type is to carefully weigh the three color properties to establish appropriate contrast between letters and their background" (Carter, 2002, p. 33). The *principles* and *properties* are exemplified as the three color attributes: hue, value and chroma. In addition, it is recommended that the designer limit the number of colors to just a few and select **one** to serve as **dominant** (Carter, 2002). However, a sustained effort to develop conclusions that these hypotheses are true has not been tested experimentally.

Suggestions for selecting colors are found in the writings of Edward Tufte, author of several books on information design, including *Visual Explanations: Images and Quantities, Evidence and Narrative, Envisioning Information* and *The Visual Display of Quantitative Information*. In addition, Tufte published an article entitled *The Cognitive Style of PowerPoint* (2003). Using color to encode information, he advocates several principles for organizing information visually with color. From his book

Envisioning Information (2001), Tufte suggests four rules for color application. A summary of the four rules follows:

Rule one: Pure, bright or very strong colors have loud, unbearable effects when they stand unrelieved over large areas adjacent to each other, but extraordinary effects can be achieved when they are used sparingly on or between dull background tones.

Rule two: The placing of light, bright colors mixed with white next to each other usually produces unpleasant results, especially if the colors are used for large areas.

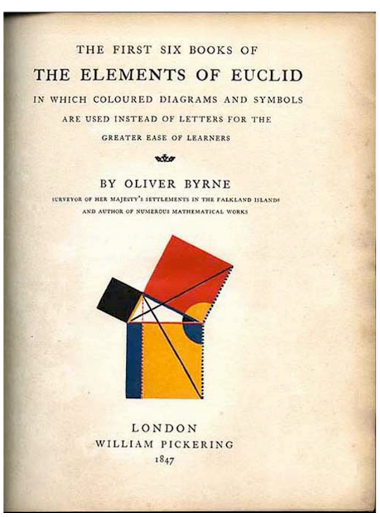
Rule three: Large background or base-colors should do their work most quietly, allowing the smaller, bright areas to stand out most vividly, if the former are muted, grayish or neutral.

Rule four: If a picture is composed of two or more large, enclosed areas in different colors, then the picture falls apart. Unity will be maintained, however, if the colors of one area are repeatedly intermingled in the other, if the colors are interwoven carpet-fashion throughout the other.

The use of too many high contrast colors means that nothing is emphasized. Items with the same color will inevitably be seen as logically grouped, or otherwise related to each other. Displays with high information density must use "gentle color" variations. One color selection strategy that Tufte suggests is using unsaturated colors from "nature as a calm background, against which sets of contrasting colors" are employed (Tufte, 2001). From Tufte's description, it may be presumed that "gentle colors" are those that are associated with unsaturated categories.

Tufte's suggestions for color selection are appropriate, meaningful and applicable for design students and design practitioners. In addition to relying on the emotional descriptions of color relationships, color nomenclature would be enhanced by addressing the three fundamental color attributes. The question arises, what constitutes *gentle, calm, quiet, muted* and *neutral* color relationships? Most likely, these terms refer to colors that are low in saturation and value. Each of Tufte's suggestions for color selection can be distilled into color codes and categories stemming from the hue, value and chroma structure embedded in the Munsell Color Notation System. Controlling the variables of hue, value and chroma addresses the insightful points that Tufte is making.

In *Envisioning Information*, Tufte demonstrates a color information system illustrated by Oliver Byrne in 1847. Byrne's representation of *The First Six Books of the Elements of Euclid* was based on color labeling rather than the typical letter-coding native to geometry texts (Figure 2.2). Each element of Euclidian geometry identifies itself by consistent shape, **color**, and orientation rather than by a letter label.


THE FIRST SIX BOOKS OF
THE ELEMENTS OF EUCLID
IN WHICH COLOURED DIAGRAMS AND SYMBOLS
ARE USED INSTEAD OF LETTERS FOR THE
GREATER EASE OF LEARNERS
BY OLIVER BYRNE
SURVEYOR OF HER MAJESTY'S SETTLEMENTS IN THE FALKLAND ISLANDS
AND AUTHOR OF NUMEROUS MATHEMATICAL WORKS
LONDON
WILLIAM PICKERING
1847

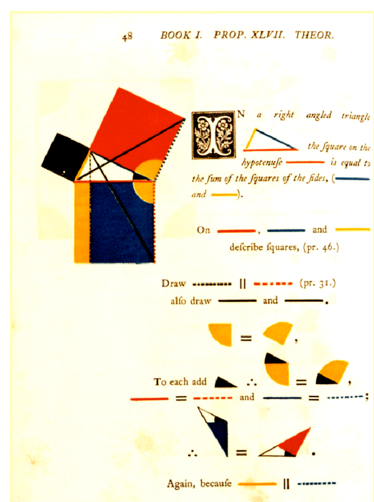
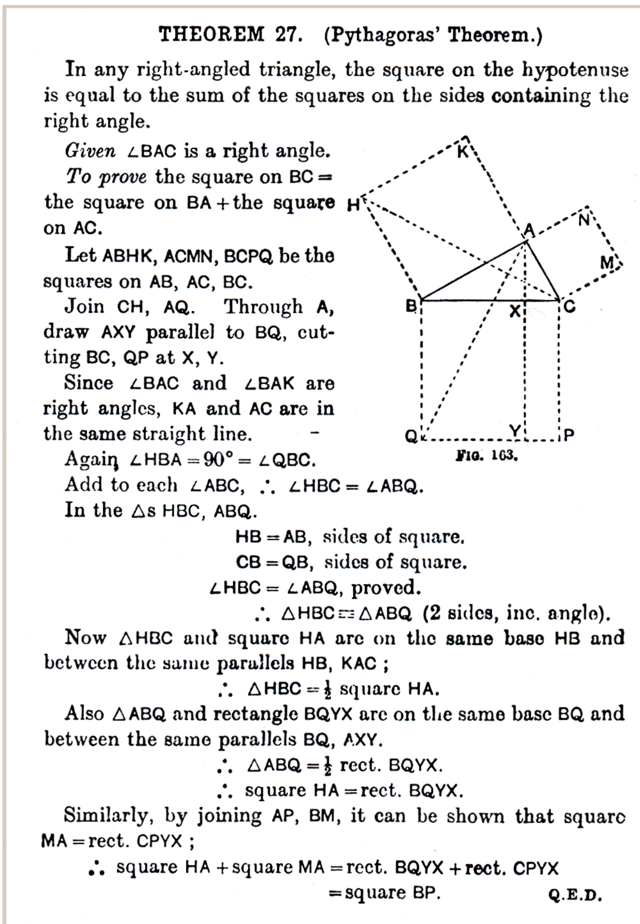


Figure 2.2: Oliver Byrne, *The First Six Books of The Elements of Euclid* (London 1847) p.48.

Tufte points to the fact that the orthodox methodology of geometric representation with lines, shapes, letters, and proof labor is intensive mental processing. Showing the Pythagoras' Theorem in typical textbook fashion (Figure 2.3), Tufte concludes, "Too much time must be spent puzzling over alphabetic macaroni of the 63 encoded links between diagram and proof" (Tufte, 2001, p.84). Tufte illustrates a *redrawn* depiction of Oliver Byrne's *First Six Books of the Elements of Euclid,* "Pythagoras' Theorem" (Figure 2.4).



THEOREM 27. (Pythagoras' Theorem.)

In any right-angled triangle, the square on the hypotenuse is equal to the sum of the squares on the sides containing the right angle.

Given $\angle BAC$ is a right angle.

To prove the square on $BC =$ the square on $BA +$ the square on AC.

Let ABHK, ACMN, BCPQ be the squares on AB, AC, BC.

Join CH, AQ. Through A, draw AXY parallel to BQ, cutting BC, QP at X, Y.

Since $\angle BAC$ and $\angle BAK$ are right angles, KA and AC are in the same straight line.

Again $\angle HBA = 90° = \angle QBC$.

Add to each $\angle ABC$, $\therefore \angle HBC = \angle ABQ$.

In the $\triangle$s HBC, ABQ.

$HB = AB$, sides of square.

$CB = QB$, sides of square.

$\angle HBC = \angle ABQ$, proved.

$\therefore \triangle HBC \equiv \triangle ABQ$ (2 sides, inc. angle).

Now $\triangle HBC$ and square HA are on the same base HB and between the same parallels HB, KAC;

$\therefore \triangle HBC = \frac{1}{2}$ square HA.

Also $\triangle ABQ$ and rectangle BQYX are on the same base BQ and between the same parallels BQ, AXY.

$\therefore \triangle ABQ = \frac{1}{2}$ rect. BQYX.

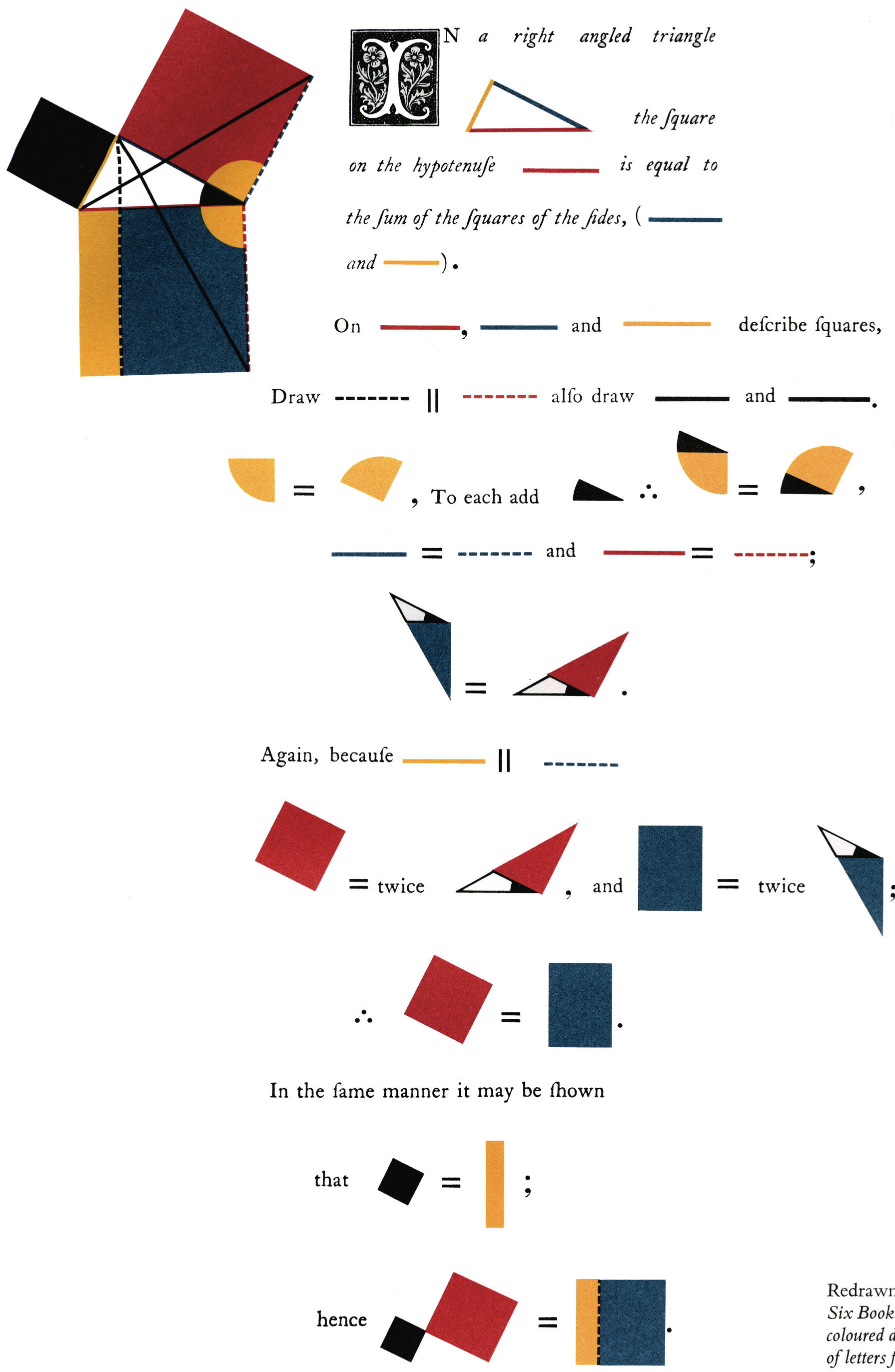
$\therefore$ square HA = rect. BQYX.

Similarly, by joining AP, BM, it can be shown that square MA = rect. CPYX;

$\therefore$ square HA + square MA = rect. BQYX + rect. CPYX

= square BP. Q.E.D.

Figure 2.3: *Pythagoras' Theorem,* from Tufte, 2001, p.84.



Redrawn from Oliver Byrne, *The First Six Books of the Elements of Euclid in which coloured diagrams and symbols are used instead of letters for the greater ease of learners* (London, 1847), pp. 48–49.

Figure 2.4: Byrne's Representation of *Pythagoras' Theorem* – Tufte's Redrawn Version, 2001, p.85.

Byrne's 1847 color representation of Euclidian geometry also incorporated conventional letter encoding. "Deflecting the fussiness that often results from redundant signals, the intermingling of the two labeling techniques seems to speed recognition of geometric elements as the eye moves between diagram and proof" (Tufte, 1990). Thus, Oliver Byrne's color representation operates as a language that communicates an understandable and meaningful mathematical message.

Color does not function in a vacuum. In two-dimensional representation, color perception or color identification is dependent upon color contextures and interactions. Josef Albers clearly demonstrates the effect that one color has on another color. A color has many faces. A color's appearance is relative to its surroundings and many colors are inclined to exert influence on another. Appearance is also influenced by quantity relationships (Albers, 1975). In the *Interaction of Color*, Albers offers an explanation of the characteristics of color and the conditions under which certain optical phenomena occur. Albers' color studies are based on the perceived differences in hue, value and chroma. The fundamental interaction of color relates to contrast of hue, value and chroma. The manner in which a color interacts with other colors affects the appearance of hue, value and chroma. Albers' *Interaction of Color* appears to work apart from perceptual psychology. Yet, all of the color principles addressed by Albers are substantiated in the discipline of perceptual psychology.

While unique differences and features of individual perception exist, design cannot respond to each end-user on an individual basis. Rather, designers must search for some areas of commonality that reach out to a larger and, in some cases, a specific population. As Jacobson argues, "Information design, whatever its label, will enhance our society's ability to collect, process, and disseminate information and to produce understanding" (Jacobson, 1999, p.10). For people with normal color vision, it is generally believed that color discernment is most likely the same for all human populations but various languages classify color differently. Colors serve as conventional signs as our lives are informed by color. According to John Marshall, "The basic mechanisms of color vision should be universal across all (normal) members of the human species, although subject to limited parametric variation …" associated with environmental light conditions (Davidoff, 1991, p.ix).

Information and direction are key elements of human-task-oriented operations (Norman, 2002). Table 2.1 is an adaptation from Norman's descriptive guidelines urging designers to incorporate several essential components into their thinking process. These components are functions of visual processing and representation. Color organization is one factor in visual representation and recognition that can affect a user's action and operation. In addition, to have value, data must be organized, transformed and presented in a way that gives it meaning (Jacobson, 1999).

Table 2.1: Descriptive Guidelines – Designer Thinking Process
(Adapted from Norman, *The Design of Everyday Things*)

Task Recognition	**Concept Model**	**Visual Representation**	**Mappings**	**Error**	***When all else FAILS***
Simplify the structure of tasks.	Present a clear conceptual model.	Make things visible.	Appropriate use of natural mappings.	Assume that all possible errors will occur.	*Standardize*
		Provide visual cues.	Design that depends on labels may be faulty. *Minimize the need for labels*.	Design to minimize the chance of error or its effects.	
				Recognize the user's capabilities and fallibilities.	

In this research study, the strategy for color selection and categorization is based upon the contrasting relationships of hue, value and chroma intrinsic to the Munsell Notation System of color organization. Therefore, the principles of color selection and organization are founded upon objective criteria that form derivative color combinations. Evaluating which categorical derivative color combinations are perceived to be important or dominant is an observable phenomenon that can be scientifically tested, documented and analyzed quantitatively.

2.3 Theoretical Orientation

Colors serve as conventional signs as our lives are informed by color. As earlier propositioned by Marshall, perceived color is believed to be consistent for the general population with normal vision. To some degree, color perception is moderated by environmental light conditions. However, it is also not surprising to find people of the same or different cultures identifying or naming one color in different ways. Undoubtedly, it is important for makers of color communication systems to understand cultural, social, semantic and psychological differences related to color. Reactions to colors are created by a combination of biological, physiological, psychological, social and cultural factors. It is widely agreed that color does have an effect on emotions and behavior.

The focus of this research was not directed at color naming and categorization as described by Hardin, Berlin, Kay, and others. Nor is the study centered on finding meaning in cultural color symbolism. Rather, for people of normal color vision, the intent was to determine if patterned color categories derived from inherent color attributes could cause a consistent human reaction to perceived color dominance. Through cognitive processing, perceived color dominance assigns relative importance to color within a structured pattern, thus establishing a visual hierarchy. Hierarchy organizes items by magnitude and order of importance. Assigning value and weight to information, hierarchical structure is the mode to use (Wurman, 2001). An orderly visual hierarchy determined by hue, value and chroma coding authenticates an objective color language independent of color naming, which may be anchored in subjective persuasion or cultural practices. Therefore, the meaning of color is represented through perceived dominance within one of the structured categories: hue, value and chroma.

Color structuring is one aspect that contributes to the identity of various cultural artifacts found in the contexts of products, print and digital media. According to Paul duGay in the book *Doing Cultural Studies: The Story of the Sony Walkman*, cultural meanings assist our ability to interpret, classify and make sense of things; meaning is intrinsic to culture. Objects can be "read" culturally and color is just one aspect that contributes to that reading. Thus, bringing an object into meaning constitutes it as a cultural artifact since the object invokes an image and idea constructed by a culture. As Hall persuasively argues, culture is not so much a "collection of things" as it is a "set of practices" concerned with the production and the exchange of meanings among members of a society or group (Hall, 1997). This research is concerned with color application as a set of controlled practices connected to meaning that advocates useful information. "Information is that which leads to understanding" (Wurman, 2001, p.19). As demonstrated in the work of Oliver Byrne, color can function as an information language that makes things clear and understandable (Figure 2.4).

From a cognitive structuralist theoretical framework, information processing (color as it informs) may be studied as an experiential means that builds and expands tacit knowledge (Figure 2.5). The source of color is an information system emerging from structured pattern types that communicate order and understanding. "Color concepts have an internal structure, with certain colors being focal" (Lakoff and Johnson, 1999, p.24). The issue is – which color structures offer the best fit to the phenomenon of perceived color order? Within this theoretical framework, a quantitative and qualitative research methodology was implemented and actualized.

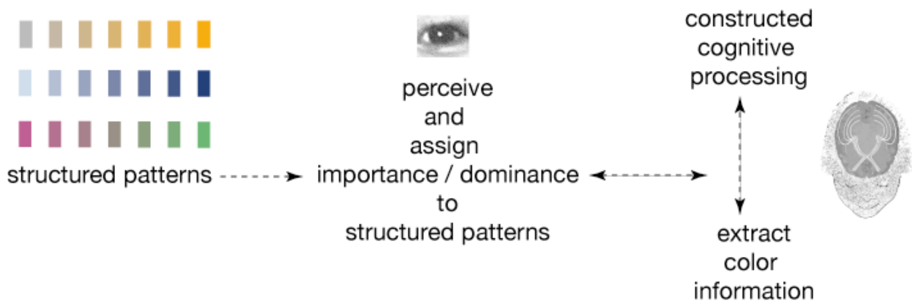


Figure 2.5: Theoretical Orientation.

The multidisciplinary domains of philosophy, anthropology, psychology, linguistics, semiotics and education engage the theoretical perspective of cognitive structuralism. Varying interpretations of structuralism exist. According to Roderick Lawrence, two different interpretations of structuralism exist, *global structuralism* and *analytical structuralism*. "In the first interpretation, the term *structure* refers to the systematic nature of an object or event (or a set of objects and events). In the second interpretation, the term *structure* is commonly used to describe and *explain* the systematic composition of objects and events—including language, texts, and music—in terms of social signification that specific elements or component parts acquire as signs" (Zube and Moore, 1989, p.38). Analytical structuralism encompasses global structuralism but also represents a more "… distinctive body of theoretical and methodological concepts, derived primarily from studies in the fields of human cognition, structural linguistics, and Marxism" (Zube and Moore, 1989, p.41). As human beings become aware of something in the world through use of their senses and the human mind, cognitive structuralism is a framework for the study of perceived color and the cognitive ability to assign a level of importance to it.

Structuralism and human cognition are grounded in the analytical concepts that encompass tacit ideas, processes or structures (Lawrence, 1989). Cognitive structuralism shares common boundaries with semiology and semiotics. Semiotics is the study of signs and symbols as elements of language or other systems of communication within a given culture. Since structured color patterns constitute a visible language, color and semiotics are inextricably linked. This research study is informed by objective reasoning in the theoretical orientation of cognitive structuralism.

2.4 Key Words and Terms

For centuries, scientists, astronomers, mathematicians, architects, philosophers, psychologists, physicists, chemists, engineers, and painters have contributed the manifestation of discrete theoretical color models. A review of the chronology of color theory demonstrates varying definitions, methods and organization of color categories (Table 2.2). Color classification systems are identified from the Classical Greek period to the present. The most notable systems are: Newton, Sowerby, Goethe, Chevreul, Maxwell, Benson, Munsell and Ostwald. In most systems of color organization, every color is located in three dimensions or attributes: described by hue, value and chroma (saturation). While the vocabulary in each of the color models may vary, all systems agree on the identification of color that are bounded by the visible spectrum.

Table 2.2: Color Theory: Chronology of Organizational Systems (condensed).

COLOR THEORY CHRONOLOGY

1672	Isaac Newton (1642-1726) Scientist	England	Published: "A new theory of light and colours"
1772	J. Heinrich Lambert (1728-1777 Astronomer	Germany	Three-dimensional color-system.
1772	Ignaz Schiffermüller (1727-1806)	Austria	Color-circle: red, blue, green and yellow
1775	Tobias Mayer (1723-1762) Mathematician / Astronomer	Germany	Color triangle Color theory by math
1809	Philipp Otto Runge (1777-1810) Painter	Germany	Color wheel primary colors: red, yellow, and blue plus black for shades.
1809	James Sowerby (1757 - 1822) Author: botany and natural history	England	Published: *A New Elucidation of Colours, Original Prismatic and Material*
1810	Johann Wolfgang Goethe (1749-1832) Scientist	Germany	Color wheel: double intersecting triangle. Published 1400-page treatise on color theory.
1839	Michel Eugène Chevreul (1786-1889) Chemist	France	Twelve-step color wheel
1859	James Clerck Maxwell (1831-1879) Physicist	England	Published: "Theory of Colour Vision", seen as the origin of colorimetry. (quantitative color measurement).
1868	William Benson Architect	England	Cuboid system
1874	Wilhelm von Bezold (1837-1907) Physicist	Germany	Color-cone: red, green and blue.
1874	Wilhelm Wundt (1832-1920) Psychologist / Philosopher	Germany	Color-sphere of eight basic colors: white and black placed at the poles, the equator comprises eight colors-green, green-blue, blue, violet, purple, red, yellow and yellow-green which form a circle with grey at its center.
1878	Ewald Hering (1834-1918) Physiologist	Austria	Three opposing sets of colors theory: yellow and blue, red and green, and black / white.
1879	Nicholas Odgen Rood (1831-1902) Physicist	USA	Scientific color-circle: double cone color model – white on top, black at the bottom, red, green and blue formed the triad.
1905	Albert Henry Munsell (1858-1918) Painter	USA	A numerical system – eight colors with white and gray.
1915	Albert Henry Munsell (1858-1918) Painter	USA	Published: *The Color Atlas* – organization of numbered hues within a color sphere in hue, value and chroma categories.
1916	Wilhelm Ostwald (1853-1932) Nobel-prize winner for chemistry	Germany	*The Colour Primer:* color circle composed of two cones that met at the flat circumferences of the top circles.
1921	Johannes Itten (1888-1967) Painter	Switzerland	Color circle is based on 12 paint colors; the primary colors Red-Yellow-Blue.
1942	Richard Sewall Hunter (1909-1991) An American instrument maker	USA	Created the widely used *delta E* for color differences.
1982	Harald Küppers (1928 - …) Reproduction Technology Engineer	Germany	Published first US edition: *Basic Law of Color Theory.*

The Munsell Notation System is the one of a few organizational structures that provides a categorical arrangement specifically defined by these three color attributes. The 1905 Munsell Color Notation system is founded upon objective visual combinations and is utilized in interface design today. Munsell's codification structure is defined and specified by color families that are qualified by three color attributes: hue, value and chroma. Munsell also provides a clearly prescribed communication system of visual order and literal context. The visual stimuli for this research study were intrinsically tied to Munsell's principles of organization. The three color attributes were independent variables which provided a control for color selection and structure. The composition of the visual stimuli consisted of the system represented in Figure 2.6.

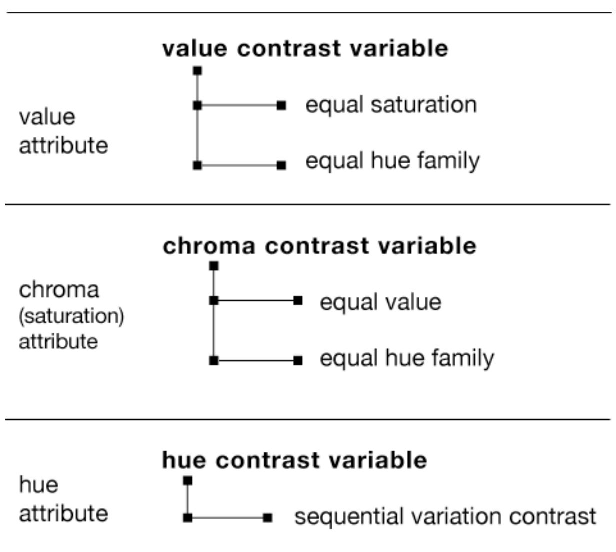


Figure 2.6: Color Contrast Independent Variables.

2.4.1 Color Attributes Defined

Color is the phenomenon that results from the interaction among a light source, an object and an observer. Color contains three attributes: hue, value and chroma. **Hue** is the family or generic name of color. It is a term used for colors contained within the visible spectrum. The visible spectrum is that portion of the electromagnetic spectrum between 380 nm and 700 nm (*nm* - a metric unit of length equal to one billionth of a meter) that can be seen by the human eye. The commonly referred to color "names" in the visible spectrum are yellow, orange, red, violet, blue and green. As illustrated by Johannes Itten, these colors are ordinarily depicted in a color wheel arranged in likeness to the visible spectrum (Figure 2.7). This color wheel positions the primary colors in the center triangle. The secondary colors are situated as separate triangles at the central triangle's perimeter. The 12 colors comprising the circle include the tertiary colors yellow-orange, red-orange, blue violet, and yellow-green.

Figure 2.7: Itten's Color Wheel.

Value is the relative lightness and darkness represented in a white to black scale. Colors that contrast in value constitute a monochromatic value scale. Monochromatic colors are the light and dark contrasting relationships of a single hue. Colors modified by white or black are referred to as tints and shades derived from one full chroma hue (Figure 2.8). Each unit of color represents a visually equal degree of value contrast.

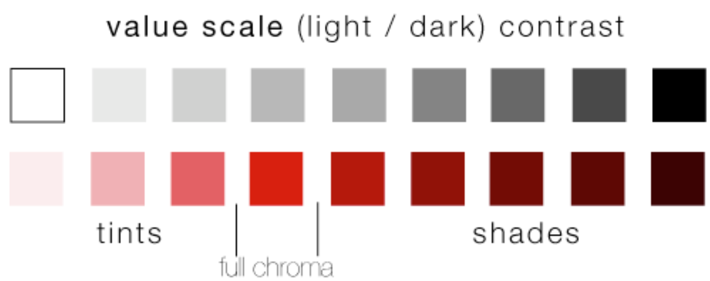


Figure 2.8: Value Scale Defined.

Additionally, the hues of the color wheel consist of a value structure from light to dark. The light to dark order follows the sequenced position of the hue in direct relationship to the color wheel. Yellow is the lightest in value followed by orange, red, green, blue and violet the darkest value. In relationship to the gray scale, the hues represented in Figure 2.9 are similar in value.

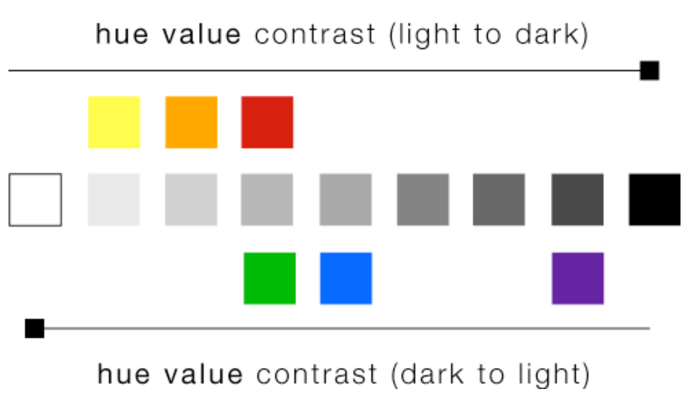


Figure 2.9: Primary and Secondary Hue Values Defined.

The **chroma** attribute is defined by a color's saturation point. Contrasting relationships in chroma are compared in terms of color fullness and color reduction, which correlates with the dimension of **saturation**. Specifically, the chroma of a color indicates the degree of departure from a fully saturated hue to chromatic grays of the same value (Figure 2.10). Fully saturated colors, which have been modified by gray, are referred to as tones. Chroma also encompasses brightness/intensity. In perceptual psychology, brightness is referred to as a cognitive function of eye and brain. Brightness is a perceived phenomenon. In the hard sciences, intensity is referred to as a phenomenon of light wavelengths. With instruments, intensity is measurable.

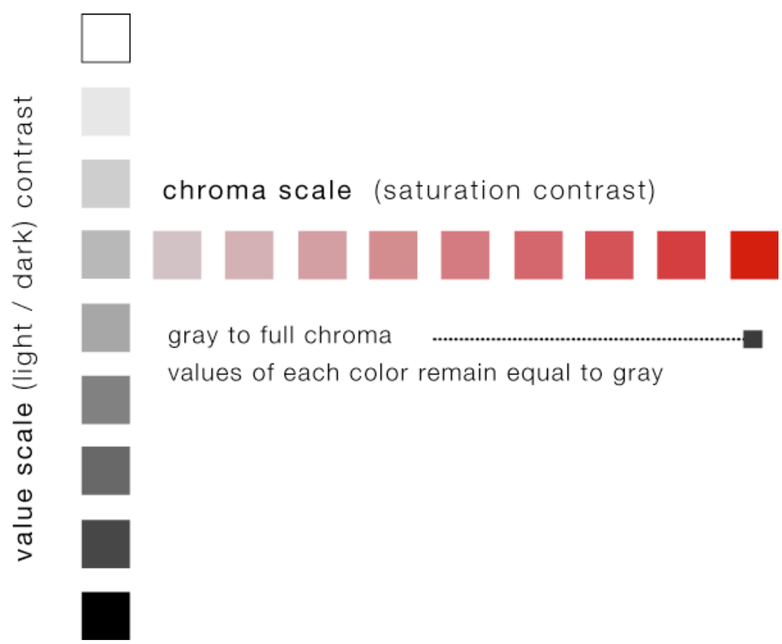


Figure 2.10: Chroma Scale Defined.

2.4.2 Munsell Notation System

Color sensation unites three distinct qualities, defined as hue, value and chroma. One quality may be varied without disturbing the other (Munsell, 1946). Munsell established numerical nomenclature scales with visually uniform steps for each of the three color attributes. Munsell's method was not based on instrument measuring; rather, it was formulated by visual comparisons. The attributes constitute specific color relationships and color order.

Munsell defined hue as the quality by which we distinguish one color from another. The family of blue includes many different colors of blue within a color range designated as a blue hue. Value is based on the human ability to see differences in relative light and dark. It is not an exact set of mathematical values from a light source. An attribute of value used in the Munsell System indicates the lightness of an object viewed in daylight, on a scale from 0 for the ideal black to 10 for the ideal white, in steps that are perceptually equal. Munsell defines chroma as the quality that distinguishes the difference from a pure hue to a neutral gray.

This system configuration is modeled as a non-symmetrical sphere around which run vertical and horizontal bands of colors. A value scale consisting of 10 gradients plus white make the center vertical axis of the sphere. The chroma axis extends from the value axis at a right angle. Colors along this horizontal axis are the same in value but contrast in saturation. The full chroma hue is positioned along the vertical axis in relationship to its equivalent gray value. The full chroma hue extends horizontally from the neutral gray scale in the required number of gradients that constitute equal degrees of saturation contrast until it reaches (100%) full chroma. Fully saturated colors for individual hues are positioned at different places in the non-symmetrical sphere. To reach full saturation along the horizontal chroma scale, each hue progresses at a different rate from the vertical neutral value scale. Subsequently, the global configuration is radically asymmetrical (Figure 2.11). The colors are simply identified by alphanumeric nomenclature. The line drawing in Figure 2.11 is a representation of color identification. By using this method of identification, Munsell avoided the problems with color naming which were discussed in the previous section.

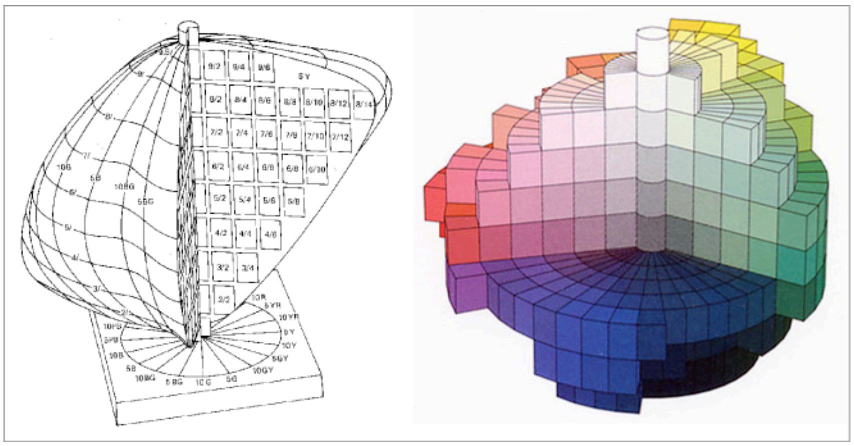


Figure 2.11: Munsell Asymmetrical Color Sphere.

The fully saturated color on the right of the scale is equal in value to the neutral gray color in the central axis. Consequently, the colors located between neutral gray and the fully saturated color are the same in value.

From the Munsell Notation system, two hues, *yellow* and *blue,* are depicted in Figure 2.12. The full chroma yellow is defined as equal to gray at the unit value “9/” and is positioned at the full chroma “/20” unit. The full chroma blue defined as equal to unit value “4/” neutral gray and is positioned at the full saturation “/20” unit. Within each of the two hue families, colors are organized as vertical planes that are structured in value contrast, top to bottom. Chroma contrast is confined within the same vertical plane, left to right (Figure 2.12).

The vertical position of each hue constitutes a value scale contrasting light and dark and is the same in hue family. The horizontal positioning of colors constitutes contrast in saturation and remains the same in value. Every hue family embedded in the Munsell ordering system characterizes an objective harmony. Color harmonies comprise two fundamentally inseparable ingredients: similarity and contrast. The attributes of color formulate the foundations for the orderly joining of color similarities and color contrast. Color patterns can be constructed by ordering fundamentals found within the Munsell Color Notation System.

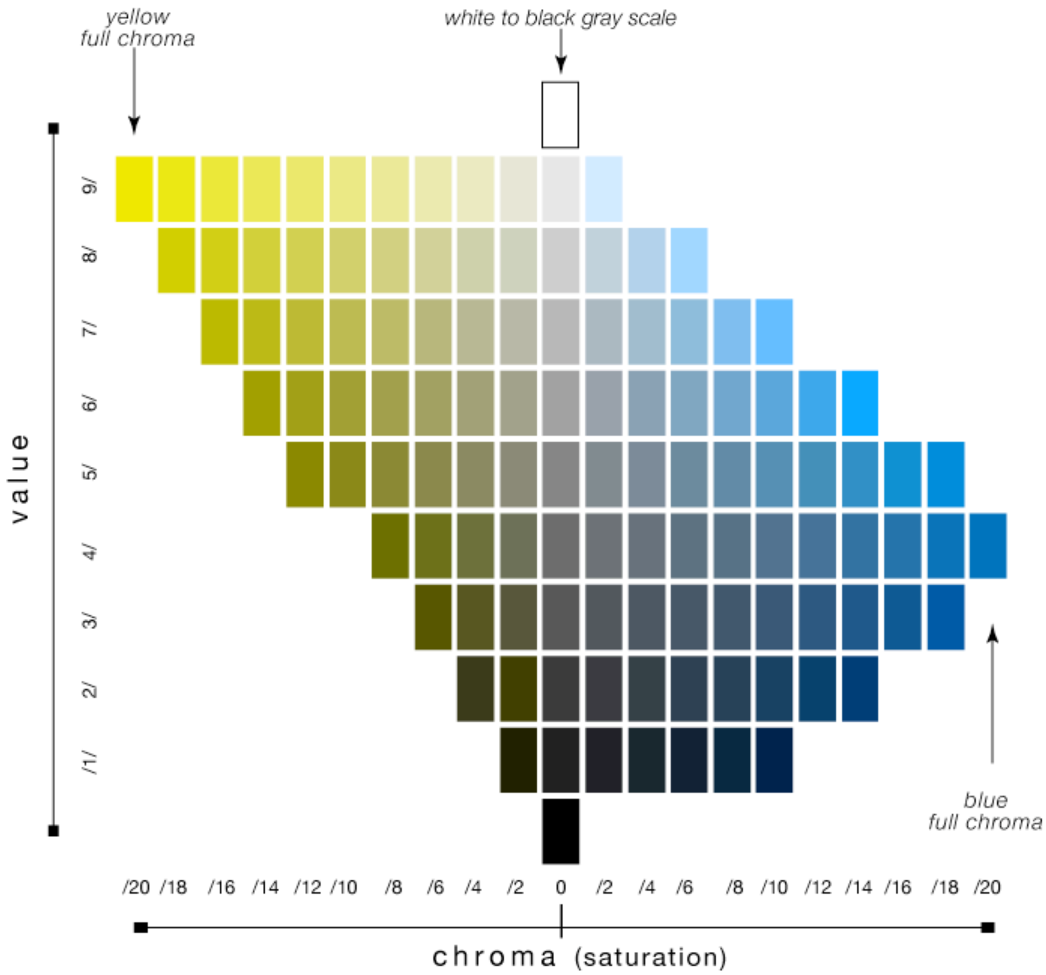


Figure 2.12: Two Hues Organized along Value and Saturation Axes.

Although the Munsell Notation System dates back to 1905, it is still an internationally accepted, leading color system. A variety of software programs use a terminology and color manipulation system based upon the attributes defined by Munsell. Software programs from leading graphic developers Adobe, Microsoft and Macromedia have created interface software that operate under the principles of the Munsell ordering system.

Software created by Adobe integrates the attributes of hue, value and chroma on one screen. Hue may be selected by dragging the arrows along the slider bar represented by the visible spectrum (Figure 2.13). Chroma (saturation) is modified with a gray similar in value to the hue's value. Dragging the arrows along the vertical bar changes the color to neutral gray (Figure 2.14). Value is manipulated by dragging the curser in the color field screen to light or dark areas (Figure 2.15). The size of these displays discourages users from making clear distinctions among color options when using the picker.

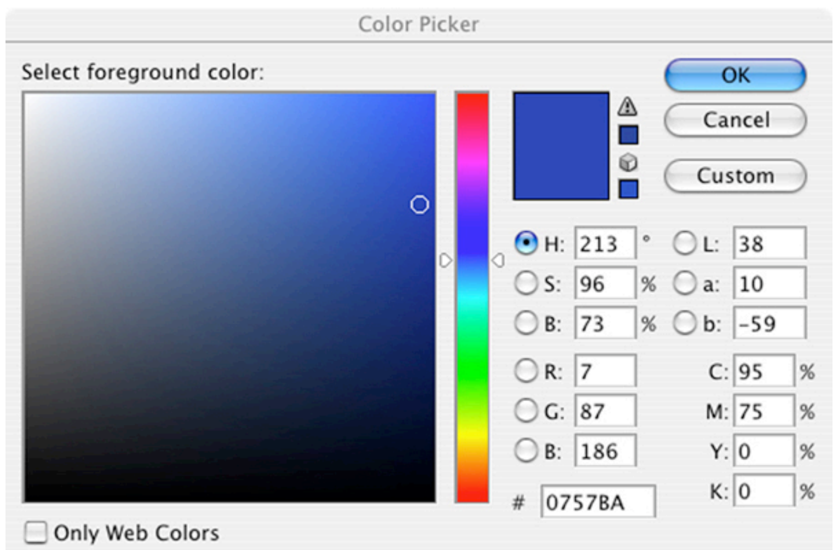


Figure 2.13: Color Picker Interface: Hue.

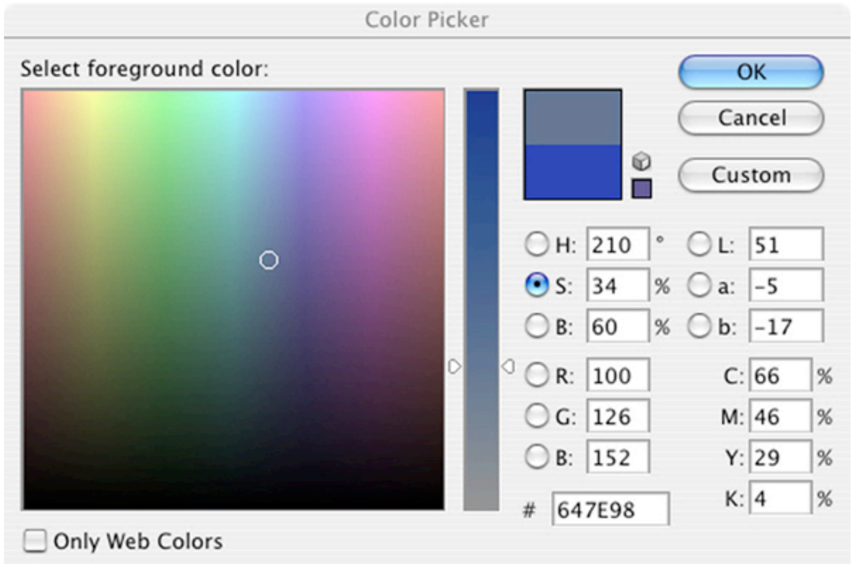


Figure 2.14: Color Picker Interface: Saturation.

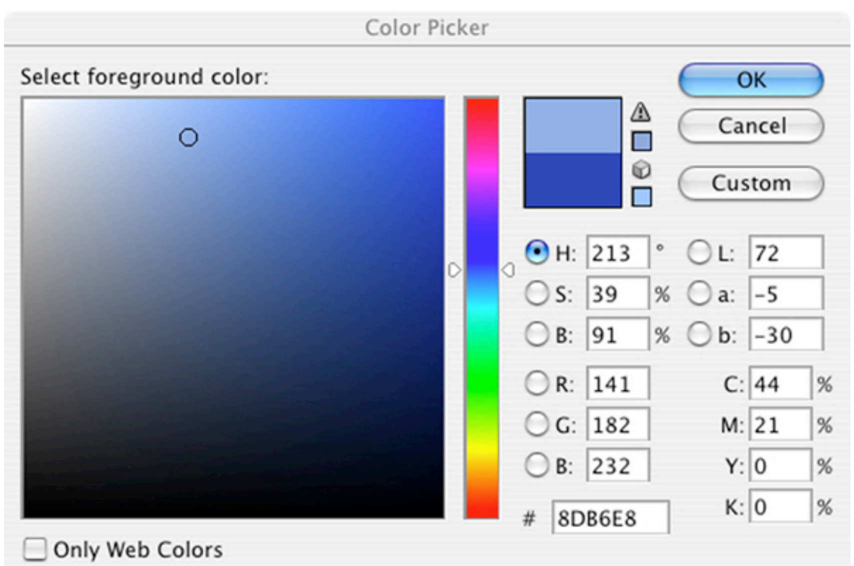


Figure 2.15: Color Picker Interface: Value.

Unlike Adobe, Macromedia color palette interface design includes five options on five separate screens. The color wheel is used for selecting hue and a light value, and a slider bar to adjust for dark value (Figure 2.16). A gray scale window provides an additional method for adjusting light and dark value but the terminology for light / dark is called “brightness” (Figure 2.17). In addition, colors may be selected from a list of four options: *Apple, Developer, Crayons, and Web Safe* (Figure 2.18). Images are adjusted from a spectrum palette (Figure 2.19). An additional method for color selection is found in the crayon window (Figure 2.20).

Figure 2.16: Hue/Value Macromedia.

Figure 2.17: Value Slider Macromedia.

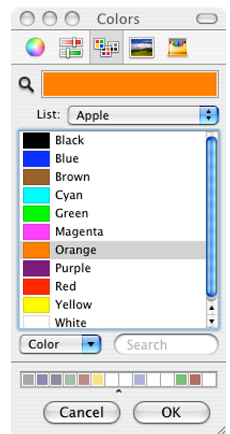


Figure 2.18: Four Palette List Macromedia.

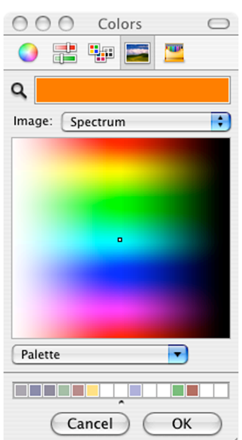


Figure 2.19: Spectrum Palette Macromedia.

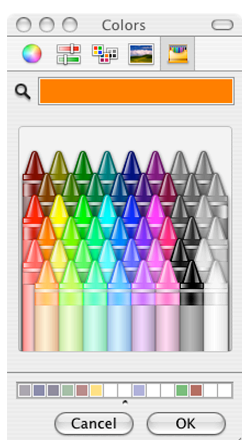


Figure 2.20: Crayon Color Selector Macromedia.

Microsoft *Word* limits color adjustments for images within a document. By adjusting the sliding scale, the value within the image is made lighter or darker. The altered image is previewed in the preview screens along the bottom. Chroma (saturation) adjustments may be made for red, green and blue (Figure 2.21).

Microsoft *PowerPoint* integrates a custom color method of selection. Value adjustments are controlled within the visible spectrum hue circle and the chroma (saturation) is adjusted to a selected gray by the value bar vertical slider (Figure 2.22). Newly selected colors may be dragged to a palette bar located at the bottom of the color wheel. This feature allows the user to retrieve and maintain control of colors used within a presentation document.

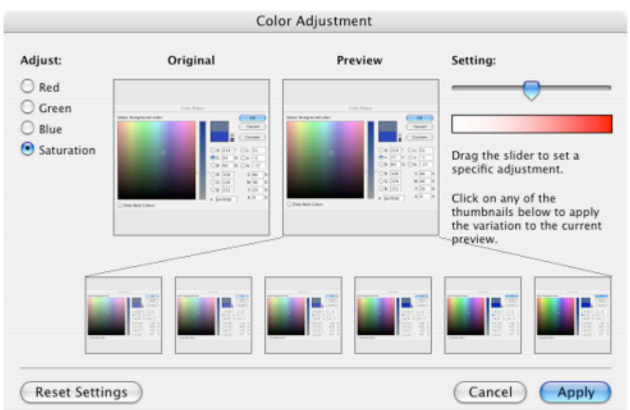


Figure 2.21: Color Alteration Interface Microsoft Word.

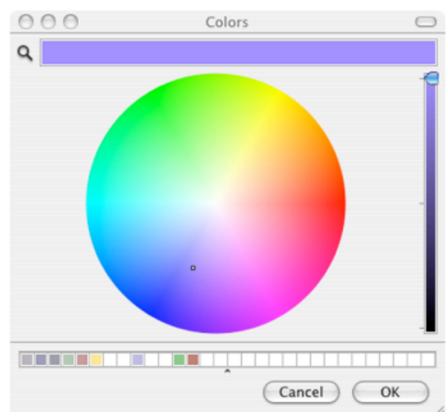


Figure 2.22: Selection Interface PowerPoint.

2.5 Depth of Attention to the Issues in the Study

The principles of the Munsell Color Notation System provided the framework from which derivative color combinations were formulated and clearly defined. The variables of color consist of the three attributes of color: hue, value and chroma. Each of the three attributes formed categories initiating a structure and facilitating a control mechanism. Within the value contrast structure, hue and chroma were restrained. Similarly, within the chroma contrast structure, value and hue were restrained. Both structures displayed a visual color hierarchy. Contrast in hue alone was not enough to generate a visual hierarchy. Variable contrasting configurations within the hue structure achieved detectable color hierarchies. Since dominant colors were consistently perceived, this study produced credible empirical evidence to support the hypothesis.

The findings in this research provided a rationale for the basis of understanding color selection processes. It is generally accepted among design educators and in the design literature that color harmonies are fundamentally described as primary, secondary, tertiary triads and so on. Typically, the dialogue stops there. That is, a primary color harmony comprising red, yellow and blue does not in itself establish a visual hierarchy. By analyzing the hue, value and chroma scheme of a primary harmony or any other fundamental harmony, color coding and categorization are possible. The objective was to facilitate the development of common color selection strategies that work for as many different disciplines as possible

A discrete property and distinguishing characteristic of an informational organism is a hierarchical color system. Factually, we do not have definitive taxonomies for the attributes of informational color organisms or for the uses to which they may be put. Controlling the contrasting relationships among the attributes of color is a methodology that helps to define new taxonomies. The new taxonomies may in themselves define the ways in which they are used. By focusing attention on the intrinsic properties of the color attributes, criteria for color selection become objective, not subjective.

Since this research experiment was conducted by implementing Microsoft *PowerPoint*, the study design was consistent with the intent of discovering perceived color hierarchy in a digital presentation environment. Consequently, the setting, equipment and software application used in this study design is an authentic representation for which the research was directed. In addition, the visual stimuli in the setting are consistent with color selection processes derived from the Munsell Notation System in which color is organized in relationship to the attributes of color – hue, value and chroma. In the presentation setting, the participants identify, respond and record perceived color dominance. The presentation of visual stimuli and the respondents' interpretation of color dominance were independent of the researcher or the researcher's assistant. The data analysis represents quantitative confirmation of perceived color importance. The research design methodology was a simulation of a real world condition.

2.6 Breadth of Attention to the Issues in the Study

The application of objective color order is critical to making information understandable. Controlling the visual relationships of color contrast and similarity can significantly assist a person's cognitive ability to extract information in a prescribed order of importance. Haphazard color application creates visual noise and dilutes information. Tying color to information is not an elementary endeavor. Encoding abstract information through color application is a design problem that is exceptionally complex.

As software applications have become accessible and uncomplicated, the general population has embraced the new media. Software programs have made it relatively simple to create a digital presentation, a website, and an interactive DVD, just to name a few. As discussed earlier, graphic software applications provide an assortment of methods to select color and manipulate its variables or attributes. While these programs have become easier to use, they have not provided color selection methods that address the necessary limitations to assemble colors in a logical and meaningful way. An analogy can be drawn from music. Suppose an individual with no musical training was asked to sit at the piano and play. It is highly unlikely the result would be anything other than musical noise. Given the method of color selection in software applications, individuals are given the choice of selecting a color palette from a vast array of colors within the visible spectrum. With an untrained eye, a decision regarding color selection is uninformed and most likely to be nothing more than visual color-clutter. The number of colors within a given palette is crucial to understanding information. As the number of colors increases, color discrimination becomes more difficult. Stringent control on color selection mechanisms within software applications is an alternative option. "Recommendations on the number of *usable* colors for display coding purposes have been found to be in the range of three to seven colors" (Durrett, 1987, p.36). Even that number may be too many.

In addition to the current interface design for color selection, a transparent, limited color selection methodology would facilitate intelligent color usage. Color adds significance to visual images as it accentuates and makes perceptible the identification of that which is perceived first, as the main idea, before decoding additional elements in the message. Perceived hierarchy represents a sequence of visual commands in the hue, value and chroma language of color.

Real world color application may also include visual recognition tasks. These are tasks in which an individual looks at the context of color organization as a means of ordering information to determine importance. Therefore, color adds functionality and definitive relationships to many informational entities – signaling systems, way-finding systems, maps, instrumentation, educational/instructional material, etc. Effective color articulation and representation permits users to view, retrieve, access, decipher, interpret, understand, and experience a variety of information systems in a meaningful, valid and authentic manner. Subsequently, implicit color application implies meaningful usability.

Consideration must be given to size, shape, space, position and motion. The contextual elements of text/type, signs and symbols are additional factors. While the vehicle for color presentation in this study was limited to projected digital media, findings might be tested to include these additional visual components. Credible guiding principles for objective color selection expand the body of knowledge in the design community and the larger community.

CHAPTER 3

RESEARCH METHODOLOGY I

In this chapter and the next, the conceptualization, operationalization, and findings yielded by this research project are addressed. This chapter focuses specifically on the following topics: the research paradigm and its assumptions; conceptual framework; research question; research design overview.

3.1 Research Paradigm and Its Assumptions

The previous chapter reviewed literatures that indicated color ordering and application affect the ability to understand information. The chapter also presented the outline of a cognitive structuralism model, which suggests that objectivity can be established by observing the response to visual stimuli arranged in categorical color patterns. In an ordered structure, the unspoken language of color appearance may be interpreted as a system of signs or signals that classify conventional meaning. The attributes of color – hue, value and chroma – constitute objective color relationships and harmonies according to the Munsell paradigm. That is, structuring color patterns and harmonies are determined by the ordering principles found in the Munsell Notation System. The attributes of color formulate contrasting color relationships and color similarities. Attributes can be measured through a visual comparison of contrasting color relationships. Color combinations affect the human ability to understand information. These combinations can be formulated objectively for effective communication, thereby improving comprehension. In short, color is an observable variable that can significantly assist a person's ability to extract and understand information.

The perception of structure is critical to the construction of meaning or interpretation: color can direct us to an appropriate perception of structure, and color can increase the speed with which we detect that structure. The organization of hue, value and chroma patterns serves as a mechanism to construct a structure that functions as language and message (Figure 3.1).

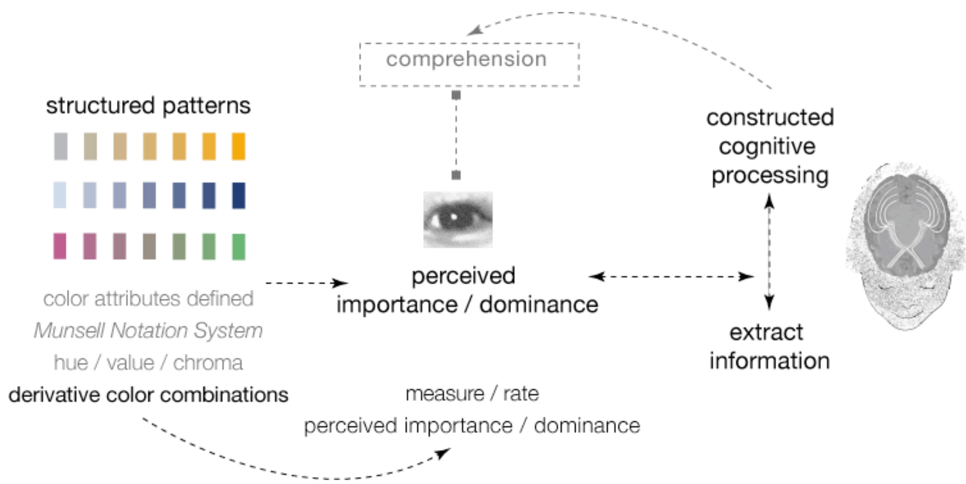


Figure 3.1: Paradigm and Assumptions.

3.2 Conceptual Framework

Color combinations can be formulated objectively for communicative purposes. As discussed in the previous literature review, language is any system of representation and is therefore more than the written or spoken word (du Gay, 1977). Colors derived from Munsell's paradigm provide a framework of connections that manifest a system of representation. It is a representational system comprised of hues constituted by the visible spectrum. Normal color vision is clearly situated in that part of the electromagnetic spectrum visible to the human eye, extending from extreme red, 760.6

nanometers, to extreme violet, 393.4 nanometers. The structure of color appearance is a perceived facet of things in the world. Visual perception generates an active exchange between our "sensory modalities" and our "cognitive expectancies and memories." These modalities actualize patterns of recognition and object classification that make it possible to arrange color in a sensible understandable space. Since color-cognition is independent of color-language, perception and meaning is not affected by color terminology or naming.

Arranging color in a sensible and understandable space prompts the cognitive processes to interpret information about the character and appearance of a color pattern. In this study, the sensible understandable space of color arrangement was contained in categorical patterns. As explained earlier, the variables in this research study are the attributes of color: hue, value and chroma. The relationship of these attributes was compared in terms of contrast and similarity through a grouping of colors in three structured patterns embodied by specific hue, value or chroma contrast derived from principles of Munsell's ordering. Therefore, color selection strategy and methodology were objective.

The derivative colors were structured in patterns and visually represented in three separate two-line phrases. The structured patterns were controlled by the three color variables. The three phrases were organized within one of the three color pattern categories. The text phrase remained constant in typeface, type size, position, number and direction. Shape, space, motion, signs, and symbols were excluded from the study. Projected light for the digital stimuli, research environment, and equipment were controlled variables (Figure 3.2). The participant's task was to evaluate the visual stimuli, (at their own pace) and identify which of the three phrases appeared to be the most visually dominant or important. The task response and elapsed time were digitally recorded. The administrator recorded the response and sat as an objective observer, uninvolved with the respondent. A detailed description of the experiment design follows in the next section.

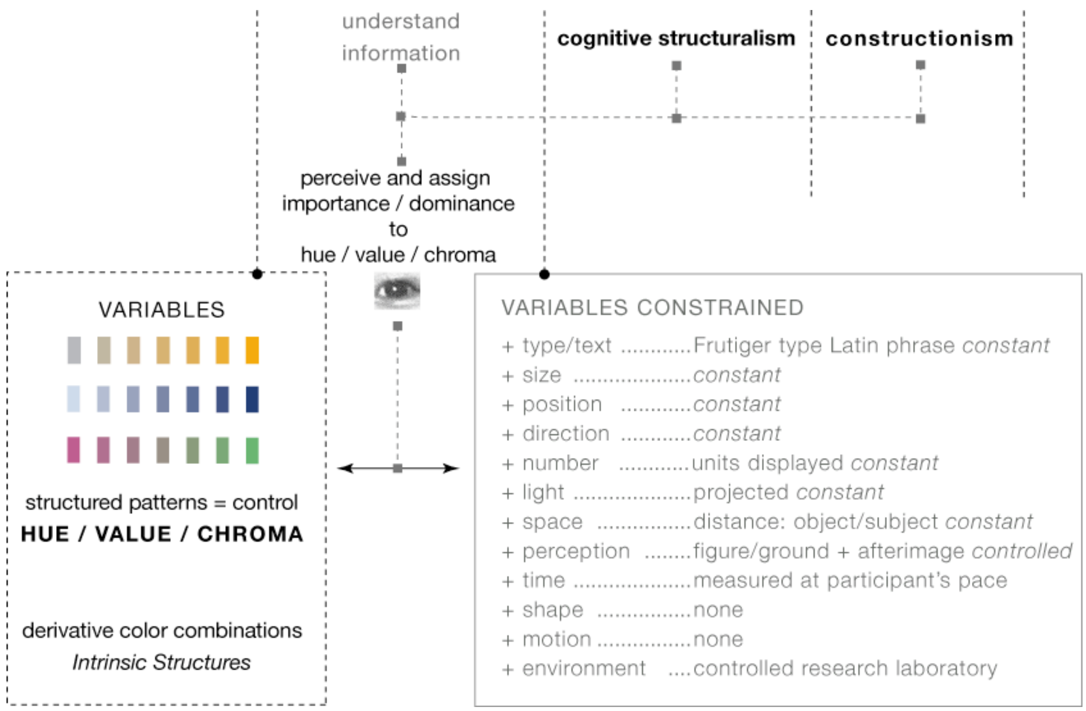


Figure 3.2: Conceptual Framework.

This study focused on the following research question and sub-question:

1. Research question:

Can derivative color combinations function as a visual information system that generates the human cognitive ability to visually perceive and process information in a dynamic digital communication environment?

1a. Research sub-question:

Will derivative color combinations in the categories of hue, value and chroma communicate visual order and hierarchy?

3.3 Experimental Research Design

The experimental research was entitled, *Intrinsic Color Structures*. In order to determine if color combinations could be identified and objectively qualified and quantified, an experimental research design strategy offered the strongest possibility for internal validity. The experimental design was organized to determine whether an objective selection of organized color would cause a consistent human response to visual importance/dominance. The experimental research implemented a precisely defined method that was central to causal or cause-effect inferences (Groat and Wang, 2002). Within the *Intrinsic Color Structures* experimental research framework, the three independent variables (hue, value and chroma) were tested. The study was designed to determine if specific color combinations structured within each of the three categories communicate a color hierarchy or order of color importance.

Prior to designing and administering the *Intrinsic Color Structures* research experiment, three exploratory experimental pilot studies were performed in May 2003, November 2004 and April 2004. The outcome of those three studies pointed toward a favorable statistical response, namely that intrinsic structuring derived within hue contrast, value contrast and chroma contrast demonstrated a perceived order of importance. Each of the three studies presented color structures constrained by hue, value and chroma variables. To test the representation of color, shape, text and motion, images were modeled in Macromedia Flash, Adobe Photoshop and Illustrator software applications. Microsoft PowerPoint was the method of presentation for the three separate studies. Shape, position, text, background and motion were differentiated in the studies. These studies were not intended to produce conclusive results. Rather, they were done to test a preliminary notion concerning color hierarchy; experiment methods and procedures; stimuli representation and presentation.

The stimuli in the first study in May included a set of three different hierarchical color combinations defined by the each of the three color attributes (Figure 3.3). A total of nine combinations were designed and presented. Each combination comprised four colors: a black background color and three colors of equal size and shape. One color structure consisted of value contrast without contrasting the hue and chroma (saturation). The second set was comprised of chroma contrast and constrained the hue and value. While confining value and chroma contrast, the third set contrasted in hue. The outcome of this study provided relevant information about the design of the experiment itself and the participant's response to interpreting hierarchy in a color system.

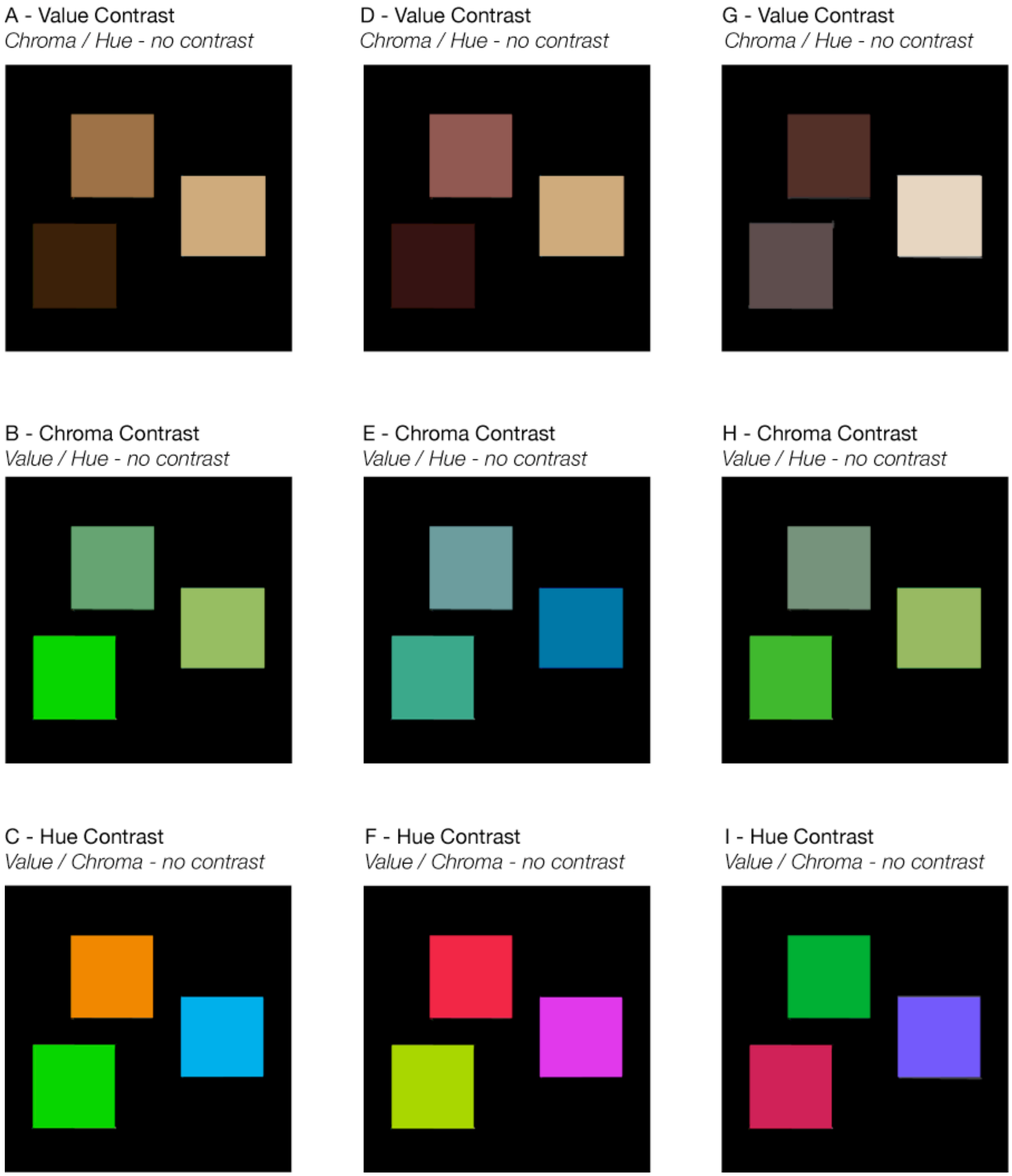


Figure 3.3: Pilot Study #1 May 2003.

The November study included a variety of visual stimuli. All color sets included groups of three colors and one common background color constructed of prescribed hue, value and chroma combinations formulated on Munsell principles. The same combinations were articulated in static geometric shapes, and others in letterforms. Another color set was presented in rotational motion graphics (Figure 3.4). It appears that shape, letterform and motion did not affect the perceived order of color importance. However, problems with the study were evident. A group setting was distracting; the number of stimuli far too large, and the time to complete the tasks was rigidly set.

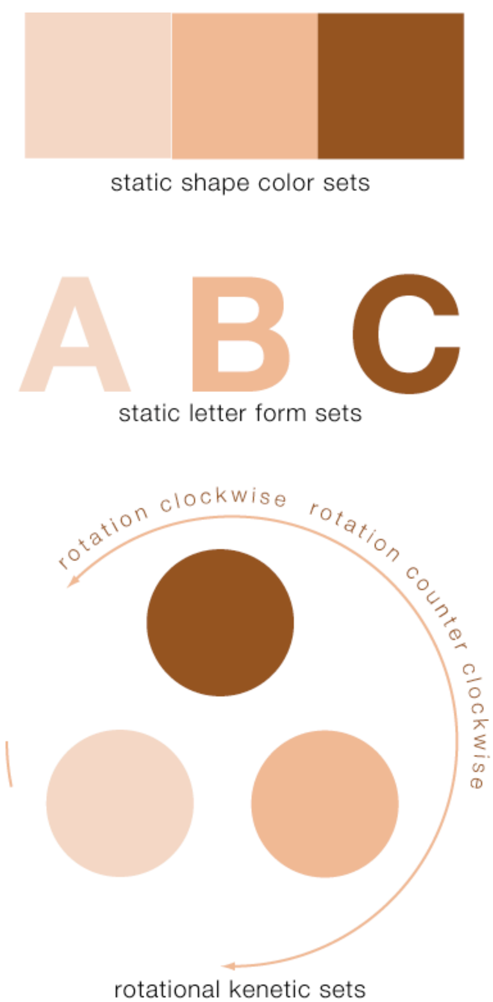


Figure 3.4: Pilot Study #2 November 2003.

A third pilot study was conducted in April 2004. This study was significantly simplified and refined (Figure 3.5). This study provided the foundation for the experiment entitled *Intrinsic Color Structures*, the focus of this research. This study produced remarkable evidence supporting the notion of color hierarchy represented by color categories of hue, value and chroma was perceived as explicit.

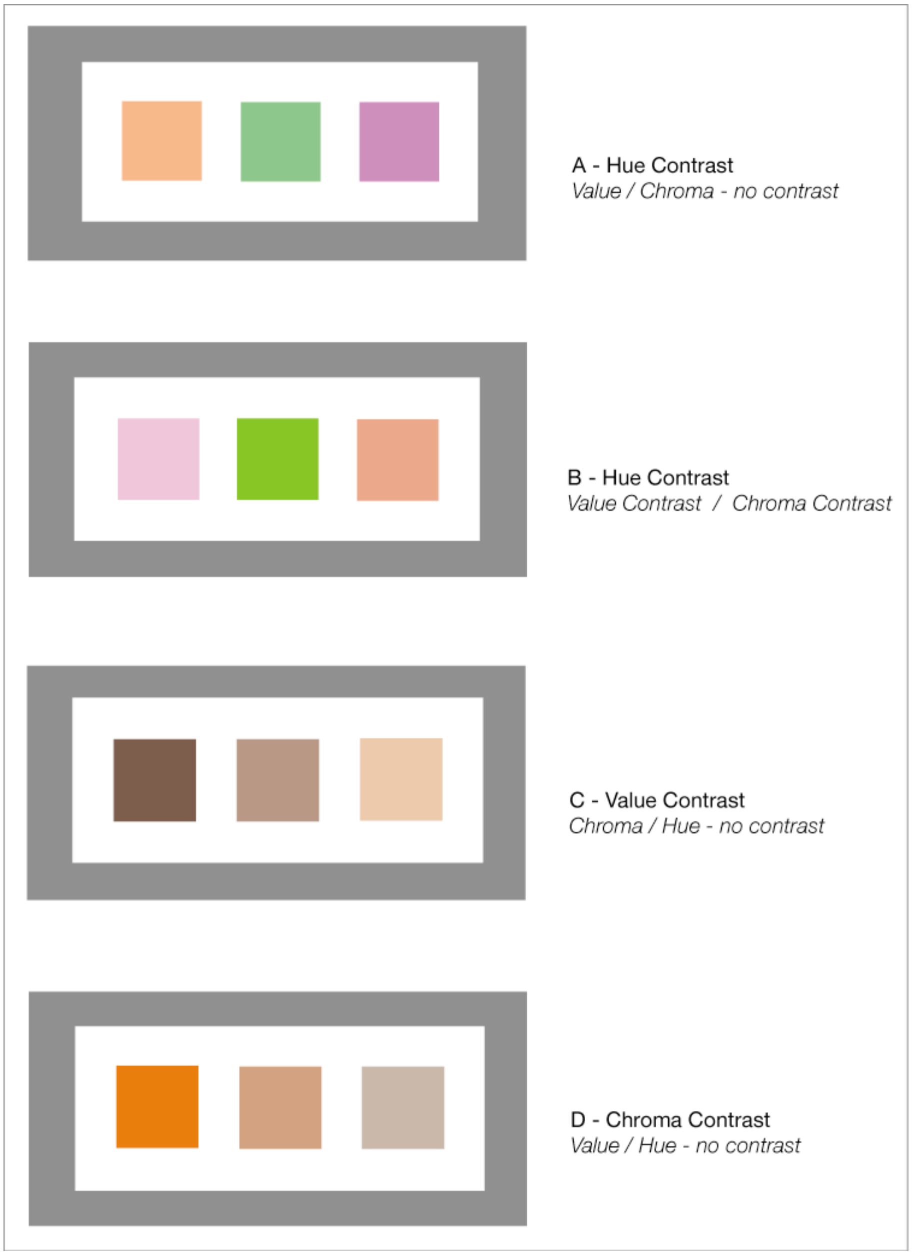


Figure 3.5: Pilot Study #3 April 2004.

On the basis of those promising initial findings, the research concluded that further investigation of the intrinsic color structures constituted by the Munsell Notation System was warranted. Since Munsell's descriptive color model is organized in relationship to hue, value and chroma, it provided a contextual method of controlling the three variable attributes.

Subsequently, *Intrinsic Color Structures* research design was modeled after Pilot Study #3. The method of testing was done one person at a time. The data was collected during the course of the experiment. The experiment was conducted in a controlled setting using a color selection methodology based on the principles of the Munsell Notation System. However, it readily became apparent that text was in important element to include in the study, since communication software like *PowerPoint* are primarily text based. A polygonal figure provides a surface area of color that is considerably different from the linear geometry of type. Consequently, the color type mixes with the colored background and produces a less saturated color appearance compared to a colored polygonal figure.

3.3.1 Participants

Students at North Carolina State University were recruited to participate in a research study. Participants were a *representative sample type* that came from various majors within the Department of Communication and the Department of Sociology & Anthropology. Participating students had no formal course work in color theory, application or visual communication design. The participants' age and gender varied. Since this study was not concerned with color preferences related to age

The recruited students were provided the following information in written and oral form:

The primary purpose of the study is to find empirical evidence that intrinsic color combinations can be categorized upon variables defined by three attributes–hue, value and chroma. The application of objective color ordering is critical to making information understandable. The presentation vehicle for the Intrinsic Color Structures Study will be limited to digital media.

and gender, the sample population was inherently related to the makeup of the courses from which students were recruited. Following the Internal Review Policies for Human Subject Research, all participating students reviewed and signed the *Informed Consent Form for Research* (Appendix A).

3.3.2 Sample Size

The *Intrinsic Color Structures* experiment consisted of enough units in the population to achieve the desired probability to assess whether or not the specific color categories caused a significant response to color dominance or importance. A total of 101 students elected to participate in the experiment. From the 101 potential participants, two were found to be color deficient in various portions of the visible spectrum and were excused from the experiment. The actual number of student participants totaled 99.

3.3.3 Setting and Equipment

The experiment was conducted at North Carolina State University, D.H. Hill Library's Usability Research Lab. The Usability Lab is specifically designed to conduct controlled experiments following the principles of user-centered design (Figure 3.6 – Appendix B). Usability is the practice of designing products so that users can perform required operational tasks, with a minimum of stress and maximum ease of use (Woodson, 1981). The setting and equipment for the experimental research process provided a mechanism that focused on the user (participant) and task rather than technologies. The environment provided a systematic, structured approach to the collection of information from and about the user (Rubin, 1994). Additionally, behavioral measurements of task effectiveness and task efficiency were actualized.

Figure 3.7: Usability Lab Recording Room.

Figure 3.8: Usability Lab Testing Room.

The lab consists of an observation room for the monitoring and recording of data (Figure 3.7), and a testing room for users (Figure 3.8). The lab is equipped to accommodate the following:

Collect video and audio of user behavior.

Record a "screen capture" (a real-time image of what happens on the screen during the test).

Mix the video sources so that the user's face and the screen capture are displayed in separate panels on the same screen.

Burn a timestamp onto the mixed image.

Record the mixed video and audio onto VHS tape.

The usability research laboratory accommodated video recording and participant observation of participants by means of a one-way glass. The testing room computer was a 2.8 GHz PC running Windows 2000 operating system. The color stimuli slides were running on Microsoft Office 2000 *PowerPoint* software. The monitor was a 17" LCD screen. The recording setup was a custom setup designed for analog VHS capture. In the testing room, the experiment administrator orally explained the instructions for the experiment and recorded the response data.

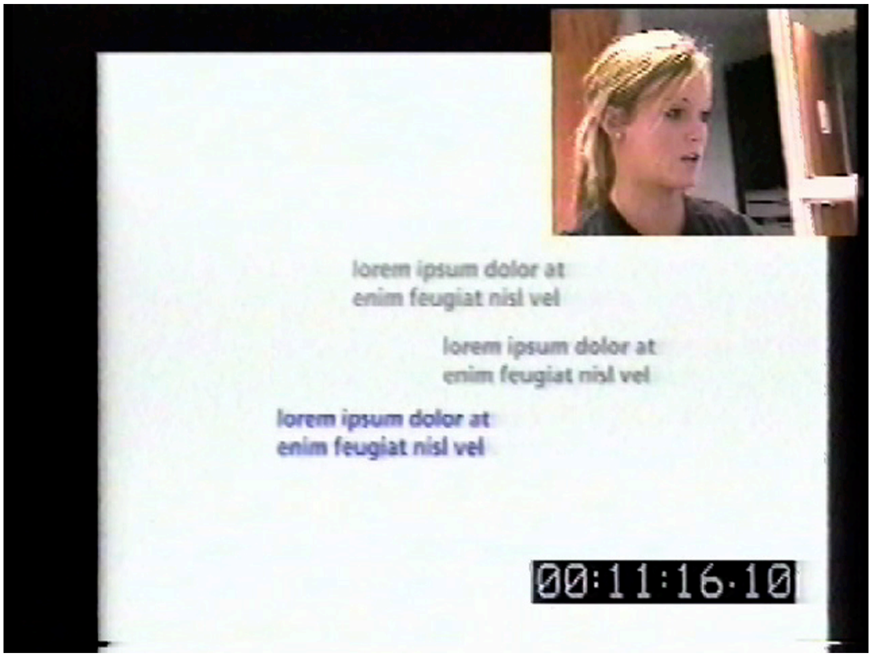


Figure 3.9: Video and Audio Screen Capture.

All participants in the *Intrinsic Color Structures* experiment were recorded on videotape during the experiment. With equipment in the observation room, a video captured the participant's audio response, visual reaction to the stimuli and time stamp. Simultaneously, the video capture records the screen of the color stimuli with a smaller split screen of the user's image in the upper right corner (Figure 3.9).

3.3.4 Test for Color Deficiency

To detect color deficiency, the *Dvorine Pseudo Isochromatic Plates* were administered to each participant (Figure 3.10 – Appendix C). These 16 plates were authored by the Psychological Corporation and continue to be utilized by the military as well as in the general population to test for optical color deficiencies. This test consists of a numerical character formed by dots of various colors and sizes. The numerical character is placed in field of colored dots, which also vary in color and size (Figure 3.11). Participants found to be color deficient were excused from the experiment.

Figure 3.11: Dvorine Color Plates Sample.

Color blindness is often associated with the inability to see all colors within the visible spectrum, perceiving only black and white. This misconception is not true since it is extremely rare to be totally color blind. Less than .005% of the population is color blind. There are different types and degrees of color deficiencies. Approximately 5% to 8% of men and .5% of women in the world are color deficient. The color test is designed in color patterns that are associated with red, green and blue deficiencies.

Color Deficiencies Conditions

Monochromasy: the complete absence of color sensation.

Protanomaly: a deficiency in red sensitivity (1 of 100 males).

Deuteranomaly: a deficiency in green sensitivity (5 of 100 males).

Tritanomaly: a deficiency in blue sensitivity (<.003% of population).

(Wagner, 2004)
http://www.colorvisiontesting.com

3.3.5 Research Stimuli

This portion of the experimental research design addresses the following topics: participants, sample size, setting and equipment. Additionally, it addresses the complexities of logical objective color selection methods. Other research design operational procedures are also discussed.

3.3.5.1 Stimuli – Color Selection Logic

The stimuli for this study were based on the selection of color harmonies (color structures) that were intrinsically derived from objective logic based upon similarity and contrast of hue, value and chroma. Therefore, the method of color selection was based on objective criteria rather than subjective appeal. The preliminary experimental studies were referenced to determine the constructed relationships of three colors and a background. The constructed relationships were derived from principles of the Munsell Notation System. Consequently, color categories were formulated on objective criteria established by the three color attribute variables. The value contrast category comprised color variables that were constrained in chroma and hue, no contrast. The chroma category comprised color variables that were constrained in value and hue, no contrast. The hue category consisted of four contrasting relationships.

Following the principles of the Munsell Notation System, Figure 3.12 illustrates the concepts, principles and strategy of color selection for the value and chroma categories. The horizontal chroma axis *(yellow)* represents contrast in chroma as it progresses from 0 to /20. The full chroma *yellow* and the tonal colors along the horizontal axis are equal to *value 9/*. The *yellow scale* example demonstrates no contrast in value since the lightness of colors along the horizontal axis are similar. Since the colors within the system are derived from the yellow family, there is no contrast in hue.

The vertical value axis *(blue)* represents contrast in value as it progresses from light value (8/) to dark value 1/. The *blue scale* example demonstrates no contrast in chroma since the chroma (saturation) of colors along the vertical axis are similar. Since the colors within the system are derived from the blue family, there is no contrast in hue.

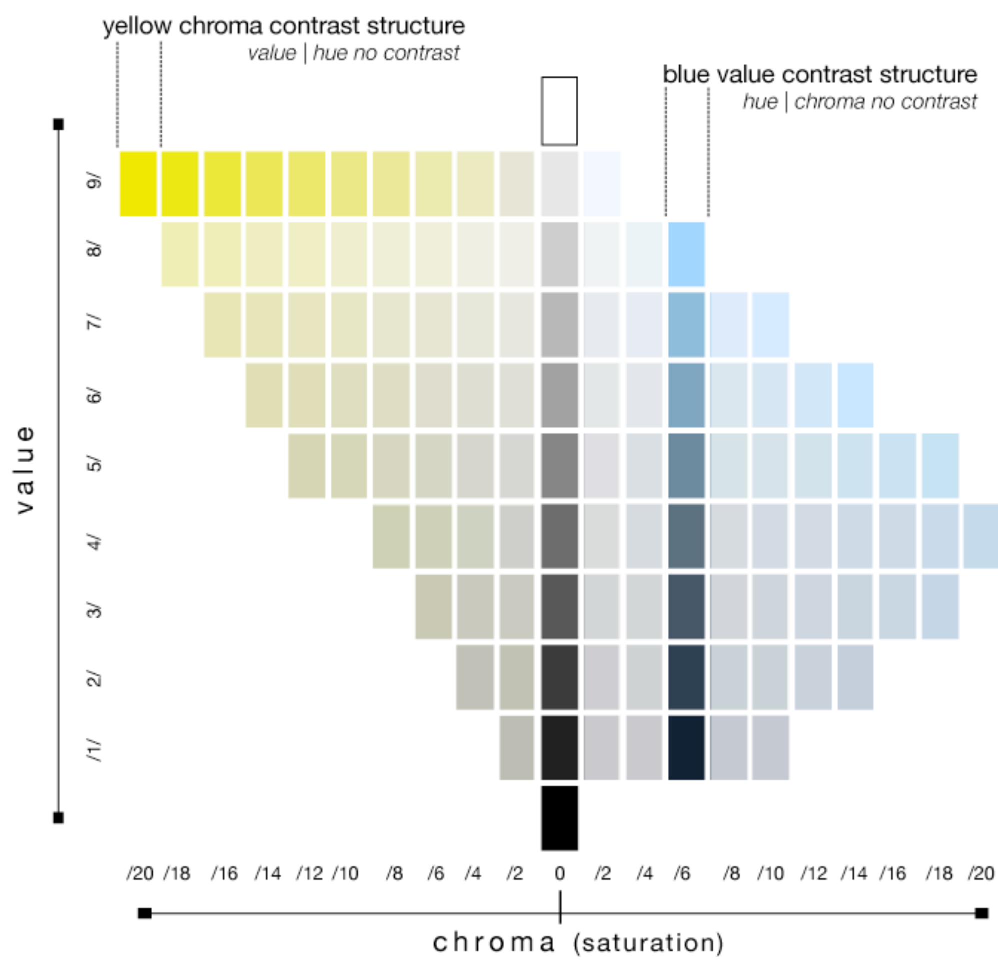


Figure 3.12: Color Selection Methodology.

3.3.5.2 Stimuli – Value / Chroma / Hue Categorization

The *Intrinsic Color Structures* experiment comprised 18 color combinations. The **value** color structures consisted of six hues that were derived from the primary (red, yellow, blue) and secondary (orange, green, violet) colors. Similarly, the **chroma** color structures consisted of six hues that were derived from the primary and secondary colors. The rationale for selecting the primary and secondary colors was based on their light to dark value dimension within the visible spectrum (Figure 2.8). The **hue** structure was formulated on variable value and chroma configurations of contrast. Following variable contrast configurations for each attribute, the number of possibilities for color organization was substantial. Consequently, it was necessary to limit the number of hue families to three (orange, green, blue). The 18 color structures were constructed on and derived from objective criteria established by color positions that were *intrinsic* to the Munsell System. By restraining the hue, value and chroma variables in this manner, the method of color selection placed significant limitations on the final color structure.

3.3.5.3 Value Structure Stimuli

Six value scales from the primary and secondary color families were constructed. Each of the six value structures consisted of 15 units equally contrasting in light to dark succession. The six value structures were constrained by hue, the color family did not change. While the value dimensions were successively contrasting, the hue family remained constrained. Employing a digital rendering technique, the method of color selection was based on the creation of a gradient blend constructed from a light value color to its dark value color within the same hue family. From a digitally constructed gradient scale, colors were visually analyzed for chroma. Although colors contrasted in value, no one was more or less saturated than another. Hence, the chroma and hue dimensions remained relatively constant in their visual appearance.

The 15 value units were sufficient in number to create a range of light/dark contrast. The structure distributed an attainable dimension of visually apparent gradients in lightness and darkness. From the 15 unit scale, three values were selected: one color light value, one dark value and one between the light and dark (Figure 3.13). The value structure characterized an intrinsic logic from which contrasting colors were derived. Establishing an order of contrast hierarchy was thereby based on objective criteria essential to light to dark contrast alone.

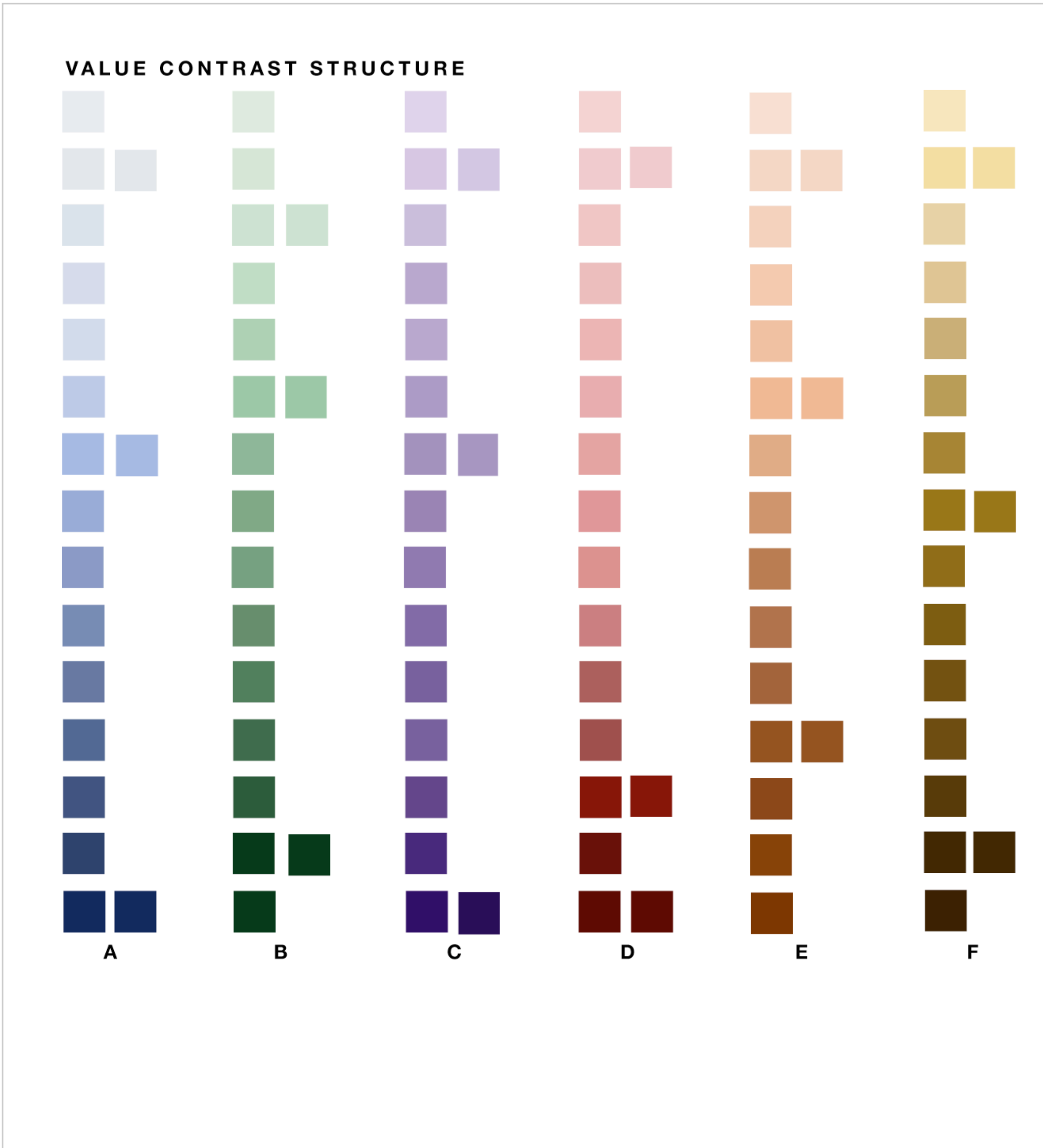


Figure 3.13: Six Value Structures – 3 Color Selections within the Structure.

3.3.5.4 Chroma Structure Stimuli

The chroma structure followed the same principles as the value structure. Six chroma scales from the primary and secondary color families were constructed. The chroma structure consisted of 20 units equally contrasting in saturation to a neutral gray dimension within the each hue family. The six chroma structures were constrained by hue since the color family did not change. While the chroma dimension was successively increasing, the value and hue family contrast remained constrained. The method of color selection was based on a gradient blend (scale) constructed from the saturated color to its neutral gray in a digital format. By converting colors to a gray scale in the digital format, the method of selecting colors of equal value was accomplished by visual comparison analysis. Appropriately, the value and hue dimensions remained similar in their visual appearance.

The 20 chroma units were sufficient in number to create a continuum of a fully saturated color to neutral gray contrast. The structure dispersed an attainable dimension of visually apparent gradients. Emerging from the 20 value units within each hue family, three colors were selected. One was a low chromatic gray, one highly saturated and one between the two (Figure 3.14).

The chroma structure characterized an intrinsic logic from which contrasting colors were derived. Establishing an order of contrast hierarchy was thereby based on objective criteria essential to chroma (saturation) contrast alone.

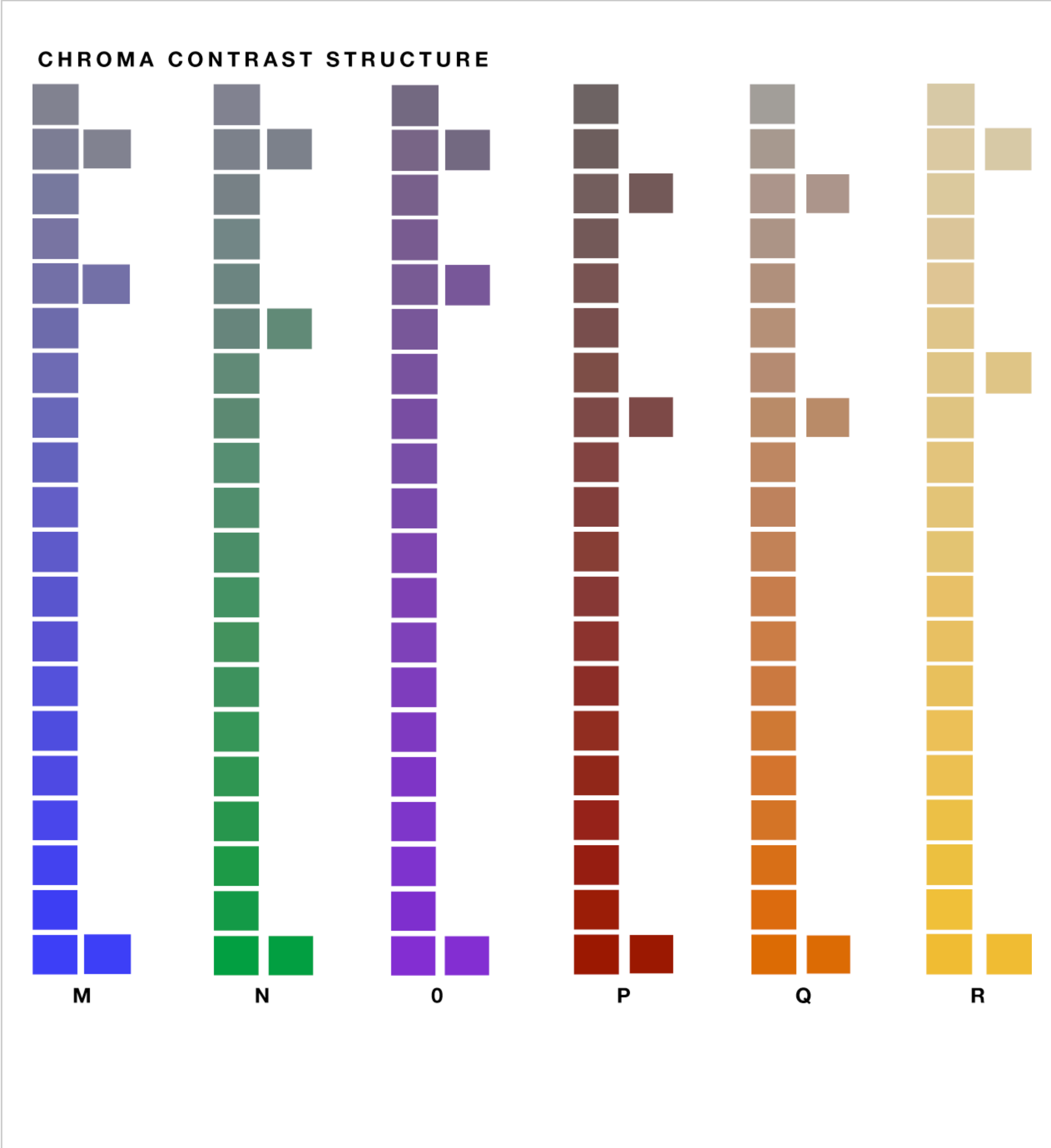


Figure 3.14: Six Chroma Structures – 3 Color Selections within the Structure.

3.3.5.5 Hue Structure Stimuli

The hue structure was formulated on variable value and chroma contrast configurations. To be consistent with six combinations within each structure, it was necessary to limit the number of hue families to four: orange, green, blue and violet. The yellow hue family was eliminated due to its lightness of value at full chroma. The hue red was eliminated since the pilot studies had demonstrated that individual preferences for red were significant. As previously noted, the effects of colors arise from culture, cognition, physiology and environment. Colors with long wavelengths are visually more stimulating than ones with short wavelengths. Red has a visible wavelength of about 750 nm (Figure 3.15).

Figure 3.15: Visible Spectrum Wavelength.

Consequently, red is "… the most stimulating color that will attract the eye faster than any other" (Gobé, 2001, p.78). Visible red induces physiological symptoms of emotional arousal that change the heart rate, skin resistance and the electrical activity of the brain (Kay and Maffi, 1999).

In addition, the *Atmospheric Sciences Data Center Website* reports the following: at sunrise and sunset, red or orange colors are present because the wavelengths associated with these colors are less efficiently scattered by the atmosphere than the shorter wavelength colors: blue and purple. A large amount of blue and violet light has been removed as a result of scattering and the long-wave colors are more readily seen: red and orange. These conditions warrant further study but were not applicable to the focus of this research.

It was hypothesized that contrasting hues with the same value and chroma would not create an objective hierarchy of color order. Contrasting hues of the same value and chroma should reside at the same level of hierarchical visual importance. If human perceptions of a hierarchical order were not objective, the motivating force behind the visual interpretation of color importance would be subjectively biased. Therefore, the method for structuring the hue attribute consisted of four distinct categories of contrasting relationships in value and chroma.

Four categories were constructed for the three-color hue contrast combinations. *Contrast Variable 1* consisted of two colors equivalent in value, two colors equivalent in chroma, and one color contrasting the other two in chroma and value. *Contrast Variable 2* category consisted of three colors equivalent in saturation; two of those colors were equivalent in value and one contrasted the other two in value. *Contrast Variable 3* category consisted of three colors contrasting in hue that sustained equivalent value and chroma. Category 3 was established to test the hypothesis that "contrasting hues with the same value and chroma would not create an objective hierarchy of color order." *Contrast variable 4* category was classified as sequential variation contrast. In this category, all three colors contrasted in hue, value and chroma (Figure 3.16).

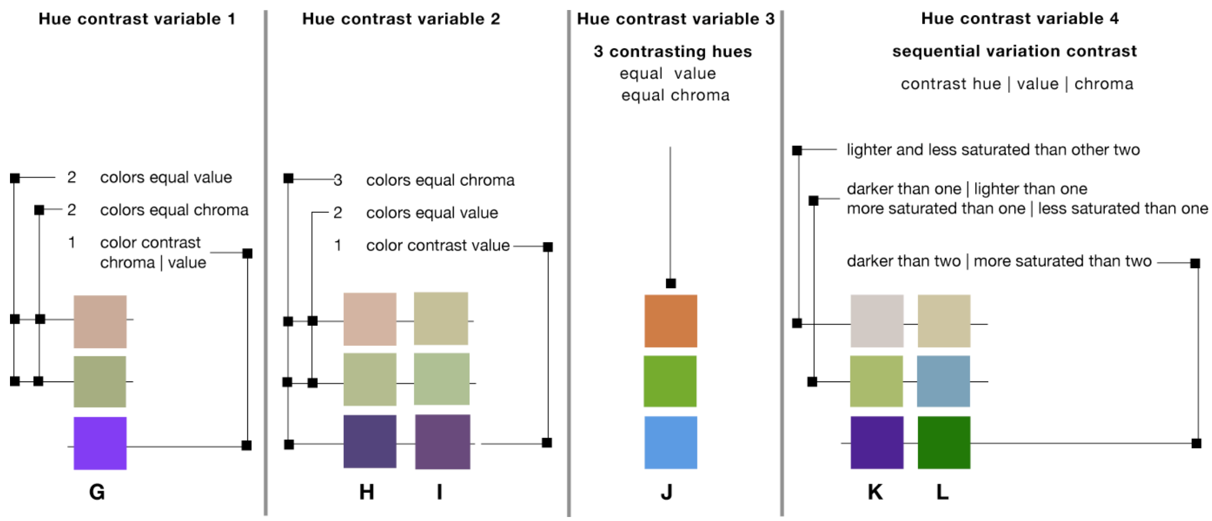


Figure 3.16: Six Hue Structures – 4 Categories of Contrasting Variables.

Within the four contrasting variable categories, the hue structure characterized an intrinsic logic from which contrasting colors were derived. Establishing an order of contrast hierarchy in hue was dependent upon contrast in value, chroma or both, thereby based on objective criteria essential to hue contrast.

3.3.6 Stimuli Output Tools

In order to achieve consistent contrast within the limitations of the color constructs derived from the Munsell System, the stimuli were constructed in Adobe *Illustrator*. Adobe *Illustrator* files were saved as *Portable Network Graphics* (PNG). PNG files are known to be compatible for raster and vector imaging. In addition,

> Raster refers to a pattern of parallel lines or dots also known as “bit maps” that form the display of an image projected on a display screen.
>
> Vector refers to a graphic image formed by points and joined by angles called paths projected on a display screen.

PNG files are stable and images maintain integrity. Therefore, file conversions from Adobe to Microsoft permitted relatively consistent color quality and color appearance. The structures were designed on a Macintosh G4 computer with an Apple flat panel cinema LCD display. A study was done to test the stimuli on the Windows Operating System and the 17" LCD display that would be used for the experiment. The color structure image transfer from MAC OS to Windows appeared consistent and no color adjustments were necessary. The intrinsic color structures were designed for digital media. Consequently, printed versions were expected to vary in appearance from the digital display.

3.3.7 Stimuli Sequence Order

To constrain human preference for order and visual sequencing, two progressions of the stimuli were presented. Considering that human response to the stimuli might differ from starting point to ending point, the 18 combinations were presented in a forward and reverse order.   The sequence of set one was arranged "A–R" [value 1-6 —» hue 7-12 —» chroma 13-18]. The sequential order of set two reversed the arrangement to "R–A" [chroma 18-13 —» hue 12-7 —» value 6-1]. In operation, one-half of the participants progressed through the color stimuli sequenced 1-18 [A-R] and the remaining half of the participants progressed through 18-1 [R-A] (Figure 3.17).

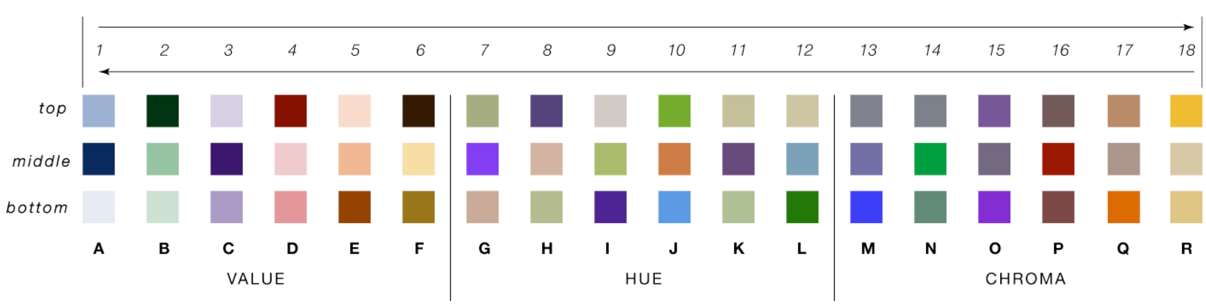


Figure 3.17: Color Structures Sequential Order and Dominant Color Position.

The top, middle and bottom position of the strongest contrasting color was evenly distributed among the 18 color structures. Five were positioned at the top, six were positioned at the middle and six were positioned at the bottom. One color structure was deliberately constructed with no contrasting variables other than the hue category (color combination 'J').

3.3.8 Gray Screen

A gray screen separated each of the 18 sequenced color stimuli. The gray screen function allowed the eye to refresh before moving to the next color image. Due to physiological reactions in the brain, colored afterimages appear after fixating on a color from 1 to 20 seconds (Figure 3.18). The afterimage is a perceptual phenomenon caused by the eye/brain system that produces the awareness of a color complement in response to viewing a color figure. Color complements are opposites on the color wheel (red–green | blue–orange | yellow–violet). In psychology complementary color representation is referred to as *opponent-colors*. For a few seconds, the complementary color appears when the eye shifts to some neutral (gray or white) surface. The precise color of this afterimage depends upon the wavelength composition of the original color stimulus.

Afterimage:
The perceptual phenomenon caused by the eye/brain system that produces the awareness of a color complement. Focus on the red dot for 20 seconds. Then, shift the eyes to the gray field. Red's opponent-color green will appear.

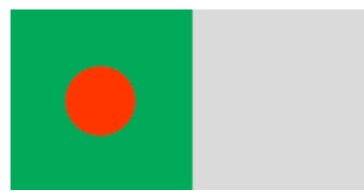


Figure 3.18: Afterimage.

Complementary colors:

High contrast colors which are opposite each other on a color wheel – red/green | blue/orange | yellow/violet.

3.3.9 Text / Type / Background

Since the *Intrinsic Color Structures* study was intended to address color composition in digital presentation software applications, the representation of color and text simulated a condition compatible with the purpose of the experiment. Pilot study #2 conducted in November (Figure 3.4) suggested that the human response to color prominence was not necessarily influenced by shape, motion, position or type. Before arriving at the final display format, 17 variations in the display format were prepared (Figure 3.19 - Appendix D). Typeface, text position, text body length and color orientation were arranged in an assortment of schemes. The display formats were presented to design educators and practitioners. After analyzing the problem, it was concluded that a body of text minimal in length would sufficiently establish color presence. In addition, the minimal length would constrain the variables of position, size, and text block shape.

The color and text blocks were generated in Adobe *Illustrator* and saved as PNG files for Microsoft *PowerPoint*. As previously described, color selections were derived from the hue, value and chroma scales (Figures 3.8 / 3.9 / 3.11). Each of the 18 color structures was sequentially presented on a separate screen in Microsoft PowerPoint. The colored text was placed on a white background.

A white background was used to ensure that the foreground text colors and the background color provided sufficient contrast. Color contrast and the screen display luminance contrast affect readability. The percent of primary screen display luminance for white is 100%. In the chapter "Human Factors for Color Display Systems: Concepts, Methods, and Research," Louis Silverstein states that "Color symbols presented on a light background are perceived as more saturated than the same colors presented on a dark background" (Durrett, 1987, p.36). The increased chromatic sensitivity resulting from screen display luminance generally facilitates color discrimination. Color contrast enhances performance at all levels of luminance contrast. Also, white is the most often-used background color for text in digital media. Working with color and type requires strong contrasts to arrive at legible combinations (Carter, 2002). In addition, white would not influence the appearance of the text color, thereby minimizing the effect of simultaneous contrast (Figure 3.20). Furthermore, most communication software and Internet browsers default to a white background. Moreover, the white background would not be affected by the Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD) color display resolution.

Figure 3.20: Simultaneous Contrast.

A neurophysiological phenomenon that occurs when the surrounding color influences how a color is perceived. The centered dot in each color field is the same color as the strip below.

The color stimuli were presented in Frutiger, a *sans serif* typeface. Frutiger is known to work well for text and display design. The design of Frutiger "geometry" was intended to reduce the severe edges of the generic *sans serif* faces like Helvetica and Futura, and to improve the legibility of characters (Figure 3.21).

Serif – type with serifs:
a fine line finishing off the main strokes of a letter at the top and bottom of a letter form.

Times New Roman

Sans Serif – type without serifs:

Frutiger

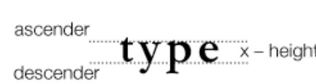


Figure 3.21: Type Description.

Every typeface possesses unique qualities that include proportion, weight and width (Carter, 2002). In the experiment, the typeface and type size remained constant for each of the 18 color structures. No alterations were made to the kerning or space between letters or to the leading (space between lines). Since kerning and leading affect the amount of white space around the letters, both factors influence color appearance. A greater amount of white space between the letters produces less color contrast. In addition, the anatomy of the typographic characters used within the text block comprised letterforms that were open and closed, angular and curved, and with ascenders and descenders.

3.3.10 Text Block and Screen Position

The text was composed of two single-spaced lines that were approximately the same length. The two lines of text, identified as text blocks, remained constant throughout the 18 color structures. Each screen contained three text blocks arranged in a staggered position on a white screen background. The staggered arrangement was utilized to minimize the effect of sequential order by position or placement. Predictable arrangement of visual order moves from top to bottom and left to right. Descriptively, the text blocks were positioned middle top, right middle and left bottom (Figure 3.22).

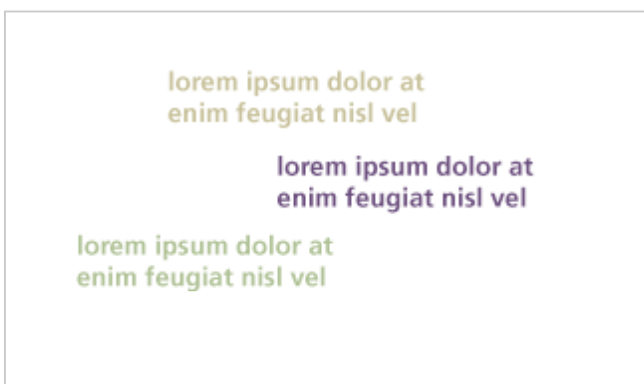


Figure 3.22: Text Position + Typeface.

3.3.11 Text Content and Meaning

To avoid confusing meaningful text of various hierarchical levels of importance, the two lines of text were composed in a Latin phrase commonly used as “dummy text” in graphic design comprehensives. It is a long established fact that a reader will be distracted by the readable content of a page when looking at its layout. The point of using Lorem Ipsum is that it has a fairly normal distribution of letters, and has been the industry's standard “dummy text” ever since the 1500s. Adobe *Illustrator* and many other software publishing packages and web page editors use Lorem Ipsum as default model text.

3.4 INTRINSIC COLOR STRUCTURES EXPERIMENT

The following is a description of the *Intrinsic Color Structures* experiment. The topics of which include: an overview and explanation, procedures, instrumentation and method of data collection.

3.4.1 Research Design Instrument Overview

The *Intrinsic Color Structures* experiment was divided into two sections. Section one consisted of the test for color deficiency and section two provided the means by which the color stimuli were presented. The experiment included a linear sequence of 71 screens (Figure 3.23 - Appendix E). In order to accommodate a reversed sequence of the color stimuli, the 71 screens were duplicated. One-half of the participants viewed "forward" sequence and the other half viewed the "reverse" sequence. The presentation was "looped" to permit seamless continuity.

The name of the experiment and researcher were identified on the first screen. The second screen identified the title of the color deficiency test: *Dvorine Pseudo-Isochromatic Plates*. In the subsequent screen, an explanation and instructions for the color deficiency segment were presented. Following the 15 Dvorine Color Plates, a title screen identified the intrinsic structures study. Continuing, the instructions for the experiment were provided visually and verbally. Thereafter, a "begin" screen acted as a holder permitting the administrator to start a timer as the participant advanced to the first color stimuli screen. The participants advanced independently through the 18 color structure screens. An "end" screen finalized the experiment.

3.4.2 Explanation and Instructions for Experiment

Upon completing the test for color deficiency, the administrator gave the participants oral and written descriptions of the experiment. Participants were tested one person at a time. The color structures were presented in a linear sequence made operational through Microsoft PowerPoint.

It was explained that the participant would see a sequence of 18 screens that contained two lines of text (text blocks) in three different positions and in three different colors. Additionally, they were informed that the text blocks would be identical in typeface and type size with the same wording throughout the experiment. They were told the text would be in Latin and the content would be meaningless. They were asked to identify the text block that appeared to be the more important or dominant. They were to identify the text block verbally by indicating its position on the screen: top, middle or bottom. Identification by position was important since color naming would be inconsistent from one person to another. If no one text block appeared to be visually more important than the other two, they were to verbally respond *none* to the administrator. It was explained that they would advance through the screens at their own rate and that they had as much time as necessary to identify the location of the dominant color in the text block. After each response, the participant would advance to the next screen by pressing the right arrow key on the keyboard. Also, they were informed that each of the 18 color screens would be followed by a blank gray screen that would allow the eyes to refresh and clear the afterimage.

3.4.3 Procedure

Participants advanced through the stimuli one screen at a time at their own pace. So that the response time could be measured for task efficiency, participants were asked to wait for the administrator's permission before advancing to the next color screen. When the participant advanced to the following color text screen, the administrator started a digital timer. Upon hearing the participant's verbal response, the administrator stopped the digital timer. Participants were instructed to advance to the gray screen and wait for a verbal cue before advancing to the color text screen. After recording the response and elapsed time, participants were given a verbal cue to advance to the next color screen.

3.4.4 Method of Data Collection and Instrumentation

Two types of data were collected in the experiment. Data generated by a participant's response to the stimuli was identified as *task effectiveness*. Data generated by a participant's time to complete the task was identified as *task efficiency*. The instrument used to collect each data type was a software program named Usability Datalogger. The instrument provided a means to electronically record *task effectiveness* and *task efficiency*. The instrument was an application created in Microsoft Excel that was authored by Todd Zazelenchuk, Ph.D. Lead User Research, Global Consumer Design, Whirlpool Corporation.

The Usability DataLogger was adapted and configured to suit the needs of data collection for the *Intrinsic Structures* study (Figure 3.24 - Appendix F). The data logger included three major entry logs: *Administration Log, Tasks Log,* and the *Participant Log*. Entries in the **administration log** included: participant name; effectiveness labels with effectiveness value measure and the sequencing of tasks associated with the 18 color structures. The **tasks log** provided a recording mechanism identifying the stimuli in the experiment. In this case, the tasks were the color structures sequenced 1-18 (A-R). The **participant log** included the participant's name and experiment date. In addition, the participant log included the **Start-Stop Timer**. Under the **score** column in the participant log, a pull down menu listed the color position for each of the 18 color stimuli screens: *top / middle / bottom / none*. The record of time to complete the task was entered under the **time** column adjacent to the score. Participant logs accommodated 12 subjects. Therefore, nine separate data logs were required to create a data summary document for the 99 total participants.

CHAPTER 4

RESEARCH METHODOLOGY II

4.1 Data Collection

The aim of the study was to produce quantitative results for task effectiveness: participants' response to the color stimuli and task efficiency: participants' time to complete the task. The data was collected during the course of the experiment as each participant responded to the stimuli. The administrator was positioned near the participants' testing station. Using the Usability Datalogger instrument, the administrator recorded participant's response. Participants were not permitted to advance through the sequence until receiving a vocal "go-ahead" to start from the administrator. At the beginning point, the administrator started the timer on the Datalogger. Upon hearing the response to the task, the timer was stopped. The administrator recorded the time in the time column and the position of the color in the score column in the Datalogger.

4.2 Data Analysis

The data analysis was computed for task effectiveness as ordinal scale measurements for task effectiveness. For task efficiency, minimum, maximum, mean and median scores were computed. Additionally, for each of the 18 color structures, Chi-Square analysis was calculated for the 99 participants. To analyze task effectiveness, three ANOVA calculations were made for value, hue and chroma. The rationale for Chi-Square and ANOVA analysis is explained later in this chapter.

4.2.1 Ordinal Scale Tabulation Results

Data summaries collected from the datalogger were tabulated for task effectiveness. The task effectiveness (frequency) illustrates the number of respondents selecting a particular color in a grouping of three. Participants had the option of selecting "none," thereby acknowledging that no one color was more dominant than the others. In 17 of the 18 color structures, the recorded response for task effectiveness confirmed that a significantly high number of the 99 participants agreed upon one color being more dominant than the remaining two in a frequency of choice (Table 4.1). As noted in Table 4.1 and shown in Figure 4.1, a fairly high percentage of the respondents (40 of 99) concurred that no one color was dominant for the color structure (J).

Table 4.1: Task Effectiveness.

Task Effectiveness		Color Position on Screen			
task		top	middle	bottom	none
VALUE					
1	A	1	98		
2	B	96	1	1	1
3	C		99		
4	D	93	4	2	
5	E	1	3	94	1
6	F	87	5	5	2
HUE					
7	G	1	98		
8	H	95	3		1
9	I		5	94	
10	J	18	13	28	40
11	K		96		3
12	L		5	94	
CHROMA					
13	M	1	2	96	
14	N	1	98		
15	O	2	4	90	3
16	P	1	98		
17	Q		1	98	
18	R	98	1		

Task Effectiveness

The frequency of response for "task J" hue 4 represented an anomaly in relationship to the other 17 color structures. The participant response to this hue structure was predicted, since the variables of value and chroma were equal.

Contrast of hue alone was not enough to determine a clearly dominant color. As noted, 40 of the 99 respondents determined that no one color was dominant.

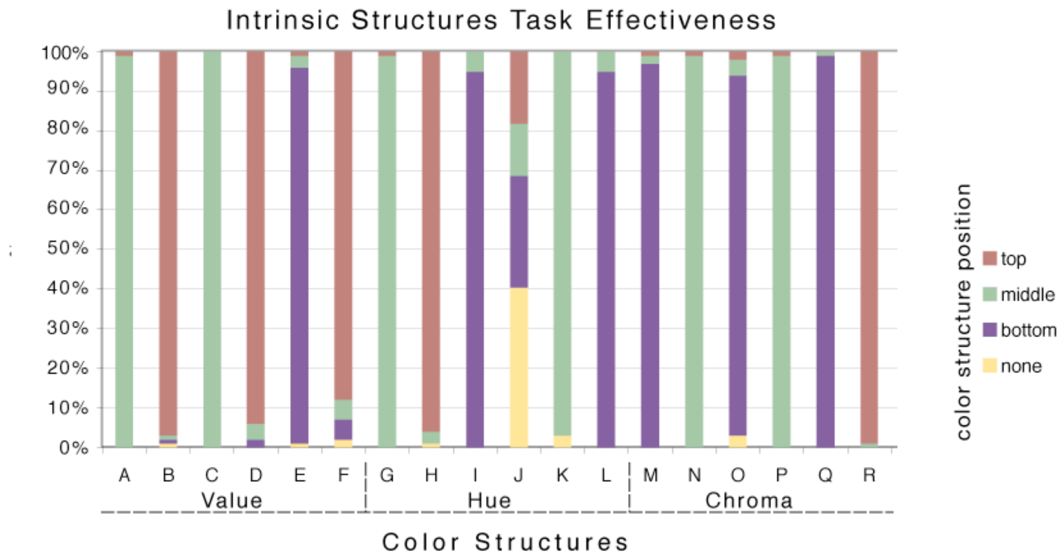


Figure 4.1: Task Effectiveness Percentage Response to Value/Hue/Chroma Stimuli.

Frequency for hue 10 / task "J" represented an anomaly in relation to the other 17 color structures. As the variables of value and chroma were equal and the hue contrasting, it was hypothesized that the participant response to this hue structure would be indiscriminate. Contrast of hue alone was not enough to determine a clearly dominant color. As noted in Table 4.1, 40 of the 99 respondents determined that no one color was dominant, 28 selected the bottom color, 18 selected the top color and 13 selected the middle color. No other color structure received this type of frequency distribution.

The color structures were ranked by frequency response and illustrated in Figure 4.2 and Table 4.2 (Appendix G). The ranking order lists the largest number of participants responding to a particular color structure to the fewest number responding to a particular color structure. The frequency of response summary broke down into nine numerical categories. Color structure C (value 3) received a frequency response of 99, which was 100% of the participants' response. For color structure "J" (hue 10), 40 participants agreed that none was more dominant than the other (Table 4.2 – Appendix G).

color structures ranked		frequency response				
C	value 3	0	99	0	0	**99**
A	value 1	1	98	0	0	
G	hue 7	1	98	0	0	
N	chroma 14	1	98	0	0	
P	chroma 16	1	98	0	0	
Q	chroma 17	0	1	98	0	
R	chroma 18	98	1	0	0	**98**
M	chroma 13	1	2	96	0	
K	hue 11	0	96	0	3	
B	value 2	96	1	1	1	**96**
H	hue 8	95	3	0	1	**95**
E	value 5	1	3	94	1	
L	hue 12	0	5	94	0	
I	hue 9	0	5	94	0	**94**
D	value 4	93	4	2	0	**93**
O	chroma 15	2	4	90	3	**90**
F	value 6	87	5	5	2	**87**
J	hue 10	18	13	28	40	**40**

Figure 4.2: Ranked Frequency Response.

Task efficiency, time to complete the task, supports the predicted indecisive frequency response factor found for hue 4 in the task effectiveness table. The time responses reinforce the frequency results in a sensible way. The maximum time to complete the task was 16 seconds with a mean score of 3.4. The task efficiency represented a slower response time and indecisiveness from participants (Table 4.3 and Figure 4.3).

Table 4.3: Task Efficiency Scores.

Task Efficiency		Time in Seconds			
task		Min	Max	Mean	Median
VALUE					
1	A	1.0	5.0	1.8	2.0
2	B	1.0	6.0	1.6	1.0
3	C	1.0	4.0	1.5	1.0
4	D	1.0	6.0	1.5	1.0
5	E	1.0	7.0	1.5	1.0
6	F	1.0	14.0	2.0	2.0
HUE					
7	G	1.0	3.0	1.4	1.0
8	H	1.0	4.0	1.5	1.0
9	I	1.0	5.0	1.5	1.0
10	J	1.0	16.0	3.4	2.0
11	K	1.0	4.0	1.6	1.0
12	L	1.0	4.0	1.6	1.0
CHROMA					
13	M	1.0	5.0	1.5	1.0
14	N	1.0	3.0	1.4	1.0
15	O	1.0	11.0	1.9	2.0
16	P	1.0	3.0	1.4	1.0
17	Q	1.0	6.0	1.6	1.0
18	R	1.0	4.0	1.7	2.0

Task Efficiency

Task “J” hue 4 represented an anomaly in relation to the other 17 color structures. The participant response to this hue structure was predicted, as the variables of value and chroma were equal.

Contrast of hue alone was not enough to determine a clearly dominant color. As noted, 40 of the 99 respondents determined that no one color was dominant.

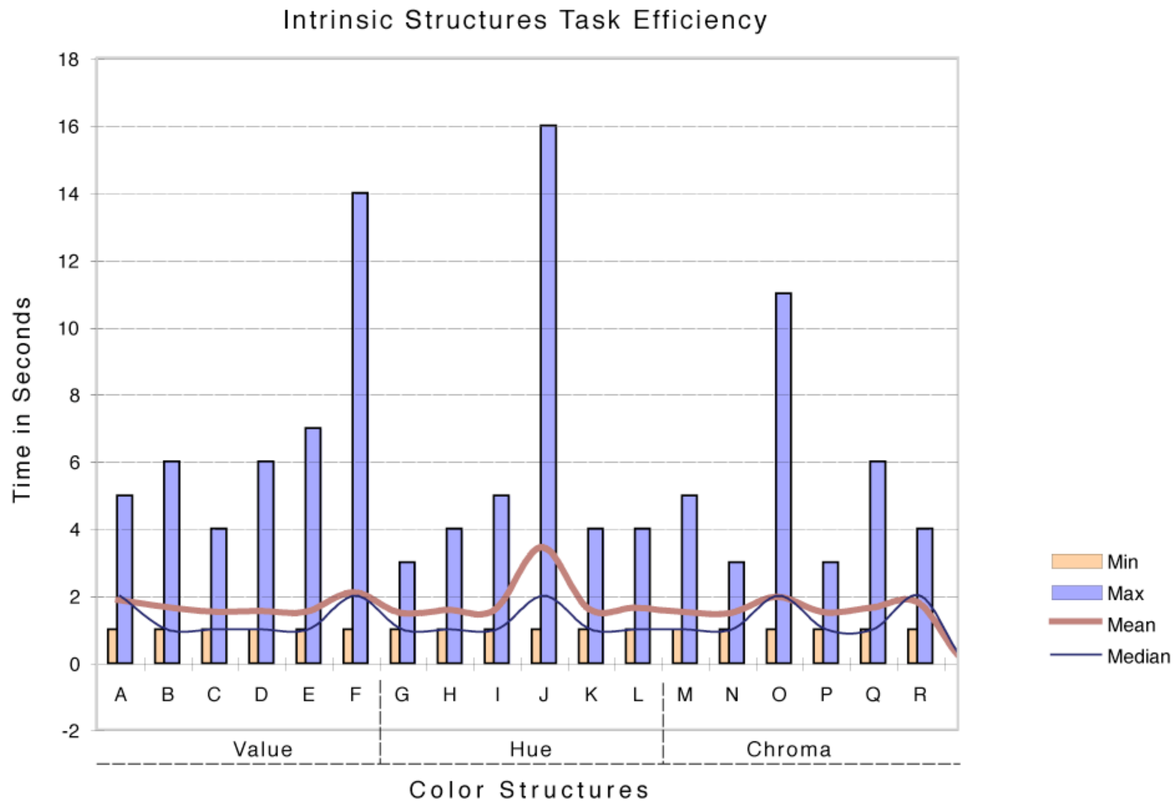


Figure 4.3: Task Efficiency Response to Value/Hue/Chroma Stimuli.

4.2.2 Chi-Square Analysis for Task Effectiveness - Frequency

The typical wide spread statistical model used in communications and education research is the Chi-Square analysis (Williams, 2001). Chi-Square analysis is a nominal scaling that permits the comparison of the categories among themselves and of how the contrasting samples differ in relationship to the categories. A nominal scale is a specific scheme for assigning numbers or symbols to designate categories that represent unique characteristics (Williams, 2001). Values for the Chi-Square analysis are identified by the x^2 symbol.

The research results required setting up the null hypothesis of no difference. The null hypothesis "… is a statement that statistical differences or relationships have occurred for no reason other than laws of chance operating in an unrestricted manner" (Williams, 2001, p.63). For the intrinsic structures experiment, the null hypothesis would stipulate that average ratings for the 18 color structures would not be different one from another. The Chi-Square analysis allowed the rejection or acceptance of the null hypothesis. A typical level of probability for rejecting the null hypothesis is set around .05 long-term probability (Williams, 2001). If the experiment were to be conducted over again, the probability of getting the same results of the first is significantly favorable. Calculations for Chi-Square analysis used the following formula: [observed frequency – expected frequency^2] ÷ expected frequency.

$$x^2 = \Sigma \left[\frac{(O - E)^2}{E} \right]$$

Figure 4.4: X^2 Formula.

The Chi-Square analysis was used to measure the agreement between categorical data and the frequency of response. Chi-Square analysis predicted the relative frequency of outcomes in each color category. The data analysis for the intrinsic structures experiment found that the probability calculated for the null hypothesis is less probable, thereby rejecting the null hypothesis and accepting the research hypothesis. The probability factor for each of the 18 color structures was found to be less than .001 *(p < .001)*. Since the p value is less than .001, the distribution of the data was found to be significant.

The x^2 single-sample calculations for the 18 color structures are represented in Figure 4.5 and Table 4.4 (Appendix H). Figure 4.5 delineates the observed and expected frequency response for each of the 18 color structures; the degrees of freedom *(df)*; the observed significance level *(p value)* which is the smallest fixed level at which the null hypothesis can be rejected; and the *distribution*. The bar chart summarizing the frequency data presents evidence that within controlled color structures, value (light/dark) and chroma (colorful/colorless) contrasts play a prominent role in the participants' response to selecting a dominant/important color. Within the hue category, the 8.515 Chi-Square value for the "J" color structure is represented by a *p* value less than .001.

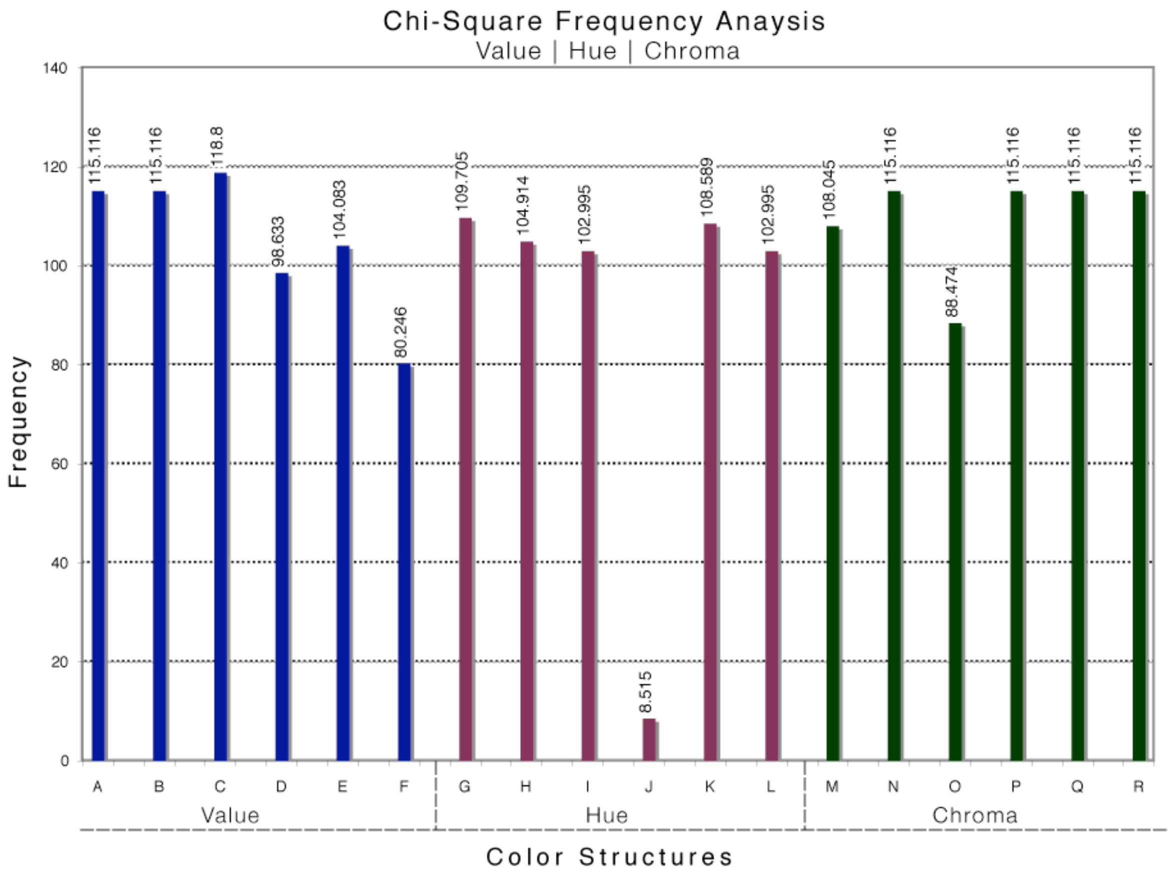


Figure 4.5: Chi-Square Frequency (Effectiveness) Analysis.

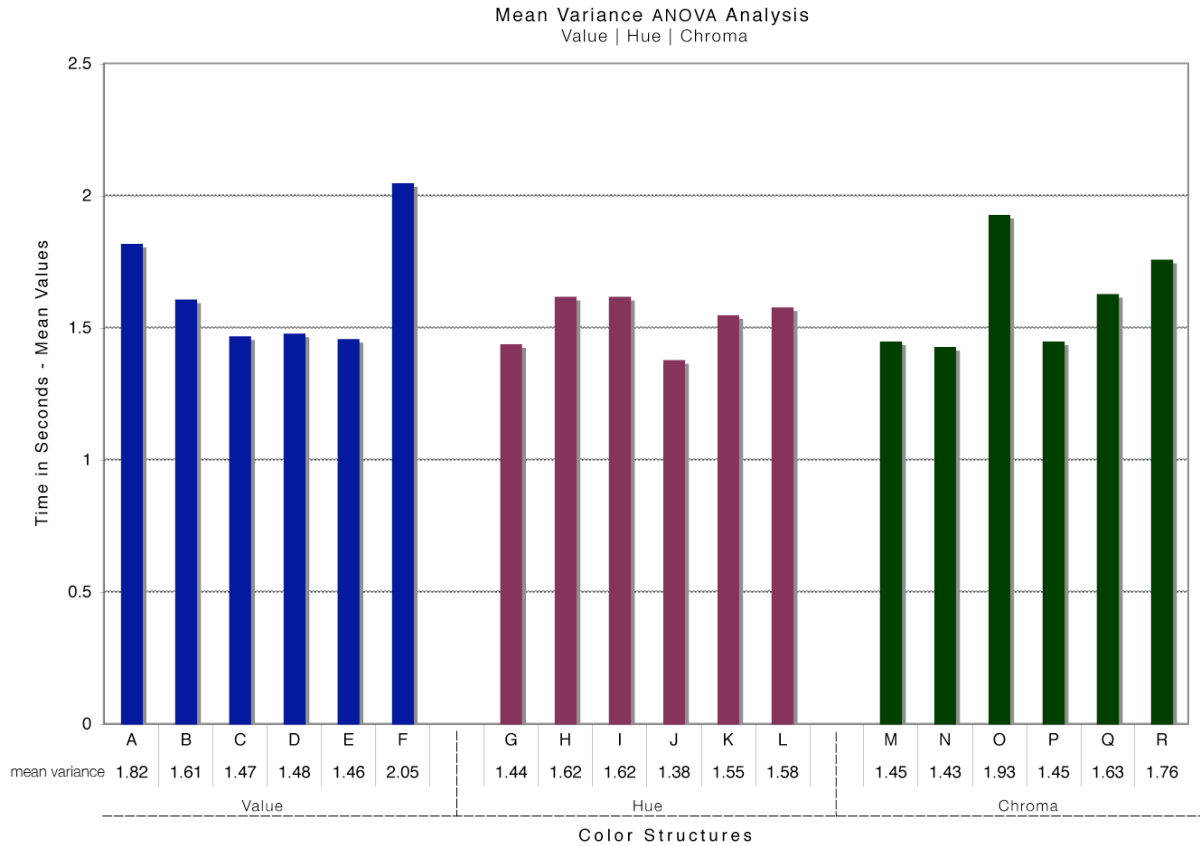
4.2.3 ANOVA Analysis for Task Efficiency

Analysis of Variance is a way to test the equality of three or more means at one time by using variances. To determine if the responses within each of the three groups were different, three ANOVAs (Analysis of Variances) were calculated: one for value (Tables 4.5 / 4.6 – Appendix I); one for hue (Tables 4.7 / 4.8 – Appendix J); and one for chroma (Table 4.9 / 4.10 – Appendix K). A summary of these tables is illustrated in Figure 4.6. The calculations permitted analysis *between group variation* and *within group variation*. Since every person taking the test responded to every item within each set, a repeated measures ANOVA was used to control for variance attributable to individual test takers (Winer, 1971).

ANOVA method of computation: In terms of the details of the ANOVA test, the number of degrees of freedom *("df")* for the numerator (found variation of group averages) is one less than the number of groups (593) for each group. The number of degrees of freedom for the denominator (so called "error" or variation within groups or expected variation) is the total number of items (594) minus the total number of groups (6). The ***formula for F ratio:*** F = (found variation of the group) ÷ (expected variation of the group averages). The F ratio was computed from the ratio of the mean sum of squared deviations of each group's mean from the overall mean [weighted by the size of the group] ("Mean Square" for "between") and the mean sum of the squared deviations of each item from that item's group mean ("Mean Square" for "error"). The *mean* is determined by dividing the total "Sum of Squares" by the number of degrees of freedom. That is, the between group variation divided by its degrees of freedom, (Intrinsic Structures F 95 [490.5] = 2.21).

The analysis of variance followed the application of Newman-Keuls method (Winer, 1971). The analysis of variance is summarized in each of the three groups (Figure 4.6). The data summaries for time variances within value are shown in Table 4.6 (Appendix I). Time variances in hue are represented in Table 4.8 (Appendix J). Variances within chroma are depicted in Table 4.10 (Appendix K). The F ratio was used in testing a hypothesis about reaction time as a function of the stimuli (value, hue and chroma). Based on the hue, value and chroma tables, a summary of the time variances mean analysis is shown respectively in Figure 4.6.

Inspection of the data from the ANOVA summary calculations for the *value color structures* demonstrates consistent variances for values *C, D, and E.* The time variances for values *B, A, and F* increase significantly. Given that the value structures were presented in the first linear sequence for one-half of the participants and last in the linear sequence for the remaining half of the participants, human fatigue would not appear to be a factor.



Assuming the null hypothesis: the probability of the value result is less than .001

Figure 4.6: ANOVA Time Variances Mean Analysis.

4.3 Findings

Hue, value and chroma categories generated *significant* probability results. Contrast within the value structure and within the chroma structure was dependent upon constraining the two remaining variable attributes. Within the hue contrast categorization, at least one additional contrast variable was required.

The data summaries in Figure 4.1 specified a strong acknowledgement for chroma (saturation) contrast. Participants selected the most saturated color within each of the six structures. Four of the six chroma structures received a 98% of the population agreement to the dominant color. However, the ANOVA time variance analysis within the chroma category shows significant differences in response time (Figure 4.6). It is not certain what contributed to the time variance within the chroma category. One might speculate the time variances within the chroma category are related to particular hues. As described earlier, the chroma combinations comprised six different hue families. In these combinations hue and value remained constant while chroma (saturation) was contrasted. This appears to suggest that some hue families are not as convincing and decisive as others.

The value structures charted a fluctuating frequency response rate from the population. Among the value structures, participants selected the darkest contrasting color. In one of the value structures, 100% of the population agreed upon a dominant color (Table 4.2, Appendix I). At the other end of the scale, one value structure demonstrated a frequency response at 87%. This same structure revealed a task efficiency level at a greater number of seconds to respond to the stimulus. Within the value category, ANOVA time variances specify a relatively similar response time to determine the dominant color stimulus.

The contrast of hue category consisted of four contrasting variable structures. Given the composition of the four contrasting categories, participant response to stimuli demonstrated a pattern that recognized contrast in all three variables (hue, value and chroma). One of the six hue structures followed the methodology of color composition as defined for value and chroma. Specifically, this structure was composed of contrast in hue with no contrast in value and saturation. It was hypothesized that the frequency response to this structure would be erratic and inconsistent. As represented in Table 4.1 and Figure 4.1, 40% of the population recognized no one color to be dominant. Chi-Square analysis confirmed this finding to be significant (Table 4.4, Appendix H). Contrast of hue alone was not enough to discern a clearly dominant color. Demonstrating indecisiveness among the population, the timed reaction to this color stimulus reinforced the frequency response factors. While this color structure does not demonstrate a hierarchical order, it does advance the proposition that the colors are perceived to be similar in importance.

The remaining five hue summaries were similar in percentage range to value. One hue structure received 98% of the population in agreement on the dominant color. The composition of the hue structure consisted of contrast with all three variables (hue, value and chroma). In addition to contrast in hue, the three colors contrasted in light to dark value and from less saturated to a greater saturation. When two colors were similar in value and chroma contrast and the third darker and more saturated, a significant percentage agreed upon the dominant color.

4.4 Quality Considerations

Quality considerations were based upon validity, generalizability, objectivity and reliability. These considerations elucidate a theory that support the proposition that color hue, value and chroma categorization influence cognitive interpretation and human response to hierarchical combinations within each classification.

4.4.1 Validity

Quality measures stem from the characteristics of cognitive constructionism theoretical perspective. Validity and generalizability are systematic factors included in the research design and are intended to generate efficacy in the research findings. The research methodology takes into account those color factors that can be objectively qualified. Factors related to subjective considerations were not addressed. All participants were screened for color deficiency as depicted in the Dvorine Pseudo-Isochromatic Plates, (Figure 3.10, Appendix D). The construct validity of the experiment was operationalized through the use of the Munsell Notation System. Objective measures were determined by Munsell's organization of the color attributes and vocabulary. The color combination categories were consistent for all participants. The principal investigator administered the color deficiency test and the *Intrinsic Color Structures* experiment. As the stimuli were generated through digital presentation technology, the experiment simulated reality.

4.4.2 Generalizability

The population of this study was college students from North Carolina State University. Therefore, transferability and generalizability are directed to a specific population. However, the purpose of the proposed study was to generalize to a theoretical idea. External validity is based upon the number of participants and the theoretical orientation of derivative color categories.

A purposeful representative sample type describing a particular population was employed. Students were recruited to participate in the experiment to ensure a representative selection of the population. This population represented the general gender, age and area major characteristics of the enrollment in the Departments of Communication, Anthropology and Sociology at North Carolina State University. The sample size of 99 represented a significantly greater number than needed for credible data.

Percentage data for task effectiveness was exceptionally favorable. Where predicted, mean scores for task efficiency were steady. Chi-Square data analysis for task effectiveness clearly illustrates a significant probability that the results were not due to chance alone. ANOVA analysis for task efficiency compared the elapsed time differences within value, hue and chroma categories. The analysis illustrated that some color structures were more stable than others.

The principles of color contrast developed for this study are generalizable to color theory for projected screen display. However, the results from this study may not be generalizable to conditions other than screen luminance and projection media. Applying these principles of color contrast to alternate variables manifested in reflective surfaces of pigment, background, and solid materials deserve similar research experimentation.

4.4.3 Objectivity

The objectivity of the experiment was rooted in the methodology. The methods of the experimental design were explicit and replicable. Participants were screened for color deficiency and tasks were clearly defined. The influences of context, audience and the visual form of the application were not compromised or mediated.

Upon completing the instructions for the experiment the participants advanced through the color stimuli at their own pace. Participants selected the perceived dominant color by position on the screen and verbally identified the dominant color by its location on the screen.

In the course of the experiment, the researcher functioned as a non-biased, objective observer. The researcher recorded the participants' response to the stimuli and the lapsed time to stimuli response. The task effectiveness and task efficiency response was calculated for 99 participants. Data from the instrument was calculated numerically and percentages were based upon the 99 participating individuals. Chi-Square analysis measured task effectiveness and ANOVA analysis measured task efficiency. The measuring instrument (data logger) was consistent for all participants.

In addition, the researcher was the designer of the derivative color combination systems. The color stimuli selected for the experiment was not compromised by subjective prejudice. An objective color selection methodology was employed. The stimuli were the same for all participants with only the sequence of the stimuli reversed in order. The experiment can be replicated and administered by anyone with or without a design education in color application and theory. The structure of the stimuli presentation and data-recording instrument contributes to internal validity.

4.4.4 Reliability

The experimental design for the study was operationalized through digital simulation, Adobe and Microsoft software. The digital simulation represented a duplication of the real world condition in which color is organized, managed and experienced. The digital environment was the mode used to present the color combination stimuli for the experiment. The principles for derivative color combinations formulated by hue, value and chroma construction in digital environments were the focus of the study. The design and presentation of color stimuli were fundamentally inherent/intrinsic. The data-recording instrument provided computer generated calculations. Chi-Square and ANOVA data analysis produced dependable probability results.

4.5 Inferences

The natural inferences of the study support the proposition that there is a natural relationship between objective color ordering principles and human comprehension. The consequences of the study could have an extraordinary effect on color selection, application, interpretation and teaching. The study offers an alternative to current methods and techniques for color selection anchored in subjective psychological intentions and marketing tactics.

Understanding color recognition, related to perceived order and importance, could have useful applications to a naturalistic, real world display of visual information systems based upon objective color selection strategy. Real world color application also includes visual recognition tasks. These are tasks in which an individual looks at the context of color organization as a means of ordering information to determine importance. Color adds significance to visual communication as it accentuates and makes perceptible the identification of that which is perceived first, as the main idea, before decoding additional elements in the message. Perceived hierarchy represents a sequence of visual commands in the language of color. Therefore, color adds functionality and definitive relationships to many informational entities – signaling systems, way-finding systems, maps, instrumentation, educational/instructional material, etc. Effective color communication permits users to view, retrieve, access, decipher, interpret, understand, and experience a variety of information systems in a meaningful, valid and authentic manner. As stated earlier, color communication implies meaningful usability.

This research provided a rationale for the basis of understanding color selection processes. Generally, design literature accepts the proposition that color harmonies are fundamentally described as primary, secondary, tertiary triads and so on. A primary color harmony comprising red, yellow and blue does not in itself establish a visual hierarchy. By analyzing the hue, value and chroma scheme of a primary harmony or any other fundamental harmony, color-coding and categorization are possible (Figure 4.7).

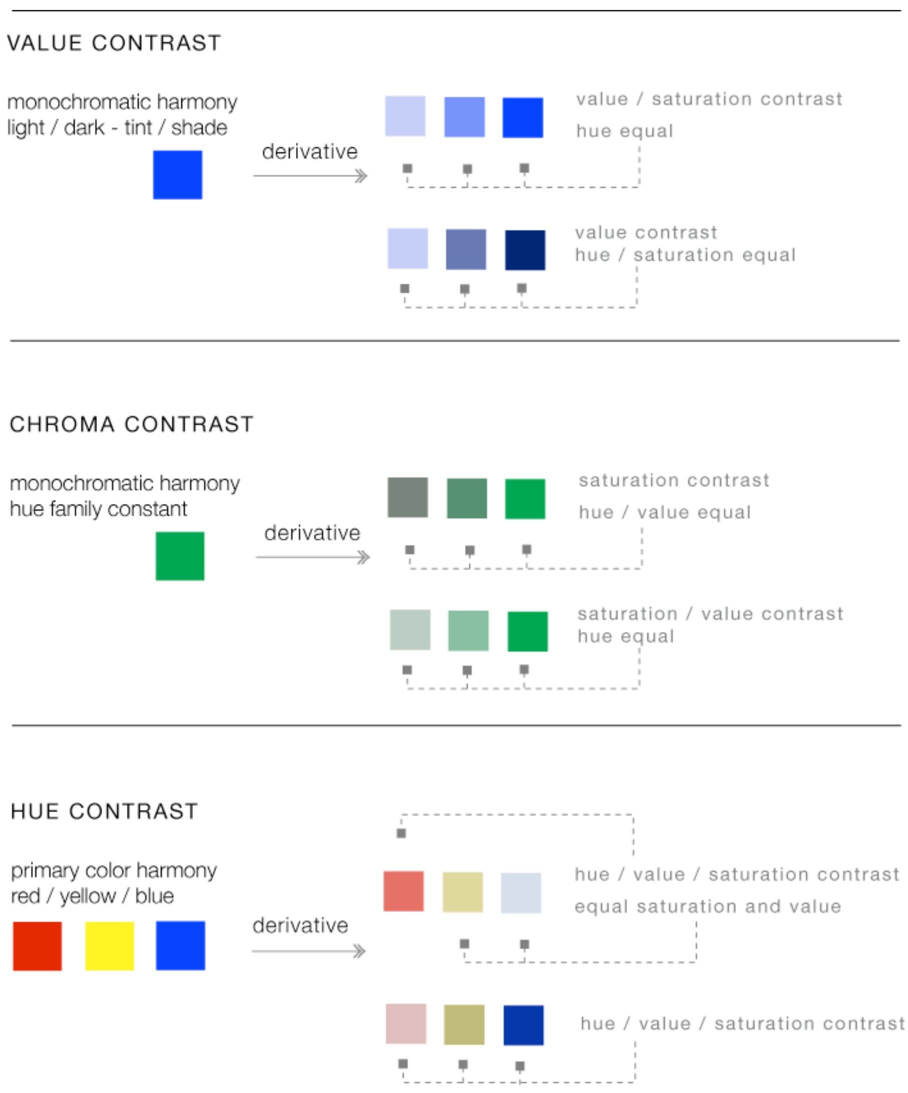


Figure 4.7: Derivative Color Harmonies.

Three color organization patterns form hierarchical contrast patterns. Value and chroma structures generate two contrast levels. At the first derivative level, value is the contrasting attribute; hue and chroma can remain equal. At the second derivative level, value and chroma are the contrasting attributes and hue must remain the same (Figure 4.8). The value and chroma structures imply that the following visual characteristics occur: *level 1* – two colors reside in the same hierarchical visual space and *level 2* – three colors reside in three different levels of visual hierarchical space.

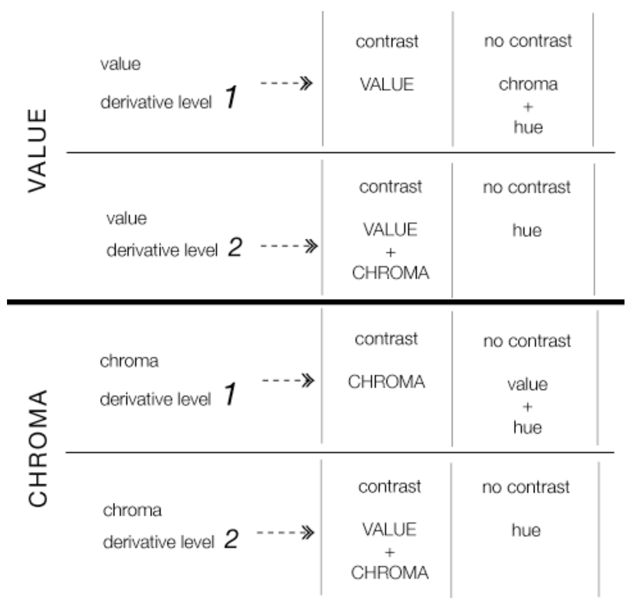


Figure 4.8: Derivative Levels of Value and Chroma Contrast.

The hue structure yields four levels of contrast. Within the hue structure, visual differentiation shifts. As the research study demonstrates, contrast in hue alone (no contrast in value or chroma) does not create a visual hierarchy. This relationship is identified as *derivative level 0.* Inferring from the findings, no one color is dominant. Therefore, all three colors in this structure reside in the same visual space. At least two attributes must be contrasting to establish a hierarchy in the hue structure (Figure 4.9).

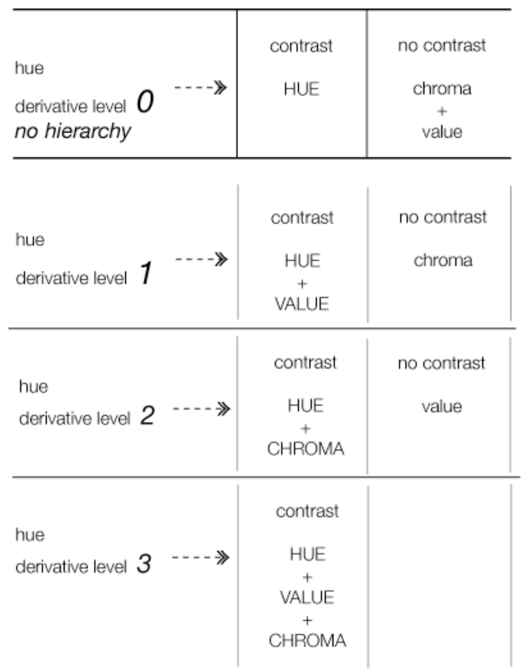


Figure 4.9: Derivative Levels of Hue Contrast.

Color structures contain patterns of visual harmony. Color harmonies are traditionally defined in visual design as having an internal orderly structure comprised of a dynamic equilibrium between homogeneous and heterogeneous parts. Since the value and chroma structures stay within the same hue family, they may be classified as a monochromatic harmony (Figure 4.10). In the value structure, the homogenous part is the hue family and the heterogeneous parts are the contrasting value and/or chroma. The inherent structure of the color wheel and perceivable attributes of color provide communicative color combinations. These color formulations are at the heart of the chromatic displays found in nature and serve as the root of effective color structures (Carter, 2002). Innumerable color configurations can be formulated by nine conventional color harmonies. Conventional color harmonies include the following combinations:

1. Monochromatic value – colors within the same hue family, light/dark contrast.
2. Monochromatic chroma – colors within the same hue family, saturated/unsaturated contrast.
3. Primary triad – red, yellow and blue are primary colors.
4. Secondary triad – orange, green and violet are secondary colors.
5. Tertiary triad – hybrid colors that occur between a primary and secondary colors:
    a. yellow-orange
    b. red-orange
    c. red-violet
    d. blue-violet
    e. blue-green
    f. yellow-green
6. Analogous – adjacent colors on the color wheel.
7. Complementary – colors opposite on the color wheel.
8. Split complementary triad – any two hues located adjacent to an opposite color, orange + blue-violet and red-violet.
9. Incongruous – one of two hues positioned left or right of its complement.

Figure 4.10 illustrates nine conventional harmonies in relationship to visual hierarchy. The monochromatic harmonies of value and chroma yield two levels of contrast hierarchy. Since the remaining conventional harmonies consist of hue contrast, three levels of hierarchical contrast are constituted. As stated previously, a color structure with hue contrast alone does not easily produce an objective visual order. Under certain conditions, colors appear to reside in the same visual space. Figure 4.11 illustrates a few color combinations based on hue, value and chroma structures in relation to nine conventional color harmonies.

CONTRAST

	COLOR HARMONIES	value	chroma	hue	
	monochromatic – *tints / shades*				
1	derivative 1	●	□	□	value structure
	derivative 2	●	●	□	
	chroma / saturation – *colorful / neutral gray*				
2	derivative 1	□	●	□	chroma structure
	derivative 2	●	●	□	
	primary – *red / yellow / blue*				hue structure
3	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	
	secondary – *orange / green / violet*				
4	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	
	tertiary – *hybrids between primary / secondary*				
5	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	
	analogous – *adjacent on color wheel*				
6	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	
	complementary – *opposites on color wheel*				
7	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	
	split complementary – *1 hue / 2 opposites*				
8	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	
	incongruous – *complements not opposite*				
9	derivative 1	□	●	●	
	derivative 2	●	□	●	
	derivative 3	●	●	●	

● contrast □ no contrast or equal contrast

Figure 4.10: Derivative Color Structure – Matrix of Hierarchical Contrast – Conventional Harmonies.

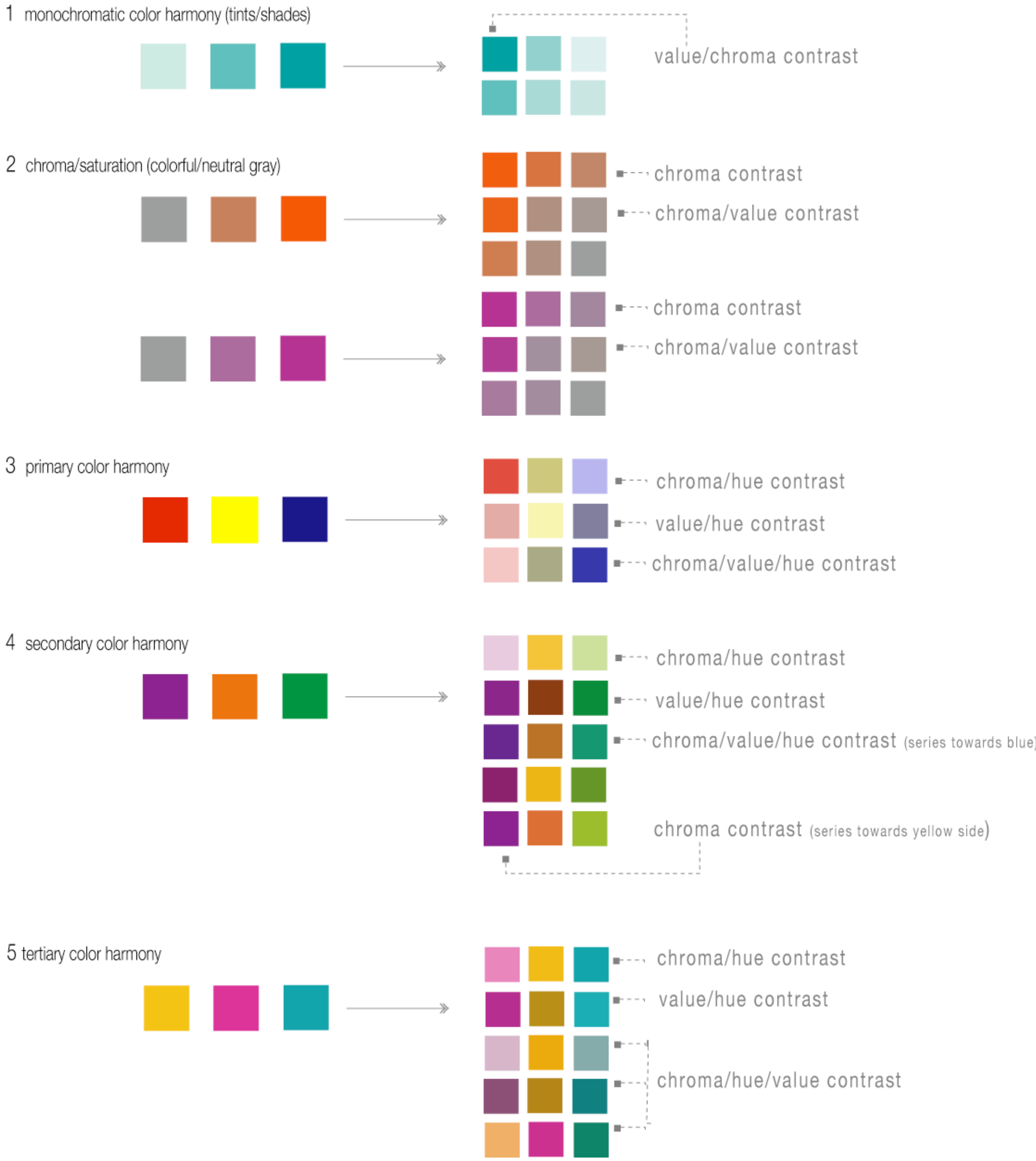


Figure 4.11: Derivative Color Structure – Conventional Color Harmonies.

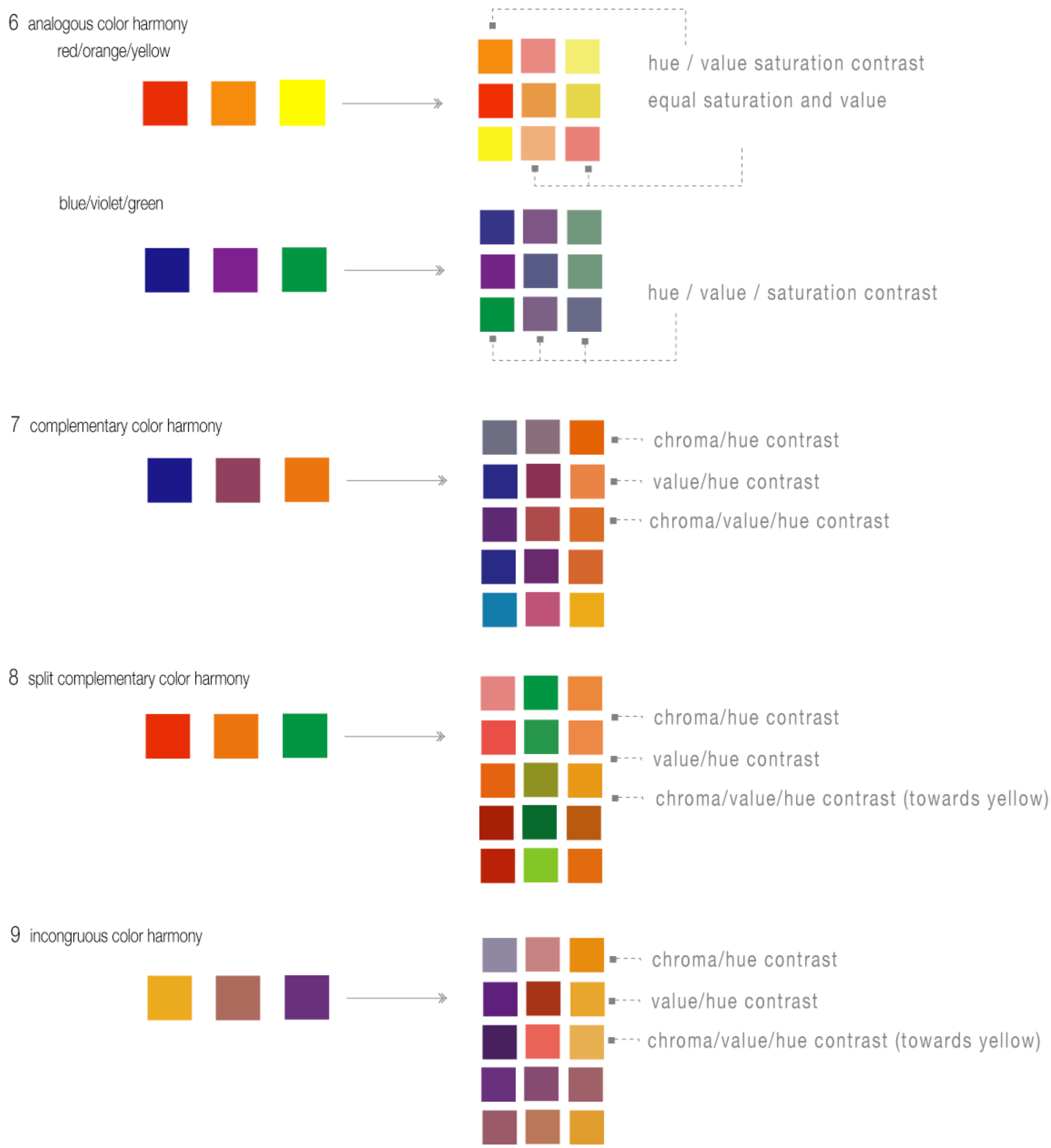


Figure 4.11: Derivative Color Structure – Conventional Color Harmonies (continued).

A discrete property and distinguishing characteristic of an informational organism is a hierarchical color system. Factually, we do not have definitive taxonomies for the attributes of informational color organisms or for the uses to which they may be realized. Controlling the contrasting relationships among the attributes of color is a methodology that helps to define new taxonomies. The new taxonomies may, in themselves, define the ways in which they are used. By focusing attention on the *intrinsic properties of the color attributes*, criteria for color selection becomes objective not subjective. The Munsell Color Notation System provides the framework from which derivative color combinations are formulated and clearly defined. Three color selection categories would include: hue, value and chroma. The variables that mediate choices include background colors: white, gray and black. The objective is to facilitate the development of common color selection strategies that work for graphic software applications. Figure 4.12 and Figure 4.13 represent a controlled color system within a color picker window arranged in chroma, value and hue.

Figure 4.12: Color Selection Palette – Concept.

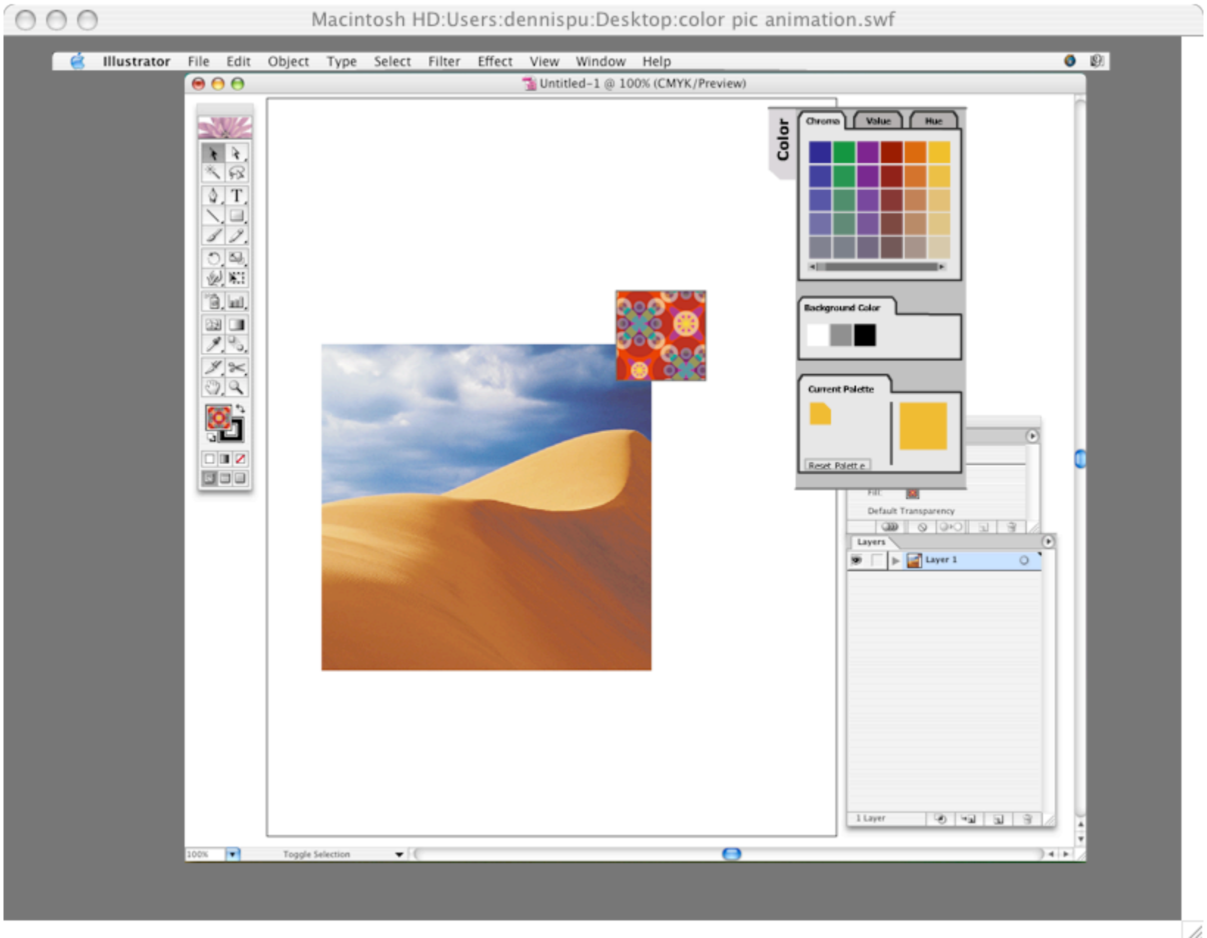


Figure 4.13: Color Selection Palette in Application Window – Concept.

Mainstream graphic software applications designed by Microsoft, Adobe, Macromedia and others could include an additional color selection method. This would provide an audience with the option to make a complex or simple color selection choice within the application. In most instances, end-users are inexperienced with visual organization and the manner in which color influences understanding information. Therefore, color decision-making is arbitrary and subjective. This often leads to confusing and meaningless messages. A controlled color system would provide the audience with an informed choice. Then rules for color selection would be made invisible for non-designers without color education for color presentation material. The interface configuration within the application would need to be made simple and transparent.

4.6 Implications

Credible conclusions can be drawn from the empirical evidence found within the study. As related previously, the strategy for color selection and categorization was based upon the contrasting relationships of hue, value and chroma found within the Munsell Notation System of color organization. Therefore, the principles of color selection and organization were founded upon objective criteria that form derivative color combinations. As described in Figure 4.10 the *Matrix of Hierarchical Contrast*, principles of derivative color combinations have been established. Visual order contributes to the human cognitive that assists the ability to understand information. In addition, the synthesis of the data can be recognized and applied to visual presentation software. Visual recognition tasks, memory retention and recall are components of meaningful information delivery.

Since this study applied quantitative analysis strategy, the findings provided evidence to support principles of color organization that are intuitively understood by designers. Much of the literature related to visual communication and color selection has been criticized as having a weak scientific basis with little predictive value. The intent of visual communication literature may not be scientific but it is insightful, useful and credible. Often scientific researchers doubt the existence of a simple law of color structuring, suggesting that color factors are skewed by human subjective responsiveness. Researchers have produced documented quantitative analysis of color and visual response, naming and categorization. However, these studies have not provided much insight for color application methodology.

Many of the principles in visual communication literature can be scientifically tested. The research conducted in this study incorporates quality measures, demonstrating and supporting explicit evidence that color-coding, color categorization and color selection can be objectively derived.

This definitive and objective analysis of hierarchical color patterns is useful to design students, design educators, design practitioners, computer scientists as well as the end users (non-designers) of digital communication software – Microsoft *PowerPoint*. Relating color principles to color application as communication and language links concepts to design education and practice.

4.7 Further Studies

This study was limited to the use of derivative color combinations as a means to communicate visual order for the purpose of meaningful information transmission. It has been demonstrated that the application of objective color selection and ordering is critical to making information understandable. In this study, the vehicle for color presentation is limited to projected digital media. If the inferences, implications and synthesis of the proposed study as described above are probable, credible empirical research needs to be moved forward exploring this fertile ground of research opportunity.

The findings in the study also raised questions. The ANOVA analysis for task efficiency demonstrated time variances within each of the three categories. It was speculated that the time variances were most likely due to perceived contrast within a hue family. What is the logical explanation for the time variances within each of the three categories?

In order to produce a manageable study, color combination selections were limited to a small number. With the infinite number of possible categorical color combinations, it was impossible to investigate all plausible combinations. Using the methodology in the *Intrinsic Structures* experiment, hierarchical structure within conventional color harmonies could be examined and tested. In the experiment, typeface, spacing and size were constant. How do these additional variables influence color contrast and visual hierarchy?

As the study yielded favorable findings, additional research is reasonable and compulsory. Additional factors need to be identified, clarified and evaluated for further testing. Background color for particular color structures could be tested. Further studies should address specific typeface and size as they are additional factors that influence the appearance of color contrast. Color position, direction, and motion should be researched and tested. An examination of the effect of color on memory, recall, and task efficiency would also be useful to the design community and the community at large. Further research could provide a framework for future objective color selection processes and color organization research.

Human reaction to color communication is created by a combination of biological, physiological, psychological, social and cultural factors. In this research study, these factors were not examined. The foundation of color research is rooted in the construction of meaning in digital communication that transcends psychological and cultural conditions. The focus is specifically related to the visual representation of hue, value and chroma. When individuals respond to visual stimuli coded by the categorical representation of hue, value and chroma, meaning is constructed. These categorical representations are means in which objective visual communication forms a language and delivers a message. The structural organization in this study establishes a language of visual hierarchy. Hue, value and chroma play an important role in bringing visual meaning to an object. The structure of the color assembly invokes an image of the object that is constructed by human perception. This visual meaning constitutes the object as a cultural artifact.

Color should function as a code transmitting a message, thus making things easy to understand and to assimilate. Effective color assembly strategies produce strong visual impact, improve legibility and define product identity. Meaningful color communication should improve the efficiency and efficacy of the message perceived by the end user. Simultaneously, color must function successfully on several levels. Colors must function competently as the primary structural element in the organization of print, digital and product design. In this capacity, color must create appropriate spatial and navigational identities that are specific to the operational tasks. The designer must identify ideal and normal sequences: what the user should see first, where the eye should move next, and how much time the viewer's attention should be held within each area.

For design in particular, the gaps in color research are apparent. Among the scientific community of scholars, an enormous amount of empirical evidence in color research can be found in the social and cognitive sciences. Designers minimally relied on the research findings conducted in the social sciences. To some extent research in human factors, ergonomics, sustainability and marketing have provided design worthy findings. This research study applied an epistemological and theoretical orientation. The research methodology addressed quality measures that include validity, generalizability, objectivity and reliability. The findings of the studies, bounded by a methodological framework, were therefore quantifiable and verifiable. The human aspects of design have always been a central issue of design strategy and practice. However, research in design has not always followed a scientific methodology. Scientific or formal methods of conducting design research are now in their infancy and we are just scratching at the surface of uncharted territory.

On a final note, the natural/intrinsic order of color within the categories of hue, value and chroma provides a guiding principle of fact for the purpose of useful color selection methodology. These principles of fact are rooted in simple, common and ordinary relationships of color formations. In many instances, observing and understanding the simple/ordinary state of things is not a simple/ordinary task. However, this type of observation and comprehension is a necessary exercise if we are to turn the ordinary into the extraordinary. As we are reminded in an Italian proverb:

Quai que cosa qui e ordinario in la vita que non podeva transformare in lo extraordinario.

There is nothing in life so ordinary that it cannot be made extraordinary.

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APPENDICES

Appendix A. Informed Consent Form for Research.

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study **Intrinsic Structures** – *a study for the doctoral dissertation* ***Color as Cognitive Artifact***

Principal Investigator **Dennis Puhalla PhD candidate** Faculty Sponsor **Professor Meredith Davis**

We are asking you to participate in a research study. The primary purpose of the study is to find empirical evidence that intrinsic color combinations can be categorized upon variables defined by three attributes–hue, value and chroma. The application of objective color ordering is critical to making information understandable. The presentation vehicle for the Intrinsic Structures Study will be limited to digital media.

INFORMATION

If you agree to participate in this study, you will be asked to:

Sit at a computer monitor and keyboard.
Read the instructions on the monitor defining the images that will be projected in the PowerPoint Presentation.
An administrator will verify your understanding and answer any questions.
The first set of the 15 PowerPoint slides are comprised of various colored dots depicting numerical character(s). You will be asked to verbally identify the numerical characters.
Students who are capable of identifying the numerical characters correctly will continue with the remaining study. Those who cannot identify the numerical characters will be excused. *In the event this happens, there is no penalty.*
The next set of 18 slides are comprised of 3 text blocks arranged in 3 different positions and in 3 different colors.
You will be asked to identify which block of text appears to be visually more important than the other two.
This study will take 5 – 10 minutes in total time There are no repeat sessions planned.
Students will participate individually with the assistance of an administrator/data recorder.

RISKS

There are no known risks. You will be looking at a computer monitor and using a programmed PowerPoint presentation. This experiment is not a test or measurement of your visual perception or preferences.

BENEFITS

There will be no direct benefit to the participants. Generally, product designers intuitively agree on the most pleasing color combinations, though established verifiable theories do not exist. There are no rules. The importance of this study is to find guiding principles of fact. It is, therefore, necessary to attempt to determine statistically the predominant trend or tendency in viewers' perception of color organization. As an outcome of this study, documented findings will present explicit evidence that addresses specific mechanisms for objective color ordering phenomena within digital environments.

CONFIDENTIALITY

The information in the study records will be kept strictly confidential. Data will be stored securely in the researcher's private files in an undisclosed location. No reference will be made in oral or written reports which could link you to the study.

COMPENSATION

For participating in this study, you will be granted appropriate credit in lieu of a paper/project required of the referring professor of record. Credit/extra-credit will be left to the discretion of the referring professors. If you withdraw from the study prior to its completion, you will not receive partial credit. Those excused from the study will receive full credit/extra-credit.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, **Dennis Puhalla** at the College of Design, North Carolina State University, 515-8308. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact **Dr. Matthew Zingraff**, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or **Mr. Matthew Ronning**, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed at your request.

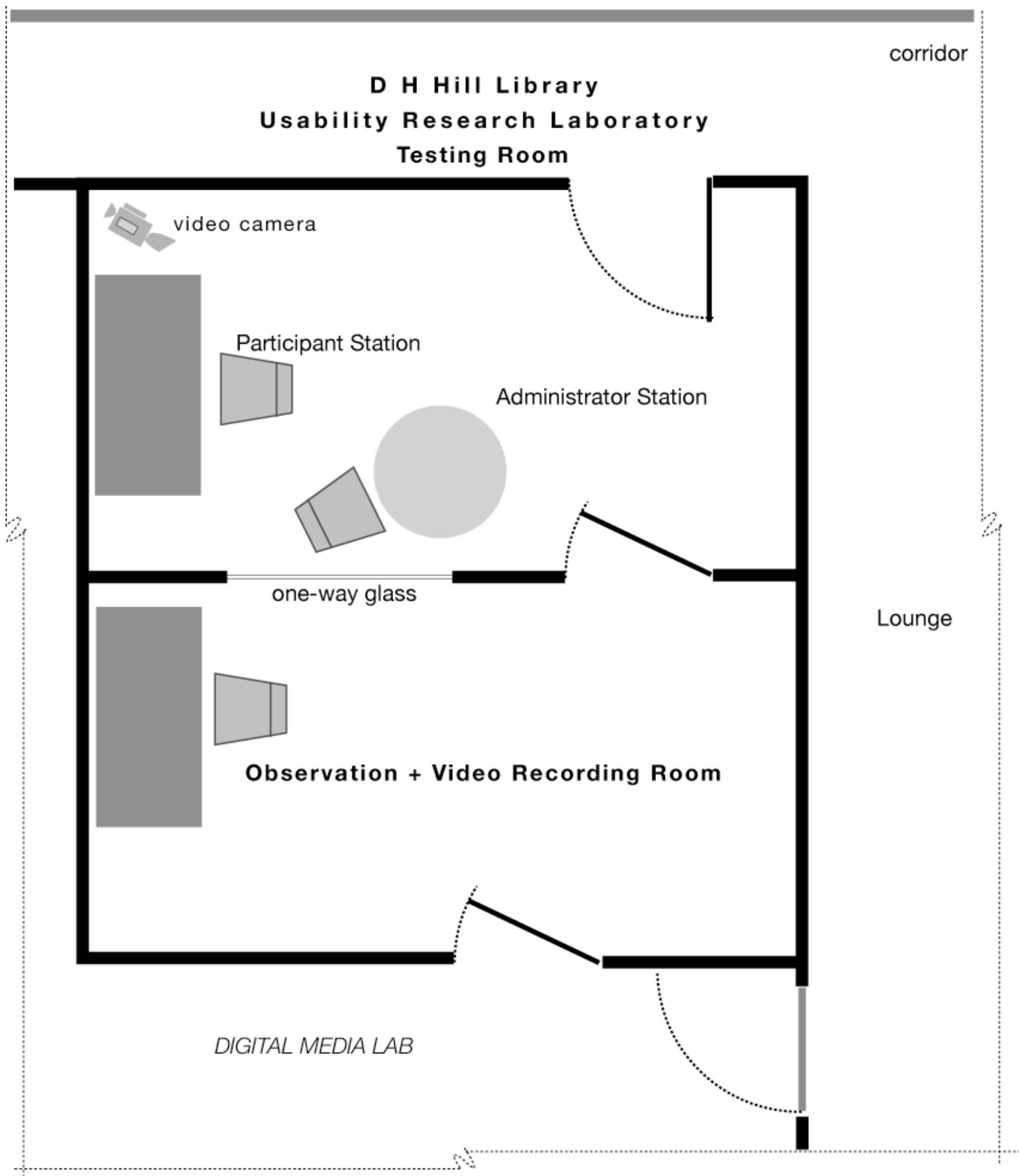
CONSENT

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time."

Subject's signature______________________________ **Date** ______________

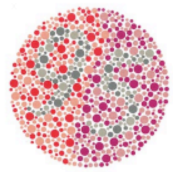
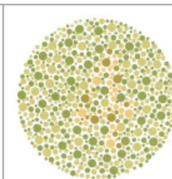
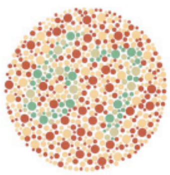
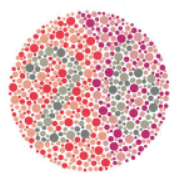
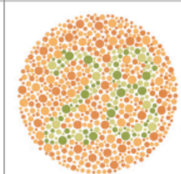
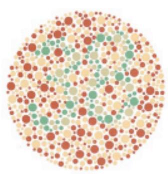
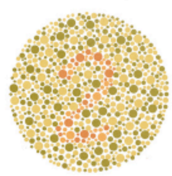
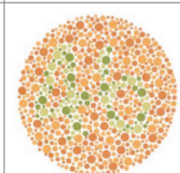
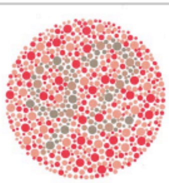
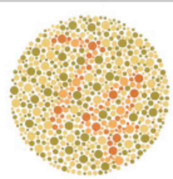
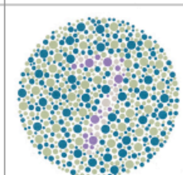
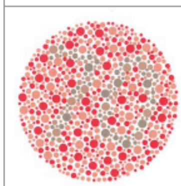
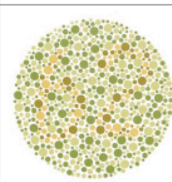
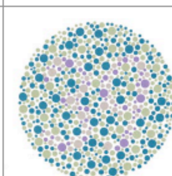
Investigator's signature___________________________ **Date** ______________

APPENDIX B. Usability Research Lab Floor Plan, North Carolina State University (Figure 3.6).

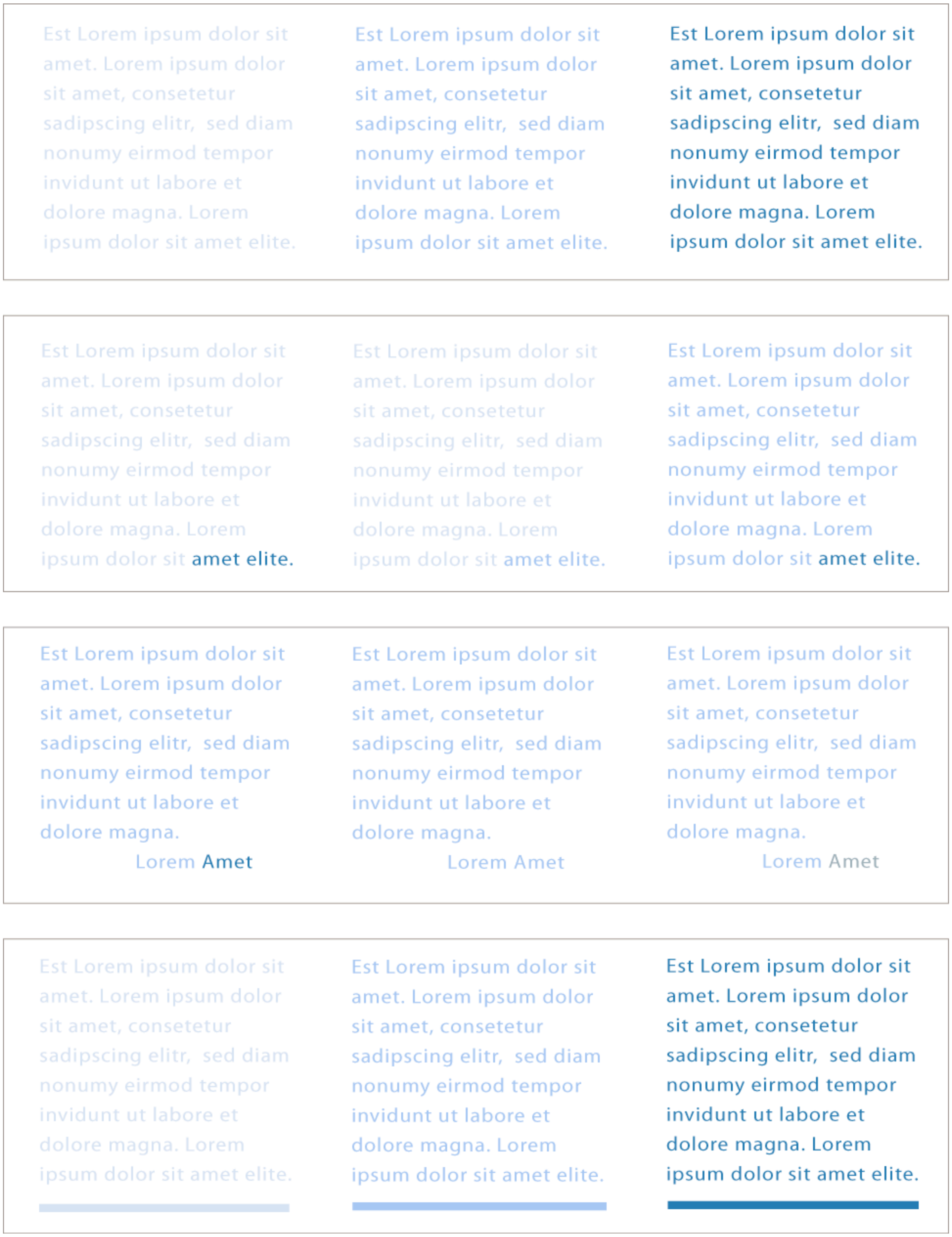


APPENDIX C. Dvorine Pseudo-Isochromatic (Figure 3.10).

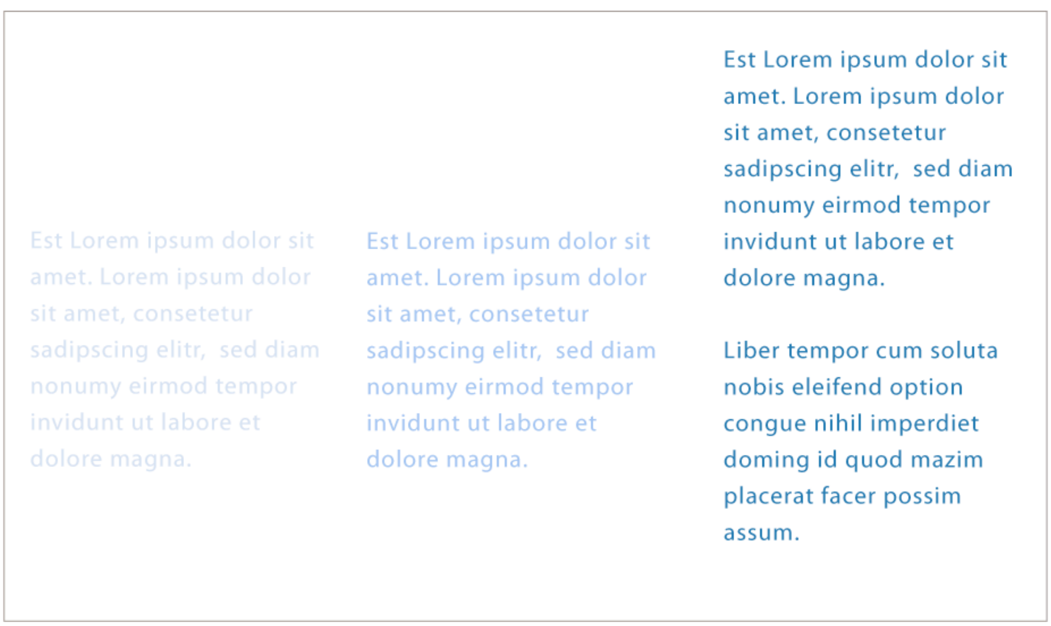
Dvorine Pseudo-Isochromatic Plates, 2nd Edition The Psychological Corporation
Israel Dvorine, O.D., F.A.A.O.

	48			95			4
	67			26			28
	38			2			46
	92			74			7
	70			62			39

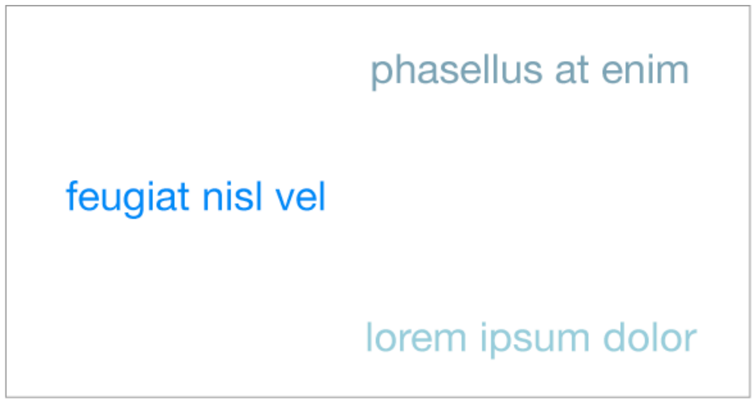
APPENDIX D. Text Block Studies (Figure 3.19).

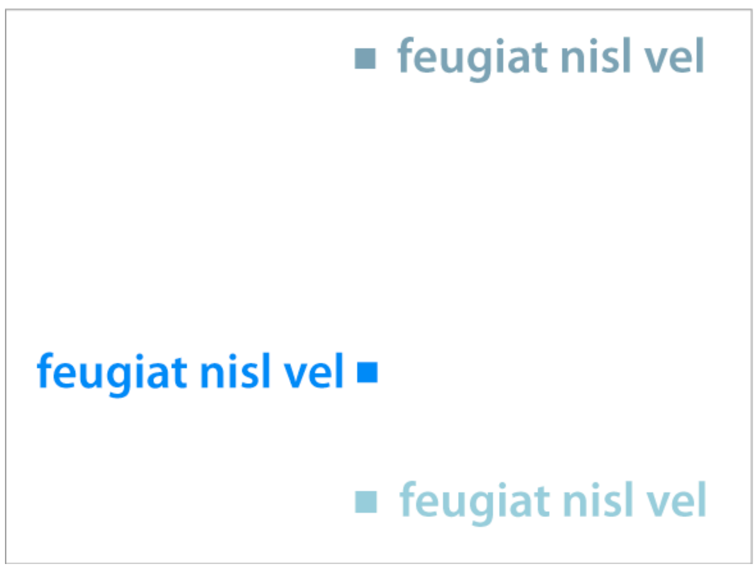


Appendix D. Text Block Studies (Figure 3.19) continued.

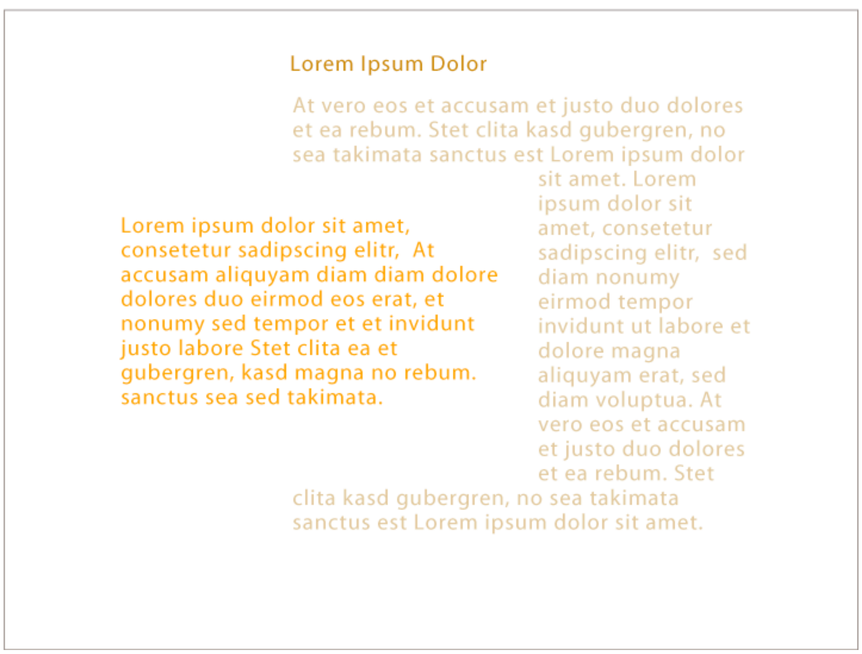


Appendix D. Text Block Studies (Figure 3.19) continued.

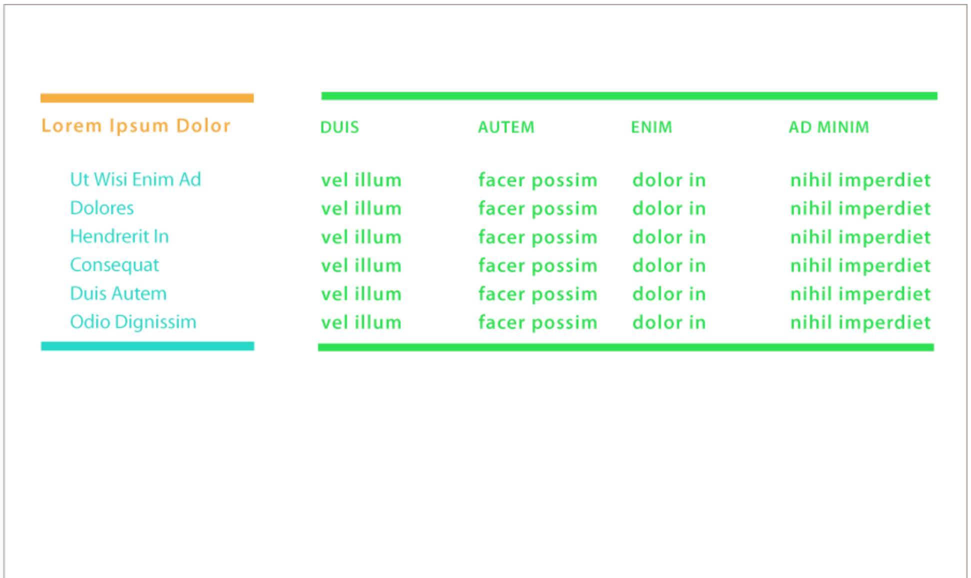




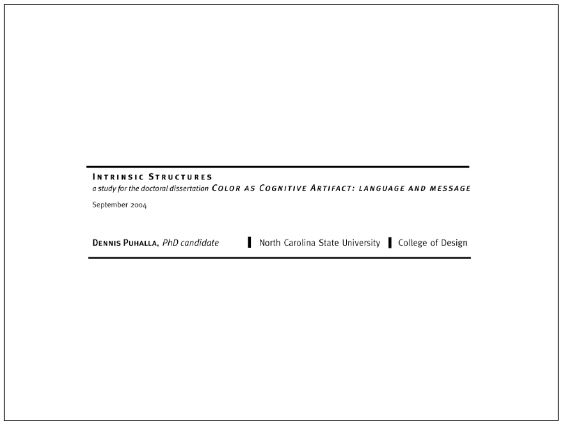
Appendix D. Text Block Studies (Figure 3.19) continued.

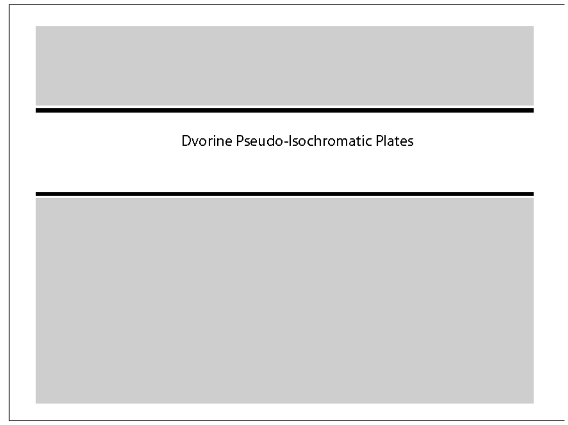


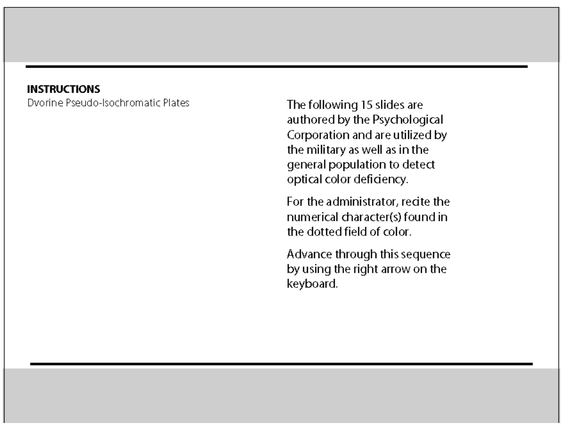
Appendix D. Text Block Studies (Figure 3.19) continued.

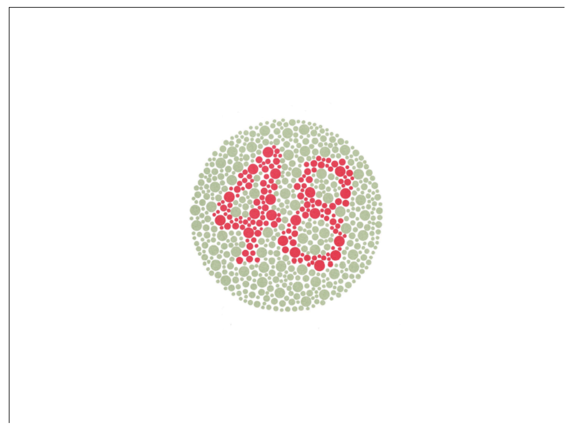


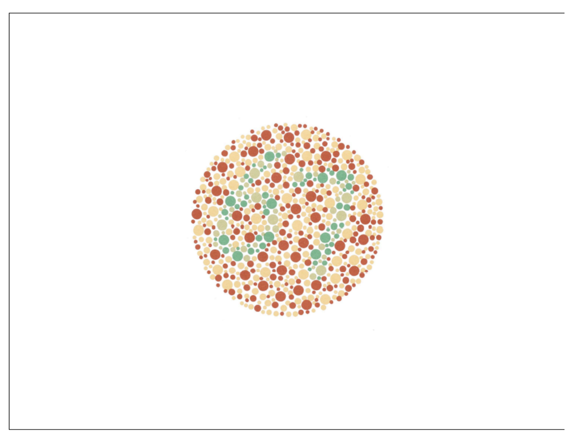
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23).





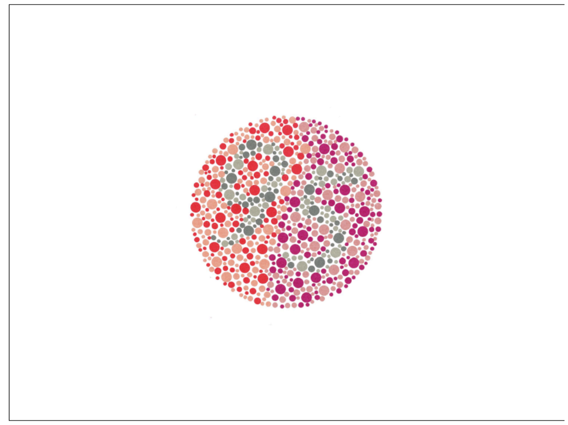


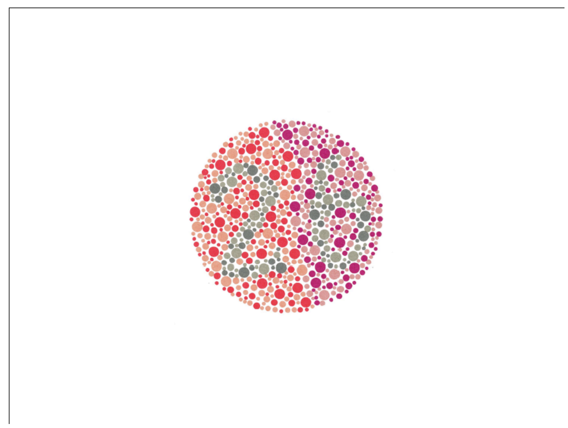


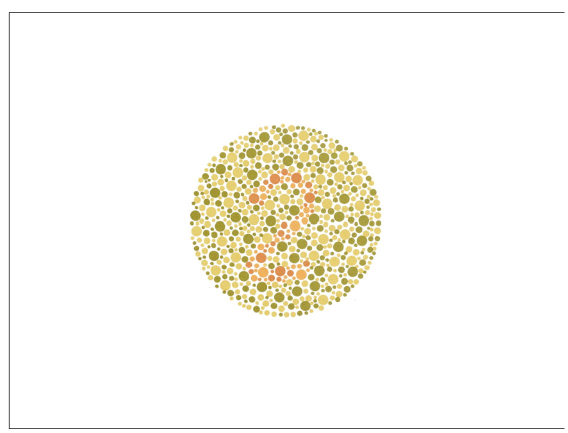


Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

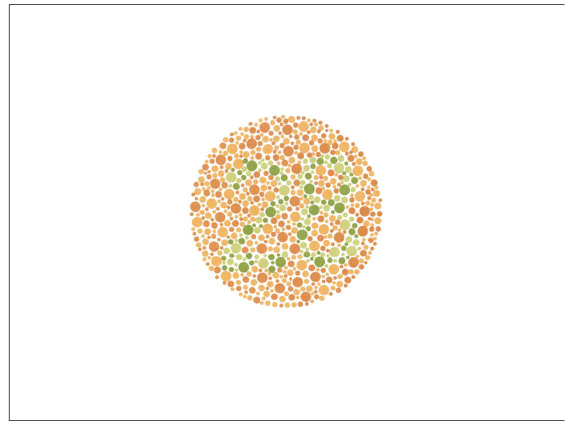



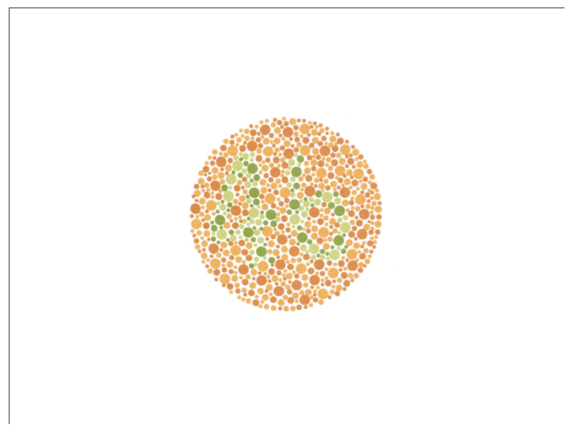



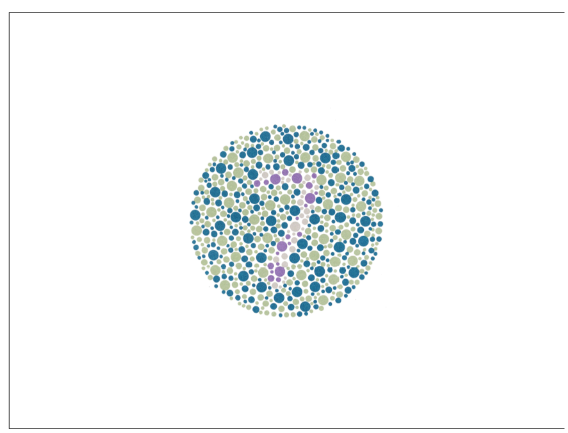



Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

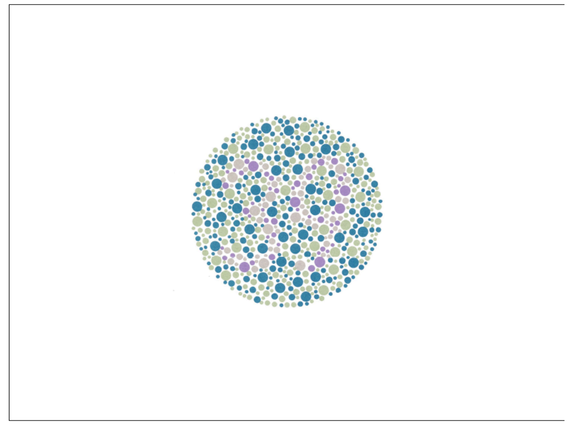
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

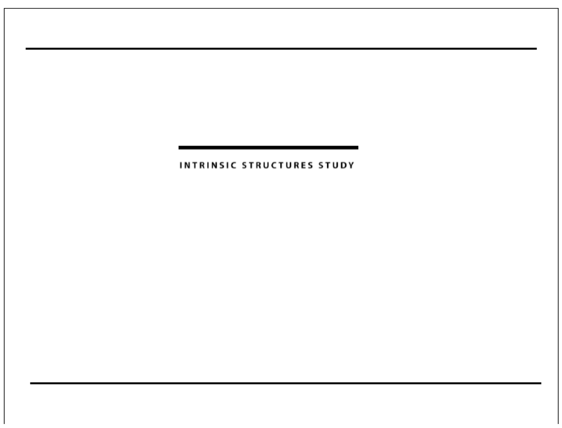


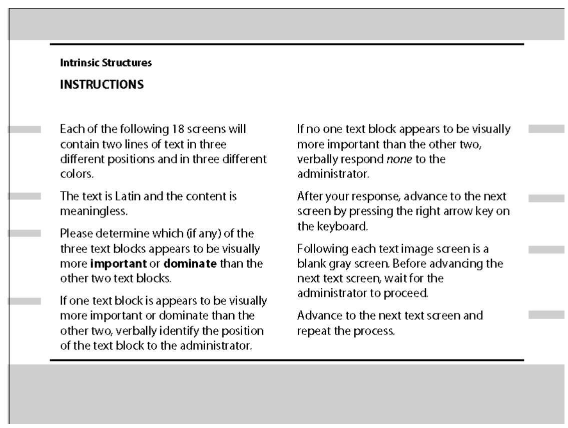




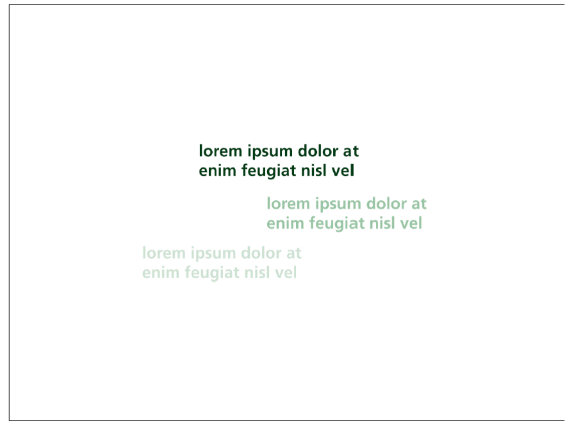
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

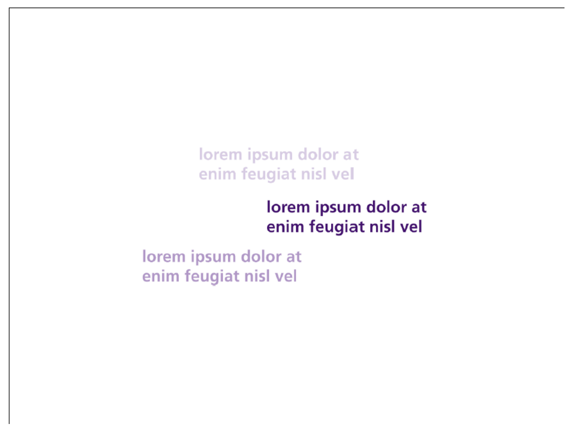


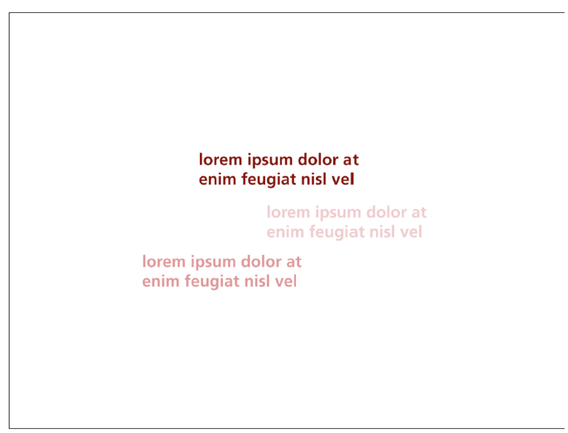




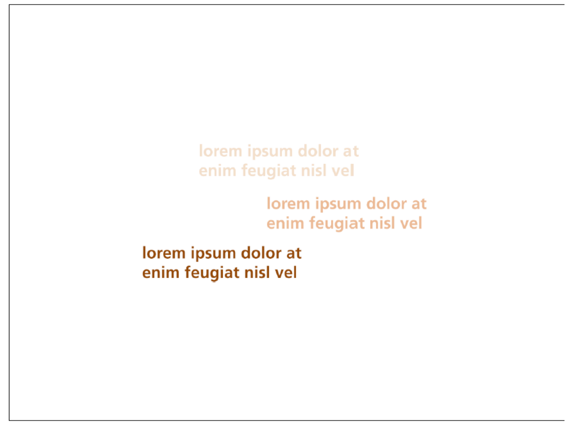
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

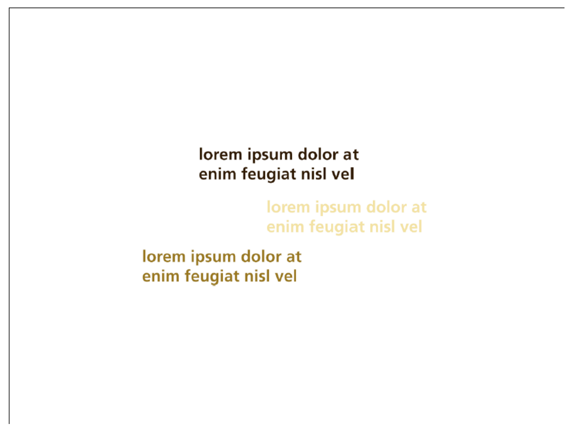


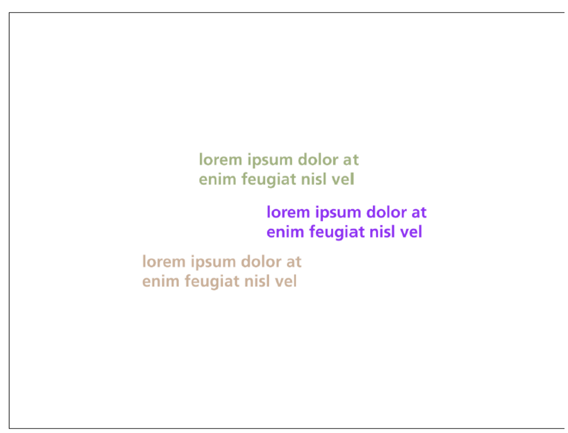




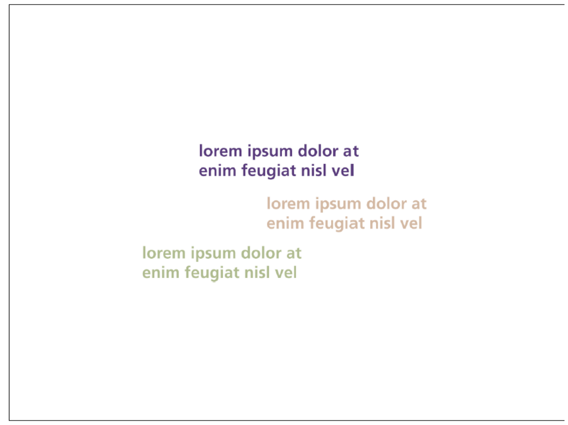
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

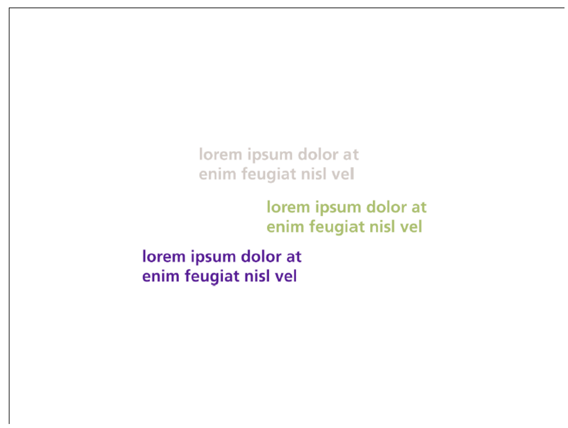


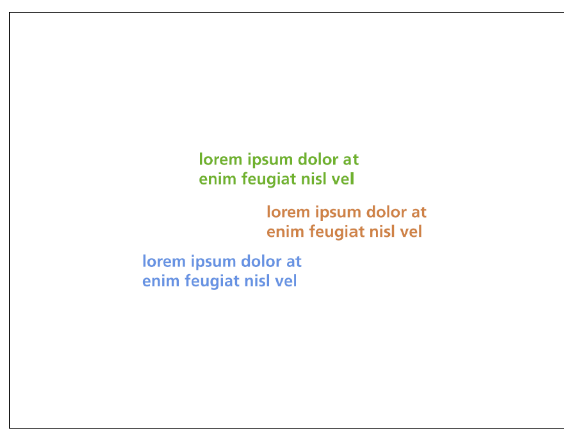




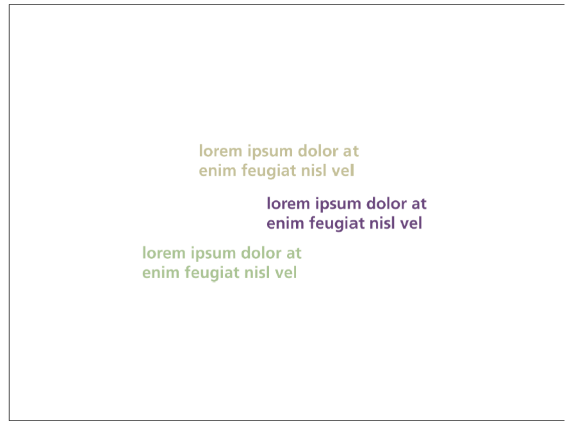
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

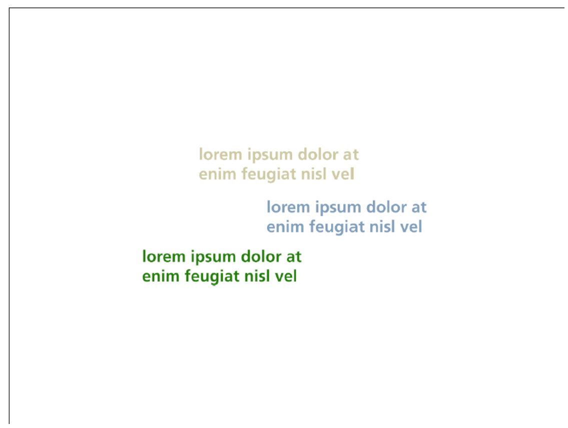


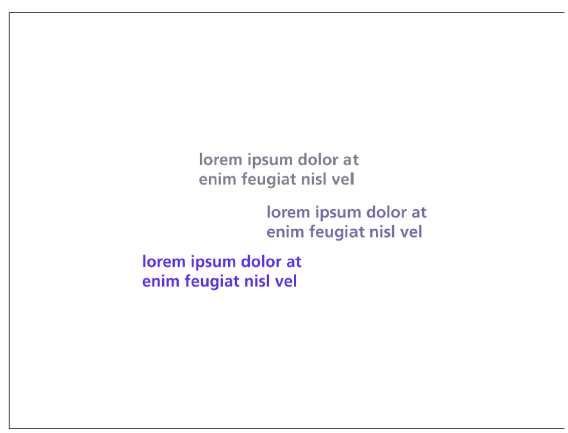




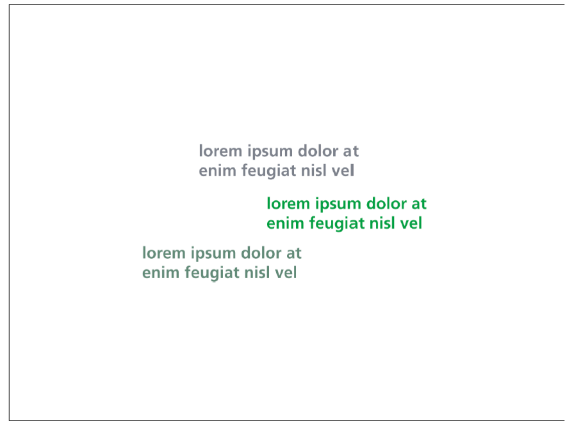
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

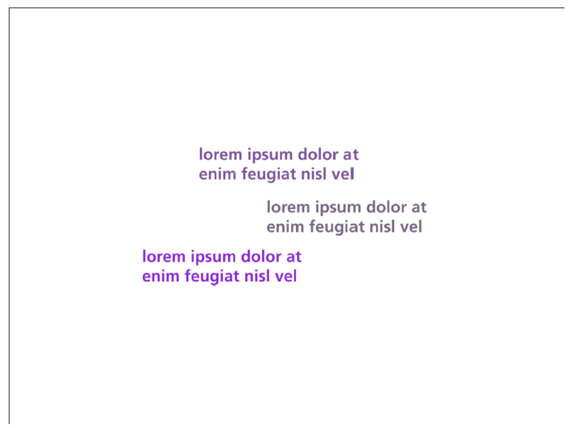


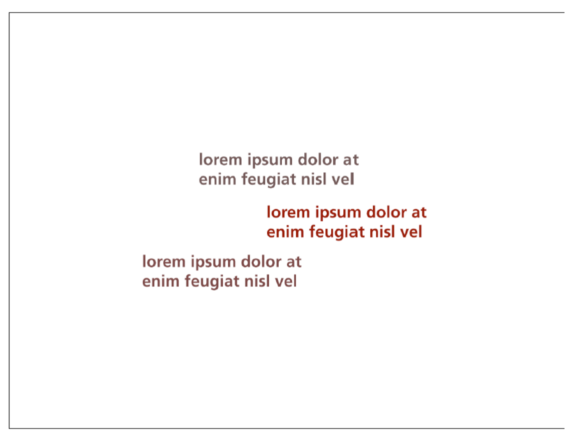




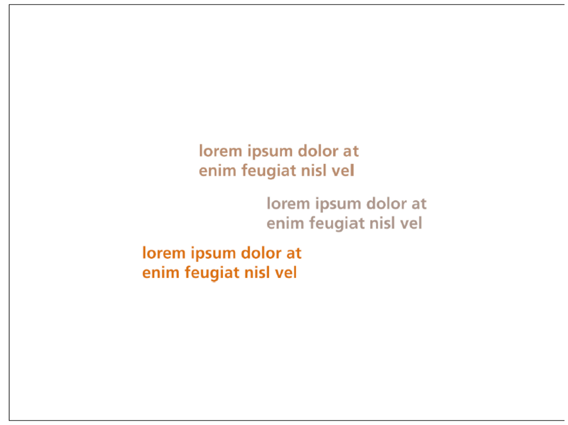
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

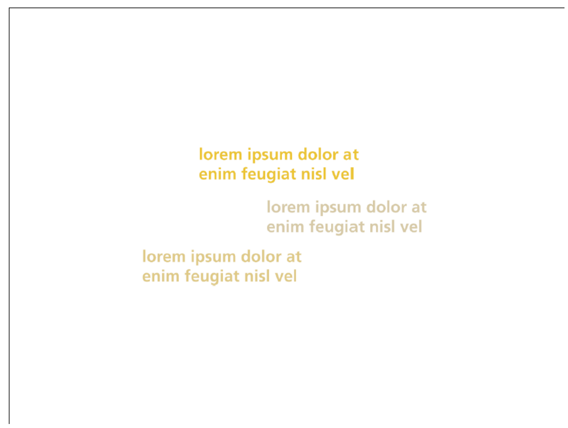


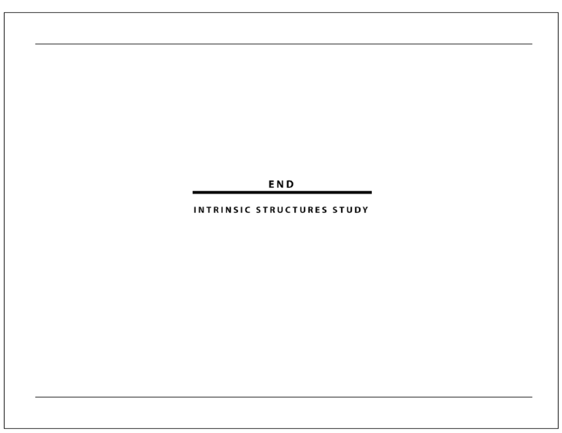


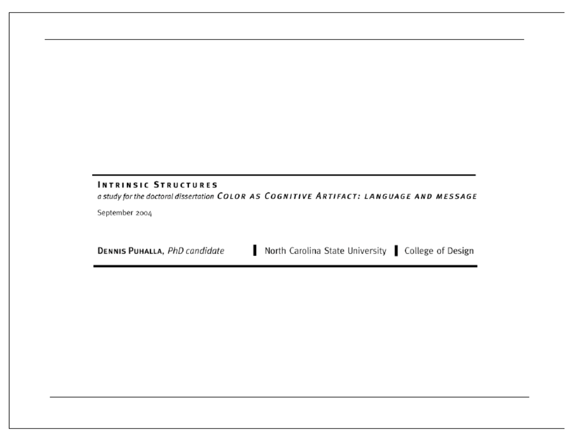


Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

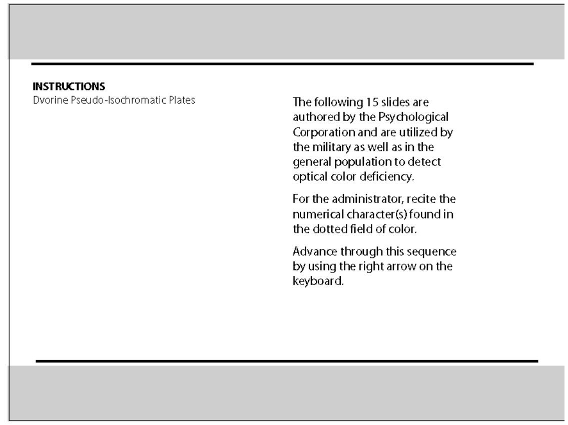


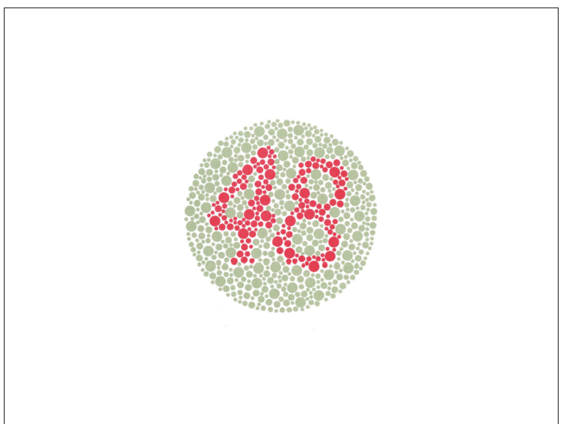


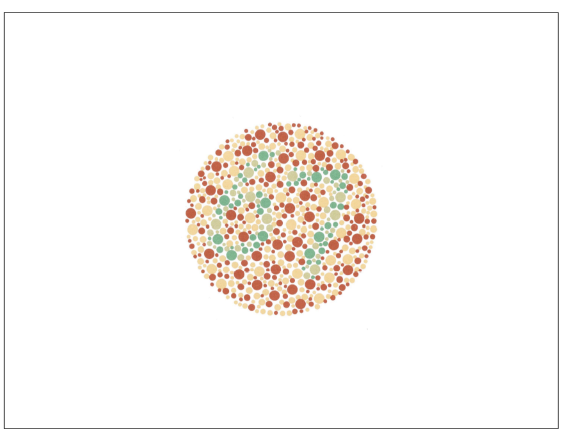




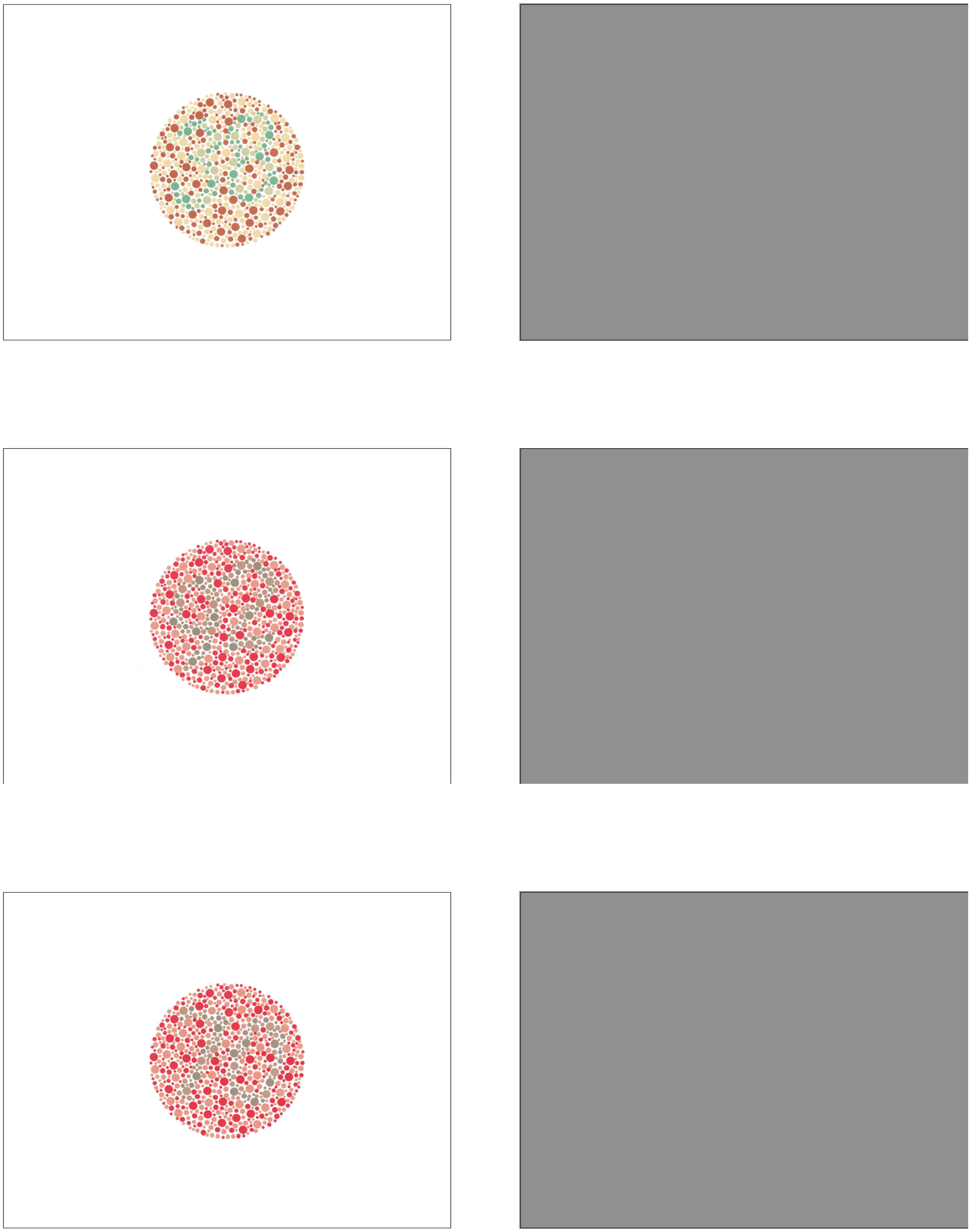
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.



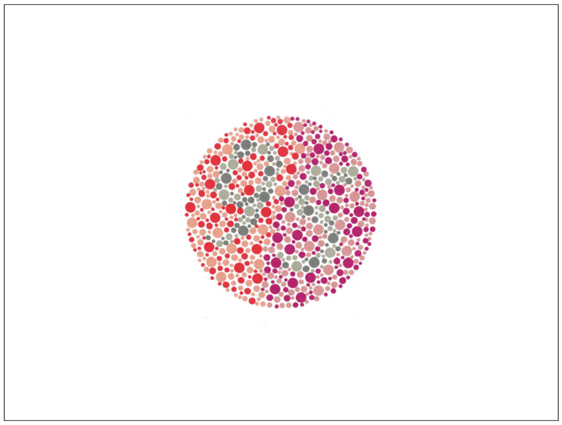


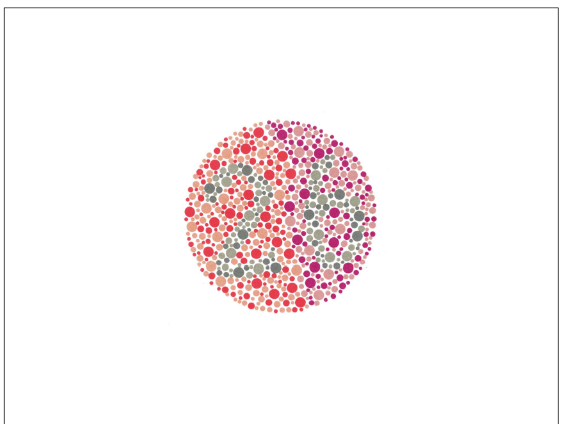


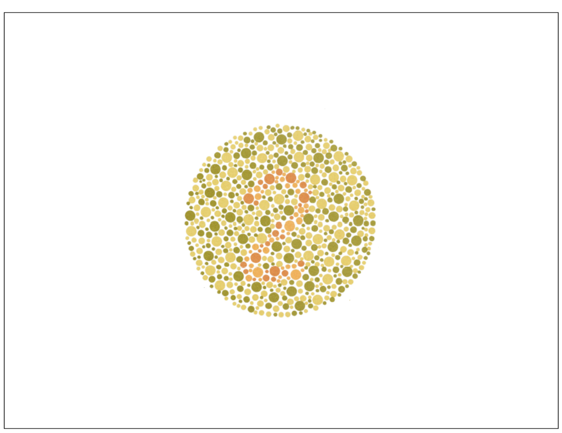
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**



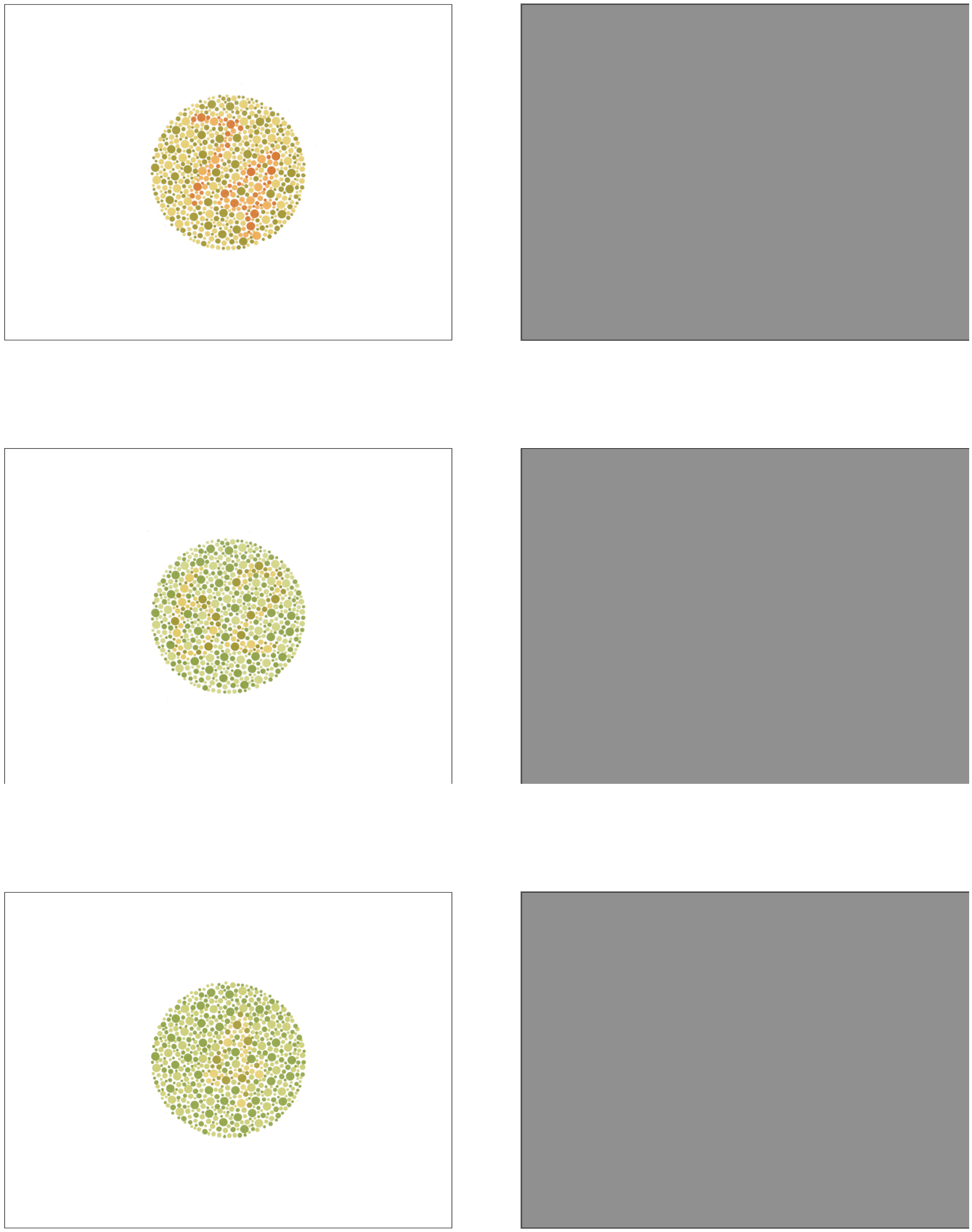
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**



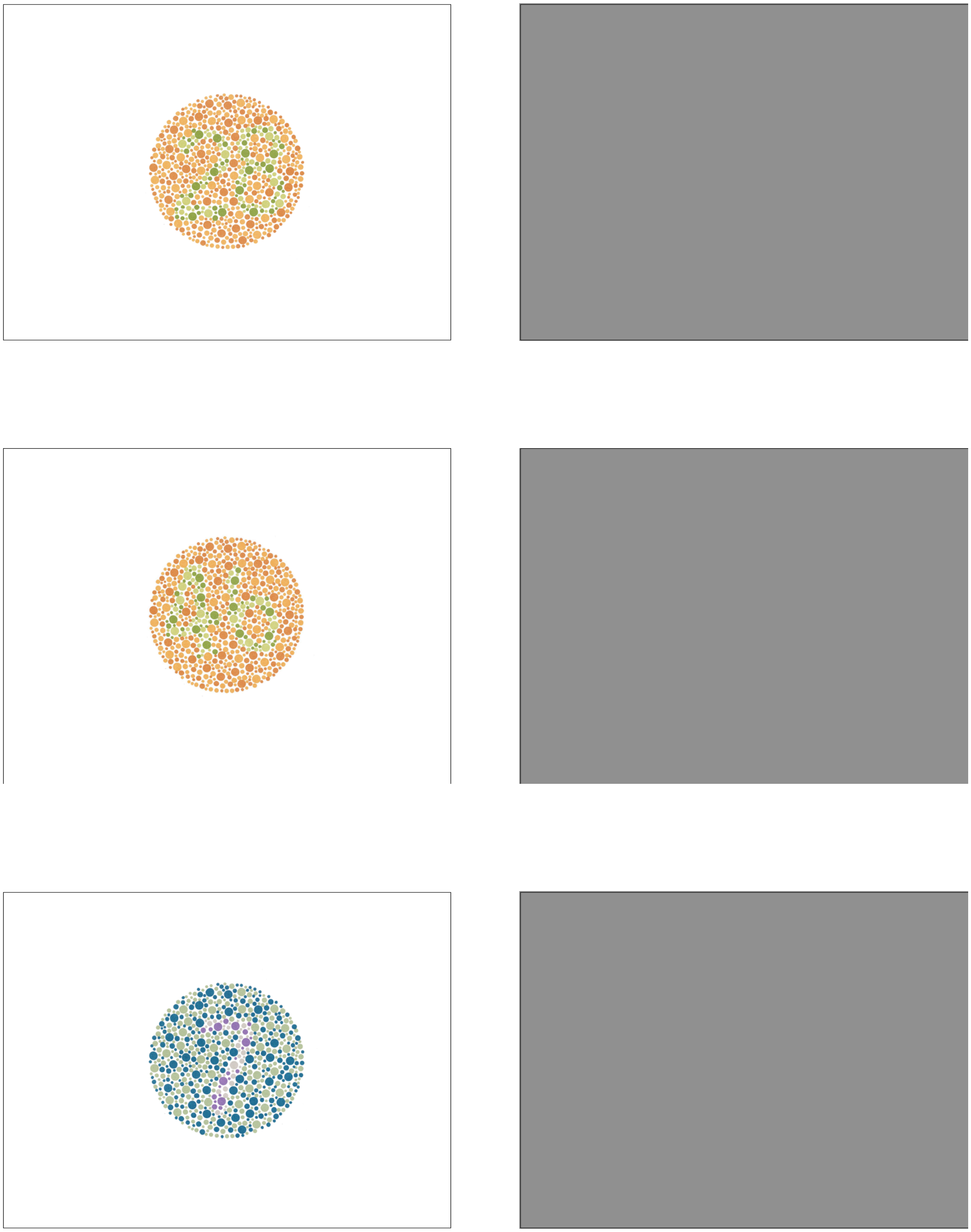




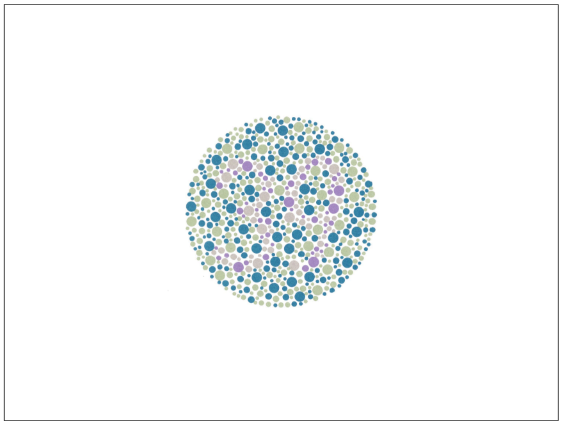
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

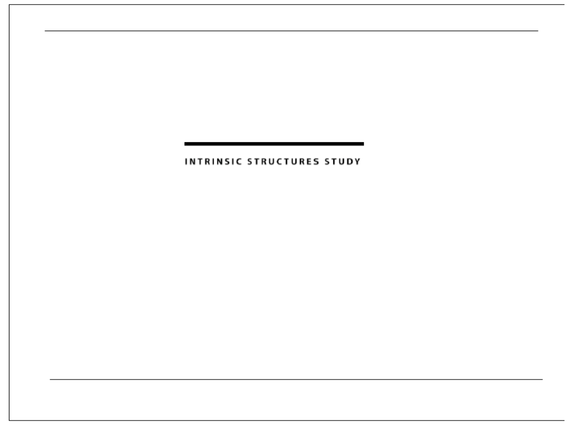


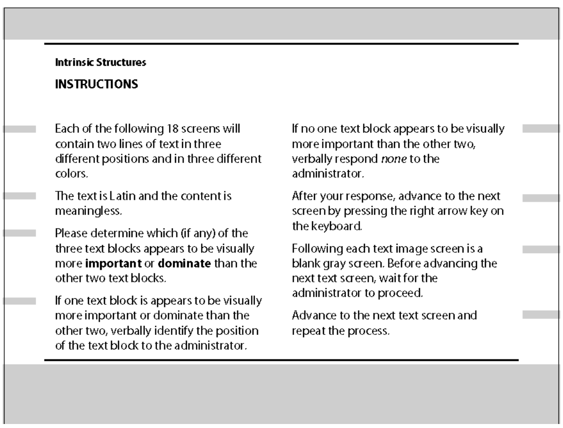
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

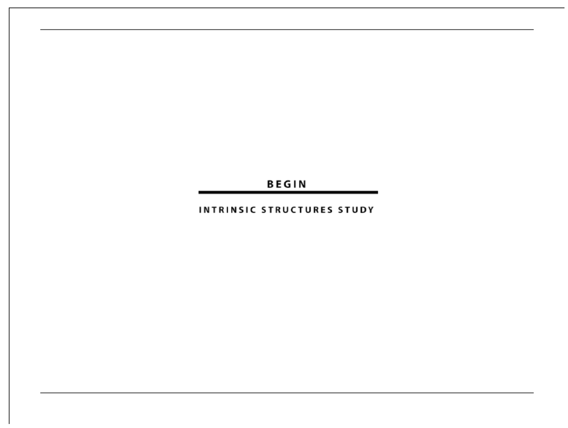


Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

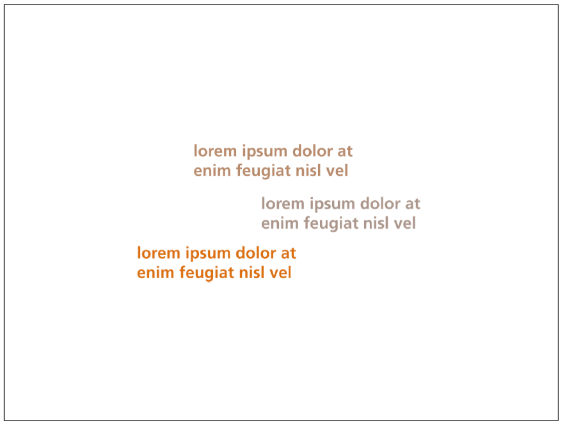


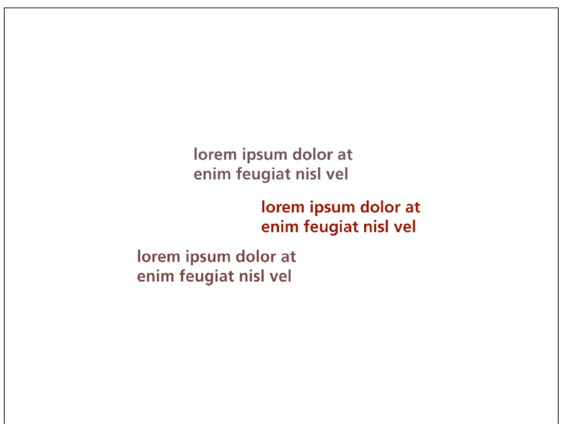


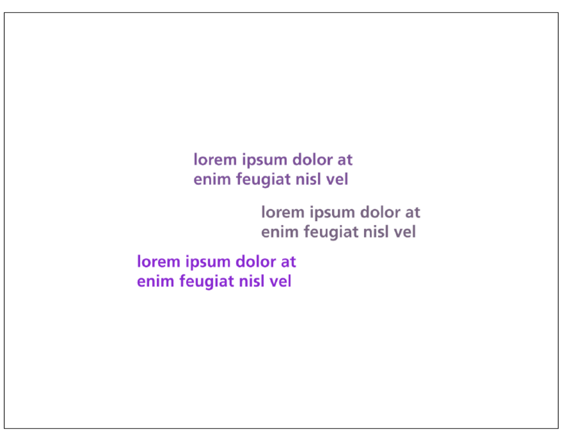




Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

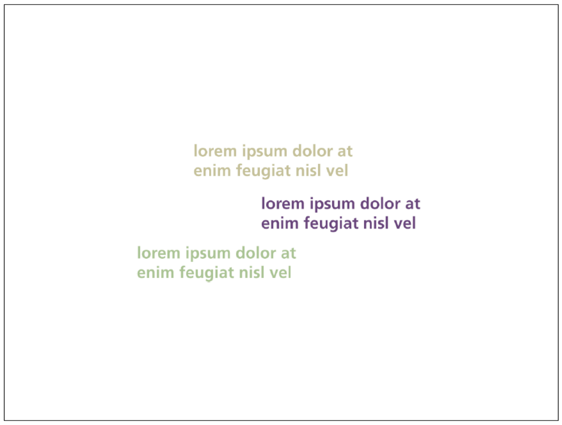


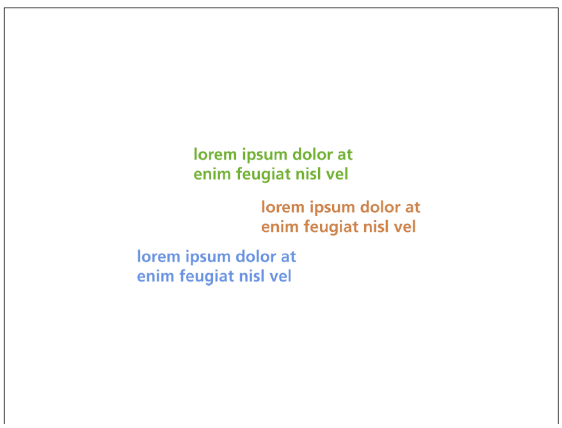


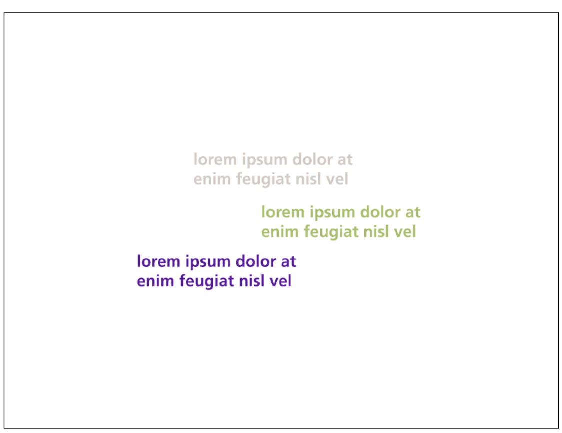


Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

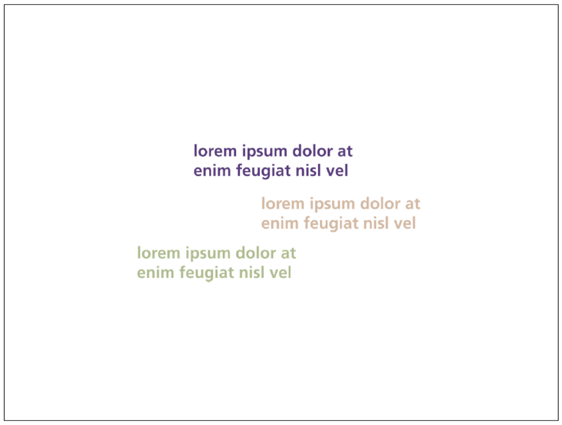
Appendix E. ***Intrinsic Structures*** **Visual Stimuli Screens (Figure 3.23) continued.**

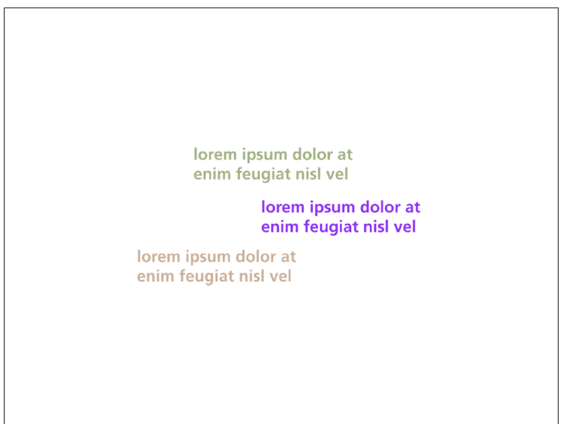


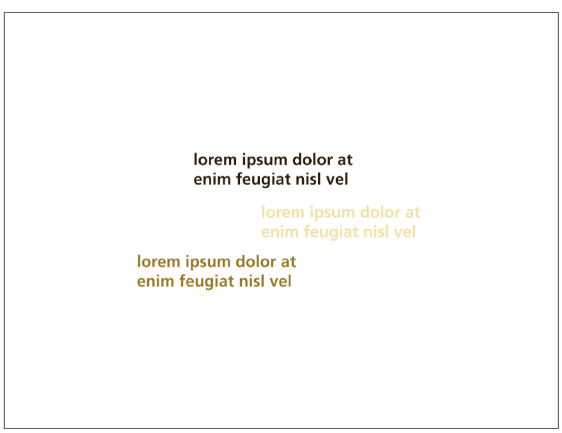




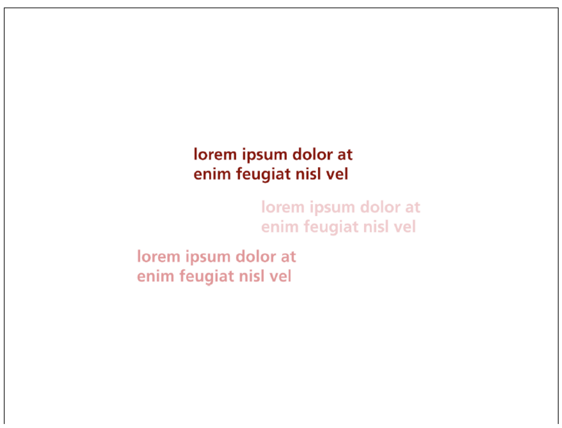
Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

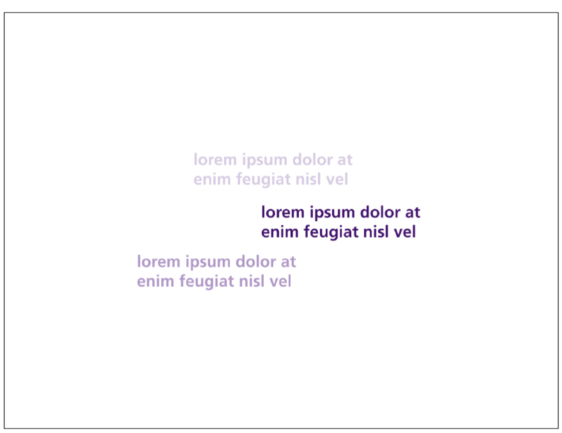




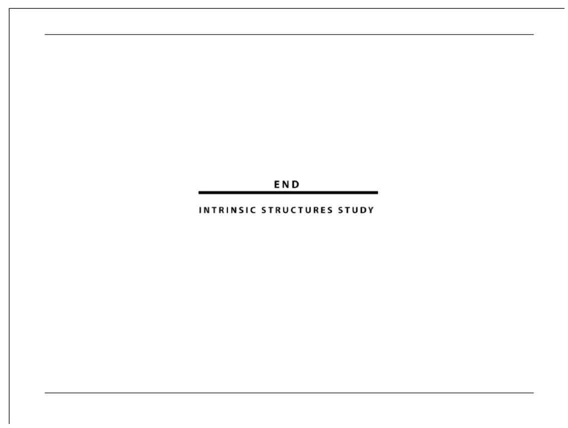


Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.

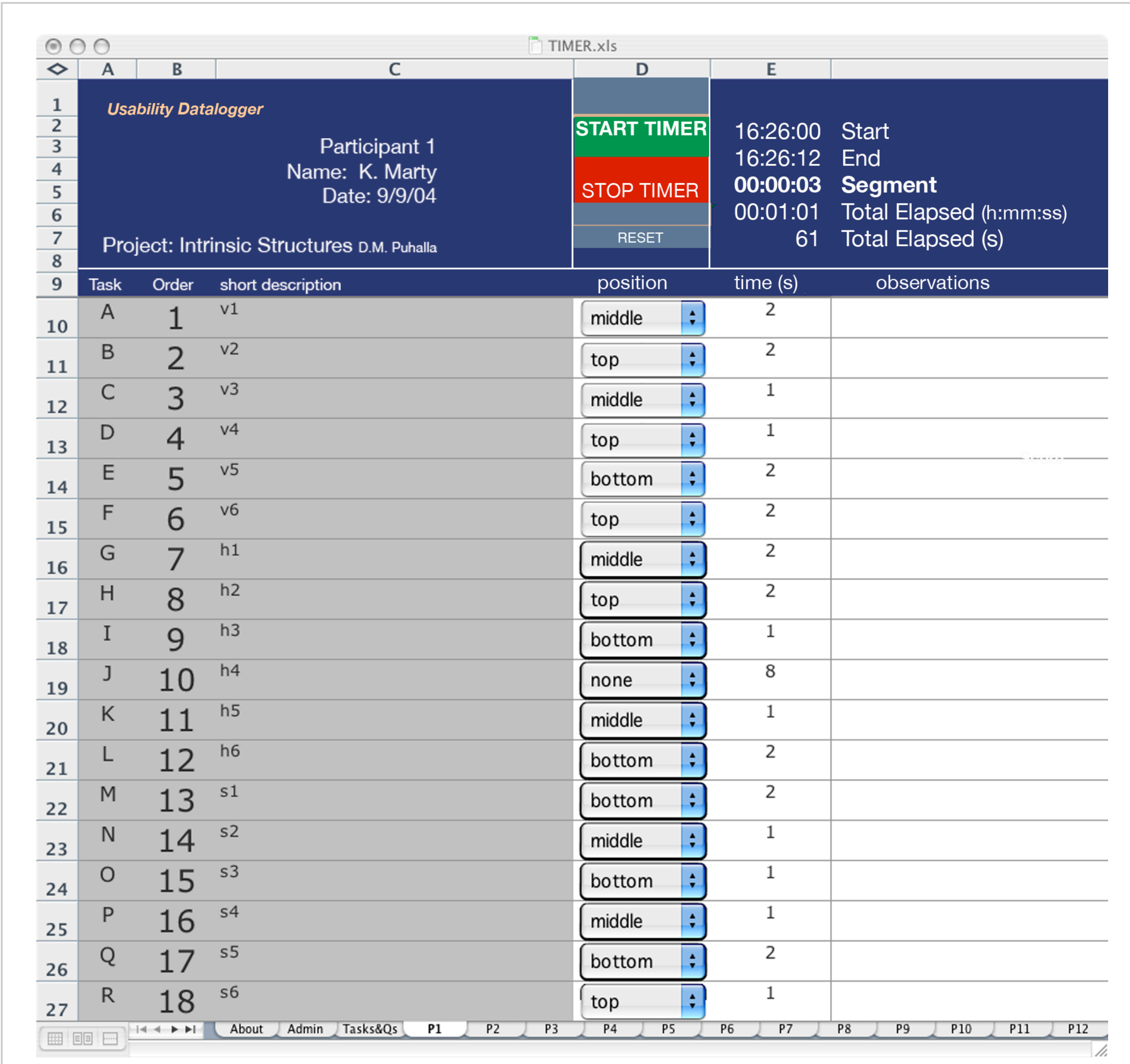




Appendix E. *Intrinsic Structures* Visual Stimuli Screens (Figure 3.23) continued.



APPENDIX F. Usability Datalogger Recording Instrument (Figure 3.24).



TIMER.xls

Usability Datalogger

Participant 1
Name: K. Marty
Date: 9/9/04

Project: Intrinsic Structures D.M. Puhalla

START TIMER
STOP TIMER
RESET

16:26:00 Start
16:26:12 End
00:00:03 Segment
00:01:01 Total Elapsed (h:mm:ss)
61 Total Elapsed (s)

Task	Order	short description	position	time (s)	observations
A	1	v1	middle	2	
B	2	v2	top	2	
C	3	v3	middle	1	
D	4	v4	top	1	
E	5	v5	bottom	2	
F	6	v6	top	2	
G	7	h1	middle	2	
H	8	h2	top	2	
I	9	h3	bottom	1	
J	10	h4	none	8	
K	11	h5	middle	1	
L	12	h6	bottom	2	
M	13	s1	bottom	2	
N	14	s2	middle	1	
O	15	s3	bottom	1	
P	16	s4	middle	1	
Q	17	s5	bottom	2	
R	18	s6	top	1	

About Admin Tasks&Qs P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12

APPENDIX G. Table 4.2: Color Structures Ranked by Frequency of Participant Response.

Ranked Frequency Response

99	98	96	95	94	93	90	87	40
C value 3	**A** value1 **G** hue 7 **N** chroma 14 **P** chroma 16 **Q** chroma 17 **R** chroma 18	**M** chroma 13 **K** hue 11 **B** value 2	**H** hue 8	**E** value 5 **L** hue 12 **I** hue 9	**D** value 4	**O** chroma 15	**F** value 6	**J** hue 10

APPENDIX H. Table 4.4: Chi-Square Data Analysis Single-Sample Calculation.

Color Structure	Frequency	Top	Middle	Bottom	None	Total	*d.f.*	x^2	*p*	distribution
A value 1	observed	1	98	000	000	99	3	115.116	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
B value 2	observed	96	1	1	1	99	3	115.116	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
C value 3	observed	000	99	000	000	99	3	118.800	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
D value 4	observed	93	4	2	000	99	3	98.633	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
E value 5	observed	1	3	94	000	99	3	104.083	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
F value 6	observed	87	5	5	2	99	3	80.246	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
G hue 7	observed	1	98	000	000	99	3	109.705	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
H hue 8	observed	95	3	000	1	99	3	104.914	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
I hue 9	observed	000	5	94	000	99	3	102.995	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
J hue 10	observed	18	13	28	40	99	3	8.515	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
K hue 11	observed	000	96	000	3	99	3	108.589	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
L hue 12	observed	000	5	94	000	99	3	102.995	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
M chroma 13	observed	1	2	96	000	99	3	108.045	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
N chroma 14	observed	1	98	000	000	99	3	115.116	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
O chroma 15	observed	2	4	90	3	99	3	88.474	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
P chroma 16	observed	1	98	000	000	99	3	115.116	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
Q chroma 17	observed	000	1	98	000	99	3	115.116	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				
R chroma 18	observed	98	1	000	000	99	3	115.116	p < .001	significant
	expected	24.75	24.75	24.75	24.75	99				

Appendix I. ANOVA Data Analysis – Task Efficiency Within Value Structure.

Table 4.5: ANOVA Analysis: Value

Source of Variation	SS	*df*	MS	F
Between	222.832	98		
Within	406.333	495		
Items	210.013	5	56.003	72.542
Residual	378.320	490	.772	
Total	629.165	593		

F 95 (490,5) = 2.21 $p < .05$

Table 4.6: Value Items Mean Scores derived from ANOVA Analysis

A *Value 1*	**B** Value *2*	**C** *Value 3*	**D** *Value 4*	**E** *Value 5*	**F** *Value 6*
1.82_{a}	1.61_{e}	1.47_{c}	1.48_{d}	1.46_{ab}	2.05_{bcde}

$p < .01$

Appendix J. ANOVA Data Analysis – Task Efficiency Within Hue Structure.

Table 4.7: ANOVA Analysis: Hue

Source of Variation	SS	*df*	MS	F
Between	244.494	98		
Within	1040.333	495		
Items	287.787	5	57.557	37.472
Residual	752.546	490	1.536	
Total	1284.827	593		

Table 4.8: Hue Items Mean Scores derived from ANOVA Analysis

M *Hue 13*	**N** *Hue 14*	**0** *Hue 15*	**P** *Hue 16*	**Q** *Hue 17*	**R** *Hue 18*
1.44_{a}	1.62_{b}	1.62_{c}	1.38_{abcde}	1.55_{a}	1.58_{e}

$p < .01$

Appendix K. ANOVA Data Analysis – Task Efficiency Within Chroma Structure.

Table 4.9: ANOVA Analysis: Chroma

Source of Variation	SS	*df*	MS	F
Between	301.054	98		
Within	132.333	495		
Items	20.114	5	4.023	21.286
Residual	112.219	490	.189	
Total	433.387	593		

F 95 (490,5) = 2.21, $p < .05$

Table 4.10: Chroma Items Mean Scores derived from ANOVA Analysis

G *Chroma 7*	**H** *Chroma 8*	**I** *Chroma 9*	**J** *Chroma 10*	**K** *Chroma 11*	**L** *Chroma 12*
1.45_{bgj}	1.43_{afi}	1.93_{abcde}	1.45_{ehk}	1.63_{dijk}	1.76_{cfgh}

$p < .01$