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By

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ABSTRACT

COLOR AS A CUE TO ORIENTATION IN THE GERIATRIC INSTITUTION

By

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The institutionalized elderly may be characterized as experiencing a loss of control in man/environment interaction and information exchange. One aspect of that information is orientation to the physical milieu. This thesis is organized to study the design element of color as an orientational cue relative to the elderly individual's ability to receive, detect, and perceive it. It is established that while color may possess orientational potential its relevance to the elderly user is still unknown. The ability of the individual to receive and detect colored stimuli is studied, with available research indicating that degeneration of pre-receptor elements should effect color vision. Nevertheless, the precise character of that degeneration and its prevelance among the elderly has yet to be established. Research on elderly perception is shown to be irrelevant to the environmental designer's informational needs. Throughout the thesis areas for future research are suggested and potential research questions generated.

Rarely in one's lifetime does a person find dedicated friends who care regardless of the circumstances. To Dr. Robert Summitt and Dr. Robert Moore I dedicate this thesis with love.

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CHAPTER 1: INTRODUCTION

> The environment is organized as intricately and systematically as any spoken language. It has a system of cues that tells us how to respond to particular situations. However, the environment communicates meaningfully only to the degree that the cues which are sent out can be received and perceived by the individual. (Pastalan, 1971, p. 4)

Wherever the social group is concerned for the welfare of its members, it has been faced with the problem of caring for its elderly. In the past this has not been a significant problem because the older and weaker members of the group usually died before their needs could become a burden on the society. In this century, however, medical, technical, and social changes have led to an ever increasing population of elderly people (popularly defined as those age 65 and older), based on retirement statistics. The 1930 census placed the elderly population of the United States at 6.6 million. By 1970, that number had increased to 19.8 million, with projections indicating that our total elderly population will be 27.5 million by 1990. Furthermore, the number of persons of old, old age (Neugarten, 1968) is also increasing steadily. The 1930 data show that 29% of the elderly were age 75+ and a negligible number at age 85. By 1970, these figures had grown to 38% and 6.7% respectively. Although 95% of the present geriatric population maintains adequate health and financial viability, which can be translated into independent or semi-dependent living arrangements, the remaining 5%, totaling 1.5 million people, must reside in an institutional setting. Moreover, it has been estimated that 40% of the elderly population at one time or another will require institutionalization for some period of time (Koff, 1977). Institutionalization occurs when the individual experiences physical or mental deterioration, when he/she is isolated from the supportive services of family and friends, or when there is insufficient political, economic, or social support in the community. These developments, characteristic of the aging process, have been summarized in the geriatric literature as a 'loss of control' or effectance in one's man/environment interactions (Schwartz and Proppe, 1970).

There are many types of institutions currently available to the elderly which vary widely in the amount of supportive services available to the resident. The essential characteristics of the institution are: 1) the dwelling is designed for communal living, with varying amounts of private space available to each resident and shared public spaces; 2) the facility is designed to provide a supportive environment for the particular needs of its population; and 3) it is designed for individuals who will reside there for an extended period of time. The elderly individual entering an institutional environment faces a new and complex physical, social, and cultural milieu at a point in time when his/her own energy resources are at a low ebb because of the 'loss of control'. Therefore, it is the responsibility of those involved in institutional design to provide a physical milieu which will compensate for individual disabilities and lead to successful incorporation of the individual into the institutional environment. The study of institutional design only recently, however, has become a topic of concern for the theorist, geriatric researcher, and designer.

Problem Area Definition

Environmental theorists draw from a variety of disciplines to describe human adaptation to the environment as an ongoing interaction and mutual modification process. These theorists rely heavily on the basic tenet that the individual partakes in man/environment interaction by use of sensory modalities in a stimulus/response mechanism. Extracting evidence from physiology, psychology, and anthropology, Amos Rapoport (1975), Alton J. DeLong (1974), and Edward T. Hall (1969) have posited that one assimilates and shares culturally the milieu of environmental stimulation in such a way that the built environment is conceptualized as the organization of time, space, communication, and meaning. Furthermore, Roger Barker (1963) contends that human behavior patterns and milieu exist in a synomorphic relationship. That is, human behaviors are inexorably linked to a time-place-object framework called the behavior setting. The built environment can then be conceived as a system of potential physical resources capable of being endowed with stimulus meaning by the user. Meaning is evaluated according to effectance ability of the individual, termed 'sense of competence' (Perin, 1970) in negotiating the physical and social milieu in order to carry out everyday activities and behaviors.

M. Powell Lawton (1977) has organized these theories into an Ecological Model for the design of geriatric institutions. This model counterbalances the individual's competence (ability to perceive stimuli and respond to them) with environmental press (impinging stimuli). Appropriate competence/press interaction results in successful cognition of the behavior setting and adaptation. The elderly individual entering an institutional environment must partake of an entirely new and different set of stimuli (press) and his/her competence level is severely stressed. Inherent in Lawton's model is the assumption that the designer, as organizer of environmental stimuli, manipulates the environment in order to provide better congruence between competence and press. This congruence, in principal, is the same process underlying the concept of the 'prosthetic' environment (Lindsley, 1964). The intent of the prosthetic environment is to 'fit' competence to press, either by effecting a change in the individual (e.g., raising competence level) or in the environment (e.g., decreasing press). The goal of the environmental designer, then, is to promote man/environment congruency by organizing a physical milieu that provides those resources necessary to enhance human competency.

One function of organized physical stimuli is to provide the individual with orientational cues to the behavior setting. Webster's (1965) defines 'orient' as, "to acquaint with the existing situation or environment". Orientational cues in the environment serve as predictors of the generic meaning of the behavior setting. They define the space and its relevance to human needs and activities. To facilitate effectance, such cues must allow rapid, unambiguous identification of their meaning. In the prosthetic environment the designer employs redundant cueing systems to enhance orientation. Because 'loss of control' involves diminished ability in detecting and perceiving stimuli, redundant cueing systems use a variety of stimuli, activating different sensory modalities, to communicate a single meaning. It is a message amplification device. For the elderly individual, amplification means decreased environmental press.

Redundant cueing systems necessitate the simultaneous use of a variety of design elements such as size, shape, light, color, and texture. It is, by definition, holistic. Nevertheless, appropriate use of redundant cues requires that the designer be cognizant of the implications of tools employed. It requires a knowledge of sensation, perception, and response processes. Design research, directed at specific environmental stimuli can provide such knowledge. This study is directed at the use of color as an orientational cue for use in the geriatric institution.

The designer employing color as a cueing mechanism takes a serious approach to the design of colored environments in the realization of its potential as a tool enabling effectance. Appropriate use of color for a geriatric population requires an understanding of the informational character of color, the color detection abilities of the aged visual system, and the perceptual experience of color in the elderly. It draws on psychological, physiological, and ophthalmological research. A survey of psychological research indicates that color not only communicates to the individual on a variety of levels, but also may serve as an orientational cue to the behavior setting by defining space, enhancing focal points, and communicating affective meanings about the environment. Geriatric researchers, however, have failed to investigate the informational character of color for older people, preferring instead to generate highly prescriptive uses of color based on color vision research.

Human color vision always has held a fascination for man, but only recent technological advances have permitted serious investigation of the physiological elements of color sensation. Those concerned with the physiological changes which accompany aging have accumulated some data that characterize the degeneration of the visual system. Those changes affecting color vision specifically are: 1) the pupil diameter diminishes with age, thus reducing total retinal illumination; and 2) lenticular light transmission is reduced, with short wavelength light being reduced to a greater extent. Although current research on the visual system has yet to achieve the sophistication necessary for conclusive generalizations, most authors tend to agree with R. A. Weale (1963) that degeneration of the ocular media, specifically rigidity and yellowing of the crystalline lens are the primary causes for the wavelength-specific decline in color vision. Others, however, more recently are studying the possibility that degeneration along the neural network also could be a contributing factor (Stordant, 1972).

There also have been several attempts in the last fifty years to characterize geriatric color perception (e.g. color detection). The study of color perception in general, however, is still in its infancy and investigators not only are wrestling with the multitude of variables inherent in such a system, but also are attempting to correlate the findings of various testing procedures in order to identify the nature of perception that is being measured. Geriatric studies have been plagued further by inadequate testing procedures, small sample size, and a tendency to elaborate on age differences between decades rather than concentrate on the elderly. Nevertheless, their conclusions are in general agreement with physiological studies in that they indicate a decline in visual sensitivity with age, particularly at the blue end of the spectrum (Lakowski, 1969).

Thus, the results of color vision research suggest that elderly people may experience some difficulty in discriminating hue, saturation, and value in the environment.

It is the designer's responsibility in developing the prosthetic environment to consider these difficulties not as an aesthetic liability but as a potential hazard hindering the elderly's effectance in behavior setting identification, and thus, inhibiting appropriate man/environment interaction.

The design process initiates with problem definition and proceeds to goal setting and information gathering. Thus far, a situational context has been developed and a problem area defined regarding the role of color in an institutional setting for geriatric users. Furthermore, an overriding goal, congruency development, has been established. But the designer requires a more tangible set of goals in order to facilitate design implementation. Although specific goals would be set for a particular environment, five general goals may be generated that would apply to all design problems regarding color in the geriatric institution. They are:

1) Color should be used to facilitate initial adaptation to the institutional environment. It has been noted in a wide variety of studies that institutionalization is a stressful event. Depression increases and mortality rates may reach 50-60% among relocated elderly during their first year in the institution (Blenker, 1967). Initial adaptation involves the user's ability to orient to the physical configuration of the space. One requires information from the environment regarding the location and arrangement of objects and spaces. This involves the use of color to

delineate areas such as unit wings or floors, room location, level changes, exits, and so forth. Beyond location, however, it facilitates human movement through the spaces, toward or around objects, by providing an orderly progression of similarities and contrasts. Thus, color as a design tool should be organized within and throughout the institution in a rational order to facilitate location recognition and directionality for movement.

2) Color should be used to facilitate social adaptation within the institutional environment. Appropriate manipulation of the physical environment allows for a certain degree of satisfaction because physical needs are being met. But man is a social being requiring ongoing interactions with other people in order to enhance self-esteem and self-actualization. Successful adaptation to an extended care facility must involve socialization. Therefore, a second level of adaptation involves the user's ability to orient to behavior settings in order to enhance person to person communication. This involves the use of color to not only delineate location, but also activates the cognitive and emotional reflexes of the individual to recognize the socially shared affective meaning of the spaces. Thus, color should be used to delineate a spatial framework, and also provide a milieu of informational resources that facilitate human interaction. This involves the use of color schemes congruent to human behavior patterns such as stimulating colors in a work environment and relaxing colors in rest

areas.

3) Color should be used to maintain a slightly higher degree of press relative to user competence in order to maximize human potential for adaptation through growth. The person entering an institution is stressed because the environment is totally new. Therefore, the initial phases of adaptation to the environment require a degree of stability in order to facilitate rapid assimilation of a wide variety of information. In other words, environmental press should be minimal to facilitate integration of a low competence individual. But as adaptation proceeds, competence level may also increase, so that the individual may desire greater complexity and variety in the environment. A degree of challenge is required. This would allow for maximization of human potential and provide some stimulus for change and growth. Thus, color should be organized in the environment to communicate differences between behavior settings, but also allow for some diversity and complexity within the spaces. This necessitates the use of a broad range of colors throughout the spectrum followed by variations in value and saturation. Leon Pastalan (1979) has suggested also that color schemes be devised that would change through time (e.g. seasonal variations) in order to introduce complexity as well as maintain reality orientation to events occurring in the external environment. In any case, the use of color to provide complexity and variability in the environment negates the possibility of simple color schemes

with merely focal point emphasis. It requires sensitivity and a well developed plan for implementation.

4) Color should be used to provide an aesthetically pleasing environment that reflects user preferences and values. Although a goal of any design is to provide an aesthetically pleasing environment, the designer should be cognizant that user preferences play an important role in determining the final effect. Colors should be chosen to provide not only for functional adaptation, but also for perceived pleasantness to the geriatric users.

5) Color should be chosen relative to user capabilities for stimulus detection. In order to facilitate adaptation to the physical arrangement of the space and its behavior settings, to provide for variety and complexity, and to provide an aesthetically pleasing entity, the physical stimulation must be detectable to the perceiver. This goal may be conceived of as an enabler to achieving all other goals. As noted, it may be deduced from the literature that the elderly individual may perceive colors differently than a younger person because of ontogenetic changes in the visual system. If this is true, it is of utmost importance that colors be selected relative to user capacity to receive and detect them. Then, and only then, may the other goals be achieved.

In order to achieve these goals, the designer requires a considerable amount of information. But first a variety of questions should be generated that would provide for information gathering, analysis, and synthesis. The primary questions to be answered are:

- How does the individual interact with the environment in order to obtain needed information?
- What is the form and content of information to be transferred?
- How may adaptation be evaluated?
- Does color provide information?
- If so, what is the content of that information?
- Is the content of that information the same for old and young alike?
- How may color as an informational cue be evaluated?
- May color be employed to provide complexity and variety?
- What are geriatric user color preferences?
- What are the parameters of elderly color vision capability?
- What are the parameters of elderly color perception?

Given this information the designer could proceed to generate alternative solutions to the design problem. This requires a broad review and summation of a wide variety of research into perception, man/environment interaction, and color as an informational resource. To date, however, there has been no serious effort to collect and review existing theoretical and experimental data concerning the effect of color and its usage for a geriatric population. The information remains scattered and poorly related. Physiologists have outlined the visual problems peculiar to a degenerating visual system. Psychologists have documented the informational character of color as an orientational cue. And environmental researchers have studied the impact of the physical milieu on human behavior. But there has been no attempt in the literature to correlate the geriatric perception of color and the use of color as an environmental cue affecting their behavior.

Approach to Problem

As stated, the designer should have accurate and appropriate information concerning the visual characteristics of the elderly in order to select color cues to code the environment. He/she should also have reliable information regarding the manipulation of color as an orientational cue to the behavior setting. This information should include a comprehensive review of the literature, the development of statistically reliable research, and finally, a reliable model to be used by the designer. Inasmuch as no such compilation exists at this time, the objective of this study is to assemble a complete and critical review of the state of the art. This review studies available physiological, psychological, and sociological data determining the role of color in the built environment, the perception of color by the elderly, and current views as to the use and applicability of color cues in designing a prosthetic environment that is sensitive to the needs and characteristics of the elderly. The methodology employed in this study includes extensive search of library resources as well as correspondence and conversations with some of the major authors. This study analyzes and discusses research techniques used in the study of color and color vision and their reliability. It is, therefore, an attempt to summarize the available knowledge required to answer the above questions. Nevertheless, it will be shown in this paper that there are considerable gaps in the information required. We need to know much more before the design process may proceed. Therefore, throughout the work further questions are generated that suggest possible routes for future research.

Organization of Thesis

This thesis is divided into a series of chapters providing an ecological approach to the use of color in a geriatric institution. Chapter 2 outlines a theoretical framework of man/environment interactions and examines the relevance of theory in geriatric research. Chapter 3 concentrates on the informational character of color through a study of current psychological research. It then focuses on the specific characteristics of color as an orientational cue. The chapter ends with a discussion of current views of color in the geriatric institution. Chapter 4 analyzes the human visual system, color perception mechanisms, and the methodology of color vision testing. Chapter 5 expands on this foundation to compile an objective review of current research on geriatric vision and color perception.

It serves to identify methodological problems existing in the literature that have led to an oversimplification of the visual capabilities and needs of the elderly. The final chapter of this thesis serves as a summation of the state of the art, identifies unanswered questions, and suggests future research avenues for the study of color as an orientational cue in the geriatric institution.

CHAPTER 2: MAN/ENVIRONMENT COMMUNICATION

'Design' of the human environment implies a commitment to maximizing human potentials and values. Achieving this goal requires an understanding of the systemic relationship of the individual and his/her environment. Humans are living systems that experience their environment through metabolic and sensory perceptual mechanisms. The environment can be conceived as the organization of material and informational resources in a spatial and temporal framework. At the interface between the two systems, matter and information are exchanged and transformed, resulting in a mutually modifying relationship. The direction and flow of that exchange, coupled with the systems' transformation capacity, will determine ultimately the quantity and quality of human adaptation. The primary elements of concern that have been identified in this study are the individual, the institutional environment, and their communicational exchange at interface. It is now necessary to define and characterize these elements relative to an ecosystem approach.

1) The Environed System: The Individual

While the elderly population of this country clearly is a heterogenous group, it is unified by its stage in the human developmental process called aging. Aging is multidimensional, affecting the physical, psychological, social, and cultural processes of the human being. It is generally characterized by the gradual or traumatic degradation of the living system, described as a "loss of control or effectiveness in the environment" (Schwartz et al, 1970, p. 230). Loss of control is precipitated either by individual factors (e.g., loss of physical or mental acuity) or by environmental factors (e.g., loss of income, emotional ties, or role status). Schwartz et al have stated that the loss of control contains at least three dimensions:

a) Barring catastrophy, loss of control usually occurs in developmental increments so small as to be imperceptible. Research indicates that sensory sensitivity declines from age 30 until death. Similarly, role status and social integration are usually highest in the productive middle years. Thereafter, they also decline.

b) Loss of control is multi-faceted including all realms of the human system. Just as diminished sensory acuity signifies loss of control, so too, does the shrinking size of the individual's home range.

c) Loss of control is cumulative. Diminished sensory sensitivity affects mobility in the home range, territoriality, and social interaction. The process can lead to alienation and 'disengagement'.

Loss of control is, in and of itself, a highly negative concept. Nevertheless, purposeful man/environment interactions may inhibit or deter the cumulative effects of this process, allowing for adequate matter and informational exchange. The degree to which interaction controls this process can be related to man/environment congruency.

2) The Environment: Institution

The American Heritage Dictionary defines institution as "a place of confinement". Traditionally, the nursing home or geriatric hospital has been viewed as a place of confinement and 'where the old people go to die'. This attitude was reinforced by institutions that served as catch-alls for the old, mentally indigent, and orphaned, all of whom were viewed by society as non-productive. In more recent years, the elderly have been segregated and institutionalized in former low income housing projects, university dormitories, and sanitaria when these buildings were abandoned as inadequate for the original users. It appears that, if confinement is the primary objective, any place will do.

An ecological definition approaches this concept from two levels. First of all, institution may be generically defined as an organization established by humans to provide access mechanisms for the fulfillment of human needs and values. This implies a relationship of feedforward and feedback in the interaction. Figure 1 demonstrates this concept where E stands for the environment and O for the human organism. Secondly, institution may be defined as a bounded system serving as an environment for the individual

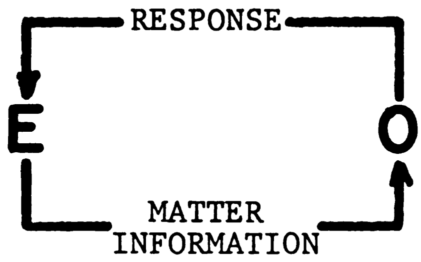

Figure 1: Generic Definition of Institution.

system or a collective group of individuals. In this sense, it is an organized system with the goal of providing a supportive milieu for the aged. The concept of the supportive milieu (*e.g.,* prosthetic environment) assumes that environmental input into the exchange process may be manipulated relative to human capacity in order to enhance congruency.

3) Communication Exchange

All living systems are energy driven. From an ecological standpoint, energy resources are of two types: matter and information. Matter energy consists of fossil fuels, mechanically produced energy, goods, and services. Information energy is composed of knowledge, norms, and values. At interface, linkages are established that provide for energy flow between the two systems. The primary concern for the development of information exchange linkages is the ability of both the individual and the environment to receive and code the communication of stimuli. Reception of stimuli is based on the system's ability to detect its existence in the milieu and to comprehend its relevance as information. It relies on sensitivity of the receptor system and is mediated by experience and established code. Upon detection, the system develops codes whereby the stimuli are organized, condensed, and given meaning. In the man/environment interface, information transfer flows in both directions. For example, the individual receiving stimuli from the environment develops codes concerning locations and relationships. Similarly, the environment receives and codes information from the individual regarding his/her physical and mental state. From this process of information exchange, the systems move to response actions. Response itself produces a new set of stimuli (Laszlo, 1960).

Throughout the exchange process of receiving, coding, and responding to stimuli, man/environment transactions are driven toward a state of dynamic equilibrium if successful adaptation is to occur. Positive adaptation of the individual to the institution would be developed when the energy flow from the environment is in equilibrium with the individual's ability to detect, code, and respond to it (*e.g.*, congruency). Figure 2a indicates this ~~ideal transactional~~ process. But other modes of adaptation are possible when the transactional process is discordant and linkages either are not established or information is distorted. Figure 2b depicts a man/environment transactional process where the energy flow from the environment is too forceful when impinging on the individual's ability to receive it or code it. In this instance the environment overwhelms the individual and the feedback response is haphazard and discordant with the environmental code. Furthermore, feedforward is virtually halted. In the institutional environment this process occurs when stimulation of the individual is too strong for the capacity of the physical, mental, and emotional energy stores to handle. Confusion, disorientation, and 'senile' responses are the inevitable result. Conversely, a reciprocal process may occur in which the individual overwhelms the environmental energy flow. In this situation (Figure 2c), the individual's capacity is greater than environmental stimulation and could result in monotony and boredom for the individual. Continuation of such a transactional process would lead to either overdependency or escape through fantasy. In either case, communication is again distorted or lost.

a) Dynamic Equilibrium

b) Low Capacity Individual

c) High Capacity Individual

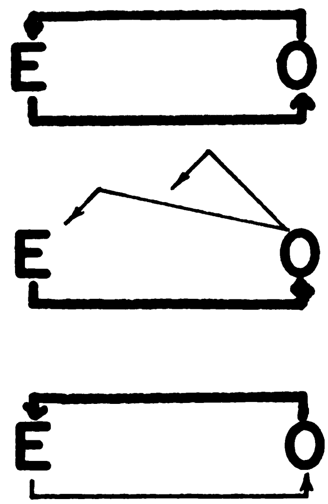

Figure 2: Man/Environment Communication Exchange
(After DeLong, 1974)

Thus, it may be inferred that the two primary mechanisms at work in the interaction of individual in the institution are the organization of environmental stimuli to communicate informational content and the individual's capacity to perceive and code the stimuli. An analysis of these mechanisms relies on information obtained from environmental research, communication systems theory, and geriatric research.

Communication: Content and Code

As stated, congruence in man/environment interactions involves an equilibrium between the energy flow from the environment and the processing capacities of the individual. In studying man/environment congruence in the physical realm, Leon Pastalan of the University of Michigan Geriatric Institute has conducted a considerable amount of design related research for the elderly. Pastalan's thesis is that effectively programmed environmental stimuli will enhance the individual's capacities. From his work, Pastalan reports that two basic principles have emerged:

a) organized space as stimulus (e.g., environmental communication)

b) organized space as orientation (e.g., cue to the behavior setting) (Pastalan, 1971)

Regarding space as stimulus, Pastalan states "the environment is organized as intricately and systematically as any spoken language" (ibid., p. 8). The communication transmitted from the environment to the individual involves the cueing of the individual as to the appropriate response to the specific situation. Just as Perin (1970) has stated that the environment responds to the stimulus of human needs, Pastalan states that it does so with information-laden cues. The second principle to emerge from this work, organized space as orientation, deals with the design concept of manipulating spaces to communicate a singular, unambiguous definition of the space and its relevance to human activities. He is referring generally to the same concept as Barker's Behavior Setting. Barker (1963) contends that the milieu is a composite of time-space-object which serves as the generic place for human standing behavior patterns (e.g., systematically recurring episodes of human activity). In other words, orientation to the behavior setting requires the organization of stimuli into recognizable patterns for shared identification of space as 'place' for individual or group actions. Thus, material resources cue informational exchange. Orientational cues provide three levels of information that enable behavior setting identification:

1) Orientation involves the individual's ability to comprehend the physical form and boundaries of the environment. The configuration of physical resources provides the individual with information about the location and attributes of mass and void and defines locus, scale, and directionality for human movement.

2) Orientation involves the individual's ability to identify meaningful information amid a myriad of stimuli impinging on the sensory system. It

allows discrimination of information relevant to needs and behaviors from meaningless cues. It provides a hierarchy of focal points relative to behavior in the milieu.

3) Orientation involves the individual's ability to sense the congruency between environment and behavior. By definition, the behavior setting implies that place and behavior possess a synomorphic relationship. The environment cues the individual to appropriate behavior in the place, and conversely, the appropriate place for behavior. Failure to achieve sensed congruency could result in some form of disequilibrium.

Relating these concepts to the ecological framework that initiated this chapter, it may be inferred that Pastalan's principles of organized space as stimulus and orientation correspond directly to the individual's detection, perception, and coding mechanisms in the man/environment interface. Thus, it is the establishment of a communicational linkage at interface that allows exchange of orientational cues.

Alton J. DeLong (1972) has developed a comprehensive study of man/environment communication systems. He assumes basically that the environment constitutes a system that is learned and shared socially. Internalization of the environmental language enables orientation to the behavior setting and recognition of socially acceptable, adaptive behaviors. Any communication system is composed of two primary elements: form and content. Content is the information that is passing through the system (e.g., orientation), while form is the physical, formal property or structure of the expression (e.g., stimuli). Time, space, and culture determine the form and content of the message. Participation in a communication system implies several things. First of all, it delineates group membership. In order to belong to a group, one must be able to receive and transmit its communication. The codes and signals must be understood in both form and content. While in person/person communications, one's ability to manipulate codes will determine his position in the society, in man/environment communication code mastery will determine one's ability to orient and manipulate the physical environment. Secondly, degree of participation depends upon the person's ability to encode the environmental signals. Child development theorists hold that these abilities are developed as a direct function of physical and mental maturity and require maximum use of one's faculties (Piaget and Inhelder, 1956). Finally, participation implies that if the envrionmental signals are sufficiently internalized, "the organism has transformed the environment into something predictable and redundant" (DeLong, 1972, p. 276). Furthermore, internalization implies that while behavior is reliant on signal usage, the signal itself or its meaning may be intangible to the individual. Therefore, resultant behavior may be difficult to associate with specific signals. Nevertheless, internalization and transformation of environmental communication allows the person to orient to the physical milieu in order to accomplish his goals. These aspects of participation will be further analyzed as they pertain to the elderly individual in the institutional environment upon further development of DeLong's theory.

With environment being characterized as the entire milieu impinging on the organism, one organizes that milieu by the coding process of receiving stimuli, analyzing content, and storing the information for future reference (DeLong, 1972, Laszlo, 1960, Struder, 1976). Psychophysical research indicates that this is accompanied by feature detection and analysis (see Chapter 3). According to DeLong, the process of coding in the man/environment relationship involves three aspects. The first is the perception that the apparently discontinuous milieu of stimulation can be characterized as continuous, regular, and redundant. The organism detects and orients the stimuli. This aspect is labelled ETICS after Pike (1967) who coined the term from phonetics to describe the study of behavior from outside of the system. The second step in the coding process is EMICS, from phonemics, or studying behavior from inside the system. This involves the grouping of stimuli into discrete units, thereby increasing code redundancy. Finally, EMICS are further organized to provide specific combinations of stimuli by which the organism can control the flow of information in in the system. Figure 3 indicates the development of these concepts.

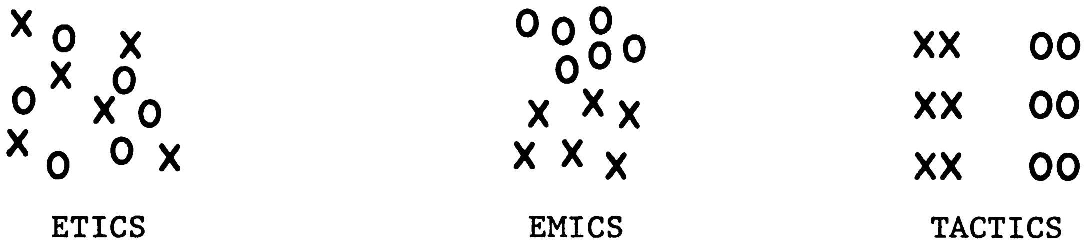

Figure 3: The Coding Process (after DeLong, 1972)

Implications of the coding process are complexity reduction, constancy, variability, and change. Codes reduce complexity in the environment by relying on classification and redundancy. In the EMICS process, complex stimuli are ordered into classes with a single-featured characteristic. TACTICS further reduce complexity by limiting the possible combinations of EMICS that will be regarded as necessary and meaningful. Furthermore, complexity reduction allows the organism to maximize contrast between stimuli, thus, enhancing figure-ground relationships. The second implication of the coding process involves the concept of constancy, which allows for a certain degree of predictability in the environment. While the environment is in constant flux, it does retain a certain degree of constancy. "An organism could not tolerate a different Universe every moment of its existence. It would suffer information overload. Predictability in the environment implies regularity, a degree of constancy despite inherent environmental variability"

(DeLong, 1970, p. 357). Constancy is achieved by selective desensitization to many aspects of the stimuli by genetically and culturally controlling the EMIC and TACTIC combinations. Although uniformity in the environment is a necessary condition for human participation in the communication exchange, the code must also allow for variation and change concomitant with human development. Variability delimits the range over which the codes are differentiated from one another, and allows the individual to ignore irrelevant information. The final implication of the coding system, change, allows the reorganization of TACTICS to enhance congruency between environment and human activities. Thus, the coding process allows the three levels of orientation to be comprehended by the individual; spatial form and boundaries are identified, focal points established, and behavior settings comprehended. DeLong concludes that,

> Codes...give every appearance of having evolved precisely to regulate the fine balance between relative simplicity, or redundancy and relative complexity, or information...the code represents the amount of complexity that can be reliably handled without intolerable error in performance. (DeLong, 1972, p. 643)

Thus far, this discussion has relied on a pair of assumptions which are that environmental messages are transduced by the human sensory system and transmitted to the brain for coding and that this process is accomplished by all persons. Both of these assumptions have grave consequences for the elderly person attempting to code the institutional environment. Successful coding depends upon the intellectual and physical capacities of the human system (*e.g.*, acuity of the transduction system). Studies dealing with the intelligence of the elderly cohort indicate that, in general, they demonstrate poorer performance than younger subjects in concept attainment, problem solving, learning, and memory (Schaie and Gribbon, 1975). Other investigators contend that intelligence *per se* may not diminish with age, but rather, certain intervening variables may have a stronger effect on information processing abilities (Wallace, 1956). In a series of studies on information processing of complex stimuli presented serially, Wallace concluded that slower response times in the elderly subjects could be explained by physiological decline at the sensory level and along the neural network, rigidity of set (TACTICS) precluding recognition of variability, and a general lack of confidence among the subjects. Similar conclusions have been drawn by other investigators (Birren, 1964, Geist, 1968, and Surwillo, 1973).

Although further study of age-related information processing speed and accuracy is needed, considerable research already has been done to characterize the decline of sensory functioning concomitant with aging. Chapter 5 discusses this work relative to the human visual system. While there is sufficient information available to stimulate conjecture, it should be noted that the precise relationship between sensory function and human behavior has yet to be established. Furthermore, the human system is capable of adapting to varying ranges of sensory deprivation through time. As sensory degradation in the elderly is usually a gradual process, the individual may have adapted to decreasing information flow by learning to perceive the message with very little redundancy or by relying on other sensory modalities to supply the missing information. Nevertheless, to study the man/environment coding process, a knowledge of sensory functioning is necessary and further research is needed to identify the nature of the loss and its effect on information processing. In summary, however, it may be generalized that the sensory sensitivity of the older person is diminished, and that the time required for processing and reacting to environmental cues has increased. These liabilities in coding ability, coupled with other aspects of the loss of control, characterize a group of individuals who may experience difficulty in participating in man/environment information exchange.

As stated, participation in a communication system implies that one is able to receive and transmit signals delineating group membership and to orient to the behavior setting. Failure to adequately internalize the informational code could lead to haphazard responses in orienting to other members of the group, activities, and places. Both stability and variability in the environmental code are perceived as irrelevant to behavior. The individual may wander, disengage, or ritualize behaviors. Human response to the institutional environment has been studied by several geriatric researchers. Sommer and Ross (Sommer, 1970) report that the simple rearrangement of furnishings in a dayroom resulted in confusion, disorientation, and distress among the subjects. It may be inferred that the subjects had ritualized response to environmental signals to such an extent that variability destroyed their coding. Other investigations have expanded on this concept to examine the behavioral effects of diminished man/environment information exchange by studying social interaction and self-perception. In the Sommer _et al_ study, the researchers' organization of the furnishings introduced greater redundancy into the behavior setting code. Results indicated that the subjects were eventually able to internalize the new TACTICS, and social interaction increased significantly. Social interaction was also studied by Snyder (1973) in three New York nursing homes. After observing social interaction on three levels -- congregation, brief interaction, and conversation -- Snyder found that the significant variables affecting interaction included the location and attributes of the space, traffic pathways, and furniture arrangement. Lawton's (1973) study of 12 housing sites indicated that the behavior of older people was affected by the location and type of environment they were in (_e.g._, behavior setting). Lawton and Simon (1968) compared deliberate transversal of space for social interaction to reliance on passive encounters. They concluded that the intervening variable affecting choice was docility of the residents resulting from decreased competency levels. This may be related to lowered coding capacity. To date, however, there has been no serious attempt to analyze this relationship.

For the designer of institutions, as provider of the environmental stimuli, this represents a serious gap in information required for appropriate design. A major question remains unanswered: How may environmental stimuli be organized to facilitate coding mechanisms for orientation to the behavior setting? In order to better understand the parameters of this question, a series of other questions bear investigation:

- What are the physical parameters of stimuli that indicate redundancy?
- What parameters of redundancy mark insufficient cueing (understimulation) or excessive cueing (noise)?
- What are the preferred stimuli for orientational coding?
- Do orientational cues possess a hierarchial order?
- Can the environmental stimuli be simultaneously congruent with both the low competence and high competence individuals?

Conclusion

The objective of this chapter has been to develop a theoretical framework of the man/environment communication process and to establish a potential area for future design related research for congruence enhancement. While DeLong and others have provided an intersting analysis of the communication process, there still exists a definite gap between theory and practical application. The designer has not been given the necessary information for implementing a coding system in the environment. Geriatric research, on the other hand, has attempted to deduce from data on existing environments the effect of codes on the individual. There does not exist at this time a bridge of research that develops a code and analyzes the coding process. It appears that the major stumbling blocks to developing such research lie in the inability of practitioners to adequately define, clarify, and operationalize such concepts as stimuli, orientation, code, and energy transfer. Thus, we do not know whether or not the coding process, as theoretically outlined, actually occurs in the human adaptation process to the environment. It appears plausible, but until researchable hypotheses are generated, the gap will remain.

CHAPTER 3: COLOR AS AN ORIENTATIONAL CUE

Introduction

Color in the physical environment involves the complex interaction of technology, artistry, and human perception. Information from a variety of disciplines enables the designer to employ color as a resource for optimal behavior setting performance. Physics defines and measures the interaction of light and color to allow for intended visibility and color rendition. Chemistry standardizes pigmentation and color identification. Art provides harmonious color patterns. Physiology describes the sensory stimulation of color and the related physiological responses. And psychology provides predictions of the behavioral response to colored environments. Ignorance of any aspect of color may result in nonfunctional design.

In Chapter 2, design of the behavior setting has been described as the manipulation of physical resources to communicate informational cues in response to human needs. Moreover, it has been established that humans relate to their environment only to the degree that it contains information relevant to them. Thus, coding the prosthetic environment requires the manipulation of color relative to geriatric needs to ensure perception and identification of the behavior setting. This suggests that color may be treated as both an independent variable influencing environmental perception, and as a dependent variable being affected by the organism's ability to detect stimulation. The objective of this chapter is to study the informational character of color in general, and specifically, color as an orientational cue.

Color and Communication

Color communicates environmental information to the human organism on several levels: physiological, psychological, and cognitive. Perception and response to such communication may be categorized as unconditioned, conditioned, and reinforced. Unconditioned perception involves the physiological response of the organism to a color stimulus. Within the visual apparatus, perception initiates with absorption and transformation of light energy into an electrochemical impulse and culminates in stimulus detection. This process is discussed in Chapter 4. Malfunction of the visual system inhibits or diminishes the individual's ability to perceive environmental information. Blindness, color blindness, and the developmental level of the individual all affect ability. In blindness, the organism is insensitive to all radiated and reflected light. Color blindness involves varying degrees of insensitivity to wavelength differences resulting in color confusion. And finally, physiological development of the organism affects color perception. Chapter 5 deals with color vision tests that indicate that color sensitivity increases up to age 20 and diminishes after age 30 (Lakowski, 1969). Moreover, since the visual apparatus can process only a limited amount of spatially or temporally contiguous data, false perception, or illusion, may occur. Phenomena such as afterimage or subjective color perception are related to the system's information processing ability and result in an unconditioned response incongruent with true environmental information.

Beyond visual perception, the human organism also experiences other unconditioned responses to the colored environment. As early as 1938, Podolasky summarized available research linking colored lights with respiratory, muscular, and psychomotor responses. More recently, Gerard (1958) describes a series of experiments studying normal adult response to colored lights. Test results indicate that red and blue lights produced differential effects on blood pressure, respiration rate, eyeblink frequency, palmar conductance, and cortical activity. Norse and Welch (1971) found varying galvanic skin response to violet and green lights. Although these tests do not offer conclusive results, they do tend to support the proposition that colored environments affect the autonomic functions of the human organism.

The second level of human response to color deals with conditioned perception, or the associative aspects of psychophysical response to colored stimuli. The term conditioned is employed as it implies the developed ability to cognitively associate color with size, weight, depth, and temperature. Although studies employing color as an independent variable have often yielded contradictory results, the evidence is strong that color does ellicit a conditioned response. The major difficulty in early research appears to be the inability of the test to differentiate the dimension of color (hue, luminance, and saturation) actually affecting perception. Nevertheless, in his summary and analysis of current work, C. Payne (1964) found that in general, luminance appeared to be the major cue to size, distance, and apparent weight, while hue cued thermal perception. He concluded that future laboratory study of color as a cueing mechanism deserved greater study particularly regarding the interactions of gradients of the color dimensions. Some work in this area has been done and will be discussed later.

How color has come to cue has also been a controversial topic in recent years. Are conditioned responses (*e.g.*, red associated with fire, and blue with ice) inherent in the human psyche or are they more closely aligned with reinforced response (*e.g.*, culturally shared)? Morgon, Goodson, and Jones (1975) studied the correlation of age to the conventional responses of red/hot, yellow/warm, green/cool, and blue/cold. Although 18-year-old subjects showed significant tendencies to these associations, the 12-year-olds only agreed with red/hot, and the 6-year-olds showed no associations beyond mere chance. Future work in this area probably will be directed toward a greater understanding of the psychophysical and cognitive foundations of conditioned response.

The final level of human response to color communication, reinforced perception, involves the integration of unconditioned and conditioned responses with cognitive, emotional, and cultural variables. It is the realm of symbolic or affective meaning of color and color preferences. While this level affects the intimate informational character in man/environment interaction, it remains the least understood because of the multitude of variables associated with it. To date, the bulk of experimentation related to reinforced perception has yielded inconclusive results and highly intuitive generalizations. Schaie and Hess (1963) have described early work that led to generalizations such as red is exciting, passionate, aggressive, yellow is vital, energizing, blue is restive, calm, and so on. These early works, however, were characterized by grossly oversimplified technique leading to unidimensional characterization. For example, the technique employed by the often referenced Wells' (1910) study involved placing a color chart of 12 hues (full saturation) before a group of students. A series of words (e.g., quiet, sad, lively) were written on the blackboard, and the subjects were asked to place the hue number next to the word they felt best described it. Responses were simply tabulated and presented.

The introduction of the Osgood Semantic Differential (S.D.) has provided a more sensitive instrument for measuring affective meaning. The S.D. is based on a three dimensional 'semantic space' employing sets of bipolar adjective scales. The subject is presented a color stimulus and rates his/her response on a seven-point scale (e.g., good-----bad).

Factor analysis of the scales yields concept clusters that describe a single dimension of affective meaning subject to statistical analysis. The S.D. has been employed successfully in several studies in recent years. They have shown distinctive affective connotations related to hue, value, and saturation with both colored surfaces and full-scale environments. The results of some of these studies are discussed later in this chapter.

The value of generalizing about color preferences is questionable. Nevertheless, it is an element of response as it affects the liking/disliking of an environment. Color preference studies are numerous and it remains the unique area of color psychology that has employed elderly subjects. Katz (1931) found a positive correlation between preference for long wavelength colors and length of institutional tenure using elderly psychiatric patients. A comparable study (Mather, Stare, and Brienin, 1975) yielded contradictory results. Of the 102 subjects tested (65 female, 37 male) the majority preferred blue. Males preferred red second, green third, and yellow last. Females chose green second, followed by red and yellow.

In summary, a broad range of psycho-physical research supports the proposition that color in the environment stimulates human response on a variety of levels. The questions of how and to what extent color communicates environmental information remain unanswered. Nevertheless, with the research base currently available, it is possible to deduce that color can and does serve as an orientational cue in the behavior setting.

Color as a Cue to Orientation

It has been established that orientation in the behavior setting involves the user's ability to comprehend the general spatial boundaries and form of the environment, to identify meaningful information, and to sense the congruency of space and activity. The use of color, then, must necessarily address all of these aspects in order to serve as an orientational cue. This is particularly true if the designer/encoder intends to provide an environment compensating for the elderly individual's loss of control. To date, there is no available research providing a comprehensive study of color as an orientational cue, but the summation of a variety of work supports the general hypothesis that color does serve as a cue to orientation in the physical environment.

Color as a Cue to Spatial Form

The basic processes of form and space perception lie in the detection of contrast and contour, also integral parts of color perception. Contrast involves the system's ability to detect differences in the optical array. For example, the outlines of a room, objects, light, and shadows provide differential stimulation of the visual system. But the optical array projected on the retina is a two-dimensional image of a three-dimensional world. Therefore, while difference detection is simple in theory, it involves the complex interplay of constancy, edge, and light detection. This interplay allows the observer to comprehend not only the difference between white object and blue background, but also that the background remains constant in hue as it turns a corner and that a bright spot is a patch of sunlight, not an object.

Constancy refers to the phenomenon that a colored surface is perceived as uniform in hue and lightness independent of illumination. For example, a piece of paper is perceived as white and a lump of coal as black regardless of illumination level. Furthermore, even when crumpled, the paper remains white and the contrasts are perceived as shadows. Without the constancy principle, any change in illumination or viewing angle would disallow stability in the environment. Constancy has been shown to be linked to a figure/ground relationship (Kauffman, 1977). So too has a second phenomenon, simultaneous contrast. In this instance, two figures of equal reflectance will appear unequal when the grounds are different (e.g., red appears more orange on a blue ground and more purple on a yellow ground).

Questions on both constancy and simultaneous contrast have led researchers to place greater emphasis on the role of edge information in color and form perception. This movement has paralleled psycho-physical research in feature detection and cortical activity. Experimentation on edge perception in these areas has revealed the importance of edge information for the comprehension of visual space.

But first the work of E. Land (1977) and A. Gilchrist (1978) in color perception should be examined as it indicates the importance of edge in color detection. Land's early experiments dealt with black and white photographs of a scene taken through red and blue-green filters. A red object would show up as very light through the red filter, but almost black through the blue-green filter. When the two images were projected onto a screen again through their respective filters, the composite scene was revealed in full color. He then postulated that the visual system could contain three retinex systems, sensitive to long, middle, and short wavelengths, that would integrate color perception based on lightness comparisons as in the photographs. To test this hypothesis he developed the Mondrian experiments in which the visual scene contained patches of color similar to the namesake's paintings. His tests indicate that each retinex system measures reflected light point by point as it scans the field. Measurements of closely spaced pairs are converted to a ratio and subject to a threshold test. If the ratio does not vary from unity, it is judged as constancy; while variation is deemed a change. Integration of the three retinex systems provides the sensation of color. Although such point by point measurement sounds a tedious task, it is readily linked to the saccadic movements of the eye. The eye scans a surface with flickering tremors with a frequency of 30-150 cycles per second. Krauskopf has shown that these tremors cause a constant relative displacement of the retinal image resulting in edge detection and color perception (Gilchrist, 1978). The Land system holds under uniform, graded, and colored illumination, but Gilchrist contends that it breaks down under nonuniform illumination such as the corner of a room. He has proposed that color perception is inexorably linked to depth perception and that color detection is based on the visual system's ability to discriminate illumination edges (e.g., planar change and shadow) from reflectance edges (e.g., color). Although his work using miniature rooms is still in the early stages, evidence indicates that the visual system contains parallel detection mechanisms for both illumination and color, but both based on edge perception. These conclusions readily relate to constancy and contrast phenomena but now include the important principle of edge detection.

Psycho-physical studies of form perception also emphasize the role of edge perception. D. Hebb's theory of feature detection notes that observers analyze a form through fixation on the composite lines and angles rather than the figure *in toto* as the Gestaltists claim (Kauffman, 1977). Repeated exposures to the stimulus lead to cell assemblies in the brain sensitive to that feature. Cell assemblies then fire in phase sequence that reveal the form (*e.g.*, three angular cell assemblies fire sequentially to indicate a triangle). Furthermore, Harris and Gibson (Kauffman, 1977) have surmissed that the same feature detection channels carry both edge and color information. Thus, a psycho-physical link can be established between the detection of color and the perception of form. To date, the scant experimentation in this area has been limited to single features (*e.g.*, one-hue line gratings), but the route for future research using complex scenes is evident.

Color as a Cue to Meaningful Information

Color codes can provide specific information in the environment by establishing a sense of direction and focal points. Evidence to this fact comes from data display experimentation on visual search tasks requiring rapid and precise identification of target information. Search type tasks are important because they require the observer to discriminate meaningful targets from visual clutter. In such tasks, color as a component in a redundant code has repeatedly aided in decreasing target identification time. Erickson (1953) found that using a multi-dimensional code (hue-size-brightness-form) in two, three, and four-way combinations, the inclusion of hue consistently decreased search time. Moreover, hue, hue-form, and hue-form-brightness codes decreased search time more than the four-dimensional code. This could be related to the shared channel concept of feature detection. The findings of Promisel (1961) reinforce this assumption. They indicate that a target defined by hue-form was the most readily identifiable from visual clutter including objects of the target's hue or form, but not both.

Several factors influence the reliability of a color code. The first is that of hue number. While data vary, they generally indicate that the normal observer can absolutely identify only nine hues (Jones, 1962). Secondly, background contrast affects code legibility. Hurvich and Jameson (1959) have found that targets of low saturation and/or brightness compared with the background produce adverse effects. Gustafson (1960) suggests that figure/ground brightness contrast should be at least 75% to keep discrimination errors to less than 1%. Third, stimulus size must increase with distance to minimize the effects of color distortion caused by chromatic abberation. Conover and Kraft (Jones, 1962) indicate that the stimulus must subtend a visual angle of at least 20' for the code to be reliable. And finally, illumination level affects the use of a color code. Jones (1962) summary of available data concludes that mid-spectrum hues provide greatest reliability under low illumination; blues, greens, and reds being more variable.

In the physical environment color codes may be employed for focal point emphasis just as those used in visual search tasks. This can be shown to work effectively for identification of hazardous areas or materials and as a directional cue. Furthermore, it may be assumed that a color code used in combination with affective meanings of color may provide a focal point for behavior setting identification. There is to date, however, no experimental evidence to support this assumption.

Color as a Cue to Congruency

A sense of congruency between behavior setting and activity extend beyond recognition of form and focal point to the affective meanings the environment ellicits. Studies repeatedly indicate that color in the environment can and does ellicit such connotations for the user. Using the Semantic Differential, Wright and Rainwater (1962) tested the meanings of color to 3660 low income subjects. Factor analysis of the scales yielded five distinct concepts: happiness, showiness, strength, elegance, and warmth. Their results indicated linear correlations between value, saturation, and color connotations. As a similar relationship did not emerge for hue, they contended that hue must fall into a periodic type model of connotation.

The extensive research into color meanings conducted at the Swedish Color Center at Götesburg has resolved this problem somewhat. This work has centered around the use of the Natural Color System originally developed by Tryggve Johanssen and based on Hering's Opponent Mechanism Theory (Chapter 4). In the Swedish color system hue is used to denote the color's similarity to two of the four psychological primaries (e.g., redness, blueness, yellowness, greenness). Chromaticness is comparable to saturation, and brightness refers to the apparent whiteness or blackness of the color. From this framework, a color solid is developed similar in appearance to the Ostwald system. Using the S.D. format, various experiments into the meaning of color have been conducted. Correlations achieved in factor analysis of test results are mapped onto the color solid. Isosemantic mapping yields a comprehensive model of color connotation along the three dimensions of color simultaneously.

Isosemantic mapping has been employed by Acking and Kuller (1977) to study color meaning in interior spaces. Using a perspective drawing of a furnished room, they presented the subjects with 89 color combinations to judge. Factor analysis yielded five dimensions of meaning: openness, complexity, social evaluation, potency, and pleasantness. Openness was defined as the apparent spaciousness of the room. They found a positive correlation (r = .76) between openness and lightness. Chromaticness also had a correlation with furnishings, but not walls, which they attributed to a contrast effect. Nevertheless, chromatic strength had a high correlation (r = .81) to judged complexity. In general, weak colors were calming, and strong exciting, regardless of hue. Thus, a strong green was equally exciting as a strong red; a definite contradiction of existing psychophysical studies. Color blackness was correlated to both potency (r = .65) and social evaluation (r = .72). There were no appreciable correlations between color and the pleasantness factor indicating that color preferences may be maintained within hues rather than between hues. While these results are far from conclusive, they do indicate that the affective meanings of color may be manipulated in order to induce a sense of congruency between the physical environment and the human activities therein. Furthermore, it could be deduced that intended environmental congruency could be achieved even for users with visual handicaps such as color blindness or developmental insensitivity if all three dimensions of color are considered. This could be particularly important for the elderly experiencing visual degeneration.

Color in the Geriatric Institution

The use of color as an orientational cue in institutions for the elderly has been promoted by geriatric researchers (Lindsley, 1969). Drawing from ophthalomological data that identifies the geriatric visual system as degenerate, resulting in diminished visual acuity, brightness, and short wavelength detection, environmental designers have generated highly prescriptive methods for using color as an aesthetic element and as a redundant cue. It may be summarized by the rubric, "use bright, warm colors of high contrast to designate specified areas". This type of generalization may lead to considerable problems. For example, Marcella Graham (1976) describes her experience in such an environment.

> Shortly after entering, I began to feel assaulted by red, orange, and design. It was necessary for me to wait in this area for approximately 25 minutes....It was the longest 25 minutes of my life. Interior designers had been retained to make the place cheery, so they enveloped the area -- approximately 40 feet by 24 feet -- in total and unrelenting color. While it was a positive statement by the designers, it was not in any sense of the word a therapeutic environment. (Graham, 1978, p. 11)

Similarly, Pastalan reports that contour boundaries were difficult to distinguish when bright, high contrast colors were employed, "because the intensity of the colors seem to overlap and as one focuses on the boundary it appears to shift" (Pastalan, 1974, p. 6). Clearly, the use of color as a stimulus deserves greater scrutiny in order to answer the basic question -- how may color be used in the geriatric institution to enhance effectance in behavior setting identification?

To date, the only research dealing with geriatric effectance demands on the environment has been conducted at the Geriatric Institute at the University of Michigan -- Wayne State under the direction of Leon Pastalan. Wearing spectacles that simulate age related visual defects, the subjects engage in daily activities noting problems encountered. Results indicate significant problems in color, brightness, and edge detection. From these initial findings it is evident that considerable research is necessary in order to successfully employ color as an orientational cue. Furthermore, there is no available research dealing with the affective meanings of color to the elderly. Therefore, future work using elderly subjects, should be directed at an in-depth study of the following questions:

- What are the competencies/incompetencies of the elderly in detecting color cues?
- What dimension(s) of color provide the greatest amount of information for the elderly?

- What are the physical parameters of color cues that mark insufficient cueing (understimulation) or excessive cueing (visual clutter)?
- What are the affective meanings of color in the environment to the elderly?

Conclusion

The objective of this chapter has been to study color as an informational resource in the environment and to determine whether it may serve as an orientational cue for the geriatric user. Although an impressive amount of research does indicate that color stimuli do carry information, the meanings of that information remain controversial. Furthermore, we do not know how and to what extent color affects the physiological, cognitive, and emotive aspects of the human system.

Given the parameters of an orientational cue, evidence from the literature indicates that color may provide this information. The research base, however, is very diverse and quite unrelated. This paper is the first attempt to establish such a connection to date. This may be because much of the research cited herein is quite recent and still subject to much controversy. Nevertheless, it appears plausible to assume that color does serve as an orientational cue. It is obvious, however, that mere knowledge of color's role in feature detection is inadequate information for the designer. We simply do not know how color and edge perception may be applied to the environment to fit user requirements. Regarding color as a focal point, the literature does give some parameters for its use. This information, however, is at best scant and may not be said to apply to the geriatric user. The recent work at Götesburg on the affective meaning of color has shown that generalizations linking hue to affective meaning is fruitless. The dimensions of color meaning are far too complex to permit oversimplification.

Finally, the use of color in the geriatric institution was discussed. Although color may be a physical resource for behavior setting identification, its current use is based on insufficient knowledge of geriatric needs and responses to color. To date, geriatric research has concentrated on color detection abilities relative to the aging visual system. Designers have had to interpolate these findings to predict response to the informational character of color. Such an interpolation should not be acceptable to those using color as an orientational cue. Further research at all levels of response to color communication is warranted.

CHAPTER 4: HUMAN COLOR VISION

Introduction

In order to study, test, and generalize about color perception in a specific population (e.g., the elderly), the characteristics of 'normal' color vision must be understood. It is also necessary to examine the techniques used to characterize and measure the visual process and perception. This chapter will outline these subjects as they relate to the general population. This then will provide the basis for a comparative study of geriatric color perception.

Visual perception involves the interaction of radiant energy from the physical world and the human brain. The physiological system acts as receptor and detector of radiant energy which originates in the external environment. Radiant energy, or electro-magnetic energy, travels through space, behaving like waves of varying frequencies (oscillations per second), ranging from 10^{26} Hz (cosmic rays) to 10^{2} Hz (electrical disturbances). Of this broad frequency spectrum, only those frequencies between 4×10^{14} and 8×10^{14} Hz are capable of stimulating the human visual system, this band being known as the visible light spectrum. Furthermore, wavelengths related to the visible light spectrum are perceived as a range of hues from violet (380 nm) to red (700 nm). Radiant energy is related to brightness. Color vision research attempts to measure both the quantity and the quality of the human response to light stimulation in terms of hue and saturation brightness.

The Human Visual System

Light travels directly to the eye from a source or is reflected from a surface. Upon entering the sensory system, the energy is transduced, or transformed, by the visual receptors of the eye. This process is called isomerization, the transformation of radiant energy to an electro-chemical impulse, which is transmitted to the brain where it is translated and perceived. Thus, the human visual system may be characterized as the receptor, transformer, and transmitter of physical energy to the brain. A description of this system may be focused at three levels: 1) the pre-receptor level; 2) the receptor/transducer level; 3) the neural network transmitter level.

The Pre-Receptor Level

The functions of the pre-receptor elements are to control, transmit, and focus light energy striking the surface of the eye on the light sensitive visual receptors.

Cornea

The cornea is a transparent extension of the sclerotic coat (i.e., white of the eyeball). Its primary functions are to initiate refraction of the light entering the eye while protecting the interior of the eye from foreign matter.

Pupil

The pupil is an aperture in the iris diaphragm through which light enters the interior of the eyeball. The diaphragm action of the iris aids partially in adaptation to the intensity of light impinging on the eye. In adaptation, the muscles of the iris increase or decrease the size of the pupillary opening (e.g., 2 mm-8 mm). It is, therefore, in part, a brightness control mechanism. Since radiant energy admitted by the pupil is proportional to the aperture area, a brightness control effect varies by a factor of 16. Illumination levels, on the other hand, vary by several orders of magnitude. Furthermore, pupillary size may be related to visual acuity. As aperture size varies, it controls the spread of lenticular illumination directly affecting lenticular aberration. This effect will be discussed at a later point. Pupillary size is not totally dependent upon brightness. Psycho-physical studies have shown that pupil size is also related to subject interest, arousal, and emotional state (Janisse, 1977).

Aqueous Humor

The aqueous humor is a water, salt, and protein fluid between the cornea and the lens. It aids in light refraction and protects the lens tissue.

Lens

The crystalline lens is a transparent, pliable mass taking a slightly convex shape in cross section parallel to the optic axis. The primary functions of the lens are to refract light and focus it on the retina. Through accomodation, ciliary muscles exert force on the lens causing the pliable element to change its curvature. This allows the visual system to focus over a wide range of distances of varying illumination. Total lenticular accomodation is about 60-70 diopters (i.e., reciprocal of its focal length in meters). The lens exhibits a fault common to all optical instruments, viz. aberration. Aberration occurs when the spread of illumination on the lens surface exceeds its ability to bend the light to convergence at a single, unique point on the retina. The image formed is blurred. As stated, the size of the pupillary opening determines the surface area of the lens which will be illuminated. As the aperture widens to adapt to lower light levels, aberration increases. In addition, chromatic aberration refers to the inability of the lens to focus widely disparate wavelengths with equal sharpness on the retina.

Vitreous Body

The anterior chamber of the eyeball between the lens and retina is called the vitreous body. It is filled by the vitreous humor, a jelly-like fluid, of chemical composition similar to that of the aqueous humor. The approximately spherical shape of the eyeball is maintained by a structural framework of collagen fibers. Although the vitreous humor is macroscopically transparent, it does contain floating fibers of cellular material sloughed off from the retinal membrane. This accounts for the threads or specks often seen floating in the visual field.

The Receptor/Transducer Level

The functions of the receptor elements are to isomerize light energy focused on the photo-sensitive cells and to gather the electro-chemical impulses in preparation for transmission to the brain.

Retina

The retina, an extraordinarily complicated nervous structure, is a thin membrane lining the back interior of the eyeball. The retinal surface contains two distinct regions, the optic disk and the foveal pit. The optic disk, often referred to as the blind spot, is the point of intersection between the optic nerve and the eyeball. The fovea is a shallow pit, placed slightly off-center on the retina, where the sharpest image, or center of interest, is focused by the lens. It is composed of tightly compacted photo-sensitive cells and nerve endings. The macula lutea is a pigmented region surrounding the fovea in an elliptical pattern on a horizontal axis covering a 5-10° region of the visual field. This yellowish pigment decreases in density as it approaches the center of the fovea. Although the primary purpose of the macula is yet undetermined, it is known to absorb some short wavelength light (Ruddock, 1964). The retinal membrane is composed of layers consisting of the photo-sensitive cells, the bipolar cells, and the ganglion cells.

Photo-Sensitive Receptors:
Rod and Cone Cells

The rear layer of the retinal membrane is composed of photo-sensitive cells called rods and cones as defined by their shape. The human retina contains approximately 7 million cone cells and 120 million rods arranged in an array with cones centered behind the *fovea*. Outside of the foveal region, cones exponentially decrease in concentration, but rods are increasing. The primary purpose of the photo-sensitive cells is to isomerize the electro-magnetic energy into electro-chemical impulses. In isomerization, light striking a photo-sensitive cell is absorbed by cell photo-pigment, bleaching the photopigment. This action triggers an impulse to the brain. In a series of experiments on the detection of light, Hecht, Schlaer, and Pirenne (1942) noted the following conclusions: 1) sensitivity to light stimulation increased with increasing time of dark adaptation; 2) the peripheral region of the retina was more sensitive to weak stimulation than the *fovea*; and 3) that as light level increased, the foveal region produced greater activity than the periphery. The retinal location of the rods and cones is directly correlated with these findings. It was concluded that the ability of the rods to function at low levels of illumination, called scotopic vision, was a function of threshold (*i.e.*, the point of light detection) based on the bleaching properties of the photopigment. Cone sensitivity, called photopic vision, is not activated until the level of illumination is so elevated as to render the rods transparent.

Rod and cone sensitivity to monochromatic light also varies as a function of wavelength. The human eye is not equally sensitive to all wavelengths. In general, both systems are more sensitive to mid-frequency spectral light (i.e., green and yellow) than to either of the extremes. Furthermore, sensitivity varies between the scotopic and photopic systems. The scotopic sensitivity curve peaks at 510 nm (green) while the photopic peaks at 550 nm (yellow). This phenomenon is referred to as the Purkinje shift. Because of rod photopigment characteristics and the fact that it bleaches at such a low level of illumination, the rods are generally considered to be color blind. Therefore, the primary source of color sensitivity and detection in the human visual system exists in the cone cells.

The Bipolar Cells

The bipolar cells lie directly in front of the photo sensitive receptors in the retinal membrane. They function as "relay stations" of the electro-chemical impulses produced in the photoreceptors. Either several receptors terminate at a single bipolar cell, or one receptor connects to one or more bipolar cells. Therefore, there is some impulse condensation at this level. The bipolar cells then converge on the ganglion cells at the next level of the retina.

Ganglion Cells

The ganglion cells, just below the retinal surface, mark the point of major impulse condensation. The input of a multitude of receptors is pooled at the ganglion level, leading to the speculation that each ganglion cell is responsible for 'coding' the stimulation of an area of the retina (Kufler, 1953). Kufler's experiments established a model of concentric ganglion receptor fields in which light stimulates an 'on', 'off', or 'on/off' response. This response is critical in brightness and hue perception as it serves as an enhancement mechanism (e.g., simultaneous contrast). Nerve fibers issuing from the ganglion cells travel across the inside surface of the retina to form the optic nerve.

Choroid Membrane

The retina is backed by the choroid membrane, a coating of brownish-black pigment. Its general purpose is to absorb stray light, thus preventing a degraded image. It has also been suggested that the choroid coating regenerates the photopigments of the rod and cone cells (Padgem and Saunders, 1975).

The Neural Network/Transmission Level

To date, the neurological foundation of sensation and perception is still vague. Although experimentation has mapped the general route of the electrochemical impulses originating in the retina, it has yet to define the actual cortical response to sensation. Historically, many psychologists have believed that perception was a picture-in-the-head version of the real world. Although some regions of the brain respond when the retina is stimulated, it appears evident that the neural response is considerably more complex than this original hypothesis would suggest.

Nerve fibers issuing from the ganglion cells leave the region of the eyeball by forming the optic nerve. Some 30% of these fibers (from the temporal side of the eye) move directly to the Lateral Geniculate Nucleus (LGN). The remainder cross the optic chiasma before proceeding to the LGN. In the LGN an impulse synapse occurs. Fibers leaving the LGN are routed to either the Superior Collitus for additional synapse or directly to the visual cortex at the base of the brain. Studies similar to those of Kufler have led to the mapping of receptor fields in both the LGN and the visual cortex (Hubel and Weisel, 1961). These fields have responded to hue, brightness, size, orientation, and directional movement of the stimulus.

Human Color Vision

Color vision begins with the ability of the human eye to receive and detect light stimulation. Light entering through the pupil is refracted, focused, and absorbed by the visual system. An electro-chemical impulse then is transmitted to the brain along the neural network. Although this process describes the physiological mechanisms at work in human vision, it fails to describe systematically the perceptual experience of the physical environment. Historically, a variety of scientific disciplines have contributed knowledge to generate a theoretical fraemwork concerning the human experience of color.

In his experiments with light, Newton observed that he could break down a beam of white light into the visible spectrum using a prism. Furthermore, he demonstrated that the spectrum could be combined again to produce white light. This additive principle of colored light also could be expanded to produce metameric matches to monochromatic lights. These experiments led Newton to develop a circular model for colored light mixtures. The color wheel, however, had its flaws. It was found that although an admixture of red and green lights did produce a yellow light, the mixture was less saturated than either of the two original elements.

In 1802 Thomas Young proposed that a triangle, with apices of red, green, and blue spectral lights, would be more appropriate in that it corrected for the saturation change. These lights were labelled the colored light primaries. In 1924 Helmholtz adapted Young's theory to his own theory of color vision and speculated that the eye must contain three distinct fiber types with sensitivity to the red, green, and blue primaries. He also proposed that this type of configuration would lend itself readily to the detection of all colors through the additive principle. This theory is known as the Young-Helmholtz Trichromaticity Hypothesis.

Microspectrophotometry has provided physiological support to the Trichromaticity Hypothesis. In his work with cone cell photopigments, Rushton (1962) discovered two distinct pigments called Chlorolabe (green-catching) and Erthyrolabe (red-catching). He postulated, but did not isolate, Cyanolabe (blue-catching). Each of these cone cell pigments is capable of absorbing a broad range of spectral wavelengths, but sensitivity peaks at either 570 nm (red), 535 nm (green), or 445 nm (blue). Figure 4 indicates the absorption spectra of the three photopigments. Therefore, the photopigments in the cone cells possess the potential to detect all discriminable hues in the visible spectrum through the additive principle.

The Trichromaticity Hypothesis, however, does not provide the entire explanation for color perception. It contains two main flaws: 1) it concerns itself only with chromatic color perception, making no allowance for achromatic colors, and 2) it ignores the complementary process which precludes the existence of greenish-reds and

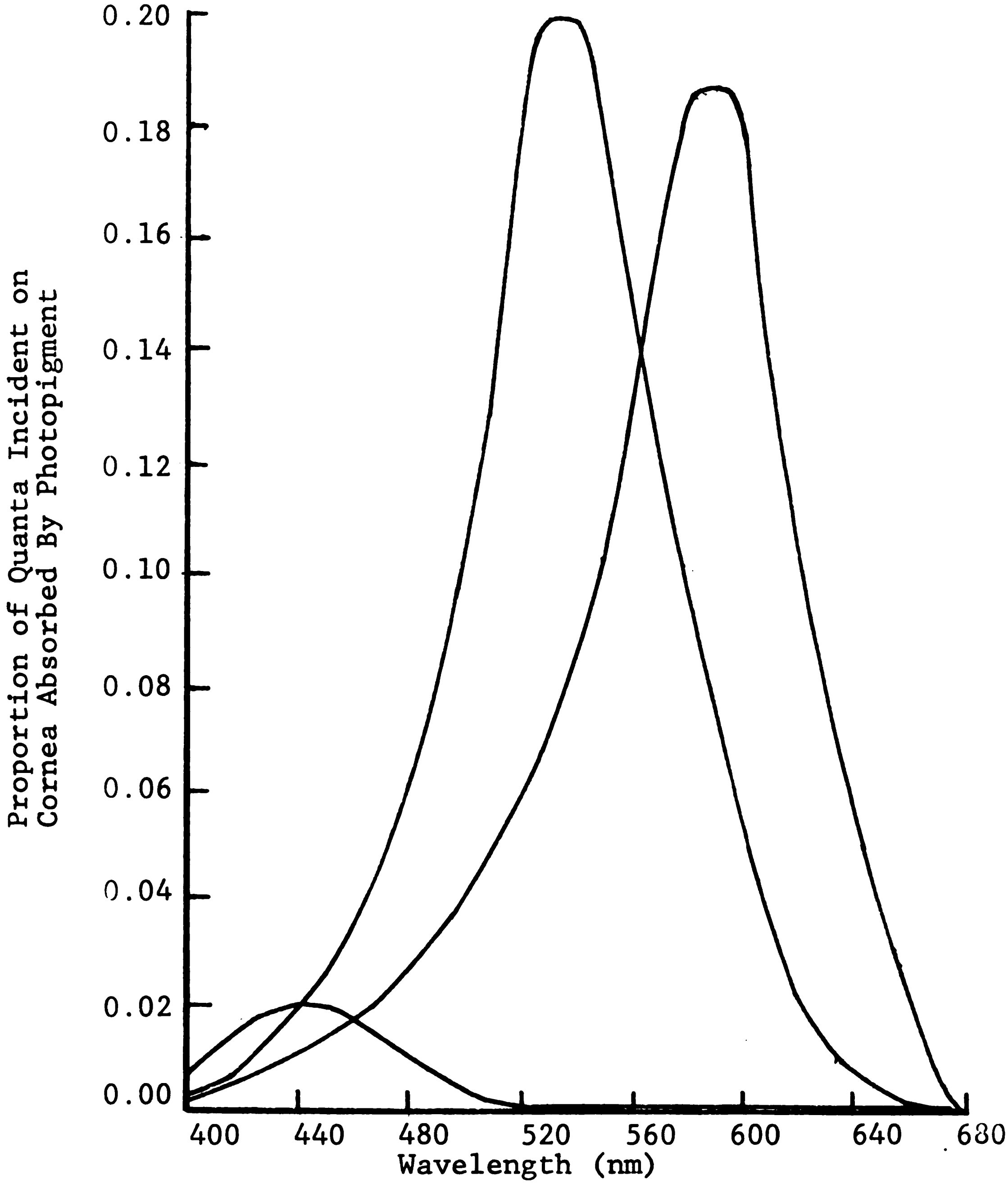

Figure 4: Absorption Spectra of Three Photopigments of the Human Eye

yellowish-blues. In 1870 Herring addressed these problems when he proposed the Opponent Mechanism Theory. Herring contended that the visual system operated a switching mechanism of complementary colors (e.g., 'on' yellow/'off' blue). He hypothesized three sets of opponent mechanisms: yellow/blue and green/red, corresponding to the psychological primaries, and black/white controlling for value changes. The work of Hurvich and Jameson (1957) has provided some experimental support to the Herring theory. Their opponent mechanism model places the process at the neuron and ganglion cell levels rather than in the photoreceptors. Moreover, instead of an 'on/off' mechanism, Hurvich et al have proposed an excitatory/inhibitory effect on the opponent mechanism centers. For example, a yellow stimulus would excite neural activity signaling yellow while concurrently inhibiting blue output.

The Opponent Mechanism Theory also considers black and white detection. Often referred to as the luminosity unit, this system accounts for the lightness and darkness of all four primaries. It is excited/inhibited equally by either red, green, yellow, or blue centers, or in combination to produce gray. This allows not only for perceived value differences, but also for the rather neutral chromaticity of low luminance surfaces (above cone threshold). Finally, the studies of Wagner, MacNichol, and Walborst (1960) at the ganglion cell level seem to reinforce further the Opponent Mechanism Theory. They have mapped a color-coded ganglion cell to find areas of 'on/off' response that can both be excited and inhibited by red and green lights. Research beyond the ganglion cell level is as yet inconclusive.

Recent studies have supported both the Young-Helmholtz Trichromaticity Theory and the Herring Opponent Mechanism Theory. These two positions, once thought to be in direct opposition, now are perceived as being complementary. The Trichromaticity Theory relates to color sensation at the receptor level, whereas the Opponent Mechanism Theory reflects post-receptor activity. Together they yield an adequate model of the process of color vision. And together they have been employed by ophthalmologists in the preparation of color vision tests.

Color Vision Testing

Thus far, this chapter has considered a description of the human visual system and the physiological evidence supporting a theoretical framework of color perception. Although a detailed study of the ocular media and the neural pathway is necessary to understand human color vision, it does not provide an analysis of perception. Color vision is a complex interrelationship of a human organism and its environment. Color vision testing has been developed in an effort to expand upon physiological data by characterizing the experimental component of perception. Its primary objective is the detection of the individual's ability to discriminate colors along the hue, saturation, and value axes as they relate to the population mean. It is concerned with assessing man's physiological abilities in contrast with psychological tests, which include the intervening variables of psychological, sociological, and cultural sets. Color vision testing may be categorized into two primary areas: 1) laboratory assessment of the color vision system, and 2) clinical assessment of the functional ability of the system. Their objectives are to test discrimination ability (i.e., the observable difference between given energy relationships) and color confusion (i.e., the false perception that one mistakes one hue for another).

Laboratory Assessment

Colorimetry, measuring color vision efficiency, is accomplished under rigidly controlled laboratory conditions. Its objective is to characterize discrimination ability in detecting monochromatic wavelengths and their luminosity function. Measurement is based on detection of a threshold difference called the just noticeable difference (j.n.d.). Threshold denoted that point where the subject accurately reports a difference 60% of the time. The concept of the j.n.d. is derived from the combined work of Weber and Fechner in the mid-1800's. In studying luminance difference thresholds, Weber noted that the threshold increment for any stimulus relative to its surround is a constant ($C = \frac{C}{C}$). Fechner expanded on this by deducing that luminosity increased as a logarithmic function of luminance in equal j.n.d. steps. Colorimetry employs these concepts to test brightness discrimination ability. Similarly, j.n.d. steps are calculated for hue differences. The Nickerson-Stoltz Formula (1942) was devised to measure color difference (c) by employing the American National Bureau of Standards color scales. In this measure, 1 NBS unit is equivalent to 5 j.n.d.'s as perceived by the normal observer under ideal viewing conditions. The measure of hue and luminosity discrimination ability is performed with the subject under rigid experimental control, usually positioned in an apparatus which limits his freedom of movement, pupillary size opening, and level of adaptation to background luminosity. The subject is initially presented two matched fields of monochromatic light. The experimenter then varies one field until the subject reports that the two fields no longer match. Discrimination ability is determined by the number of j.n.d. steps required to detect the difference. Although the colorimetric study of color vision yields data of high reliability, it has severe drawbacks as an instrument for popular usage. It requires a battery of optically sophisticated instruments, a rigidly controlled environment, and a trained subject willing to spend considerable time and energy in performing the test.

Clinical Assessment

Clinical tests assessing color vision have been devised to provide a more readily manipulated instrument for large sample testing. Their primary objective is to detect color vision defects in the population by measuring discrimination ability and the loci of color confusion characteristic of deuteranopia and tritanopia. Lakowski (1969) conducted a comprehensive survey of clinical color vision tests currently used in the field, condensing them into four primary categories: 1) anomaloscope discrimination tests; 2) Farnsworth-Munsell 100 Hue tests; 3) pseudo-isochromatic tests of color confusion; and 4) color aptitude and memory tests. The basic elements of test comparison were mode of appearance, complexity of task and stimulus, and administrative considerations. Specifically these elements are:

Mode of Appearance: According to Katz (1935), color is perceived in a spatial/temporal context determining its mode of appearance. Color vision tests are presented in two modes: surface mode, where color is perceived as belonging to a plane (e.g., paper), and film mode where color is perceived as occupying a void (e.g., peephole effect).

Complexity of Task and Stimulus: The complexity of the task will affect the subject's performance, and, thus, may be an intervening variable clouding test results. For example, the test may require the subject to read numerals, detect figures, or arrange color chips. This assumes either a prior knowledge of the symbolic context of the stimulus or le

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a cognitive process sufficiently developed to understand a scaling process. Stimulus complexity involves the variation of hue, saturation, and brightness in the test. Band width and brightness range of individual stimuli may vary along the visible spectrum within and between tests.

Administrative Considerations: Administration of the test involves not only the instrument, but also the emotional state and attitude of the subject, the expertise of the experimenter, and the environmental factors influencing test results. These include illumination level, thermal and acoustic conditions, viewing angle, and retinal angle of subtense of the stimulus. As both foveal and parafoveal stimulation are related to the perceptual experience, stimulus location in the field is a critical factor.

Considering these elements as factors in the design of color vision tests, the four types of tests as outlined by Lakowski are:

Color Discrimination -- Anomaloscopes

The anomaloscope has been developed to provide a clinical test of color vision yielding a greater control of data than other clinical tests. They are devised to detect discrimination ability based on the process of metameric matching. Metamers are defined as a pair of hues which differ in spectral composition but are perceived as being colorimetrically equal. Employing both the Trichromaticity and Opponent Mechanisms Theories, the test requires the subject to match a monochromatic light with an admixture of two light primaries. Brightness fluctuations, inherent in hue changes, are controlled by the instrument. Using the film mode of appearance, the instrument places both the standard and the test stimuli in the field of vision. Retinal angle of subtense ranges from 1°30' to 3°15'. Discrimination ability is determined through repeated matching exercises from which the matching range (MR) and the mid-matching point (MMP, mean of the MR) may be calculated. The scores then may be plotted graphically and compared in percentile rank with population statistics developed for that particular instrument. While the anomaloscope yields a precise calculation of hue discrimination ability, it requires rigid control of the environment as well as the subject, considerable training and practice, and a high degree of concentration for extended periods of time. As a result, a study employing the use of an anomaloscope usually relies on data collected from a small sample in order to generalize to a population.

Color Discrimination/Confusion -- Farnsworth-Munsell 100 Hue Test

The Farnsworth-Munsell 100 Hue Test was designed to delineate color confusion lines, and also to quantify minute differences in color discrimination ability. The instrument is prepared in the surface mode using the Munsell Color System. In testing, the subject scales a series of color chips, according to hue difference, between two given standards. The chips are calibrated for equal saturation and brightness within the Munsell system. Retinal angle of subtense of the individual color chip is $3^{o}15'$, and the mean j.n.d. steps is 2.2 NBS units. Test results are determined by the number of errors caused by transposition of chips and compared in percentile rank with a population median established by Farnsworth's 1957 study of industrial workers. Because the 100-hue test is capable of measuring discrimination ability, it may be an appropriate tool for studying visual system deterioration if performed under controlled experimental conditions with subjects possessing the cognitive ability to understand a hue gradation series. It does have, however, its drawbacks, as will be discussed in Chapter 5.

Pseudo-Isochromatic Tests (PIC)

The general objective of the popular PIC tests is to classify defective color vision according to color confusion types. They are based on the Herring Opponent Mechanism Theory and are developed in relation to opponent pairs. The instrument is a series of color plates in the surface mode composed of colored dots ranging from 2^{o} to 10^{o} angle of retinal subtense. The colors contain both broad and narrow spectral bands, varying reflectances, and a wide variety of j.n.d. steps (18-50 NBS units). The dots are designed to vary along known color confusion lines (*e.g.*, red/green), with one set forming the figure and the other forming the background. The subject's task is to detect and identify the figure which may be arabic numerals or geometric shapes. Data obtained from PIC testing yield primarily quantitative measures of color confusion, and secondly, general qualitative results. For example, some transformation type plates, in which the defective subject detects a figure different from the norm, are capable of measuring a degree of color discrimination ability by studying perceived pattern clarity.

There are two primary concerns with the use of PIC color plate tests. First of all, test results provide only a probability measure of color defect, because the degree of color confusion lies in the criterion established by the experimenter (*e.g.*, error score related to degree of confusion). Secondly, the PIC are not structured to distinguish accurately between their measurement of color discrimination and color confusion. Therefore, these tests are suspect in their ability to assess color vision deterioration caused by chronic disease or aging.

Color Aptitude and Memory Tests

A variety of clinical tests have been developed in the last forty years to measure color aptitude and memory rather than discrimination ability or color confusion. They are particularly meaningful in industrial applications where a worker must be able to discriminate and sort colored materials, but their usage is becoming more popular for the study of general populations. The Color Aptitude Test designed for the Inter-Society Color Council (C.A.T.-I.S.C.C.) by Dimmick in 1942 is meant to assess the subject's ability to discriminate saturation differences. The test field is a fixed standard of four rows of colored chips each subtending an angle of $4^{o}30'$ on the retina. Each row contains a random distribution of saturations, with j.n.d. steps ranging from 0.8 to 3.0 NBS units. The subject matches a set of test chips to the standards, and scores are compared in percentile rank to the sample population.

Color memory tests study the subject's ability to remember hues. Employing a simplified 100-Hue Test, the subject is presented a standard for five seconds. This is followed by a rest period of no stimulus. The subject then selects a test stimulus that matches the original standard. Scores are calculated by percentile rank.

Table 1 summarizes this discussion by comparing the characteristics of the four major categories.

Conclusion

This chapter has outlined the mechanisms involved in visual perception and discussed the techniques used to test human color perception. This was necessary in order to develop a model and the types of criteria currently used to judge that model. There has been little effort to evaluate these criteria, particularly as they relate to the testing of the elderly. The following chapter examines color vision in a geriatric population. Throughout that chapter, we will study the application of color vision research to a specific population and the conclusions currently accepted in the field. All of the tests described in this chapter have been employed to test the color vision of elderly samples with varying degrees of success.

Table 1: Clinical Tests Employed in Detection of Hue Discrimination

Characteristics	Anomaloscopes	Farnsworth-Munsell 100-Hue Test	Pseudo-Isochromatic	Color Aptitude Tests
Objectives	Hue discrimination	Hue discrimination	Detect color confusion types	Saturation discrimination
Theoretical Basis	Trichromaticity and Opponent Mechanisms	Munsell color system	Opponent Mechanisms	Munsell color system
Format	Metameric matching	Hue chips in color series	Plates of colored dots forming figure/ground	Hue chips in saturation series
Mode of Appearance	Film	Surface	Surface	Surface
Task	Note hue change in metameric pair	Arrange series	Detect figure	Arrange chips
J.N.D. (NBS units)	---	0.6 - 5.7	18 - 50	0.8 - 3.0
Retinal Angle Subtended	$1^{o}30'$ - $3^{o}15'$	$3^{o}15'$	2^{o} - 10^{o}	$4^{o}30'$
Scoring	Matching range/ mid-matching point	Number of chips transposed	Number of plates read correctly	Number of chips transposed
Degree of Control	Rigid	Rigid	Moderate	Moderate
Reliability in Hue Discrimination Detection	High	High	Low	Moderate

CHAPTER 5:

COLOR VISION CHARACTERISTICS OF A GERIATRIC POPULATION

Optimal performance in a man/environment communication system that employs color cues for information transfer depends upon the user's ability to receive, detect, and code stimuli. Presumably, all individuals possessing the characteristics of 'normal' color vision could participate equally in the reception/detection process and, thereafter, differentially respond according to individual knowledge and acceptance of established code. Impaired color vision could diminish ability to participate in such a communication system. Thus, the designer employing color as an orientational cue should be aware of possible deviations from the norm among the user population. In the last fifty years, the field of ocular gerontology has concentrated on the characteristics of the aged visual system relative to the norm. Systematic study has revealed that certain ontogenetic changes occur in the human visual apparatus which render the aged eye histologically and chemically different from the normal system discussed in Chapter 4. This chapter will outline these changes relative to the aging process and discuss the resulting implications for the detection of color cues in the environment.

Ocular gerontology studies the visual system with age as the independent variable. Research generally follows one of two specific modes of investigation with transverse or longitudinal techniques. Transverse, or cross-sectional, studies attempt to identify age differences between sample cohorts, the population being divided by decade from childhood to old age. This type of study provides a good indicator of structural changes in the visual apparatus. Longitudinal studies, on the other hand, are developed to measure ontogenetic changes in the same subjects through time. It provides a reliable indication of functional changes in a given system. There are, however, serious drawbacks to the longitudinal study. First, there is considerable attrition because of subject withdrawal from the parent population. Intervening variables, such as disease or accident, may affect vision more radically than aging. Finally, advances in measurement techniques may invalidate correlations of prior work. Therefore, the bulk of current research on both structure and function is of the transverse type. This does raise the problem of validity in transverse studies of functional changes due to aging. Beyond the problem of developing sample cohorts of comparable size and composition, it remains questionable whether one measures actual ontogenetic changes or merely generational differences. This is particularly true of color vision studies. The perception of color is tied uniquely to cultural patterns and personal experience. As these experiences may differ among generations, they may play a significant role in determining age-related differences. To date, this problem has yet to be addressed by psycho-physical color vision research dealing with the elderly.

The Aged Visual System

Although methodological difficulties must be considered in any discussion of ontogenetic functional changes in vision, both longitudinal and transverse research supply a relatively complete analysis of structural changes. Paralleling the description of the normal visual system outlined in Chapter 4, it may readily be discerned that the aged physiological network is degenerate and should result in diminished sensitivity to visual stimuli. In his classic work, The Aging Eye, Weale (1963) provides a systematic study of the morphological changes in the visual network, accompanied by supportive evidence as to functional changes. Briefly summarized, they are as follows:

The Pre-Receptor Level

In the normal system, the pre-receptor elements control, transmit, and focus light on the retina. With age, developmental changes in their structure lead to a decline in the total amount of light entering the eye, the spectral distribution of that light, and the quality of the focussed image.

Cornea

While the cornea undergoes considerable ontogenetic change, this generally affects the appearance of the eye more so than its functional attributes. There is little appreciable change in corneal diameter and thickness (Berliner, 1949), but there is a slight flattening of the curvature (Hogan and Zimmerman, 1962). Fischer (1948) reported an increase in the density of the corneal stroma and described a concomitant increase in light scatter. Maurice (1957) noted the scatter was greater for short-wave than long-wave light, suggesting small-particle (Rayleigh) scattering, and accounting for the small, but significant increase in corneal light loss (Boettner and Wolter, 1962) and the gradual yellowing of the eye with age. The epithelium becomes slightly dehydrated resulting in a slight increase in the refractive index and a decline in eye luster (Fischer, 1948). The chemical composition of the cornea also changes with age resulting in the formation of the <u>arcus senilis</u>, a lipid deposition that blurs the definable circle between the cornea and sclera, and the Hudson-Stahli line, a pigmented line in the lower region of the cornea. One consequence of such changes is a possible reduction in peripheral vision because of blurring (Colavita, 1978). These chemical changes are accompanied by the accumulation of pteridine, a fluorescing substance sensitive to a stimulus of 400 nm (Cremer and Bartels, 1962).

Pupil

A gradual decrease in pupillary diameter with age has been documented in both dark- and light-adapted eyes (Birren, Casperson, and Botwinick, 1950 and Leinhos, 1959).

Weale (1963) suggests that this decrease may be accounted for by a gradual decline in the depth of the anterior chamber caused by lens thickening or slight advancement of the lens. This is complicated further by an increasing dominance of parasympathetic tone in the sphincter muscles (Kumnick, 1956) and thinning and rigidifying of the iris. The fact remains, however, that accompanying senile miosis (i.e., contraction of the pupil) is a diminished pupil area because it is proportional to the square of the diameter, and, thus, retinal illumination is reduced. Weale calculated that only one-third the amount of light reaching a 20-year retina would fall on that of a 60-year-old. Robertson and Yutkin (1944) had earlier confirmed this experimentally by noting an age-related elevation in absolute threshold to white light that was inversely proportional to pupil area. Threshold sensitivity also can account for the apparent increase in time for dark adaptation noted by McFarland, Domey, Warren, and Ward in 1960 (Weale, 1963). Dipigmentation of the iris, also a senile process, results in pigment fragments floating in the anterior chamber. These fragments may adhere to the cornea or lens, leading to some, albeit slight, deterioration in visual acuity.

Aqueous Body

While there appear to be no recorded chemical or biochemical changes in the aqueous humor, Becker (1958), noted an increase in outflow resistance. While this could result in an increase in interocular pressure, there is no significant pressure variation between ages 15 and 75 (Aurrichio and Dectallevi, 1959). Therefore, there seems to be little evidence that any change occurs in the aqueous humor affecting vision in the later years.

Lens

Because of its important role in visual accomodation and acuity, and its ability to perform metabolic activity while isolated from the blood supply, the crystalline lens has been the subject of much research. Geriatric lenticular research is prompted by the high incidence of cataract in aging populations; 65% between ages 51 and 60 rising to 96% after age 60 (Alvaro, 1953). It is also prompted by the decline in light transmission by the lens (Said and Weale, 1959).

Elaboration on physical changes in the lens requires a brief summary of its structure and development. The lens is formed of ectodermal cells which are pinched off from the optic vesicle during fetal development. This then-hollow structure consists of anterior and posterior cells. In development, the posterior cells elongate into the primary lens fibers, hexagonal in shape and with a length some 1,000 times their original diameter (Figure 5). Throughout life the lens continues to grow by mitotic divisions of the anterior cells at the lens equator, forming the secondary lens fibers. This results in a gradual increase in

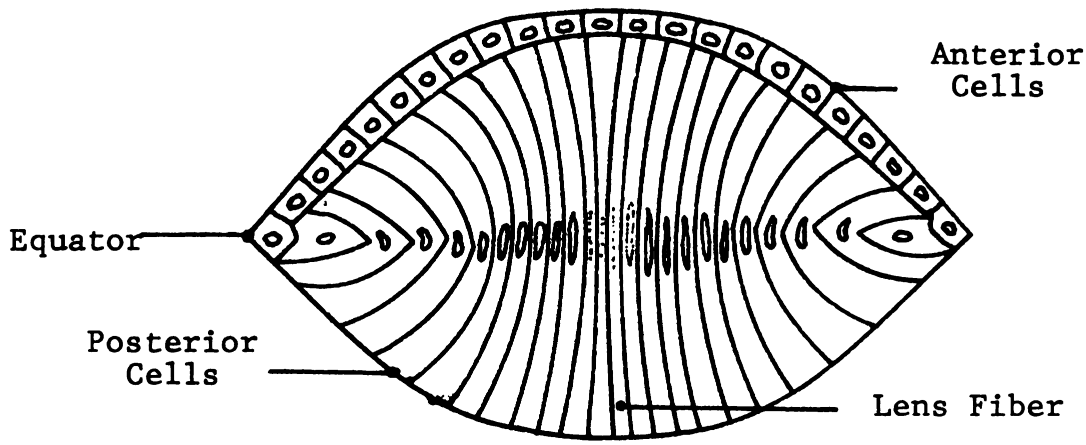

Figure 5: Horizontal Section of a Developing Lens

equatorial diameter first noted by Smith (1883) and construed in the literature as lens thickening. Weale argues that attempts to verify this conclusion experimentally are subject to doubt because of methodological limitations. Nevertheless, with age the number of mitotic divisions declines and lens fiber nuclei apparently dissolve (Ham, 1969). Thus, continual growth, or lamination, and compression of lens fibers, accompanied by nuclei dissolution cause the older lens to appear more an amorphous mass than its younger counterpart.

Lenticular mass increases some three times its neonatal value of 80 mg (Salmony, 1961). Volume, however, tends to increase at a slower rate because of fibrous compression, thus, gravimetric density increases. It is often said that older lenses are harder than younger ones. Weale (1963) contends that an experimentally viable measure of hardness has yet to be developed. It has been shown, however, that older suspensory ligaments, affecting elasticity of the lens, break with a stretching pressure of 2 g weight at 1-2 mm while a younger one requires 30 g weight (Barraquer, 1924). Thus, presumed hardness may be merely an artifact of brittle ligaments.

Three other structural changes in the aging lens have been noted, but their significance is not yet fully understood. Goldman (1937) found that histological examination of the equatorial cross-section showed disjunctive accessory stripes similar to growth rings on a tree. These disjunctions appeared at approximately four-year intervals. Weale (1963) feels that these may relate to lenticular light scatter, affecting color vision. Secondly, Duverger and Velter (1930) noted the appearance of a circular region of shagreen (i.e., rough granulations) on the central one-third of the anterior nuclear surface. And finally, Vogt and Lussi (1919) found fork-shaped ridges in the same region. As stated, the optical importance of these findings requires further clarification.

Further reference to lenticular growth provides a suitable bridge to a discussion of chemical changes attributable to aging. As mentioned, embryonic development of posterior cells form the primary lens fibers, whereas mitotic divisions of the anterior cells form the secondary fibers. These two types of fibers are differentiated as forming the nucleus and cortex of the lens. Varying chemical changes in these two parts may affect visual acuity and light transmission in serious ways. Significant chemical changes include a shift in fluorogen accumulation, apparent dehydration, and an increase in insoluble protein level. Although it is difficult to determine true fluorescing from extinction due to absorption and scatter, Klang (1948) was able to detect a rise in the fluorescence ratio of violet to green light with concomitant increase in the red to green ratio with age. He also isolated two fluorescing substances, lactoflavin and dimethyl alloxazimes. In comparing fluorescence in the nucleus and cortex, Jacobs and Krohn (1976) found a definable red shift in the nucleus at 375 nm but not in the cortex. Furthermore, this shift was not found in either at 400 nm. These results indicate that there is not only a change in predominant wavelength fluorescing intensity, but also that fluorogen accumulation varies between the nucleus and cortex.

Cell dehydration is said to be characteristic of most aging tissues. This also has been said of the lens (Bellows, 1944). In actuality, experimental data fail to confirm this conclusively (Weale, 1963). It appears that a finer distinction must be made. Lowry and Hastings (1957) contend that intracellular water remains relatively constant while extracellular content may actually increase. This could result from a shift in the Na/K ratio with increasing extracellular sodium concentrations (Weale, 1963). This ratio is again found to increase as one moves from the cortex to the nucleus (Lebensohn, 1936). The question remains open, but important, since this could have a bearing in clarifying why the refractive indices of the lens remain relatively constant as visual acuity diminishes.

The increase in insoluble protein level in the lens is important optically because the size, shape, and refractive index of the particle affect scattering of the light. Lens scatter has been shown to increase linearly with age beyond age 40 (Wolf and Gardiner, 1965). Furthermore, one of the primary factors in lenticular transparency is the high concentration of soluble protein. The data of Krause (1934) on bovine lenses showed a definite increase in the insoluble/soluble protein level with age. This has been attributed to a transformation of the soluble protein alpha-crystalline into an insoluble protein (Mok and Waley, 1968). The new protein, or its state, have yet to be identified. Spector, Freund, and Augusteyn (1971) have, however, noted that in the transformation process alpha-crystalline increases in size, and that this increase occurs only in the nucleus of the lens. Further study into the new insoluble protein obviously is warranted.

Given this broad physiological summary of the lens, it would do well to point out the major effects on color vision, namely absorption and light scatter. Said and Weale (1959) performed a major study of age-related changes in *in vivo* lenticular absorption. Their data indicate that optical density at different wavelengths varies for all ages (*i.e.*, 4-63) but clearly rises with age. The rise, however, is not uniform for all wavelengths. Optical density increases continuously, but at a faster rate as one approaches the short-wave end of the spectrum to about 430 nm. Thereafter, the increase is less steep. Their data was found to be consistent with Hess (1911) measuring absorption through sensitivity threshold in a group of unilaterally aphakic observers and Boettner and Wolter (1963) measuring transmission spectra of extirpirated lenses (Ruddock, 1972). Their conclusions indicated that absorption by pigmentation of the lens was a major factor. This unidentified pigmentation is often referred to as lenticular yellowing. Wald (1949) and Burch (1959) pointed out, however, that absorption varies too radically within age groups to be the only major factor. Furthermore, Cooper and Robson (1969) were not able to extract more pigment from older lenses than younger ones.

It appears that light scatter plays a greater role. Goldmann (1964) and Ruddock (1965) found that scatter, following Rayleigh's Law, can account for much of the shift in optical density as well as lenticular yellowing. One will recall that the increase of insoluble proteins and possible discontinuities of lenticular laminations play a major role in light scatter.

Vitreous Body

Senile changes in the vitreous body usually do not affect the visual process unless they become pathological in nature. The primary degenerative occurrence is a slight breakdown or shrinkage of the fibrular structure; its cause is unknown. In the 70's and 80's there may be an increase of floating material in the vitreous humor, but this appears to cause little more than visual distraction. It may lead to some increase in light scatter (Weale, 1963).

The Receptor/Transducer Level

The primary functions of the retinal layers are to isomerize light energy and to gather electro-chemical impulses for transmission to the brain. To date, it is generally accepted in the literature that there is little senile degeneration in these elements and their functional ability.

Retina

The retina appears to be relatively resistant to senile change except for a slight thickening which renders blood vessels less visible (Weale, 1963). There is also a gradual thickening of the walls of the retinal arteries (Belleto, 1953), and some deposition of collagen fibers on capillaries of the optic nerve (Hogan and Zimmerman, 1963). Perhaps the most significant change is the yellowing of the macula lutea, since this could result in greater absorption of short wavelength light. Although there probably is some absorption, Ruddock (1965a) demonstrated that this would not be a major contributing factor in color vision. Rod and cone cells remain intact and regeneration of the photopigments remains constant (Weale, 1963).

Choroid

While the choroid membrane shows some thickening and loss of elasticity, it is of little intrinsic interest in color vision studies.

The Neural Network/Transmission Level

Geriatric research of degenerative changes in the brain is still in its infancy. Thus, any attempt to identify changes relative to the visual process are futile at this time. Recent psycho-physical research in visual sensory/perceptual skills should help to fill this void.

It has been the purpose of this account of the elderly visual system to identify physiological elements that may impair color vision. It has dealt with the aged eye as an apparatus potentially able to detect stimuli. In summary, it may be seen that the pre-receptor elements exhibit sufficient degenerative change to affect ability in color detection. Obviously, further work is required to complete the picture, particularly regarding the neural network. For it is in the brain that perception of the stimulus occurs.

Results of Color Vision Testing

To move from analysis of potential sensitivity to a discussion of organized perception is a large step, as has been discussed earlier. It requires a concomitant understanding that perception involves the interaction of detection and established code. Furthermore, it implies that this process is measurable if given certain standards. The purpose of this section is to describe and discuss the perception of color among elderly subjects based on available data, but ever mindful that a dramatic number of assumptions have been made. There is sufficient motivation to do so, however, if the designer is to be given the information and tools for developing appropriate environments.

A review of Said and Weale's 1959 study of spectral sensitivity serves as an adequate bridge. In this study, it was found that sensitivity to monochromatic wavelengths declined with age and that the decline was greater for short wavelength stimuli. Using a Wright Trichromatic Colorimeter, Ruddock (1965a) surveyed color vision changes with age among 400 observers. He attempted to determine not only sensitivity, but also to distinguish pre-receptor and receptor roles in causing any changes. The first part of the study measured j.n.d. sensitivity to wavelengths at 590, 530, and 490 nm as this could disregard the effects of the pre-receptors. It was found that there was only a slight decline in wavelength discrimination ability for short wavelengths. A forced-choice test showed no difference. Ruddock contended that the data suggested, "that the small positive correlation between j.n.d. discrimination step and age is an artifact, due to technique" (Ruddock, 1965a, p. 41). This initial test was followed by an examination of matching ability to a C.I.E. standard light source using the same apparatus (Ruddock, 1965b). This time a significant difference was found among age groups with the elderly having a diminished short wavelength sensitivity. Thus, their matching coordinates were shifted toward red and green. He then applied this experimental data to a mathematical model for predicting the response of a 65-year-old observer to the Munsell 100 Hue Test. The results will be discussed later.

Clinical Assessment

Applying the various clinical techniques described in Chapter 4, several experiments have been conducted to characterize elderly color discrimination ability and loci of color confusion. These will be described according to the technique employed, with a note of caution that the potentials and limitations of each technique be borne in mind.

Color Discrimination -- Anomaloscope

The primary problem in using an anomaloscope for testing color matching ability among age groups lies in errors of refraction, both in and of themselves and also as a side-effect of chromatic abberation. Millidot (1976) demonstrated that chromatic abberation diminishes with age because of the increase of presbyopia. Wienke (1960) has shown that myopia requires less, and hypermyopia more, red in a red/green match of yellow than does normal vision. Both of these problems may be corrected by the use of a very small exit pupil. Thus, only studies applying this method will be considered.

Boles and Carenini (1954) performed the first accurate anomaloscope testing comparing age groups from 20 to 80. Degeneration of discrimination ability in color matching was found to begin in the third decade, but remained constant until age 60; thereafter, it decreased significantly. Stiles and Burch (1959) found a small, but significant correlation of continuous decline in matching ability with age and also noted considerable variation within age groups. They concluded that the correlation varied with the amount of pre-receptor absorption in the lens and macular pigment as much as actual aging. Lakowski (1958) employed the anomaloscope to test color confusion in a non-selected sample of 500. It was found that the number of errors on the red/green test increased after age 60, but the sample was not significant. In both the yellow/blue and violet/blue-green tests he found a highly significant decline in discrimination ability after age 40. There was an increase in anomalous readings as well as total misreadings. Thus experimental use of the anomaloscope in testing age differences in color discrimination ability has shown a red shift with age. This shift, however, is not clearly defined as to the amount of blue sensitivity that is lost.

Farnsworth Munsell 100 Hue Test

The earliest Munsell 100 Hue Test applied to elderly subjects was performed by Smith (1943). Employing 199 subjects (age 5-87) he found a definite drop in ability to match color chips in all three dimensions of hue, value and chroma after age 65. Chroma, however, was least affected. His results also showed that ability to discriminate yellows actually increases in the post-65 group. The general order of decline in the remaining hues was green, purple, blue, and red. These results are interesting in view of other studies. He attributed the results to intervening variables noting, "it is suggested that age differences in color matching ability are predominately determined by attitudinal and learning factors rather than by receptor physiology" (Smith, 1943, p. 223). Regarding the test, he noted that certain inequalities exist in the Munsell system and that illumination levels above 10 f.c. did not enhance ability. Ruddock (1972) applied a mathematical model of spectral sensitivity to determine response on the 100 Hue Test. His model indicates that, "...the older observer should be less able to discriminate between (certain) groups of hues (specifically the blue-green hue samples numbered 45-55 and red hue samples numbered 80-85 and 1-5)" (Ruddock, 1972, p. 464). Moreover, he states that the model is confirmed by experimental data of Verriest, Valdevyvere, and VanderDonck (1962) and Burch (1964), and concludes that pre-receptor transmission factors affect discrimination ability. It appears that there is a definite conflict in interpretation of results: Ruddock stating that this is an indication of subject sensitivity and Smith suggesting that it may be an artifact of the testing instrument. This controversy has yet to be resolved. Ruddock also discusses the effect of illumination on test results by noting that adaptation to the light source could influence matching ability.

Pseudo-Isochromatic Tests

In 1942, Tiffin and Kuhn attempted to test age-related color vision using 7000 industrial workers and a nondescript P.I.C. test. All 7000 were tested for red/green confusion and 500 for yellow/blue confusion. Their results established the general belief that color vision declined continuously with age. An attempt to duplicate this study, but using more reliable instruments and controlling the variables of intelligence, socio-economic status, education, and occupation yielded conflicting results (Boice, Tinker, and Paterson, 1948). The test showed only a 20% increase in the post-60 age group, and there was no gradual decline with age. Similar results were reported by Janouskova (1955). This study also pointed out the importance of education level: in the 60+ age group 18% with high level education showed color blindness while 25% of the low level education did so. By 1950 the use of the P.I.C. test was expanded to study the relationship between age, visual acuity, and color vision (Chapanis, 1950). The study was conducted at the Baltimore Sesquicentennial Exhibition using a non-random sample of 574 visitors, age 7-77. The author admits that the test conditions were hot, dusty, noisy, and crowded. Nevertheless, this is a highly popular study. Results indicated that there was a curvilinear relationship between age and visual acuity; subjects under 15 and over 50 scoring lower than the mid-years. Five different P.I.C. tests were employed and indicated that there was a slight positive relationship between color vision and age. There was no evidence that score declined among elderly subjects. At interface, there was a statistically significant positive correlation between color vision and acuity, but it was slight. The author concluded that either there was no relationship between age, acuity, and color vision or that the P.I.C. tests were too crude to detect it. Kleemeier (1955) argued with this conclusion. His results indicated that visual acuity and color vision were related. He cautioned that visual acuity could be an intervening variable when using P.I.C. tests.

As mentioned in Chapter 4, the P.I.C. tests are suspect in their ability to measure age-related changes in color vision. The conflicting evidence from available research confirms this point. Nevertheless, it is a popular test and frequently referenced in the less-scientific literature as a highly reliable indicator that color sensitivity in general, and blue sensitivity specifically, diminish with age. Lakowski (1958) compared data obtained on two anomaloscopes against P.I.C. tests and found that they agreed regarding general trends among age groups. But his data only discriminated between color normals and extreme anomalies. Deviants and color-weak were excluded from the study.

Perhaps the only reliable conclusion that can be made from P.I.C. tests was made by Dalderup and Friedrichs (1969): "Color sensitivity decreases with age, without a definite preponderance of red-green over blue-yellow disturbances, or vice versa" (p. 388).

Color Aptitude Tests

To date, very little research has been done on the elderly using the C.A.T. Gilbert (1957) applied the C.A.T. to 355 subjects ages 10-93. All scores showed a slow rise up to the age of 20 and, thereafter, a slow decline to the oldest age. The most rapid decline was in the blue range, followed by green, yellow, and red. These results appear to be as expected, but there is no other data with which to compare it.

Burnham and Clark (1955) studied color memory among subjects age 12-25. The results showed a gradual improvement in ability. There were no data available regarding the elderly and color memory.

Conclusion

In summary, this chapter has been concerned with studying the physiological characteristics of an aged visual system and the potential and observed effects on color vision. The general conclusion from this information is that there are degenerative changes and they do affect the elderly individual's perception of color. But it is this author's contention that the information base is still too scant to provide reliable indicators for the designer. We know that major degenerative changes in the pre-receptor elements affect light transmission and spectral sensitivity. We do not know, however, if physiological changes in the receptor level or neural pathway magnify these deficiencies or if an adaptive process occurs that could compensate for them. Furthermore, clinical assessments have provided only an inconclusive, incomplete, and widely disparate body of data concerning color perception. This is a result of failure to clearly designate the parameters of elderly color discrimination, the use of inappropriate testing procedures, and inadequately controlled experiments. We know only that when compared with younger populations, the elderly sometimes exhibit confusion between or within short and long wavelength hues. This confusion is exhibited predominately at the blue end of the spectrum. We do not know, however, how prevalent this is among the elderly as a unique population, or the actual parameters of the confusion. Available data on color perception fail to clearly designate the elderly's discrimination difficulties in hue, value, and saturation differences.

We do not know how these difficulties may be dealt with in a prosthetic manner. Simply to avoid the use of certain hue variations could result in a loss of some of the informational character of the environment. We do not know if color discrimination difficulties may be compensated for with variations in illumination, form, size, texture, or distance from observer. Thus, the literature, to date, does not provide sufficient practical information that could be applied to the use of color in the environment.

The designer is left to draw his/her own conclusions as to appropriate color stimuli to facilitate a color coding system in aiding the individual. It appears imperative that future information be gathered from elderly populations that would address the following issues:

- Can a color vision test be devised that would accurately describe color discrimination ability among hues, and the various values and saturations within hues?
- Can such a test be devised to discriminate between closely related hues, their values and saturations?
- Could this test be applied to an environmental situation under varying levels and types of illumination?
- Could test stimuli be varied in form, size, texture, and distance from observer?
- Could this same test then be used to measure affective meaning in the environment?
- Could the results of this test be assimilated into a model for use by the environmental designer?

Information provided by this type of testing would enable the designer to approach the realm of color coding in the geriatric institution with a firm scientific basis for selection and use of color stimuli.

CHAPTER 6: CONCLUSION

The design process follows a general model of decision making. Lang and Burnette (1974) have outlined this process as shown in Figure 6.

Figure 6: Model of the Decision Making Process (Lang and Burnette, 1974)

The intelligence phase includes recognition and definition of the problem, analysis of the problem, and a synthesis of goals and objectives in solving the problem. The design phase provides for generating alternative solutions. The choice and implementation phases involve selection of one of the alternatives and seeing it through to realization. Evaluation, the final phase, is a rational examination of implementation relative to goals and objectives.

The purpose of this thesis has been to initiate the decision making process for a design problem involving the geriatric institution. And, it has examined that problem within an Ecological framework. Two systems, the elderly individual and the geriatric institution have been bounded and an informational energy transfer at interface defined. The elderly individual as a bounded system must be viewed as a member of a heterogeneous population conforming to a developmental process known as aging. Aging is multi-dimensional, cumulative, and may result in decreased competence in man/environment interaction. One aspect of aging that may affect this interaction deals with the system's ability to receive and detect stimuli. The visual system has been considered by comparing the physiological changes accompanying age to a normal visual network. It has been found experimentally that the potential for degenerative changes in the pre-receptor elements of the eye increase with age. Diminishing pupillary diameter, and growth and chemical changes in the lens result in a decrease in retinal illumination. Furthermore, spectral sensitivity declines because of absorption and light scatter. Nevertheless, the extent to which these phenomena occur and are characteristic of a normal aged visual system has yet to be fully established. Psycho-physical research into color detection and discrimination ability has attempted to characterize the ontogenetic changes in color perception. It has been demonstrated in this paper that such techniques yield inconclusive and often contradictory results. This results primarily because of the inability of available methodology not only to establish age as a necessary and sufficient condition for change, but also to characterize the nature of the change. The result is an overgeneralization of competence level that leads to simplistic, prescriptive methods for dealing with color as an environmental stimulus for the elderly.

The environment as a bounded system has been construed as the organization of material stimuli laden with informational resources for human use. The form and content of that information may be manipulated in the design process in order to enhance congruency between individual competence and environmental press. In the geriatric institution it has been suggested that envrionmental manipulation should involve the use of a variety of stimuli to communicate a single message. The role of individual stimuli and the informational content that they possess, however, has not been established in the literature. Furthermore, the relevance of these stimuli to a geriatric user is, to date, a field of virgin soil. It, therefore, has been the objective of this paper to isolate a particular stimulus form, color, and to identify its informational content in general, and specifically to orientational cueing.

Color as an informational cue affects the human system on three levels producing unconditioned, conditioned, and reinforced responses. Extracting evidence from experimentation of these responses, it has been shown that color does meet the necessary criteria as an orientational cue. It serves to delineate spatial form via its alliance to edge perception. Color provides focal points for the transfer of meaningful information as shown in visual search tasks. And finally, color provides reinforced responses to the affective meaning of the behavior setting. Thus, as an isolated stimulus, color provides orientational cueing in man/environment interactions and should, therefore, be a viable tool in the production of the prosthetic environment. It must be remembered, however, that the prosthetic environment involves the concomitant use of a variety of stimuli. Although it is beyond the scope of this thesis, it is recommended that similar analyses be conducted with other design elements in order to establish individual roles, the relative contribution of individual elements, and an hierarchial system for their implementation. Only then may an holistic approach to the prosthetic environment be accomplished.

Thus, the initial portion of the decision-making process has been completed in this paper. The design problem has been recognized and defined. It has been analyzed through an in depth examination of the state of the art. And finally, this paper has attempted to initiate the synthesis portion of the intelligence phase by posing potential research questions. It is obvious from this analysis of the state of the art that before the designer may move confidently to the design phase, further information is required. A considerable amount of statistically reliable research needs to be done.

This thesis began with a series of general user requirements that would apply to the use of color in a geriatric institution. They were generated in order to establish a framework of design goals from which one could study the literature. They provided a direction for the type of information the designer needed in order to use color effectively in the institutional environment. In light of the literature review done in this thesis, let us reexamine these goals.

1) Color should facilitate initial adaptation to the institutional environment by providing information as to the location and arrangement of objects and spaces, and facilitate directionality in human movement. The literature has indicated that color detection and edge perception are concomitant processes following the same neural network channel. Edge perception is known to facilitate feature detection and, thus, the perception of form. Although feature detection is a refutable theory, it has been supported by some psycho-physical research. If it is an acceptable theory, then an orderly progression of color contrast should facilitate orientation. But, we have noted that high contrast is undesirable from the user's standpoint. We do not know, to date, how color contrasts may be devised to facilitate edge perception and feature analysis for the elderly user. Further information is required regarding the interaction of color variations and edge detection, and how those variations are to be organized. The primary concern of the designer is, after all, the organizational process.

2) Color should facilitate social adaptation by providing information regarding behavior setting identification. We owe a considerable debt for the work conducted at Götesburg using the semantic differential on the affective meanings of color. Isosemantic mapping of the color solid has given the designer a considerable amount of

information regarding the cognitive and emotive processes involved with behavior setting identification. This work is still, however, in its very early stages. We need to know considerably more information regarding the feature dimensions and their parameters in colored environments. Furthermore, there is a virtual void when it comes to identification of affective meanings of color to the geriatric user. If there are some elements of color discrimination confusion among the elderly, this may affect the meaning of color to the individual. This issue clearly has not been addressed in the literature, but is of considerable importance in the design of behavior settings for the elderly.

3) Color should be used to provide complexity and variety in the environment in order to pose a degree of challenge for maximizing human potential. The work at Götesburg has indicated that judged complexity was correlated to chromatic strength. But user evaluation of an environment employing strong colors noted that it assaulted the senses. Clearly, a dichotomy has emerged. Furthermore, there is no body of research that deals with the use of color as a tool for challenge with any population, much less the elderly. Does challenge imply that the environment must be complex, or is color variation sufficient? This we simply do not know. If variation is sufficient, we need to know how the designer may build in a schedule of change to be implemented by the institutional management with a minimum of difficulty. It implies that the designer should be

prepared to provide a user guide. But until the designer him/herself understands the process, such a guide will not be forthcoming. Clearly, a model is required.

4) Color should provide an aesthetically pleasing environment based on user preferences and values. It seems unfair to impinge on basic human values by employing color schemes that reflect current popular trends or magnify generational differences in color preference. To date, we know very little about geriatric color preferences, but that information indicates that they prefer colors that other elements in the literature suspect they have difficulty in perceiving. Does the designer have the right or responsibility to determine priorities of user needs and values? This question cannot be addressed until we have established a reliable body of information regarding both color discrimination abilities and preferences. One would suspect that once these aspects are clearly defined they would probably be in agreement with one another, rather than reflect their current apposition.

5) Color should be selected relative to user capacity to detect color stimuli. Chapter 5 dealt with this goal in detail. We need to know the parameters of elderly color discrimination ability. To date, the literature has done little more than provide a confusing picture that offers little information of value. We need to know much more precisely what the elderly perception of color is and what are the discrimination abilities in detecting hue,

brightness, and saturation differences. Until such a knowledge base exists, the designer can rely on little more than intuition and artistic sensibility in selecting appropriate colors for the institutional environment.

It would appear that the researcher attempting to grapple with these problems could start with the development of a color system for detecting discrimination ability among the elderly. This system probably could be based on an existing system such as Munsell or the Natural Color System in order to facilitate model building. Laboratory assessment of both sensitivity to and perception of the system could be the next step. Then the system should be applied to an environmental situation and reassessed for its orientational cueing potential. Finally, a model could be developed from which the designer could predict the potential of the system in a particular environmental situation. This would allow the design phase to proceed by generating alternative solutions founded on a scientific data base rather than intuition and generalization. The potential of color as an orientational cueing mechanism in the geriatric institution provides a challenging and exciting avenue for future environmental research. It is the fervent hope of this author that these avenues be explored.

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