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The Human Factors of Color in Environmental Design: A Critical Review

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**The Human Factors of Color in Environmental Design: A Critical Review**

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## INTRODUCTION

For those who enjoy color vision, color appears as a natural attribute of the sensed world. Color signals and conceals, warns and allures, enhances and deceives. Design at all levels, from that of computer display to landscape arrangement, uses color to express its intentions and create its impacts. Almost weekly, there appear articles about color's power: "Loud or Soft, Every Color Has Its Say" (Renner, 1984); "We're Learning to Put Color's Power to Work" (Thorne, 1980); "Red is Sexy, Yellow. . .?" (Time, 1975); "Blue is Beautiful" (Time, 1973). All are titles which suggest that colors possess inherent qualities which can influence our judgment, evaluation, and even behavior toward the people, places and things where color is applied. But is this a realistic appraisal of color's role? What is scientifically known about the effects of color in environmental design?

The intention of this study is to review the extant research literature on environmental color with special reference to its utility in the design of space station interiors. It is prompted by NASA's serious consideration of color as a means of enhancing habitability within the proposed space station or future extraterrestrial bases. This review summarizes what is empirically known about our responses to color, and how, if at all, color influences the perception of a setting or one's behavior in that setting.

In both popular and scientific realms, so much has been written about

color that the distinction between fact and myth is quickly lost. The belief in "easy eye green" is a good example of color myth. Hospitals replaced the color white on both walls and clothing with the color green, as a means of minimizing the afterimages experienced by staff in operating rooms. It was inferred (incorrectly) that a color used in hospitals to aid visual tasks would also benefit other work environments (Bernardo, 1983). However, it was not so much the hue component of this color but its relative lightness that was important in the surgical suite. Another hue with the same degree of lightness might have worked just as well if not better.

Porter and Mikellides (1976a) cite similar anecdotal stories regarding color decisions based on assumed behavioral responses. For example, the color green has been described as being calm and restful. Based on this attribution, it was selected for use in redecorating the main cell block and solitary confinement areas at Alcatraz (Porter and Mikellides (1976a). Was this a rationally justifiable application? Our review sought the bases for this and other hypothesized color-behavior links. Therein ought to lie the reasons for any 'functional esthetics' of color, and, perhaps, a guide to its applications in habitats off the earth.

Theories of color have been devised for centuries. Nassau (1983) traces the historical roots of color from the philosophy of Plato where color belonged unaccessibly in the realm of divine Nature to the calculations of

Newton, who discovered the spectrum and arbitrarily assigned to it seven fundamental colors analogous to the seven notes of the musical scale. Color has also had an eventful history of adornment in the built environment, from the cave to the high rise (Birren, 1983; Wineman, 1979; Porter and Mikellides, 1976a; 1976b). However, it was not until the late 1800s, with the advent of introspection, that color was systematically investigated in a behavioral context. The succeeding years have seen a plethora of research generated on this topic ( see Kuller, 1981; Plack and Shick, 1974; Sucov, 1973; Hayward, 1972), and Berlin and Kay's (1969) extensive survey of color terms in ninety-eight languages argued cogently for the existence of invariant patterns in the categorization of color perceptions. This would seem to indicate that subjective structuring of color has a common cognitive basis.

The phenomenon of color has been described as a subjective visual sensation produced by light. It is not an inherent property of a given object (Wineman, 1979; Porter and Mikellides, 1976a). Nassau (1983) speaks of color as being perceived by the eye and interpreted by the brain, and the aptness of his view will be neither defended nor criticized here. This paper's focus is on the behavioral aspects of color in environments and it attempts no critical assessment of visual processing mechanisms. Wright (1984), Hurvich (1981), and Boynton (1979) provide excellent contemporary overviews of this latter topic.

Our assessment begins with a distinction. Although perceived as an integrated whole, there are three recognized subjective dimensions of color. These are hue, saturation and brightness (which is often called lightness when the surface is reflecting and not self illuminated). Among design professionals, the dimensions are known as hue, chroma, and value. Hue is the term most often used to describe a color, e.g. red, green, blue, yellow, and refers to its dominant wavelength. Saturation (chroma) describes a color's purity or the extent of its departure from gray. Brightness or lightness (value) is the degree to which a color varies along the white-black continuum (Farrell and Booth, 1984). Available color systems can precisely specify a color through visual matching on these three dimensions. The Munsell Color System is the one most often cited in the literature, and its ease of use and familiarity give it near universal acceptance. Our attempted synthesis uses its terms.

Proceeding from an analytical perspective, our review attempted to determine relative contributions of the three dimensions of color in different types of responses to environmental coloration. Both space colors produced by chromatic luminance and surface colors produced by selective reflection of incident illumination are included here. The types of behavioral responses to color appeared to fall conveniently into five major categories. These categories mirror both the available literature and our personal attempt to

construe its results in the most meaningful and useful way. So we have avoided the temptation to categorize in terms of psychological variables or processes, and instead have chosen to represent responses to color in terms of judgments that designers might most like to affect. These extend from basic preferences for colors to color's influence on perceived temperature, weight and spaciousness. Preceding these sections is an examination of color's supposed effects on physiological processes since this 'sets the stage' for much of its role in psychophysical judgments. Succeeding those sections are a summary of results from color assessments in real or simulated settings, and an overview of color's role in space habitability research and flight practice to date.

Our conclusions try to succinctly extract the 'lessons learned' from these various studies without trying to make color specifications, which are more rightly the designer's role. This critical review is thus meant as a guide to critical thinking about color usage, and not as a replacement for it. Hopefully, it will encourage more considerate and innovative uses of color in the habitats and workplaces that need it most.



## Physiological Responses to Color

In an attempt to better understand the effect of color on human behavior, investigators have often focused their attention on physiological responses to color. It is from the results of these studies that various authors cite support for the premise that certain colors have the capacity to excite and arouse an individual while others are capable of calming and relaxing one. These arousing and calming properties ascribed to colors have subsequently been removed from the context of the laboratory and applied indiscriminately to dwellings and workplaces (Kron, 1983; Digerness, 1982; U. S. Navy, 1975; Birren, 1982; 1959; 1950). However, some of the original laboratory studies have come under sharp criticism for their often small and nonrepresentative sample sizes, failure to operationally define stimulus variables, confounding of stimulus and experimental design variables, and extrapolating beyond the evidence provided by their data (Kaiser, 1984; Sharpe, 1981; Sucov, 1973; Norman and Scott, 1952). Subsequent authors who rely on these studies have often merely cited their findings and drawn conclusions which are actually unwarranted and unsubstantiated. We will look at a series of studies in this area and the implications they hold for design decisions.

The most often cited work in terms of how color affects behavior is that of Kurt Goldstein (1942). Dr. Goldstein postulated an affective theory of color based on the observations and experimentation of patients with organic

diseases of the central nervous system. These patients manifested impaired motor function (unstable gait, trembling) and distortions in estimates of time, size and weight.

His experiments were conducted on a small number of patients (3-5); color stimuli were pieces of colored paper, colored rooms, colored lights, or colored clothing; and neither numerical results nor statistical analyses of his observations were ever presented (Nakshian, 1964; Norman and Scott, 1952; Goldstein, 1942). What he observed was in the presence of green, abnormal behaviors became less deviant, while in the presence of red these behaviors became exaggerated. For instance, patients who overestimated or underestimated short time spans, demonstrated more accurate (normal) time estimations in the presence of green stimulation and more distorted estimations in the presence of red.

From his work with brain-damaged individuals, Goldstein formulated a theory which he believed applied to all individuals. He viewed red as having an "expansive" effect on the senses and of being capable of inducing a state of excitation in both emotional and motor behavior. Green, however, had a contractive nature and promoted tranquility (Nakshian, 1964). Based on these premises, he felt one's performance on certain motor tasks and judgments could be disturbed (or interfered with) by the color red and facilitated by the color green (Goldstein, 1942).

Nakshian (1964) found little evidence to support Goldstein's premise that a red surround impaired and a green one facilitated certain motor performances and judgment abilities. He had 48 subjects perform a series of nine tasks in each of three colored surrounds. The tasks were comprised of fine motor tasks (hand tremor, tweezer dexterity), psychophysical judgments (length, time) and a series of motor tasks (most comfortable arm position, outward arm movement, motor inhibition). Color conditions were manipulated by painted partitions on a tabletop apparatus. Colors were red, green and gray. Matched to Munsell color samples, they were of equal lightness but the red was more saturated than the green (5R 4.5/12; 7.5G 4.5/6). Of the nine tasks, significant differences were found only for two, hand tremor and motor inhibition. Performance for both tasks (where inhibitory control over motor performance was measured) was better under the green condition than the red.

Because he only observed color to facilitate two of the nine tasks, Nakshian's findings provided little support for Goldstein's theory of color's influence on general arousal. Goldstein's theory was based on the notion that there existed a one to one mapping between color states and emotional states, which seems to be a gross oversimplification of the complex processes linking color and behavior. It has not been confirmed by the work of subsequent researchers.

Goodfellow and Smith (1973) also found no support for the general notion that red impairs fine motor coordination and blue facilitates it. They had twenty-five females perform two psychomotor tasks (pursuit rotor and dexterity) in one of five color conditions where a tabletop booth was painted in either red, blue, green, yellow or gray. Colors were matched to Munsell notations. Brightness (medium) and saturation (high) were held constant. Performance did not differ for either the pursuit-rotor task or the dexterity task across the five color conditions.

In another motor study by Hammes and Wiggins (1962), color illumination had no effect on high-anxious or low-anxious subjects in a perceptual motor steadiness task. Here, red and blue illumination was produced by Wratten filters, and brightness among the three light conditions (red, white, blue) was equated by the method of limits. The authors had predicted that due to its calming nature, subjects would perform best under the blue illumination and that high-anxiety subjects would perform better than low-anxiety subjects in this condition.

In addition to hypothesizing specific effects of color on psychomotor performance, Goldstein (1942) also postulated differential behaviors on psychophysical judgments of time passage under the colors red and green. Time distortions have since been investigated under more rigorous experimental settings.

Smets (1969) asked subjects to estimate the amount of time spent under two different light conditions and recorded shorter time estimations for the red light condition than the blue. She also observed the same behavior to occur when subjects were asked to estimate when the time exposure of a second light was equal to that of a first. However, she noted strong order effects in her data - perceived time duration was shorter for the first exposed color light, whether or not it was red or blue.

Caldwell and Jones (1985) found no significant difference in counting rates under red, blue or white illumination. (Brightness was equalized through the method of averaged error.) Nor did they observe differences under the three lighting conditions when subjects were required to estimate 35 and 45 second time intervals. Presentation effects were found to be significant in both the counting and production tasks. Of interest was the fact that sixty percent of the subjects reported in a post-experiment questionnaire that they counted faster in the red light condition than the blue. The authors suggested that possible differences between their findings and those of Smets (1969) might be attributed to the different methods used to estimate time in the two studies. Clearly, if there is any distortion in subjective time estimation due to color, it is not a very robust phenomenon.

In a series of related, unique experiments, Humphrey (1971) and Humphrey and Keeble (1977) investigated color durations as indicants of color

preferences in monkeys. Humphrey (1971) trained monkeys to produce red or blue light to a wall surface by pressing a button. As long as the button remained depressed, the wall remained illuminated. When the button was released, the chamber returned to darkness. Successive presses resulted in the wall being illuminated in the alternate color condition. He found the monkeys spent more time in the blue condition than the red. He inferred that monkeys preferred blue over red.

In a later study, Humphrey and Keeble (1977) tested monkeys in three separate conditions. The first condition was an exact replication of the earlier study (Humphrey, 1971) where successive button depressions resulted in red or blue light being displayed. The second condition was a no color choice condition. In this condition every depression resulted in either the red or blue light always being displayed. In the third condition depressing a button resulted in a colored light (red or blue) being displayed. When the button was not depressed, the alternate colored light condition (red or blue) and not darkness resulted. They found that the monkeys' responses were much faster in the red light condition than blue. To account for their findings they proposed a "subjective clock" (time passes more quickly in red light than in blue). Perhaps another explanation lies in the distinct signal properties of the color red. A lengthier discussion of this alternative will be presented later.

The previous studies had all viewed arousal properties of colors within the context of Goldstein's (1942) theory. Other studies have investigated arousal to colored lights without the theoretical framework and with direct physiological response measures. A common criticism of much work in this area lies in not providing adequate operational definitions for stimulus conditions and being vague about measures taken to equate brightness. Both Carterette and Symmes (1952) and Gerard (1958) are authors who have taken great pains to ensure a clear and comprehensive explanation of the variables they manipulated.

Two common physiological measures of arousal are changes in electrical activity in the brain (EEG) and changes in skin conductance or resistance (GSR). With increased arousal, skin conductance increases while skin resistance decreases. Alpha waves are patterns of neural activity found during periods of relaxed wakefulness that decrease and become desynchronized during periods of arousal. This process is known as the alpha attenuation response, AAR (Ali, 1972). Thus, arousal is often measured by changes in alpha wave frequency and/or amplitude (Kaiser, 1984; Wilson and Wilson, 1959). With repeated stimulation or with the increase in stimulus duration, there is a recovery in alpha rhythm (cortical habituation response) as the individual habituates to the once novel event (Ali, 1972; Wilson and Wilson, 1959).

Gerard (1958; 1959) has provided one of the most comprehensive and stringent studies of the effects of colored illumination on both subjective and physiological measures. Twenty-four males looked at a screen onto which red, blue and white light (in counterbalanced order) were projected. Subjects viewed each light for a total of ten minutes. Luminances of the translucent screen in the three light conditions was equated by the method of limits. During the time the subject was viewing the colored screen, the following physiological measures were taken: blood pressure, palmar conductance, respiration rate, heart rate, eyeblink frequency and EEG.

Gerard found statistical significance between the red-blue condition for all physiological measures except heart rate. Blood pressure and palmar conductance were lower in the blue illumination condition compared to those obtained in the red. The blue condition yielded a lower respiration rate and increased alpha wave frequency. He also observed an immediate reduction in eyeblinks at onset of the blue light. He noted that the group as a whole reported feeling more alert in the red illumination and more relaxed in the blue. From these findings, Gerard felt that his findings lent additional support to the sedative effect of blue. Responses to the white light varied, but most often were similar to those of the red condition.

Gerard (1958) does caution the reader regarding the generalizability of these findings. He notes that the study was conducted on male college



students, who may not necessarily be representative of the population at large; that only three colors were investigated (two were extreme colors of the visible spectrum); and that the results were acquired under one stimulus condition (and a rather restrictive one at that). Also, these findings are the product of active attending for ten minutes to a light source and say little about arousal or relaxation over a longer time period or when the color source is not the recipient of active attention.

The findings from other studies have not been so clear cut. When Erwin, Lerner, Wilson, and Wilson (1961) presented lights of four different colors - red, blue, green, and yellow - for five minutes each, the duration of alpha wave onset was shortest for the green condition. However, there was no difference between the red, yellow and blue conditions in terms of arousal, measured by suppression of alpha waves. The authors do not discuss how or if brightness was equated between the four color stimuli nor do they give much detail regarding their color stimuli.

Brown (1966) found differential EEG following responses to colored photic flicker to be dependent upon the individual's visualization capability. Here, subjects were classified as visualizers or non-visualizers through performance on questionnaires, interviews and eye movement recordings. The EEG photic following response for visualizers was reduced in red light; while for non-visualizers, this response was enhanced in red light. No such

differences were found between the two groups for either blue or green light. Subsequent questioning of the two groups revealed no differences in pleasant or unpleasant associations to the red, blue or green lights to account for these findings.

Alpha wave recovery has also been investigated under blue and red lights, wherein male subjects viewed red or blue light for either 5 or 10 minutes (Ali, 1972). He noted that the lights were equated for brightness by each subject. Greater alpha recovery over time occurred under blue than red light, which over ten minutes showed relatively little recovery. From his findings, Ali concluded that a higher level of arousal (cortical activity) takes place in red light which then requires a longer time period before resting alpha activity can resume.

In the previously discussed time estimation task of Caldwell and Jones (1985), no systematic effect of colored light (red, blue, white) was found for eyeblink frequency, skin conductance, finger pulse volume, heart rate or EEG measures. Here, length of exposure to the colored light conditions might be a factor, for the stimulus was only presented for a maximum of 45 seconds as compared to Gerard's (1958) 10 minutes. The exposure time here may have been too short to detect any subtle changes.

These authors did observe some gender effects (males had a consistently higher skin conductance level and larger pulse volume than

females) and some color effects which were limited to the first presentation of a given color. They found no difference in percent of alpha activity or peak EEG frequency under red or blue light conditions.

Wilson (1966) alternately presented highly saturated red and green slides of one minute exposure for a total of 10 minutes. He used mean conductance level and change in conductance level as measures of arousal, and found that both conductance scores and change scores were higher in the red condition. However, he noted that in the conductance data, the difference due to color was overshadowed by an order effect; while in the change scores most of the difference could be accounted for by subjects who received the green stimulus condition on the first trial. As a check on brightness after the experiment, subjects were asked which of the two colors was lighter and 18 out of the 20 responded, green. He unaccountably concludes that his findings generally provide support for the hypothesis that red is more arousing, more stimulating, more exciting!

Physiological correlates of emotional attributes of color were also investigated by Nourse and Welch (1971). Their contention was that hues at the ends of the visible spectrum (purple, blue) would be found to be more stimulating than those in the middle (green). Fourteen subjects were exposed to green and violet light in alternating order. Exposure to a given light was for one minute and the entire task took a total of six minutes. The dependent

measure of arousal was the difference in one's skin conductance level at the initial exposure of a color and the highest level reached in the first 12 seconds.

There was a significant difference in GSR amplitude between the two color conditions and GSR measures were higher in the violet light condition than the green. However, once again there existed a significant interaction between color and order. This response to violet was greatest for those subjects who had been shown green first. Also, the color differences were significant for only the first trial (presentation) and not the remaining two trials. Nourse and Welch explain color's significance being limited to just the first trial in terms of subject adaptation (habituation) on subsequent trials.

They do note two factors which may have influenced their results and which may be more responsible than hue for the differences observed. It seems that instead of using filters, the lights were painted. After the experiment was run, they found the two lights to have very different spectral compositions, where the green light was relatively pure spectral composition (450-630nm) while the violet had a spectral composition which covered the entire visible spectrum (peaking at 455nm and 677 nm). Also, the lights were presented in two different configurations, with the green lights forming a cross and the violet lights an 'X'. Incredibly, this study is often cited as support for differential arousal properties of color.

Another approach to the arousal issue is to look at the influence of colored ambient lighting or surround colors on one's performance. Neri, Luria, and Kobus (1986) had eight subjects engage in a CRT reaction task under four different ambient illumination conditions (red, blue, low level white, and no light). Lights were equated for only 0.2 footcandles of photopic light falling on a CRT screen. Subjects had to select the appropriate button representing the quadrant in which the stimulus was initially presented. In addition to ambient lighting, both CRT background colors and target colors were manipulated. There were no significant differences in mean reaction times under the four ambient lighting conditions. Of interest is the fact that illumination levels were quite low in comparison to some of the other colored illumination studies previously mentioned.

In a more realistic study, the influence of red and blue light was investigated in the context of gambling behavior (Stark, Saunders, and Wookey, 1982). Twenty-eight subjects (in groups of seven) played a variation on the game of three card brag in either red or blue ambient lighting. Lighting was provided by red and blue fluorescents matched for brightness. According to the authors, it was found that significantly more money was waged (although there was less than one pence difference between groups) and more bets placed in the red light condition. An interaction was also observed, - as time increased subjects waged more money, increased the number of bets, and

these behaviors were more prevalent in the red light condition.

From these findings, Stark, Saunders and Wookey (1982) concluded that red had a more excitatory effect on gambling behavior and that people's behavior became riskier in red light. Some questions remain unanswered and may provide alternative explanations to the behaviors they witnessed.

The authors failed to say how color was introduced: were sleeves placed over fluorescent bulbs, or were the lights painted as in the Nourse and Welch (1971) study? What was the spectral distribution of each of the lights? And were the lights matched for "brightness" matched for luminance or subjective brightness? Whatever the case, was there a uniform increase across all wavelengths or just a few?

We contend that another more realistic explanation for increased wagers and greater betting frequency occurring under the red condition was that the red light was bothersome and subjects were trying to get away from the situation. Discomfort under red illumination has been noted by other researchers (Howett, 1985; Luria and Kobus, 1985). This condition might have been enhanced if luminance was significantly increased in the red light condition, which would have been necessary to match blue light in subjective brightness.

Also, if one is more energized by red light, one would expect more indiscriminate wagering in gambling behavior and more losses. No

information was provided regarding average sums of money won or lost in each light condition. We truly caution casinos on major redecorating decisions based on these findings.

Jacobs and Hustmyer, (1974 ) found GSR to be significantly affected by color while heart rate and respiration measures yielded no difference. Color slides (red, yellow, green and blue) were shown to subjects (counterbalanced order) for one minute each with white slides interjected for one minute between each color. Saturation was high for each color but brightness varied with yellow being the most bright( 8/) and the red being the least (3.9/).

In terms of GSR, measured as the greatest change in skin conductance occurring within the first 15 seconds after color stimulus onset, the color condition red yielded the highest change, followed by green, yellow and blue, showing the smallest amount of change. Jacobs and Hustmyer (1974) found no significant difference between the red vs. green condition nor the blue vs. yellow condition. They note that their GSR findings agree with those of Gerard (1958) but disagree with those of Wilson (1966). Also, they point out that their heart rate data are consistent with those of Gerard (1958) but their respiration data are contrary to the findings reported by Gerard. They account for discrepancies between this study and other studies to be due to stimulus difference - lights vs. painted surfaces.

Jacobs and Suess (1975) obtained support for the hypothesis that red is

more arousing than blue. They assigned subjects to one of four color conditions (the same as those reported by Jacobs and Hustmyer, 1974). Subjects were administered a paper and pencil anxiety test three times. Between each administration, a color slide was projected and remained on for five minutes. Significantly higher anxiety scores were obtained in the red and yellow color conditions than in the green and blue conditions. They interpret their findings to the credence that color can have an effect on one's anxiety state.

More recently, Kuller (1985) found no evidence to support the notion that red interiors were more stressful than blue. He observed no difference in EEG measures when individuals sat in a red or blue-walled room.

What if anything can we conclude from these studies regarding the arousing or calming qualities ascribed to colors? It is evident that a great deal of inconsistency exists in the literature and the findings are anything but definitive. Many of the problems arise from incomplete operational definitions of the stimulus conditions and the multifaceted nature of response measures defined as arousal. In addition, these findings on color and arousal have often been indiscriminately applied by practitioners to a variety of settings without any real care for the limitations in the original data.

When colored lights were the stimuli, there appears to be an inherent problem arising from attempts to control brightness, which itself appears to



be a strong contributor to arousal. Equating red and blue light for luminance does not necessarily equate them for brightness (Neri et. al., 1986). In the studies reviewed, various means were used to equate or control brightness - method of limits (Hammes and Wiggins, 1962), method of average error (Caldwell and Jones, 1985), asking subjects which of two colors was the higher (Wilson, 1966), while others made mention that stimuli were matched for brightness (Stark et al., 1982; Nourse and Welch, 1971). Other authors (Erwin et al., 1961; Goldstein, 1942) made no mention of brightness. Gerard (1958) and Neri et. al. (1986) equated luminance. Also, few studies gave the spectral distribution of the lights manipulated. One can only wonder how comparable the colored light conditions are in these various studies and if other variables could account for the findings reported. Different means by which to control brightness or the failure to control brightness certainly could be a factor in the inconsistent findings noted among the various studies.

In later studies where the stimuli were painted surfaces, Munsell notations were provided for standardization and comparison purposes (Nakshain, 1964; Goodfellow and Smith, 1973; Jacobs and Hustmyer, 1974). It is interesting that colors chosen were often highly saturated ones. When comparing the findings of these studies or extrapolating these findings to other settings, one needs to take into consideration the spectral distribution of illumination, the color-rendering properties of the illumination and even

the configuration and type of light fixtures used. As studies (Xu, 1983; Glass, 1981; Helson and Lansford, 1970; Helson, Judd and Warren, 1952) have shown, colors can appear distorted or changed under different types of illumination. Such care with illumination sources gains in importance when one makes recommendations to real world settings, especially with the increased emphasis on energy efficient lighting.

As regards the various indices used to measure arousal, we are confronted with yet another issue. A given response measure may be operationally defined in one of many ways. For example, there are numerous ways to report EEG responses - amplitude of alpha waves, duration of alpha wave suppression, amount of EEG, to name just a few. [Kaiser (1984) presents an excellent discussion of this issue.] When one tries to compare findings from one study to another, different types of responses might be reported under the same general response name, making such comparisons virtually impossible. The same can be said of GSR data. Different authors operationally define change scores in terms of responses during different time intervals after stimulus onset. Much variability can exist in what is often thought of as a rigorous response measure.

In four of the studies reported here (Wilson, 1966; Smets, 1969; Nourse and Welch, 1971; Caldwell and Jones, 1985) presentation and/or order effects were noted. It was found that significant differences between color

conditions were evident only on the first and not on subsequent trials. Or there was the unexplained interaction between color and order (Nourse and Welch, 1971). This would lead one to believe that whatever differences might exist in arousal responses to color, they are of a short duration and a transitory nature. Wilson and Wilson (1959) reported that greatest suppression of alpha waves occurred during the first 30 seconds of repeated stimulus presentation, after which there appears to be a leveling off period.)

The focus of this discussion has been on arousal properties of colors, especially the arousal property of the color red. (In nature, colors of high brightness and chroma contrast carry strong survival signals, e. g. the monarch butterfly (Norman, 1986)). In general, colors that do not occur frequently in nature take on a high symbolic content due to their signal capacity in standing out from a background (Tuan, 1974). Red may subsequently carry unique signal properties. Humphrey (1976) notes that red is the most common color signal in nature, arising from the fact that red contrasts well both with green foliage and the blue sky. Also, because it is the color of blood, it is easily accessible by animals for the purpose of changing their coloration. Problems arise from the ambiguity of its signal - it can signal either approach (sexual display, edible food) or avoidance (aggressive behavior, poisonous substance). According to Humphrey (1976) one's response to red is a reflexive one. It serves the purpose of preparing

(arousing) one to take some form of action which is defined by the context. Mikellides (1979) also cites this explanation and finds that it puts into perspective the strong positive and negative associations engendered by this particular color.

Red may indeed carry with it signal properties which have as their function arousal of the organism. However, it is unlikely even in nature that such arousal lasts beyond a short duration, especially if presented within a context. Thus, claims that certain wall colors will arouse an individual, make one alert and thus more productive is certainly not warranted by the findings reported so far.

We agree with Kaiser (1984) that it is unlikely that a direct physiological response to color exists but rather that one makes certain associations to colors and that these in turn mediate a physiological response. We believe the arousal properties that have been demonstrated to the color red are largely dependent on the laboratory surround and the nature of the stimulus and have not been adequately demonstrated to dominate in the built environment. It is especially clear that arousal effects of color are neither strong, reliable, nor enduring enough to warrant their use as a rationalization for applying "high or "low" arousing colors to create "high" or "low" activity spaces. The danger here in ascribing any lasting arousal qualities to color derives from its potential use as a post-hoc cure-all for

otherwise poor design. A poor bedroom or private sleep space is not rendered into a suitable one by painting it blue. Human beings are not "hard wired" to physiologically turn on or off to color treatments in their surroundings. Further evidence that relates color to psychological affective states is revealed by the studies on color preferences and mood tones.

## Preferences for Colors

Undoubtedly one of the most intensive areas of color research is that of color preference. There exists almost a hundred years of investigations in this field - the first empirical study having been conducted by Cohn in 1894 (Eysenck, 1941). Since that initial effort, there have been numerous attempts to determine the relationship between feelings/emotions and colors. (Sharpe (1981), Ball (1965), and Norman and Scott (1952) provide excellent overviews of this research.) We present here only the more cited works in order to give the reader a sense of how this area of study evolved and what lasting effects it has had on our understanding of color attributes.

Imposing a structural framework on preference research is a formidable task. In part, some of the difficulty with preference research arises from understanding what was actually being studied. Early investigations focused attention not on the preference judgments ascribed to colors but rather on the process employed to arrive at a preference judgment. Their evidence supported the views of a strong associative relationship between particular preference ratings and given colors. Many of these associations were of an emotional quality. The question arose, are certain colors able to consistently elicit certain emotions? If so, is this a quality inherent in the color or innate within the organism which is released in the presence of a given color? Or is the linkage between color and emotion a purely cognitive one, which brings

up a subsequent question of whether the mediated affect and color relationship is biological or learned. We shall present research which suggests it to be the latter.

Greater practical importance accrues to what type of behavior or verbal report serves as the best response measure from which color induced emotion is inferred. Some studies measured preference in terms of one evaluative dimension, pleasantness/unpleasantness. A high pleasantness rating for a given color thus became synonymous with a high preference rating. But with the advent of the semantic differential in 1957 (Osgood, Suci and Tannenbaum, 1957) a shift in preference research occurred. Instead of looking for a single relationship between color and pleasantness, colors were rated on a series of bipolar adjective scales (semantic differentials). Results were then discussed in terms of color profiles or factors which could be attributed to a specific color or which underlie a group of colors. In addition, a research speciality developed that investigated the hypothetical relationship between colors and various mood tones. We believe that from the preference literature evolved many of the contemporary popularized concepts regarding secure colors, happy colors, active colors, etc. that have been superficially transferred to interiors' applications.

Norman and Scott (1952) point out that early work in color preference lacked rigorous controls. The three psychological dimensions of color - hue,

value (tint) and chroma - were rarely controlled and research findings were not statistically treated. Response measures were often couched in introspective reports (Bullough, 1908; Nakashima, 1909); the presentation orders of colors were not counterbalanced (Nakashima, 1909; Washburn, McLean and Dodge, 1934), nor was illumination adequately controlled (Nakashima, 1909; Washburn and Grose, 1921). Inconsistencies were attributed to subject variables (Bullough, 1908; Guilford, 1934) and not just stimuli differences.

Early color preference studies focused almost solely on the dimension of hue. Researchers presented their findings in terms of most and least preferred colors (hues). Red, blue and green were usually reported as most preferred while yellow and orange were judged to be less preferred (Guilford, 1934; Walton, Guilford and Guilford, 1933). Little consideration was given to the contributions of tint and chroma on affective judgments, although Cohn (Ball, 1965) did note that subjects preferred color pairs exhibiting strong contrast and Washburn (1911) found that the affective value of tints (lighter colors) was preferred to shades (darker ones) and that the affective judgments to saturated colors were more positive than those assigned to tints or shades.

It was not until the work of Guilford (1934) that any systematic attempt was made to study the contributions of hue, tint and saturation on affective



judgments. Using Milton Bradley colored papers, he selected 18 hues being equal in tint and chroma, 11 hues varying in value and low in saturation, and 11 hues high in saturation. Each color was judged on a nine point pleasantness scale, from greatest possible unpleasantness (1) to greatest possible pleasantness (9).

He found that with tint and chroma held constant, the colors, B, G, R were rated more preferred and Y, O less preferred. Lighter colors were found to be preferred over darker ones and saturated colors over unsaturated ones. He did observe some sex differences. The three dimensions of color accounted for 71% of the affective value judgments of women but only 26% of men's affective value judgments.

In a more recent study, Smets (1982) examined in greater detail the contributions of brightness and saturation to pleasantness ratings. She found all three attributes contributed to ratings along this dimension with saturation accounting for 88% of the variance and brightness, 12%. She sampled only 24 colors and subjects rated colors on either a pleasant or unpleasant basis.

In addition to hue, tint and saturation, size of stimulus was also found to affect preference judgments (Washburn, McLean and Dodge, 1934). Preference ratings for some colors (Y,O) varied with stimulus size, the smaller size (5x5 cm) being preferred while the larger size (25x25 cm) was judged as

unpleasant. Nakashima (1909) speculated that preceding colors or color combinations might influence the perceived pleasantness judgments of subsequent colors. These findings shed additional light on reasons for inconsistencies reported by various researchers on color preferences.

The search continued for evidence which supported a consistent preference rating of colors. It was the work of Eysenck (1941) that advocated a strong argument for a universal scale of preference. He calculated the average ranks for six saturated colors (these were the colors he determined to be shared in common amongst the various studies) from a number of studies encompassing the responses of 21,060 subjects.

He reported preference for saturated colors from most to least preferred being B-R-G-V-O-Y. From his comparison of the various studies, he found no racial difference in color preferences and no differences among sexes except for the colors yellow and orange. His tentative conclusions were that preference for any color varies inversely with the luminosity factor of that color and that there appeared to be a direct relationship between liking for a given color and its differentiation from white.

This research has been cited extensively and presented as evidence for a universal and seemingly invariant preference ordering of color. It should be noted that his comparisons were made only on saturated colors and there is no evidence that experimental conditions were comparable let alone alike in

the studies sampled. Eysenck is vague regarding the implications of these findings and refers to a general factor of aesthetic appreciation.

Granger (1955) sought a more rigorous test of Eysenck's (1941) findings. He constructed sets of stimuli from Munsell colors where one dimension would vary while the other two were held constant for each of the attributes of hue, value and saturation. He was somewhat imprecise in terms of what subjects actually did other than to judge colors according to their current preferences.

He concluded that, given isolated colors, the order of preference for all three attributes remained invariant from level to level throughout the color solid. (There appeared to be no interaction effect among the three attributes with colors independent of context.) He found wavelength to be the major factor in determining preference. In this study, 5B was most preferred with 5Y being least preferred. An interesting finding was his observation that background contributed to determining preference - preference for a color increased the more it contrasted with the background against which it was seen. Also, he noted that as saturation increased so did preference up to a point - colors seen as too vivid were rated as less preferred. From his findings, Granger concluded that color preferences were only in part determined by objective stimulus qualities.

It was the work of Guilford and Smith (1959) which provided a rigorous

examination of the roles that hue, value and saturation played in pleasantness ratings. A ten-point pleasantness scale was used to rate 316 stimulus papers; of these, 295 were colored stimulus papers matched on the three Munsell dimensions.

Across all hues, with varying levels of brightness (for females), the blue-green regions had the highest affective value (pleasantness) ratings while the lowest were observed in the yellow, yellow-green regions. This pattern existed across all levels of brightness. However, as brightness increased perceived pleasantness also increased. Within a given hue, the greater the saturation, the greater its perceived pleasantness. Guilford and Smith (1959) observed that colors at the levels of brightness which could be the most saturated were the most liked.

Their data was presented in terms of isohedonic charts. An isohedon is a line of uniform affective value. Isohedons for a given hue were plotted across varying values of brightness (y-axis) and saturation (x-axis). Representing the data in this manner allowed one to predict a likely pleasantness rating for a color defined by Munsell coordinates. (A variation on this technique is isosemantic mapping (Sivik, 1975;1974a) where color is plotted in a similar manner in relation to semantic differential values. This work will be presented later.)

The reader is cautioned by Guilford and Smith with regard to applying the

findings from their study to real world situations. They believed more examples of hue and brightness needed to be tested. They also felt that work needed to be done on color combinations, color as applied to objects, and the interaction of color and texture. Indeed, they demonstrated that the relationship between the three dimensions of color as they relate to pleasantness was a complex one even within the narrow framework of their laboratory experiments.

From the studies so far presented on color preference, we see emerging what appear to be a somewhat consistent result - blue appears to be a preferred color while yellow is not. Different explanations have attempted to account for this difference: Walton et al (1933) advocated biological factors; Eysenck (1941) referred to a universal scale of preference, which exists in each of us; Granger (1955) and Guilford and Smith (1959) purported preferences to be dependent upon stimulus qualities. Yet, in all of these studies color is being dealt with in isolation (not applied to an object or context), judgments are being rendered on only one color or one color pair, and colors are almost exclusively being judged against a neutral background - gray or black. Could background conditions be partially responsible for the preference determinations? As early as 1921, Washburn and Grose (1921) observed that one method used by subjects to lower the affective ratings of colors was to imagine a given color in combination with another color. But it

was not until the work of Helson and Lansford (1970) that color combination effects were systematically studied.

Conducted over fifteen years ago, the Helson and Lansford (1970) study remains the single most well-controlled experiment on determining pleasantness of color combinations. They presented 125 color chips against 25 colored backgrounds under five different illumination sources to ten subjects (the small number of subjects often being cited as a concern) for a total of 156,250 ratings. Color chips represented main regions from each Munsell hue dimension combined with low-medium-high examples of value and chroma. Subjects were shown twelve color chips on a background and made absolute judgments on a nine point scale.

Their data showed that pleasantness ratings were the product of an interaction between light source, background color and object color. Background color was the single most important component of pleasantness judgments due to contrast effects - the best background colors to enhance judged pleasantness of object colors were those that had either high or low value and very low chroma. The best illumination sources (average of all colors against all backgrounds) were cool white fluorescents and incandescent tungsten. Men were reported to find cool colors most pleasant while women found warm colors most pleasant. Lightness (value) contrast was the most important factor for pleasant color harmony - the greater the

lightness contrast, the more likely one is to have a color combination perceived as good. Hues of object colors which were judged most pleasant (across all backgrounds and light sources) were B-PB-G-BG; yellow and purple were ranked low, in addition to colors with strong yellow components.

Reddy and Bennett (1985) replicated these results in a cross cultural study and found lightness contrast between background and object color to be the major factor in pleasantness ratings. The three groups did vary slightly with respect to hues disliked - yellow and green being disliked by the Americans. Background colors (white, black, grey) were also found to exhibit differential effects on color preferences by Hopson, Cogan, and Batson (1971). Here, color preferences were found to be less extreme when viewed against a black background. White and grey backgrounds had similar effects on color preference. Again, blue was preferred most and yellow-red, least.

The importance of the Helson and Lansford (1970) study is that it was the first to demonstrate that preference ratings could be systematically influenced by variables other than those of the colored stimulus object. It showed that even illumination source could influence perceived pleasantness. (Size and shape of luminaires and their placement within a room have also been shown to exert an effect on pleasantness (Bennett, Perecherla, Chowdhury, Prabhakaran, and Gettu, 1985).)

Their study also showed contrast to play an important role in preference

relations and that the perceived pleasantness of a color was changeable, and *not* an invariant quality within the color itself. They demonstrated that color combinations could be experimentally investigated, and that their results could serve as a tool (although crude and limited) by which one might begin to make color decisions in the built environment (Judd, 1971).

Subsequent studies have shown preference may be influenced by the particular combinations of colors that comprise the stimuli. Gotz and Gotz (1975;1974), contrary to expectations, found some yellows to be rated highly pleasant while pinks were seen as most unpleasant. We wonder if this finding could be replicated today with the recent fashion emphasis on pastels! This raises the question of to what extent fashion trends influence preferred colors. The reviewed studies give the impression that color preference has been regarded as a static state, wherein they are invariant across time and circumstance. Evidence begins to demonstrate this may not be the case (see our section on Color Assessments in Real Environments). When office workers were asked to select the color they preferred every 15 minutes over the course of 5 to 40 hours, color choices varied with time (Walters, Apter and Svebak, 1982). Individuals did not prefer one color across all trials. This has tremendous implications when one is attempting to operationally define the criteria for color selection in a restrictive environment, like a space station.



Our discussion of color preference has been limited to subjects' ratings of color on one dimension, pleasantness-unpleasantness. The semantic differential provided another way to look at colors in terms of their connotative qualities.

The semantic differential (SD) developed by Osgood, Suci and Tannenbaum (1957) is an instrument to measure one's reaction to events (here, to colors) by ratings on scales defined by bipolar adjectives. The scale is usually divided into seven equal points. The middle point is seen as neutral (0) while the end points represent opposite extremes (+3, -3). Subjects judge/rate a number of colors against a series of SD scales. The data are usually summarized across subjects, yielding a matrix of scale x color averages. Correlations are computed between colors and scales. With a large number of scales being employed, it is often necessary to subject the data to factor analysis in order to reduce the dimensionality and seek "common factors". These factors in turn represent a communality among the various scaled connotations of the colors.

Osgood et al (1957) did one of the initial studies on the meaning of colors. Unlike earlier studies, they studied selected colors in the context of objects. One of six colors or an achromatic condition (black-white) was applied to either one of five objects (shirt, ice-cream, rug, car, cake mix) or its background. The object was then rated on 20 SD scales, representing

evaluative, potency and activity factors.

Significant color differences were obtained on the non-evaluative scales, but no consistent effects were found on the evaluative ones, although there was a significant color x object interaction on this common dimension. In terms of evaluation, yellow was rated as the "most favorable" color. (Authors did suggest this might be an artifact of the objects used.) No differences were observed for the other color conditions. Activity seemed to be related to the hue dimension - red and yellow were seen as active while green, violet and blue were viewed as passive. Potency was directly dependent upon a color's saturation.

In a second study, color was studied in relation to abstract sculptures. Again, certain non-evaluative scales showed significant color differences while no effect was observed for evaluative scales. As in the first study, the color x object interaction was significant. With abstract sculptures, blue was the most preferred color. The findings of these two studies would suggest that an acceptable color is defined by the object with which it is associated and this relation may be the product of cultural norms or expectations.

Wright and Rainwater (1962) undertook an extensive study of color meanings of isolated colors. They had over 1200 subjects rate 50 3" matte surface colors on 24 SD scales. (Each subject rated only one color on all 24

scales.) Hue, value and saturation were varied.

Six factors were initially extracted, but intercorrelations among them led the authors to propose a final four dimensional connotative framework of happiness, forcefulness, warmth and elegance. Across all scales, saturation was found to exert the strongest influence in terms of color meanings. Some general statements from their study include: redness corresponded to greater perceived warmth and less tranquility; excitation may be a linear function of hue; the relation of activity to color appears to be a direct function of saturation.

Hogg (1969) had subjects rate single colors and color pairs (manipulating degree of color contrast) on twelve 7-point SD scales. Single color results showed 70.5% of the variance to be attributable to a factor labelled color obtrusiveness, which was highly correlated with saturation. On the evaluative dimension (Pleasant - Unpleasant), blue-purple region was generally preferred while the yellow-green region showed a low preference rating.

For color pairs, sixty-one percent of the variance was accounted for by an activity-potency factor. Saturation was again the most important component of this factor - the more saturated a color, the more potent/active it was perceived. The greater the contrast in perceived value, the more potent and active a pair was judged. The evaluation factor, which accounted for 21 percent of the variance, was determined largely by the hue

dimension. When both colors were blue or blue was present, the color pair is judged more pleasant than if both were green or green was present.

Meanings assigned to colors through the use of semantic differentials rely on specific descriptor scales an author chooses in any particular study. Factor analysis in and of itself does not guarantee empirical access to fundamental connotations of colors. This is a possible explanation for the inconsistencies between authors with regard to the number and names of identified factors. Amid the inconsistencies, however, it is becoming apparent that both saturation and value influence non-evaluative scales, while evaluative scales need to be studied in the context of a given object or situation to yield most meaningful results.

It is Sivik's (1975; 1974a) work that provides some of the most comprehensive insights into the field of color meanings. Sivik uses the Swedish Natural Color System - NCS - (Hard and Sivik, 1979; Hard, 1975) as his descriptive color model instead of the Munsell color solid, but schematically, the two are almost identical. Each uses brightness as a central (y) axis and purity of color (saturation) as a x-axis. In fact, there is evidence to suggest that a simple relationship exists between these two models and that both the NCS and Munsell are describing the same color space (Judd and Nickerson, 1975).

The NCS is based on an individual's perception of color (Sivik and Hard,

1979; Hard, 1975). According to the tenets of this color system, there exists six pure color perceptions - Y, R, G, B, Black and White. The perception of any color is based on the degree of its perceptual similarity to these six elementary reference colors, which are assumed to be a component of one's own visual system. Three parameters define a given hue - degree of whiteness, blackness and chromaticness (purity).

Sivik's (1975; 1974a) initial studies investigated colors in isolation. Seventy-one colors (chosen to represent the NCS color space) were judged on 26 SD scales by a stratified sample of Swedish adults. Factor analysis yielded four factors: excitement, evaluation, potency and temperature. Instead of summarizing his data in terms of scale-color correlations, Sivik chose to present results in the form of isosemantic maps. An isosemantic map is drawn on a color triangle, which is a full section of the NCS solid axis for a given hue value. Isosemantic maps are constructed on each color triangle for a given connotative factor. The isosemantic lines on a color triangle are constructed by connecting the points of equal value. Recall that the earlier work of Guilford and Smith (1959) used a similar method which they termed isohedonic charts, where color parameters were mapped on only one scale, pleasantness. Sivik has taken this concept and expanded it to incorporate factor scores abstracted from a number of scales representing a number of different connotative dimensions.

From his findings, Sivik concluded that no difference was exhibited between hues with equal chromaticness on the excitement factor. This finding contradicts the long held stereotype that warm colors (R, Y) are exciting while cool colors (B, G) are calming. One can have a dull red or an exciting green based on the purity of the color. Sivik hypothesizes that the reason R, Y were labelled exciting might be attributed to the fact that strong reds and yellows are more prevalent than strong (pure) greens and blues (as was noted in our comments on the signal properties of colors).

What hue or color parameters influence the degree to which a color is judged beautiful or distasteful? Other researchers had sought an answer to this question through color ratings on evaluative scales. In Sivik's (1974a), analysis of the evaluation factor, it showed a complex interaction between hue and the degree of whiteness, blackness and chromaticness (purity). Generally, as the degree of blackness increased, colors were judged to be of a lower pleasantness or less preferred. Although this is a consistent finding across all hues, the degree of dislike varied with hue. For example, to obtain the same degree of judged dislike between a dark blue and a dark yellow (brown), the blue must be much darker (have more blackness) than yellow. Sivik (1974a) found that across all three parameters (blackness, whiteness, purity), there were more instances of blue being judged positive (pleasant) than any other hue. This observation might account for blue often being cited

as the most preferred color.

Blackness seemed to be the determinant of potency across all hues, but the extent of its effect varied among them. However, as chromaticness increased so did perceived potency for all hues except yellow. On this connotative dimension there apparently also exists a complex interaction between the three NCS color parameters and a given hue.

Perceived color - temperature ratings showed a strong hue component. Across all three parameters, yellow and yellow-red regions are judged warmest while blues and blue-greens are judged as the coldest. The degree of perceived warmth and coldness changed with varying amounts of blackness, whiteness and chromaticness.

Emerging from Sivik's (1975; 1974a) initial studies is the picture of a complex interaction process between stimulus color properties and connotative associations. The use of isosemantic mapping graphically represents that interactive process and even provides a framework against which earlier preference-semantic findings might be reinterpreted. The reader, however, is still cautioned. The reported findings are those of colors in isolation and may be limited in application outside this context (Sivik, 1974 b).

One final area of research arising from the preference work is that of colors and mood tones. The emphasis of this work has been the effect of

color on emotions. [This area has been extensively researched within the clinical context (see Sharpe, 1981; Norman and Scott, 1952).] Of interest to us here is whether there exist reliable mood-color associations and if color does indeed influence one's emotional state.

Wexner (1954) investigated whether a relationship between certain colors and mood tones existed. She constructed a list of adjectives judged to be best examples of mood tones, displayed eight colored papers (8 1/2 x 11") and subjects were asked to select the one color that best described a given mood tone. From her findings, she concluded that indeed there exist definite color-mood tone associations. However, she did note that some mood tones (exciting) appeared to have a strong color association (red) while others (protective; defending) did not demonstrate any clear-cut color associations.

The work of Murray and Deabler (1957) attempted to replicate Wexner's (1955) findings on three different populations. Like Wexner, they report some consistent color-mood associations. But, comparisons among their three populations and Wexner's (1955) showed differences in mood-color associations among the four groups of subjects. Groups were found to differ in the degree of association between a given color and mood descriptor and in the actual colors selected to best describe a given mood state. Murray and Deabler (1957) cite their findings as support for cultural and socioeconomic factors' contributions toward color-mood associations.



A constant-sum method was used by Schaie (1961) to study the strength of color-mood associations. Subjects were shown a color stimulus pair (red serving as the constant comparison stimulus) and told to assess the degree of association of each color with a given mood descriptor by dividing 100 points between the two colors. This procedure was done for the nine stimulus pairs across 12 scales. Unlike the works of Wexner (1955) and Murray and Deabler (1957), subjects here were allowed to assign more than one color to a given mood descriptor. Two adjectives were also used to describe each mood tone.

This study showed all colors to be associated to all mood descriptors in varying degrees of strength. Although certain colors are more strongly associated with a given descriptor, there was no evidence to suggest a one to one mapping between a given color and mood-tone adjective. Strength of association between a given color and the two descriptors for a given mood tone were also varied.

Aaronson (1970) investigated emotional stereotypes of colors. He had subjects rate the names of colors to 12 adjectives from the Emotion Profile Index (forced-choice adjective checklist presented as paired comparisons). He interprets his data as supportive of reliable color-emotion stereotypes; however, he never does present the actual color-emotion stereotypes other than for the single descriptor, "Activation". He cites red as being high in activation and blue being low. The majority of his findings show numerous

positive and negative adjective associations to given colors. Also, it is questionable as to whether a color name is capable of arousing a common perceptual experience among Ss. It is much more likely that he was tapping color stereotypes in his subject population.

The studies presented here are few in number but are often referred to as evidence of a color-emotion link. But they are plagued with problems. Stimulus materials are few in number, of a diverse nature, lacking in operational definitions and are varied only on the hue dimension. The observed color-mood descriptor associations reported may well have been induced by the methods used to study them. Even the selection and number of adjective descriptors may have influenced and constrained the reported relationships.

Aside from these problems, of greater concern is the manner in which these authors (and subsequent ones) have chosen to cognize affect. It is assumed that a particular mood (emotional state) is accessible through a cognitive command, that a mere adjective is capable of accessing a given emotional state, and that an emotion is capable of being instantly distinguished from other cognitive processes. The question of exactly what constitutes emotion and how to measure it has been and continues to be a source of much debate ( Livesey, 1986; Zajonc, 1980; Schachter and Singer, 1962).

The work in color with respect to emotion has mostly resulted in a

gross oversimplification of a very involved process. An oversimplification, unfortunately, which has been popularized in both the architecture and design literature (Birren, 1982; 1973; 1959;1950). It has even found its way into human factors. In the Human Factors Design Handbook (Woodson, 1981), one and a half pages deal with "typical colors and their effect on humans". An example is the color, blue, which is described as communicating "cool, comfort, protective, calming, although may be slightly depressing if other colors are dark; associated with bad taste" (Woodson, 1981, p. 837). Unfortunately, such effects of common colors are realistically more often associated with popularizers' fervid imaginations.

This section on color preferences has been included and discussed in detail for the purpose of placing the accomplishments and questions of this research into proper perspective. It would appear that many of the qualities popularly associated with colors today originated within this line of studies.

From the earliest articles (and even before), individuals have reported different associations to different colors, and there appeared to exist distinct preferences for some colors over others. Color preference differences were subsequently expanded to include connotative and emotional differences. Underlying all of these claims was the assumption that such qualities were inherent in the color, itself. The task awaiting the researcher was to somehow unravel what qualities went with what colors. A leap of

faith ensued and somehow the qualities ascribed to colors became transferred to the designed setting where they were judged capable of influencing the emotional state of an environment's occupant. This is simply not the case. However, for the purpose of specifying colors, there are some useful human factors implications from this work.

Studying colors in isolation (e.g. color boards) provide us with little information, other than how a subject at that moment rates a given color on a given scale. Colors need to be studied in context, especially in environmental contexts, and even then caution must be taken with respect to how generalizable the findings are. When conducting color research, one needs to employ a system (e.g. Munsell) by which colors can be quantified on the dimensions of hue, value and chroma (see Kelly and Judd, 1976). Denoting a color by a commercial color name communicates little information (Chapanis, 1965) and tends to focus attention on the hue component of color, which is a surprisingly minor determinant of many color preferences and associations.

From these studies conducted on colors in isolation, specifiers should appreciate the fact that although some evidence for a preferred hue (blue) exists, preference is not due to an intrinsic state of the color (or the colored object). Likes or dislikes and associations related to a color can be altered by changes in value and chroma (Sivik, 1974a; Guilford and Smith, 1959), different types of illumination (Sivik and Hard, 1977; Helson and Lansford,

1970), different background surrounds (Reddy and Bennett, 1985; Helson and Lansford, 1970), imagined color combinations (Washburn and Grose, 1921), cultural factors (Courtney, 1986; Chongourian, 1969;1968), the effect of texture (Guilford and Smith, 1969) and there is even some evidence to indicate that the perception of a patch of color also depends on the running history of that region of the retina stimulated by the bundle of light rays carrying potential color information (Brou, Sciascia, Linden and Lettvin, 1986). Also, the liking of one color over another is not a static state but appears to change over time (Walters, et.al., 1982). Color perception itself is a highly complex process, and one should not expect the cognitive or associative components of color appreciation to be any less complicated.

Lightness contrast effects reported by Helson and Lansford (1970) have strong implications for color selection in a space station work area. Background color should enhance and not compete with VDT monitors, color-coded equipment, etc. (This will be a critical consideration with the introduction of surface graphics into an area.) Contrast, however, should not result in high reflectance (glare). Actual mock up environments should be set up to test different colored surfaces under different illumination sources and under differing amounts of illumination. The introduction of specific tasks (e.g circuit board repair) could provide additional information regarding actual color specifications. In the workstation area, which will be filled

with equipment, it might be advisable to limit the number of hues to one and produce variation through changes in value and/or chroma in order to decrease what might otherwise be perceived as a "visually" busy environment.

From the preference area we find some interesting work on the color rendering of foods and complexions. Luminaires and background colors have been shown to affect the appearance of foods (Sharpe, 1981; Helson and Lansford, 1970; Sanders, 1959). It has been observed that in some instances, color can outweigh the impression made by flavor (Newsome, 1986). Siple and Springer (1983) reported some differences among actual, preferred and remembered colors of foods on the three color parameters. Judd (1967) has developed a lighting flattery index, where light sources are described in terms of their ability to favorably render human facial complexions. The pink lights commonly employed in restaurants make good use of this effect.

These works provide a strong basis on which color in a surround may be manipulated to enhance experiences of dining or recreation. The key lies in not looking for the magic link between color and emotions, but in exploiting the ways that color affects one's appreciation of objects and people involved in the setting.

The instrument most often used to "tap" into connotative associations of objects/events is the semantic differential. As previously indicated, it is an instrument with limitations owing to the selection of scales. There is also

considerable evidence to suggest that the stability of color-meaning associations is dependent upon the scale's relevance to a given color (Sivik, 1974d). For example, one would predict much more consistent ratings across subjects to colors on the adjective pair "hot....cold" than "smooth....adequate" (a pair reported in one of the studies).

Another concern of the SD is the assumed bipolar nature of the adjectives. The works of Sivik (1974c) and Green and Goldfried (1965) show that degree of perceived opposition between the two adjectives may vary from subject to subject. Rohles and Laviana (1985) and Sivik (1974c) have used unipolar scales, where each adjective is independently judged. Rohles and Laviana (1985) have subjects rate descriptors on their degree of accuracy (very accurate to very innaccurate) in describing a given thermal environment, but there is no reason why their scaling procedure cannot be applied to the evaluation of color in settings. Whichever method is selected, unescapable psychometric limitations are encountered, and the results are much less indicative of innate color effects than they are of cultural and learned associations to color that are mostly transitory and malleable by the contexts in which they occur. We turn now to see if claimed psychophysical effects of colors manifest similar origins and variations.

## Color and Temperature

A "natural" association would seem to exist between color and temperature in human experience. Campfires are yellow-red and hot, while the sea is blue-green and cold. Visual metaphors in language thus make stereotypic use of color and temperature through images that pervade our popular folklore.

The scientific quest for hue/heat relations has centered more specifically on three different types of questions. First, is there an isomorphic mapping between color and temperature, i.e. do certain colors reliably and unvaryingly communicate particular temperature connotations? Second, will the application of surface or illuminating colors serve to change the perceived temperature of objects or spaces? Third, can the use of colors in terms of 'room decor' affect thermal comfort of occupants?

Wright (1962) provides a capsule review of (mostly) introspective studies in color temperature relations dating back to the early 1900's. These suggest the expected association between hues and temperature, but their lack of controls over brightness and saturation obscure any finer details. Tinker (1938) found that all surface colors were judged warmer than black, yellow-green, gray and white, which were the coldest ranked. This would suggest that brightness plays no large role in temperature connotations.

In his field study, Wright (1962) also found that the partial regression



coefficient for hue ( $r=.17$ ) showed it to be the only color dimension that seemed to have a significant relation with apparent warmth. But while there appears to be a consistent labelling of a few hues as "warm" (red-orange, orange-red) and a few as "cold" (blue, yellow-green, white), there is obviously no rigid semantic mapping between all colors and temperatures. This would seem to disavow the notion that some control over actual perceived temperatures may be gained by color applications.

Indeed, Mogensen and English (1926) found that when they covered slide rheostats kept at a constant temperature with six different colored papers, there was no effect on subjects' judgment of which felt warmer to the touch.

Houghton, Olson and Suci (1940) looked for changes in physiological measures normally associated with temperature changes while subjects were kept in a constant temperature room watching illuminated screens painted either white, red or blue. They found no differences in oral and skin temperatures, pulse rate, or verbal comfort indices given the color changes. They conclude that if there is any effect of color on perceived temperature, it would have to be within a  $1.5^{\circ}\text{F}$  variation.

In a more subtle study, Berry (1961) had subjects signal temperature discomfort under the guise of a tracking task. The task was performed under different colored illumination and increasing temperatures, and the criterion measure was whether the point of discomfort could be altered by the

different colored illuminants. Although subjects later ranked the lights in a significant descending order according to "transmitted heat", (white, yellow, amber, green, blue) there were no effects of color on heat discomfort onset. Belief, here, apparently does not influence actions.

Posing the inverse question, Kearney (1966) asked if large changes in ambient temperature levels would affect hue preferences. Through paired comparisons of colors projected by means of Wratten filters, he found that subjects' preference for red strongly declined under the hottest ambient condition (approximately 40°C) and increased under the coldest (0°C). Blue preferences showed the opposite pattern. He also found no effects of brightness manipulations via the use of neutral density grey filters. Again, blue and red appear to be "cognitively connected" to temperature states, but even stated preferences for those colors are affected only in the extremes.

The past decade's concern for energy conservation has also renewed interest in whether interior color treatments can aid thermal comfort. Bennet and Rey (1972) looked for changes in thermal descriptions from "cold" to "hot" as wall temperatures were varied in an experimental chamber. Their subjects wore either blue, red or clear goggles as color manipulations. The authors found no observable effect of hue on thermal comfort judgments, and concluded that the "hue-heat" hypothesis was at best constrained to intellectual judgments.

A much more elaborate experiment by Fanger, Breum, and Jerking (1977) recorded skin and rectal temperatures of subjects under extreme blue and red fluorescent lighting conditions. In their experimental chamber, Ss had the opportunity to adjust temperature up or down every 10 minutes in order to remain optimally comfortable.

The subjects here preferred a  $.4^{\circ}\text{C}$  (about  $.7^{\circ}\text{F}$ ) higher ambient temperature under blue light than red; but, again, there was no significant difference in physiological measures under the different lighting conditions.

Although the cognitive effect of colored lights produced significant but small changes in preferred temperatures, the lighting conditions were too extreme to be acceptable in building practice. This study suggests that practical applications of color to thermal comfort is unlikely.

However, the unrealistic conditions of the previous studies and the possibility that color constancy effects may be operating under full colored illumination raise the question that more "ecologically valid" manipulations may yet confirm designer's expectations for hues and heat.

In a more representative type of study, Greene and Bell (1980) had student subjects complete emotional response, personal comfort and environmental quality scales as well as a temperature estimate while they were seated in triangular carrels having walls painted red, blue or white. While the subjects evaluated the red and blue rooms more positively than the

white, there were no reliable differences in measured heart rates or perceived temperature due to color. However, though color did not appear to mediate thermal comfort, it did prove useful in creating a more pleasant environment. Perhaps the creation of pleasant and attractive environments can affect thermal comfort where direct manipulations of color cannot?

Pedersen, Johnson and West (1978) decorated rooms using either warm (red, orange, yellow), neutral (white), or cool (blue and green) hues. The decor of the rooms differed considerably along with the hues. Their subjects completed 25 item semantic differential scales and made estimates of the dimensions and temperature of the otherwise identical rooms.

Only the natural-artificial semantic differential scale produced any significant main effect for hue, with both warm and cool colored rooms yielding higher 'natural' ratings than the white. Neither dimensional nor temperature estimates were significantly affected by the colored decor, although temperature estimates were in the predicted direction and narrowly missed significance ( $p=.08$ ). The authors were surprised that such major decor changes produced so little tangible results.

In another well controlled study, though, Rohles and Wells (1977) modified a Sherer Climatic Chamber with wood panelling, acoustical ceiling tiles and red carpeting, along with residential style pictures, chairs and lamps. They found that subjects felt significantly warmer (but not more

comfortable) in the modified chamber during two hour exposure periods. This sensed difference in warmth was equivalent to a 2.4<sup>0</sup>F rise in temperature in a plain climatic chamber. Thermal sensation had definitely been affected in the embellished environment even though it was thermally identical to the original chamber. Again, the lack of any differences in skin temperature among their subjects emphasized that these sensations were psychological, not physiological phenomena.

The authors felt that the design changes as a whole had contributed to the felt thermal response, indicating that it may have been the very artificiality of earlier studies that had restricted appreciation of color's role in the psychology of thermal responses. Later work by Rohles, Bennet and Milliken (1981; 1980) and reported by Rohles and Milliken (1981) confirmed this supposition and showed that by creating a surrogate open-plan office landscape, subjects could be made "considerably more comfortable" than others who participated in thermally identical, but unembellished surroundings. They also found that, up to one hour, orange work stations were judged more comfortable than blue, and that in a cooler than neutral environment, subjects were more comfortable when the walls were dark than when they were light.

Thus, in considering the evidence on color and temperature, it has only recently become apparent that experimental confirmation of any "hue-heat"

hypothesis relies on a radical restructuring of the original idea. The spectrum of hues is not uniquely and unvaryingly attached to color connotations or sensations. Aside from the contextually reproducible effects elicited by red-orange, blue and white, it appears that one cannot "micro-manage" thermal sensations or comfort by the simple introduction of surface or space colors, contrary to what some literature might imply (see Grandjean, 1980, pg. 288, Table 44).

What has been demonstrated is that it is possible, within the context of an overall interior design strategy, to use colors as part and parcel of a setting's synergistic effect on thermal comfort. This is purely a psychological phenomenon, and it is not accompanied by physically detectable warming of the person. The effect is also modest, worth no more than about  $1.4^{\circ}\text{C}$  ( $2.5^{\circ}\text{F}$ ) actual dbT change in the setting. In terms of the economies of scale and time, however, it is certainly a practically significant effect and could be utilized by building managers.

Again, even in this circumscribed area, the connection between color in the setting and any unitary psychological state is neither as direct nor as simple as the engineer (or psychophysicist) might wish. It is color's role in cognitive mediation that provides the controlling link. As with other proposed uses of color, overly mechanistic conceptions of its effects help neither the psychologist nor the interior designer achieve their goals.

## The Apparent "Weight" of Colors

The tacit observation that colors of objects induce an apparent perceptual weight has long been exploited by artists. Psychologists' investigations have concentrated on determining which of the three dimensions of color are most responsible and how reliable is the effect.

Beginning with Bullough's (1907) study, at least a dozen papers over the past eighty years have investigated the metaphor of "apparent weight" that can be given to colors (see Wright, 1962, for comments on earlier studies). However, this area of color research has been needlessly muddled by failure to control hue, saturation and brightness independently, and by reoccurring incompatibilities in the types of tasks utilized to operationally measure the "apparent weight" effect. Still, a concurrence of sorts seems to have emerged, which has some relevance for color applications to interiors.

In a laboratory study using 2" square cubes covered with Munsell papers, Payne (1961) had subjects call out numbers from 1 through 5 to assign "apparent weights" when they viewed cubes one at a time. The colored papers were of equal brightness and saturation. He found that the apparent weight of the blue, red and purple hues taken as a group differed significantly from the yellow, green and gray hues taken as a group - but that within groups these did not differ from each other. There was no relation between apparent weight and preference for hues.

With saturation and brightness controlled, the contribution of hue to determining apparent weight thus seems slight. Payne (1961) mentions an earlier unpublished study of his that showed brightness to correlate .94 with apparent weight.

In a much larger field study in urban West Germany, Wright (1962) performed interviews on a door-to-door basis, showing each respondent a single, 3" square of matte surface color. Subjects rated the color on a set of twenty-four semantic differential scales, where one of the pairs was "heavy - light". Across subjects, 45 colors had been selected to 'fill' the Munsell color solid. When multiple regression coefficients were computed for hue, saturation and brightness on the pair of adjectives representing apparent weight, there was a strong contribution of brightness ( $r=.44$ ), with the brighter colors being judged as "lighter" in weight.

Pinkerton and Humphrey (1974) performed a laboratory study on apparent weight by using five colored lights fixed by Wratten filters. They kept brightness constant and had each subject "weigh" a colored light against a white standard by adjusting a fulcrum point between the lights. All of the colors were regarded as "heavier" than white in terms of fulcrum placement, with red heaviest and blue, green, orange and yellow in descending order. They conclude that hues themselves can convey weight and that indirect cognitive associations are the likely causal agents.



Alexander and Shansky (1976) criticized the previous study on their failure to control colorimetric purity, saturation, and subjects' possible defective color vision. In the most sophisticated study to date, these authors had twenty subjects screened for normal color vision judge squares of Munsell color chips paired with a white standard. The subjects made magnitude estimates according to the weight of each color with the white square assigned an arbitrary value of 50.

Perceived weight was determined to be an increasing function of saturation (chroma) as tested at Munsell levels of /1, /4 , and /8. It was also a strong inverse function of value. Hue, though, appeared to be only a minor determinant and only at the highest chroma was there a significant difference in weight between the hues of blue and yellow, with yellow being heavier. Thus, "apparent weight is a decreasing function of value and an increasing function of chroma" (Alexander and Shansky, 1976, p. 74), and hue contributes very little to the apparent weight of colors.

Across a variety of studies and strategies, then, it appears that the brightness and saturation of colors may be particularly employed to communicate perceptual impressions of weight. Although there have been no studies in real environments to test these effects, much interior design seems to confirm them. The practice of perceptually lowering an overly high ceiling in a small space by painting a dark, saturated color around its

periphery exploits the perceived weight of the color. Other applications may purposefully place a "heavier" color atop a "lighter" one to decrease the perceived height to width ratio of an enclosed room in order to enhance furniture appearance or alter space enclosure impressions.

But spatial orientation also apparently influences sensed 'lightness'. Deliberate manipulations of apparent spatial position and directionality of illumination affect impressions of lightness in pictures and tabletop arrangements (Beck, 1969; 1965), showing that judged lightness (and by inference perceived weight) relies on perceptual presumptions about the orientation of a scene. But these effects are rather small, and are probably of more significance to pictorial artists than interior designers. However, applications of lighter or darker colors must exploit the room geometry and furnishings arrangements for complete effectiveness, and it is these types of careful interventions that can best utilize the color-weight effect. Just because brighter colors are perceived to be lighter, for example, is no justification for restricting their use to the "upper" parts of rooms.

Color's apparent weight is thus one psychophysical quality that appears to be rather unequivocal in its operational mechanism. It is again noteworthy that the major effect is attributable to saturation and (primarily) brightness, and not hue. These former two dimensions are the most important determinants of ecological contrast effects, which have already been shown

to govern arousal and preferential responses to color.

### Color and Spaciousness

One of color's most compelling uses in design is to alter the perceived size of interior spaces. Indeed, the earliest dictum taught to a design student is that "warm colors advance, and cool ones recede". In retrospect, such a rule appears overly simplistic given the other psychological effects of color reviewed in this paper. Would we expect such 'distance' effects to hold true for all combinations of saturation and brightness at a given hue, and under all levels of illumination and types of interior geometry? Is there no more detailed advice that can be given to designers who wish to manipulate the perceived size of settings?

Fortunately, experiments in color perception over the past ninety years have given much more insight into color's effects on perceived spaciousness than the simple 'advance/recede' rule would suggest. Again, although research progress has been meandering at best due to misplaced trust in reductionism and an inability to rigidly define and standardize experimental manipulations, there appears to be a convergence of results that provides both useful proscriptions and a way of thinking about novel applications of color with regard to spaciousness. Payne (1964), provides an incisive review of the early work on what has been called color effects on "apparent distance". Our review will only cite some of the more important studies that track the development of thought in this field.

Luckiesh (1918) as part of his extensive studies on color, investigated what he called the "retiring" and "advancing" effects of color letters placed in the same plane. His apparatus used red and blue filters ("of fairly high purity") to alter the color of the letters "X" and "E" that were viewed inside wooden boxes. The subjects moved the red "X" until it appeared to lie in the same plane as the blue "E". Although there was a lot of intersubject variability, in most cases it was necessary to move the red "X" further away in order to make it appear to be in the same plane, thus demonstrating the advancing quality of the color.

However, in a little cited note in his paper, the author also describes how, *if the eyes of the observer were nearly closed*, the red "X" appeared to move back to its true position, further away than the blue "E". Artificial pupils placed before each eye also made the blue "E" appear either before or behind the red "X" depending on how far apart the pupils were. Here was one of the first, and apparently unnoticed, clues that distance effects of colors were not as simple or as direct as designers may have since inferred.

Another piece of critical evidence was provided by Pillsbury and Schaefer (1937), who had subjects view either red neon or blue neon and argon lights through slits that compensated for the relative size of the retinal image as the lights were moved. When the lights were placed equidistantly, they found, much to their surprise, that the blue light was

judged the nearer! This was particularly puzzling given that the standard explanation for advancing and receding colors, chromatic aberration in the lens of the eye, was incommensurate with this result. Evidence to the contrary, this explanation has persisted to this day to become literal gospel among interior designers (see Kleeman, 1981).

In a pair of experiments, Taylor and Sumner (1945) and Johns and Sumner (1948) tested distance effects when color was applied to objects. They attached colored papers to small poles in a "depth perception apparatus" where one pole could be moved forward and back with respect to the other. The first experiment moved different colored poles against a fixed gray one, while the second experiment reversed this to move a gray pole against stationary colored ones. The task was to adjust the depth of the movable pole until it appeared equal to the fixed.

In both studies, they found that when the apparent distances of different colors are held constant, the brighter colors (their white, yellow and green) are seen as farther than they appear to be, while darker colors (their blue, and black) are seen at their actual position. (Red was an exception in terms of its apparent strong advancing property.) In other words, at constant distances, bright colors appear nearer than dark ones.

Their explicit introduction of brightness into the color-distance question now reveals an alternative explanation for the peculiarities of the previous

research. If brightness is the controlling quantity for apparent distance, then blue light, which appears brighter than red at low luminance levels, would appear nearer as it did for the subjects of Pillsbury and Schaefer (1937). It would also explain why blue appears to shift in position when the eyelids are closed to mere slits, as Luckiesh (1918) noticed. Viewing colors through squeezed eyelids is a favorite "trick of the trade" for color designers, who use it to gauge brightness differences independent of hues. Under this maneuver, one loses hue sensations while brightness contrasts remain. It is essentially a reduction to scotopic vision. With this and the artificial pupils that shifted vision out of the fovea in Luckiesh's (1918) experimental arrangement, the blue would appear brighter, and hence nearer, to his subjects.

If brightness is the operative cue for apparent color distance, it is in agreement with the effects of photometric brightness of achromatic lights, where the brighter is also seen as nearer (Coules, 1955). It also is an alternative to the explanation of chromatic aberration, which conflicts with the previous experiments. A better explanation for these color-distance effects would appear to lie in the relative abundance and mapping of rods and cones on the retina, rather than the optics of the eye's lens (see Hurvich, 1981; Boynton, 1979).

While the previous research has attempted to look 'into' the color

stimulus and see which dimension of color is responsible for apparent distance, it is also possible to investigate the context of color stimuli, and see how surrounds or backgrounds affect color observers' judgments. After all, in real settings color is never seen in isolation, and the interactive effects that are deliberately controlled out of laboratory studies may be critical to color manipulations in applied contexts.

Tedford, Bergquist, and Flynn (1977), in a controlled laboratory study, found that inattentiveness to background characteristics of stimuli may help explain the inconsistent findings that marked previous studies of color's effects on apparent size. They found that their size comparisons were more pronounced when the increased saturation of a color slide was viewed against a gray background, which served to heighten the overall color contrast.

Mount, Case, Sanderson, and Brenner (1956) provide the first study of color distance effects in an outdoor situation meant to simulate traffic viewing conditions. Here, four colored (Y, G, R, B) and four gray papers were mounted on plywood and viewed outdoors against a dirt bank under full sun. A color (or a gray) was compared against a dark or light gray standard on each trial, and each of the colors was matched in brightness by one of the gray series. The subjects viewed these through shutters designed to restrict field of vision to the papers, bank and sky. They were required to judge which of the two papers visible appeared closer.



Here, the experimenters found that each color was judged to be closer than its nearest brightness matching gray, and that each of the hues and the grays appeared closer when viewed against the dark standard rather than the light one. Interestingly, there was no difference in "advancement" for one hue over another. Rather, there appears to be both a saturation and a brightness contrast effect at work here. As saturation of a color increases with respect to its background its apparent position should advance, although the effect observed was small, equal at most to 1.5% of the standard distance.

As for brightness, it appears that an object's distance is judged somewhat in relationship to its similarity to or contrast with its background. Objects showing high contrast with their background will be judged in apparent position before their background. The brightness contrast effect is the greater, being equal at most to 3% of the standard distance, while saturation and contrast effects appear to be additive for an observer. Increasing relative contrast by increasing an object's brightness and saturation as compared to its background will make the object apparently closer.

In this study, the rich interplay between the dimensions of an object's color and the description of its context begins to be appreciated. The authors' conclusions are worth quoting in full: "No color variable has an inherent or unique position in space, and thus color can influence judgments of distance

only in a specific context involving primary and other secondary cues of relative position" (Mount et al., 1956, p. 213). This would appear to admit color manipulations of a much greater variety than suggested by the red-advancing, blue-receding rule.

An intricate study by Oyama and Nanri (1960) appeared to confirm the above results in the laboratory. They had subjects compare standard and variable circular figures in all combinations of achromatic and chromatic figures and backgrounds. Again they found that the apparent size of the figure increased as its brightness increased and as the brightness of the background decreased, regardless of the hue of figure and ground. They note that the effects of color on apparent size resemble its effects on apparent weight, where brightness again is the dominant cue.

Egusa (1983) in three experiments confirmed the above and also found an effect of hue when hemifields of different hues were compared for perceived depth. The green-blue difference in perceived depth was smaller than the red-green difference, with red appearing nearer. He also found that a higher saturated color was judged nearer when it was red or green, but there was no consistent effect for the blue. In one comparison of a highly saturated blue with a medium gray, the increased saturation made it appear further away. Apparently, brightness and saturation effects predominate judgments of apparent size of distance, and in the manner often demonstrated, but it is

still possible to construct a hue/background combination which yields disparate results, at least in the laboratory.

Of course, even studies that have advanced to subtle variations of background effects are a far ways from the contextual qualities of interiors. Can colors affect apparent size of spaces when applied to boundary surfaces or when admitted as space colors through the power spectra of appropriate luminaires?

Pedersen et al. (1978) found no estimated size differences when subjects rated full, equal-size rooms that were finished in either a "cool", "neutral", or "warm" manner. These manipulations included different colored walls, carpets, and furnishings. But size estimation was not the major goal of this study, and the authors apparently did not control for changes in isovists (see Wise, 1985) or mass-space ratios that can occur when different kinds of furniture are placed in rooms. Good experimentation involving full interiors treatments is still waiting to be done. For the interim, though, a few other experiments utilizing full or model size rooms have begun to demonstrate how color variables actually affect perceptions in architectural spaces.

Attempting to find some resolution in conflicting "rules of thumb" about color and spaciousness, Hanes (1960) performed two experiments; the first with a table-top depth perception apparatus, and the second in a full-scale

room with movable walls. In the first, he found that the brightness value of a color alone could account for apparent distance effects of from 5%-17% depending on hue. Hue effects varied between 9%-19% for strongly saturated colors, and only between 2%-3% for weakly saturated ones. Here, red and yellow appeared to advance relative to blue and green. A saturated red was the only hue found to advance relative to itself when unsaturated.

His second experiment took place in a room shell 12'L x 22'W x 8'H, with movable end walls and a uniform overhead illumination (type unspecified). The side walls and one end of the room were painted a medium gray, while the other end wall was colored with any one of seven replaceable panels. Observers sat 10 feet from the standard gray wall and adjusted the colored movable wall via a power driven carriage until it appeared equal in distance from them as the standard wall.

The results of these manipulations were, in Hanes' own words, "both pleasing and disappointing" (p.256). Although statistically significant, the effects were extremely small. All colors (R, Y, G, B, W, LGy) except black were seen as advancing, with yellow showing the most effect of 3.8". It was also the brightest colored panel. In fact, the order of advancement, from most to least, was a direct function of decreasing brightness of the colors. Since all hues were highly saturated, the author attributes these results to strong contrast between the colored panel and the standard wall.

Interestingly, there was no correlation between the experimental settings and a rank order of colors from their questionnaires that subjects felt were most to least advancing.

Again, as in previous studies, it seems that the controller for apparent distance is strong contrast induced primarily by brightness but also by saturation between a judged element and some established reference frame, which can be a background, or here, a homogenous room. The observed effects were very small, however, and hardly seem of practical importance.

Although this experiment shows that tabletop results for apparent distance can be scaled up to full size spaces, it does not answer the question of whether whole rooms can be made to appear larger or smaller through color treatments. But other studies that utilized scale models provide evidence on this issue.

Aksugur (1977), in a poorly described experiment, had subjects make paired comparisons of perceptual magnitude for two model rooms viewed side by side. The room sizes and shapes were constant and equal, but they varied in type of interior illumination (tungsten-filament incandescent vs daylight fluorescent) and in hue treatment of their walls (either R,Y, G, B at equivalent Munsell brightness and saturation), which was held high and low respectively.

The author reports no data, and his chosen statistical test was the wrong one for his experimental design. However, his results are in the expected

direction. Accordingly, the "perceptual magnitude of the space" in a model room increased under daylight fluorescent as opposed to incandescent light (confirmed by other investigators) and under the same light sources, the blue walled room gave the greatest "space perception". However, Aksugur (1977) gives no indications of the actual size of these perceived changes, and whether they would be of practical importance for interior design. This study is one of those that has been often cited as providing evidence for hue effects on perceived size. But these reviewers find that its poorly described methodology, obvious lack of experimental controls, inappropriate statistics, and total lack of data hardly create the sort of reassuring evidence one needs to justify color specifications.

Fortunately, another study by Ramkumar and Bennett (1979) also tested space perception within a model room while varying the color dimensions of its walls. In their experiment, they "inferred" the space effects on the room by deliberately varying the scale size of cutout figures placed in the room. Subjects had to select a scale figure that appeared "just right" for the room size, and then estimate its apparent distance from the rear wall in their view. These authors tested wall treatments of white, gray black and saturated/unsaturated blue and red. They looked specifically for brightness effects alone, and hue and saturation effects with the other two color dimensions controlled. An external incandescent light source kept

illumination at a constant 60fc in the model.

They found that the relative brightness of the walls affected size-distance estimation, with a larger figure being selected and appearing to be farther from the wall when this was white. A similar result was found for saturated blue. These effects were on the order of 15% of the actual figure distance, which agrees well with the earlier laboratory findings. Apparently, a lightly colored space appears larger, and there is a recession of blue that is highly dependent on its saturation.

Although there are demonstrable perceptual changes in distance estimation due to wall surface colors, does this have any implication for the attitudes or actions that people may take in spaces? An experiment by Baum and Davis (1976) suggests that there are indeed social implications of something as innocuous as wall colors.

They examined the impact of wall color, visual complexity, and social orientation on the experience of crowding. Again, they used scale figures in model rooms. Subjects had to (metaphorically) place themselves in the model room by positioning a scale figure, and then fill in other scale figures until the room would "begin to feel crowded". The subjects also rated the rooms on a number of adjective descriptors.

The results showed that more scale figures were placed in light colored rooms than in dark ones, especially under "non-social" activity conditions.

When subjects placed themselves in the room, they also were positioned nearby scale pictures on the walls when these were present. On the environmental descriptors, the dark room with pictures was perceived as smaller than the equivalent light room under the non-social condition. The dark room was also considered to be more stuffy and crowded. The authors conclude that light wall colors apparently cause interiors to appear larger, increasing the amount of space perceived as available for use. Visual complexity introduced by pictures on the walls appears to be helpful in alleviating perception of crowding when these are appropriate to the situation - and appropriateness is determined by the social use of the space.

Most all of the studies reviewed so far have utilized surface colors in attempts to elicit changes in distance or spatial impressions. The other way of introducing color in a setting is through "space colors" via the power spectrum of the luminaire. Studies reviewed in our physiological section have shown the undesirability of using strong monochromatic illumination. Even fairly narrow band illumination produced by high or low pressure sodium lamps are simply not acceptable to people for the lighting of habitable spaces (Lin and Bennett, 1983).

For manipulating spaciousness, then, the question practically turns to the alternatives of incandescent vs. the various types of fluorescent and HID lamps commercially available, and how these distribute light in the space



(Glass, 1981).

The best available evidence here derives from a series of studies carried out by John Flynn and his associates throughout the 1970's. Flynn, Spencer, Martyniuk and Hendrick (1973) (and also reported in detail in Flynn, Hendrick, Spencer and Martyniuk, 1979) showed how brightly lighting a space in a uniform manner at its periphery created a greater sense of spaciousness. Most of this effect was produced by the uniform peripheral "wall washing" of the light - its distribution rather than sheer amount. Inui and Miyata (1973) has also confirmed a moderate effect on spaciousness due to the overall average horizontal illuminance which agrees well with Flynn et al.'s (1973) findings for general brightness of ambient interior light.

Flynn and Spencer (1977) tested the effect of light source color on various rated evaluative dimensions. They found very little effect of light color, although cool white fluorescents were perceived more positively in terms of spaciousness and "clarity" of light, particularly when compared with high pressure sodium. In this study again, light distribution was determined to be a much more important contributor to spaciousness.

In a recent study, Bennett, Perecherla, Chowdhury, Prabhakaran and Gettu (1985) separated out the contaminating factors of luminaire size, shape and distribution from color rendering of the light. They found that cool white fluorescents yielded greater spaciousness and clarity in the furnished model

rooms the subjects judged, but caution that their results do not consider the addition of daylighting or the use of other "color" fluorescents in mixed schemes.

Summarizing the state of the art of lighting and color in architectural spaces, Styne (1979) points out the value of tri-stimulus lamps that have strong peaks in their power spectra at or near those of human color vision. He reports that such lamps have tested superiorly in terms of improved color rendition, clearer black/white contrast, and greater spatial clarity. His comments serve as a good reminder that lighting technology is evolving at an apparent faster pace than the ability of psychologists to synthesize an overall theory of lighting for interiors.

What, then, can be concluded about color effects on apparent distance and spaciousness? First, that these phenomena are not rightfully attributable to hues, as the rule of thumb about warm and cool advancement and recession implies. Rather, spatial impressions are most influenced by contrast effects, induced by saturation and, particularly, brightness differences between objects and backgrounds, or part of a spatial surround with its remainder. There appears to be something additionally compelling about bright red, probably due to its strong signal properties. But the spatial differences between red and blue surface colors seem in most part due to their relative brightnesses in photopic and scotopic vision.

Spaciousness is enhanced by increasing lightness of the enclosing surfaces, and by decreasing the contrast between elements that intrude into a space and their background. Another old design dictum of "painting out" obtrusive fixtures such as pipes and ducts thus seems to be well founded. The crucial role played by contrast can also be seen in the effects of wall mouldings that are used as wainscoting or below ceiling lines. But here the geometry of the room and the viewer's eye-point become critical considerations. Abrupt lines of contrast can be used to perceptually widen walls or lower ceilings, as long as the viewer's perspective is taken into account. But decoratively striping a wall area at eye level only introduces a strong sense of "constriction" into a space due to the advancement produced by this element relative to its background. A recent thesis by Tiedje (1986) has explored these and other means of manipulating spaciousness without adding space. Color can play a useful role in this endeavor, though not as simply as is popularly believed. Its role as a spatial accentuator rests more on color's ability to be a carrier of achromatic contrasts that help define interior perspectives, rather than on any intrinsic powers of hue.

## Color Assessment in Real and Simulated Environments

If there has been any lesson learned in the history of color research, it is that valid prediction of *color in context* cannot be reliably made from highly reductionist laboratory experiments. The reasons have mainly to do with how humans apparently process color information. There is always a background, always a contrast effect, always a running history of the retina that must be taken into account. Color on chips in isolation is not judged as it might when the color is applied to real objects in a complex setting. To understand the principles that may govern color application to real environments demands research performed in those or simulated settings. Where this has been done, the results have inevitably extended and enriched our understanding of color usage derived from more constrained studies.

Over the past twenty years, color assessments of real or simulated buildings and interiors have been performed systematically in four different countries, each from their particular cultural perspective and research tradition. Taken together, these results from Japan, Sweden, England, and the U.S.A. begin to provide a coherent body of evidence on which color proposals may be evaluated and color uses formulated for a variety of settings and intentions.

In Japan, Masao Inui (1969; 1967; 1966) has undertaken a broad survey of the actual types of colors used in different environments. This might be

called a "revealed" preferences approach to color usage. The idea is to make a careful and thorough survey of colors in everyday use, and by analyzing these patterns, reveal underlying principles of color psychology at work among people.

Inui's work used the Munsell color system, and his results are reported in those terms. He found that across all types of interiors in Japan, warm colors are used much more frequently than cool, and that YR hues, centered around 10YR (the hue of natural wood) strongly dominate. Munsell values are distributed in a more blunt cone-shaped pattern, peaking at value 8, while chroma reaches maximum frequency at 2. Thus, warm colors of high value and low chroma are the most often encountered in Japanese interiors. This runs counter to what might have been predicted from much of the color preference literature.

But Inui (1966) also found that color preference was often heavily influenced by the room type and surface to which it was applied. Theatre foyers exhibited R, G, and B hues at much higher chroma compared to the average living room. Hospital consultation rooms and operating theatres utilized more GY and G, with very high value and low chroma. Usually, there are good reasons for such customs of color usage, and these often reflect functional concerns, as for the surgeon, or marketing and cultural ones, as for the commercial establishment. Still, certain general patterns are

noteworthy. Ceilings are mostly colorless, with high value, low chroma and hue in the 5YR-5Y range. Floors, opposingly, are very colorful, with value modal at 4, and a wide range of chromas primarily between 2-8. Wall hues peak sharply in the 5YR-5Y region, with a fairly broad region of values between 7 and 4, and a strong chroma peak at 2.

Since the color impression of a room is primarily experienced as an integrated *Gestalt* by an observer, Inui (1966) also computes the color balance point as an objective means of representing the "psychological effect" of colors taken together. The color balance point is the Munsell disk mixture color when all colors used in one room are placed on the disk in proportion to the areas they occupy. Its calculation is a straightforward geometric one, though, and so it is probably better considered as a sort of summary statistic of a color description rather than a psychonomic measure.

Inui finds that in balance points for different kinds of hotel foyers, the colder the balance point (the lower the chroma for the range of hues around 5YR), the less pleasant the interior was judged to be. Cinema foyers, however, display an inflection point at around Munsell chroma 2, after which they become more pleasant as chroma is decreased towards neutrality. Here is a clear indication, to which we shall return later, that color pleasantness in real settings is determined partly by the social function enclosed, and not through an invariant psychophysical relation between color attributes and

human response.

Inui (1966) also had subjects rate thirty-one scale models of interiors made with colored paper. Ratings were collected on semantic-differential type scales. Each observer was also asked to picture him/herself in the ten types of rooms represented in the study, and to state a preference for each room in terms of the SD scales. These results were compared with the actual judgments in the model experiments, which allow deduction of the acceptable types of color compositions for each space. Interestingly, it appears that only one color composition with YR and G as its dominant groups would suit any type of room. This corresponds to the colors of natural wood with foliage. Other combinations are appropriate for certain types of rooms only, and some are unsuitable for any application.

Kunishima and Yanase (1985) have also investigated the pleasantness of different wall colors in domestic living rooms. They used slides of a 1/10 scale model. Their results confirm much of Inui's earlier work, finding that the most successful wall colors for living rooms were those that were warm in hue, high in brightness, and low in saturation.

Minato (1977) has extended these sorts of color considerations to product design. He finds that the ability of a product's color to harmonize well with others' is critical to its acceptance, and that colors which people prefer most may not be good color choices for products if these do not reflect

the "character" of a product. Even on the small scale of implements and appliances, color choice becomes a contextual issue, enriched by considerations of 'image' and function which are not properly part of the optics of color.

Minato (1977) also presents a color formula purporting to show the relation between affective values and the three color dimensions. One wonders about the usefulness of such a formalism in view of the strong effects that non-color variables appear to exercise on colors' acceptability.

An exceptionally elaborate investigation into mapping values and meaning onto environmental colors has been continuing in Sweden for the past sixteen years. This effort is represented in a series of studies within the context of their own modified Natural Color System (NCS). This utilizes four basic colors of Y, G, R, and B and a color triangle of elementary white, black and maximum chroma. Their chromatic strength and lightness play the same roles as chroma and value in the Munsell system. (See the Color Preference section for a discussion of the NCS.)

In an early study, Kuller (1970) had subjects judge colored walls in slides of a room perspective sketch on eight unipolar adjective scales. His complicated findings indicated that social evaluation increased with blackness and decreased with chromatic strength. Openness increased with lightness and with chromatic strength of interior elements only. He also



reports results for such factors as "originality", "Pragnanz", "unity", "masculinity" and "affection" although the meanings of these factors are often unclear. He concludes that it is possible to systematically map the influence of color on the perception of the real milieu, and that higher order factors are needed to understand the effect of color changes.

Acking and Kuller (1976;1972) report extending these results to a study with full scale rooms, using identical day rooms in a hospital that were painted in different colors. Hues were two greens and a white while lightness and chromatic strength were fixed at low and medium, medium and high, and high and low, respectively. While there was no overall preference for any room, the white room was evaluated somewhat lower, but seen as most open and least complex, which is in agreement with other general results from color slides.

The most comprehensive and meaningful study of colors as applied to building exteriors is reported by Sivik (1974b), who was especially interested in the connotations of colors when they are applied to objects. He utilized black and white slides of buildings that could be combined with a color print to make it appear that the building color had changed while all else remained constant. Sixty-seven color samples were prepared that could be attached to two different kinds of buildings - an apartment house and a single family house and garage. A stratified sample of passersby on the

street rated ten colors attached to each picture on 13 different SD scales.

He found that three factors of "emotional evaluation", "social evaluation", and "spatial factor" described the judgments. Adjectives such as beautiful, friendly, and pleasant apparently mean almost the same thing when used to describe exterior colors, and comprise a large part of emotional evaluation. Social evaluation is much more heterogeneous in meaning, while spatial factor deals entirely with indicants of spaciousness. As for colors, the YR colored buildings were regarded more beautiful than the blue colored ones, which is not expected from the results of color chip preferences alone. People apparently like houses that are painted in various shades of yellow through beige (or that appear as natural wood). Just as notable, people disliked dark or violet colored buildings.

As for the factor of social evaluation, the isosemantic maps (see our preference section for a discussion of this technique) showed a clear and dominant dependence on chromaticity and blackness. Much of the social meaning read into an exterior building color depends on these dimensions, and not the actual choice of hues. Spatial factor, as may be expected, was strongly dependent on blackness, with enclosedness positively related to this attribute.

In an attempt to validate some of these results, Sivik (1974b) also interviewed passersby in front of three different buildings, where they were

asked about how they liked the coloration of the building. He found that the distribution of responses on a seven-point scale was well predicted by semantic maps of a building's colors prepared from the earlier data.

Another study (Sivik, 1974b) was made of five residential areas in Goteborg, where 136 subjects were interviewed in their homes. Here, the residents who lived in grey buildings evaluated them lower than did any of the others. However, people who lived in highly saturated blue buildings really approved of the exteriors, which were also positively regarded by one of the other groups of residents who could see them. This was highly contrary to the results of the laboratory study, and also to the attitudes expressed by residents of the remaining housing areas, who had to only imagine what the blue color would be like. Again, color that is experienced is regarded differently than coloration that is simulated or viewed in the mind's eye.

What can be gleaned from these extensive and thoughtful studies on color meaning? First, that while many semantic meanings remain generally stable over the space of color samples, the colorations of objects greatly change the pattern of connotations for some of these. This is a question of how appropriate any color is to an object, and while variations are permitted, some limits can be easily exceeded, dependent on the meaning of the object. Colors also carry their own meaning to some extent, and part of the question is to what degree the two implied meanings are consonant, or even relevant to

each other. The preference of colors for objects appears in large part to be a pattern match between meanings abstracted from two different realms.

But it is not only cognition that is operating here. Kuller (1976) points out that heart rate is slower in a colorful room than a grey one, as is the alpha component of the EEG (which indicates an *increase* in cortical arousal). The hypothesis that appears supported by a number of studies is that a "captivating" environment induces cortical arousal but cardiac deceleration. Perceptual involvement in a setting orchestrates both limbic and cerebral activities.

Kuller (1980a) and Mikellides (1979) both provide rich and provocative overviews of these mutual influences in our perception and appreciation of environmental color. Their examples show that a full understanding of response to color requires consideration of different levels of processing by our neural systems.

But it is a pair of English investigators who have provided some of the most illuminating series of studies into what makes different colors appropriate to different kinds of interiors. Their efforts illustrate the subtle reliance on referential meaning that underlies any color appreciation or assessment.

Aware of Inui's (1966) and Sivik's (1974b) work, Slatter and Whitfield (1977) hypothesized that the judged appropriateness of certain colors varied

with the function of an interior. Using a perspective drawing of a room (without furnishings), they labelled it as either a bedroom or living room to their subjects, who had to select appropriate wall colors. When the drawing was perceived as a bedroom, slightly more saturated Y, YR and R was selected than when it was regarded as a living room. That designation brought a more neutral color selection.

Whitfield and Slatter (1978a;1978b) extended considerations of color appropriateness to the style of a room as well as its function. Here, Ss made appropriateness ratings for nine wall colors of a domestic interior, furnished in either modern, Georgian, or Art Nouveau manner. They found that there were no significant correlations of the modern interior with any other, but a high one between the Georgian and Art Nouveau. White was considered highly characteristic of modern, while dark red (7.5RP3/6) was most suitable for Georgian, and a light green (5G7/2) served best for the Art Nouveau. They suggest that patterns in the data seem to indicate a prototype matching strategy in category referencing. Once an interior is labelled, an "ideal" of such a category is conjectured, and then color judgments are made with respect to how well the available color set matches the ideal prototype.

Whitfield (1984) repeated this study, delving more deeply into the question of categorization, looking for differences that might appear between men and women of varying marital status. He found that there was a higher

internal consistency among women than men, and among married women than single ones. There was also higher consistency for the Modern condition than for the other two. As before, the subjects seemed to be distinguishing primarily between two types of styles, Modern and Traditional (Georgian/Art Nouveau), while designers who had prepared the presentation materials gave strong individual identities to each.

Whitfield and Wiltshire (1977) hypothesize that not only is each style characterized by a set of appearance values, but that these values tend to be unique to each style. This would seem to throw the question of color appropriateness directly onto the larger question of the nature and function of style in design.

Different perceptions of style should exist between architects and non-architects, which might be revealed in judgments about the colors of interior spaces. Hogg, Goodman, Porter, Mikellides and Preddy (1979) had these different groups of subjects rate both colored chips and model interiors. They extracted five factors from the twenty-four bipolar adjectives used as rating tools.

Generally, as chroma increased, so did 'dynamism', while increases in value yielded increased spaciousness. Emotional tone was more dependent on hue, with progression from R to P being seen as cooler, harder, and more austere. But R and Y had a negative emotional tone if they were low in

chroma and high or low in value. There was also a tendency for low chroma to be associated with low emotional tone, and high chroma to be associated with high or neutral tone. Complexity (only a factor in chips' judgements) was seen to decrease with decreasing value and to slightly increase around the hue circle from R to P. Complexity appears to be more of an interaction between chroma and value, with colors of low chroma but low or high value regarded as simple, while complex colors are generally of medium value.

Evaluation showed no correlation between itself and the dimensions of hue, value and chroma, and there was similarly no correlation between architects and non-architects on this factor. These two groups also showed strong differences in preferences for model colors. Interestingly, architects were quite consistent between their chip and model isosemantic maps in terms of Evaluation, while non-architects appeared to need an extrinsic context to meaningfully evaluate colors. Since architectural style is a learned categorization, and the appropriateness and evaluation of colors is determined by style, we see from these studies that there is good reason why clients are often quite at odds with the colors that architects select for them. The optimistic news here is that because these are learned distinctions, and not biological ones, there may be hope for rapprochement once design professionals learn to appreciate how their views differ from laypersons'.

As might be expected, the American work on color in real settings is much less concentrated and systematic than the European and Japanese. There is a potpurri of scattered research over the past thirty years that only recently has begun to focus into specific questions, primarily about enhancing productivity in high technology workplaces.

In 1953, Rice reviewed what research there was regarding color effects in classrooms. Both children and teachers strongly preferred schools that had been freshly repainted, and elementary students showed improvements in attendance and grades. But there seemed to be little effect of experimental paint schemes that involved bright warm or cool colors as compared to the standard light green wall and white ceiling. The effect of painting was more of a social one, that communicated care and respect for the school's populations. This social communication effect of paint schemes turns out to be important in the explanation of another "color" effect that has received much recent notoriety.

Srivastava and Peel (1968) were interested in color's influence on human movement through interiors. In two experiments, they compared movement patterns in the viewing of art museum exhibits when the walls were painted light beige or dark brown. By a hodometer measure, (which unobtrusively records footfalls) they found that visitors to the dark room took more footsteps, covered about twice as much area, and spent less time in the room



than visitors to the light room. These differences were not due to people in the dark room maintaining a lesser distance from the walls. In a second experiment with recruited subjects, they were unable to find differential effects, but it appeared that instructions played a strong part, and that the Ss had attended more to displayed prints than to room color.

Shipboard habitability has been of concern for years, (Gunderson and McDonald, 1973) but interior colors recommended by the NAVSEA Manual (U.S. Navy, 1975) appear to be solely based on the dubious extrapolations of one color theorist. Kuller (1979), however, reports an interview study of 140 Swedish sailors and concludes that crewmembers should be able to select their own tastes in curtains, carpets and art objects for private cabins from a common store. Here, he argues that the increase in sense of personal control over one's setting takes priority over hypothesized behavioral color effects when these colors are chosen through some outside means.

Perhaps the strangest attempt to proscribe colors to influence human behavior within a specialized setting comes from Schauss (1979), who claims that the color pink acts as a natural tranquilizer and reduces aggression and muscular strength. His claims are based on experience with this color in jail holding cells, as monitored by the correctional personnel. This report has received substantial newspaper and television coverage.

However, a second, controlled study (Pellegrini, Schauss, and Miller,

1981) found that there was little or no difference attributable to the color pink, itself. Rather, the control variable here appeared to be "any fresh coat of paint" (pg.181), which appears to send a caring social message to new inmates. As the earlier research with schools had shown, the application of any color to a surface sends a social message which is much more impactful than any supposed biological effect specific to a given color. In actual settings, real or intended social messages carried by setting attributes are often predominant for the user.

Concern with work settings and productivity within them has also guided recent color investigations that are more reasoned and credible. The BOSTI study (Brill, Margulis, and Konar, 1985;1984) had office workers state preferences for described colors, pick color chips of the most preferred colors for workstation features, and also had workers rate the colors they had.

Based on one time data for 1000 workers, they found that office personnel preferred described colors for walls and dividers that were low in chroma, while intense or zero chroma colors were clearly rejected. The color chip studies yielded similar results, with preferred colors being light blue, light aqua green, or off-white. Both of these results were in accord with worker's evaluations of what they already had. Generally, these reveal a preference for panels and walls to be of high value and low chroma, floors and

ceilings the same, work surfaces to be light wood, and for chair seats to be a high chroma, with value unspecified.

These findings reaffirm the apparent desire for a workplace that is predominantly "light" in terms of its treatment of enclosing spatial elements, but with visual interest introduced by strong chroma and value contrasts in small scale elements.

The contribution of overall lightness in a setting is also cited by Paznik (1986), who reports a Westinghouse study that showed increased productivity when moving from a dark to a light-walled room. Other authors (for example, Digerness, 1982) make much more detailed suggestions for color aids to productivity in office workplaces. Her general recommendations echo most of the BOSTI findings, but some also appear to rely more on the popular mythology of color effects than on responsible studies or critical observation of office environments.

Across the different kinds of specialized workplaces and other commercial settings that comprise American businesses, there are rather self-contained assortments of literature that dwell on case studies or exemplars of color usage. Bellizzi, Crowley, and Hasty,(1983) provide a review of color applied to store design, and present a rather ill-controlled experiment that ascertained the approach or avoidance influence of color panels. Here, female subjects were asked to go into an experimental room

with different color panels and to sit down and fill out a questionnaire regarding some color slides they had just seen of a furniture store interior. They could place their chair wherever they wished. The hypothesis was that Ss would seat themselves oriented and or closer to some colors rather than others, and their orientation and distance from the color panels were taken as an indicant of attractance or preference for that color.

The results showed, however, that there was no relationship between color and orientation, and no relationship between stated color preferences and orientation. Subjects did sit closest to the yellow wall and furthest from the white wall. When distances from the warm color walls (red and yellow) were compared with distances from the cool colored ones (green and blue), it was also found that subjects sat significantly closer to warm color walls regardless of stated color preference.

Slide judgments indicated that while warm colored interiors were seen as bright and colorful, they were also regarded as less attractive and less pleasant than cool colored ones. They interpret these findings with the advice to use warm colors to attract and draw people into stores, or toward displays. The actual coloration of merchandise displays, though, seems to depend more upon the evaluation and image of the items being sold.

Excellent recommendations for color in workplaces appeared in the work of Glass, Howett, Lister and Collins (1983), who emphasize color coding of

signage and safety symbols. Burton (1985) provides a bibliography of color in health care settings, while Wineman, (1979) gives a brief non-critical overview that includes color for therapeutic environments.

Stanwood (1983) produces a brief but balanced discussion of color and psychological effects that is aimed at writing sound construction specifications, and cautions professionals on the often contradictory advice available. Tiedje (1986) has examined many of these contradicting design heuristics, specifically in the context of spaciousness. Her conclusions agree with those presented in this review.

Finally, Alexander, Ishikawa, Silverstein and Jacobson (1977) in their monumental effort on "Pattern Language" provide some descriptions of environmental patterns that concern color usage in any space. Their patterns are like syllogisms that are concerned with invariant effects of particular light and color arrangements.

Although based on a combination of casual and serious studies as well as the authors' insights, their general conclusions agree well with what has been presented in earlier sections of this review. For example, they also recommend heterogeneous light distributions and variations in value and chroma that would introduce visual interest into interior spaces.

The results of color assessments in real environments thus appear to exhibit a somewhat remarkable and gratifying convergence. They demonstrate

rather conclusively that it is fruitless to build *up* to a theory of color application in settings from highly reductionist experiments alone. Although there appear to be some basic emotional or semantic connotations of color dimensions - particularly chroma and value - that are maintained in a perceptually rich setting, much environmental color meaning and acceptability seems to rely on cognitive appraisals between what is viewed and some ideal prototype or exemplar. Such referents, of course, are highly dependent on individual education and experience, as well as socio/cultural norms, and are probably responsible for what one often perceives as a reigning "canon of taste".

F. Del Coates (1979) has proposed the term "concinnity" for such group stereotypes of style, and we believe that (judged) appropriate interior color schemes exhibit the same underlying origins. However, even with this guaranteed source of color heterogeneity and evolution, patterns of chroma and value contrast in desired arrangements of environmental colors remain evident and enduring. At this level of color information processing may well lie the biological basis of color usage that psychologists have resolutely sought.

## Color in Space Environments

The sponsored purpose of this review is to provide a summary of human factors research relevant to specifying interior colors for the space station and possible extraterrestrial habitats. Besides laboratory experiments and assessments of color in common settings, it is instructive to review previous research and anecdotal experience regarding color usage in spacecraft. The evidence here is slight, as the question of environmental color is often swept aside by other predominant engineering concerns for sheer survivability of crewmembers.

Color simply has not been much of an issue until its possible contributions to long term habitability became evident in Skylab and Salyut missions. Habitability issues themselves have long been of interest since early in the space program (see Bluth, 1986; Connor, Harrison and Akin, 1985; Haines, 1973), and Rogers (1973) presciently conducted a confinement experiment that clearly demonstrated the behavioral benefits of an enriched setting. While these lessons were clearly ahead of their time, the planned space station and proposed Lunar and Mars bases have given them renewed importance.

There are relatively few articles which deal with color perception in weightlessness or the use of color in spacecraft environments. Most of these

are, sadly, of foreign origin. In particular, the Russian studies cited here often lack details in experimental design, methodological specifications and data analyses. This makes their scientific comparison with more available work rather fruitless.

Kitayev-Smyk (1972;1967) conducted a series of perceptual experiments in short-term weightlessness (parabolic trajectory). He noted that with the onset of weightlessness illusions of varying duration were reported by some subjects (Kitayev-Smyk, 1967). These illusions often consisted of a change in the color intensity of the figure component. He also noted that some subjects reported a decrease in brightness with the onset of weightlessness. His findings were similar to those reported by White (1965), who observed that during weightlessness a decrease in contrast was required to detect a target. He accounted for this phenomenon in terms of an exaggerated motion of retinal image.

In a subsequent study, Kitayev-Smyk (1972) reported that highly saturated yellow and red were perceived as brighter while blue was seen as less bright during short periods of weightlessness. He also found on a matching task during weightlessness that a mixed green (yellow/blue) was matched to yellow. These findings would suggest some differential changes occurring at the level of retinal processing during initial periods of



weightlessness. The duration of such changes is unknown and it is unclear as to how often they have been reported by cosmonauts or astronauts.

A frequently cited study done by Kitayev-Smyk (1979) examined the effects of color on motion sickness, especially nausea. Individuals underwent periods of prolonged rotation for at least 11 days. During that time subjects were exposed to fields of chromatic light, although the means of production of the colored light and the duration of exposure were not given. He reported that chromatic fields of yellow and brown shades increased the sensation of nausea, which resulted in many individuals vomiting, while blue light somewhat weakened this sensation. These findings have since been used as evidence of a color-behavioral linkage and have even been cited to advocate the avoidance of the hue yellow in the space station interior. We disagree. Too many methodological questions remain unanswered and these findings are most likely an artifact of the experimental manipulation of color (i.e. colored light).

As we have seen from earlier research, people have rather strong adverse reactions to environments bathed in any monochromatic illumination, so it is clearly untenable for a space station. As for brown surface colors, although some of the astronauts on Skylab (A Reporter at Large - I, 1976) voiced complaints about the golden brown clothing in terms of color monotony, there

appeared to be no increase in negative somatic effects associated with it.

A series of studies undertaken by Gurovskiy, Kosmolinskiy, and Mel'nikov (1980), although not directly concerning color, do have strong implications for lighting recommendations. Gurovskiy et al (1980) noted that as the length of a mission increased, cosmonauts desired higher levels of illumination in their surround. Under various work conditions, it was found that there was a need for increased ambient lighting as fatigue increased. In addition, when one worked under conditions of both intense visual and monotonous auditory stimulation, even higher levels of light were required.

From these findings Gurovskiy et al. (1980) concluded that a dynamic (both direct and disperse) lighting schema was needed in a space environment, which enabled one to individually control one's lighting needs. This finding is in agreement with the earlier cited laboratory work by Flynn and his associates.

From these few studies there is at least a glimpse of the types of color issues investigated. But, how do these studies relate to the actual use of color in a space habitat? There appears to have been Russian attempts to use such research to manipulate color effects in their space stations. In Salyut 6 a team of psychologists selected an interior color schema of soft pastels as a means of providing a homier atmosphere (Kidger, 1979). However, with

Salyut 7 the pastels were replaced by a right /left color distinction - the left wall was painted apple green and the right wall a biege (Konovalov, 1982). A recent experiment by Wise and Hogan (1987) suggests that such a scheme might aid spatial orientation. Photos and films of MIR indicate its interior to be a yellowish beige in color. No discussion of crew responses to the various interiors nor reasons for changing color schemes in the various spacecraft were found in any of the Russian literature available to these reviewers.

Discussions on interior colors (Gurovskiy et al.,1980; Petrov,1975) evidence a strong reliance on an intrinsic "order of preference" for colors (B-R-G-V-O-Y) and the belief that different activity levels and emotional states are directly associated with different colors.

Based on these premises, both Gurovskiy et al. (1980) and Petrov (1975) suggest certain hues for uses in specific areas of the spacecraft. In addition, both works discuss the use of "dynamic color" as a means of introducing color variety into the environment. Dynamic color refers to the development of a series of color slides or filmstrips (with strong natural and/or landscape elements) which reflect both the daily and seasonal light and color rhythms thought to exist. This is another means by which color and natural elements could be introduced into a visually monotonous environment. (The dream content of cosmonauts is mostly of landscape elements, e.g. woods, rivers,

blue skies (Oberg, 1981).] Gurovskiy et al. (1980) have even discussed the use of coordinated light and music programs to enhance health, productivity and psychological well-being.

These and other innovative approaches to interior enhancement appear to have been tested in the Soviet space program. However, the extent to which they are currently employed and their degree of success in terms of improved performance and physical/psychological well-being are unknown. From the studies discussed in earlier sections, any selection of colors on a preference or emotional association basis seems to be particularly unfounded.

The use of color in American spacecraft to date has been of a limited nature. Anecdotal comments from Skylab (A Reporter at Large - I, 1976; Skylab Experience, 1975) suggest that a livelier color scheme - e.g. light blue or green - in the wardroom might have been preferred to the existing tan and brown one. Astronauts reported problems with visually losing small objects (A Reporter at Large - I, 1976), which suggests one ought to brightly color small objects, use surface colors to create contrasts with small objects or even employ a shadowboard schema to aid in identification. A bright blue color was used to distinguish the handrails in Skylab so that other items would not be grabbed by mistake (A Reporter at Large - II, 1976).

The window in Skylab actually served as the means of introducing

dynamic color into that spacecraft setting. The view of the earth from that window was ever changing in both light and color, and was highly appreciated by the crews. Earth viewing was the single most popular way of spending the limited recreational time. (A Reporter at Large - II, 1976).

In terms of the STS (Shuttle), little variation in interior color exists. The interior is rendered mostly white in order to make the best of the low illuminance levels mandated by limited electric power, while the handrails in Spacelab continue the Skylab practice of being a bright, anodized blue. Small areas of saturated color labels are used on mid-deck lockers for identification purposes. This is an improvement over Skylab cabinets, where the complaint was that they "all looked alike" ( A Reporter at Large-I, 1976, pg. 59) despite carrying numbered and written descriptions of their contents. This labelling was not as helpful as it might seem, since the writing was small and difficult to read, particularly if approached from an oblique angle or upside down. Color coding of storage facilities appears to be a prime way of introducing color into habitat interiors.

Current astronauts, like their predecessors, have also expressed a desire for increased variety in the color of clothing, especially in terms of different colored mission t-shirts. Interestingly, it appears that the Soviets allow much more personal choice into the color selection and design of their

space crews' clothing than does the U.S.

From the studies cited, color has heretofore played a minor role in the space program. To date, from prevailing professional opinions and the literature surveyed, there appear to be no recognized lasting color perception changes due to weightlessness. As mission durations lengthen, however, this may not prove to be the case. While actual use of color in spacecraft environments has been rather restricted, the need for a more enriched color palette is noticeable and documented.

Color is one of the easier means by which variety can be introduced into a monotonous visual environment, and it can also play functional roles in terms of localization, spaciousness, orientation and wayfinding. How one introduces color poses a problem, as the proposed space station will have limited habitable volume (see Wise, 1985, for a review of *spatial* habitability concerns).

Too many different colors in small spaces simply make them appear chaotic, rather than "visually varied", and small volumes provide few opportunities for color enhancement *per se*, when available surfaces are covered with equipment. Serious consideration should instead be given to creating color variety through coloration of functional items as well as enclosing surfaces, and the latter are probably better treated through changes

in value and saturation of a given hue, with the total number of different surface hues in a single 'visual volume' kept to 2-3.

The relatively low illumination levels (20-30fc) would almost dictate that large surface areas be finished with light (high value) colors as a means of alleviating the "mole-like" feelings expressed by some crewmembers on Skylab (A Reporter at Large - I, 1976). Bright and highly saturated colors should be limited to small areas, edges, corners, trims, reveals, and hardware items.

At this time we believe it is important that the introduction of color into the space station be approached successively, from simple color treatments that aid identification of equipment or lockers to individualized 'decor' of private crew quarters. Any color proposals must also undergo the process of space certification wherein all materials and finishes meet stringent flight safety requirements. Many types of surfacing compounds outgas in weightlessness, and would be unsuitable for specification there. Minimum push-off pressures, maintainability, and cleanability standards are also prerequisites that can severely limit the choice of colors one might otherwise use.

Here, color applications still have a ways to mature, as considerations of feasibility, practicality, and the psychology of color all find a common

ground. Attempts to affect habitability in space stations through color have to date been tentative and even accidental, while the 'right questions' have yet to be asked. For the present, we must extrapolate from "lessons learned" in more mundane and commodious settings of our world.



## Conclusions

What are the summative lessons of the two hundred-odd studies reviewed here, and what do these imply for color usage in novel settings and locales?

First and primarily, these results thoroughly demonstrate that there are no 'hard-wired' linkages between environmental colors and particular judgmental or emotional states. Specifying colors on the basis of spaces being "active", "contemplative", "restful" or whatever, to be congruent with the mental or behavioral activities they enclose is simply unjustified. This simplistic view, widely adopted as a sort of shorthand for color-behavior effects, actually obscures the replicable interactions that do exist while it impedes more innovative color applications.

Second, the foregoing should not be construed to mean that there *are no* color-behavior linkages, or that color decisions are simply questions of personal tastes. There *are demonstrable* perceptual impressions of color applications that in turn can affect the experiences and performances of people in settings. These may involve the precise cognitive processing of displayed information or diffuse feelings about spaciousness and the "magic, mystery, and romance" evoked by an interiors' ambience. Just because the feeling a place evokes may be diffuse and difficult to verbalize is no indicant that the relevant design manipulations are equally insensible.

Color's influence on perceptions and feelings strongly relies on rather invariant patterns of simultaneous and successive contrast produced by its chroma and value dimensions. When prevailing attitudes of style (whose origins lie well outside of color perception) are overlain on these, the result is a superficially bewildering variety of color uses that are nonetheless fundamentally similar. But the basic color contrasts relevant to habitability issues are amenable to the same kind of rigorous analysis performed on other aspects of engineering design.

Third, behaviorally specifying color is not aided by highly reductionist experiments that treat a "color" as a unitary stimulus event. In the real world, color inevitably occurs in a higher order system of contrasts present in the setting. Tabletop models, slide representations, and color swatches inevitably do these little justice, and system variables are often constrained out by the experimental design itself. Even if such higher order variables are included in physical representations, they must also be respected in the data analysis model employed. In our review, we have felt that, all too often, the important lessons of an experiment were obscured as "error variance" by a failure to define or test for color's effects in a sensitive way.

The present state of knowledge is thus somewhat realistically impoverished. While it is possible to take a proposed color scheme and submit it to a series of "fitting tests" based on contrast effects that one

wants to enlist or avoid, it is probably too early to ask that codified results of color-behavior studies uniquely specify an optimal color scheme for a setting. Color specifying is still an iterative process using color-behavior research as a series of guide posts to make successive decisions within an increasingly focused context.

At present, for example, aerospace designers wishing to maximize sensed spaciousness through color applications within a given volume ought to do the following:

- a. Keep the major enclosing bulkheads high in value and low in chroma.
- b. Keep subdividing partitions and elements lower in value and higher in chroma than the major surfaces.
- c. Keep minor elements such as trim, reveals, edges, fixtures, hardware and small areas of furnishings either very high or very low in value and high in chroma.

This sets up general conditions for a "hierarchy of contrasts" in a setting that most increases perceived volume. But final color specifications would certainly depend on much more than these. For example, room geometry is an important contributor to visual spaciousness, and can be analyzed via Isovist Theory (Wise, 1985). An isovist is the set of all points visible from a given point, and isovist properties significantly influence perceptual and attitudinal judgments about interiors.

Here, aside from greater visual volume, increased variance of isovists from given points also improve spaciousness. The variance of an isovist is driven by long views, particularly long diagonal views. This suggests that an optimal color strategy for an interior space ought to accent such opportunities if they are present, which in turn may take exception to the contrast hierarchy rules outlined above. Color can also exist within the context of a decorative pattern, such as wallpaper, whose geometry and texture, or evocative image qualities, can produce their own effects (Wise and Rosenberg, In prep.).

The point, of course, is that behavioral color specifying must act within a context of what is known about other environmental features that affect the same desired objectives.

There is also the problem of multiple objectives. It is very reasonable to ask that a private crew cabin aboard a space station be perceived not only as spacious, but also as secure and sheltering to its inhabitant. Extant results suggest that the latter requires an enclosing surface color lower in value and higher in chroma than that which would optimize spaciousness alone.

The resolution is not to take mean color dimensional values between these two possibilities! Rather, it depends on the relative importance of each objective, and on the coordination of geometry, color, texture, and other features in a proposed design. This will be an enlightened judgment call at

best, since we encountered no research that investigated such tradeoffs between different types of color qualities.

Fourth, behaviorally specifying a setting's colors must recognize that some color-behavior effects obey a more primitive set of biological imperatives. Color is not simply a cognitive phenomenon, as its perception depends on contributions of low level retinal and limbic mechanisms. Kuller (1980b) makes a valuable distinction between light as *signal* and light as *symbol*. The same distinction can be applied to color effects, where it reflects their sources in our neural capabilities. Signal properties of colors appear to be handled by limbic mechanisms, whereas symbolic associations to colors rely on higher level cerebral functions.

Paul MacLean (Rosenfeld, 1976) has extensively developed a "triune brain" model which is quite appropriate for categorizing the general results of color-behavior research. The rich neural feedback loops between limbic, cortical and peripheral components guarantee an integrated color *gestalt*, but their respective evolutionary histories reveal different roles in the long term game of biological survival. Analysis of environmental colors means respecting the contributions of qualitatively different kinds of processing, and not demanding a full explanation from a single source. But to the degree that color effects depend on more primitive brain centers, this reassures that they will hold across changes in time, culture, or locale.

Some very useful color properties are traceable directly to receptor structure and mapping on the retina. The high detectability of "signal-orange" life preservers is a function of peak cone sensitivity in the fovea, while the improved visibility of blue lights on emergency vehicles at night follows the Purkinje shift accompanying the transfer to predominant rod vision then. Clearly, any thorough understanding of color design must include the contributions of different parts of the visual pathway. It is not only a problem of detailing the psychological responses to color.

Fifth and finally, what is known about color implies that there are certain approaches to specifying color that should probably be avoided, regardless of their ease or superficial egalitarianism.

It is not sufficient to hire a "good interior designer" and take their best judgments about appropriate colors. Designer's insights, heuristics and principles of practice are notoriously contradictory, and often have keyed on the wrong dimensions of color. Their choices are also based on historical considerations and style distinctions that are often quite irrelevant for their clientele. While an experienced designer can usually synthesize explicit criteria for interior color into a masterful solution, careful programming of the behavioral color requirements for different spaces ought to precede this task.

It is also unwise to simply "give people what they want" and to base colors on a survey of proposed inhabitants' preferences (for example, the extant astronaut corps' likes and dislikes for different interior color schemes). Human preferences for colors are exceptionally labile, being strongly influenced by individual tastes, the judgment context, and even the time of day. People also tend to choose on the basis of a concinnous image, which is highly affected by the status quo. There is by now a "standard image" of a space station interior, but there is no gurantee that it would meet behavioral color performance criteria. A survey of current astronaut preferences also ignores future crews, and foreigners or private industry scientists who may later become mission specialists.

Rather, colors should first be specified in terms of what they are *to do*, instead of what *they are*. These performance criteria would operationalize color's role in the perceptual impressions of a particular space in a way that would allow various color combinations to meet them. This would give the color designer both the information needed about the intention of the color and the freedom to create a solution.

Resolution of different color performance criteria is where experienced designers can make their best contributions, although we see considerable value in allowing some personal color decisions for the crews of any habitat. Their exercise of choice is needed to establish a sense of personal

competence in the setting, and individual selections in the colors of clothing, linens, and living accessories is an ideal way to do this. Color, however rationally devised and defended, must ultimately be accepted by the persons who are to live with it.



## REFERENCES

- Aaronson, B.: Some Affective Stereotypes of Color. *International Journal of Symbology*, vol. 2, no.1, 1970, pp. 15-27.
- Acking, C. A. and Kuller, R.: Interior Space and Colour. T. Porter and B. Mikellides, eds., *Color for Architecture*. Van Nostrand Reinhold Co. (New York:), 1976, pp. 120-122.
- Acking, C. A. and Kuller, R.: The Perception of an Interior as a Function of Colour. *Ergonomics*, vol. 15, no. 6, 1972, pp. 645-654.
- Aksugur, E.: Effects of Surface Colors of Walls Under Different Light Sources on the 'Perceptual Magnitude of Space' in a Room. F. W. Billmeyer and G. Wyszecki, eds., *AIC Color 77, Proceedings of the Third Congress of the International Colour Association*. Adam Hilger Ltd. (Bristol:), 1977, pp. 388-391.
- Alexander, C., Ishikawa, S., Silverstein, M. and Jacobson, M.: *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press, (New York), 1977.
- Alexander, K. R. and Shansky, M. S.: Influence of Hue, Value and Chroma on the Perceived Heaviness of Colors. *Perception and Psychophysics*, vol. 19, no. 1, January, 1976, pp. 72-74.
- Ali, M. R.: Clinical Note: Pattern of EEG Recovery Under Photic Stimulation By Light of Different Colors. *Electroencephalography and Clinical Neurophysiology*, vol. 33, 1972, pp. 332-335.
- Ball, V. K.: The Aesthetics of Colour: A Review of Fifty Years of Experimentation. *Journal of Aesthetic Art Criticism*, vol. 23, 1965, pp. 441-452.
- Baum, A. and Davis, G. E.: Spatial and Social Aspects of Crowding Perception. *Environment and Behavior*, vol. 8, 1976, pp. 527-544.
- Beck, J.: Apparent Spatial Position and the Perception of Lightness. *Journal of Experimental Psychology*, vol. 69, no. 2, 1965, pp. 170-179.
- Beck, J.: Lightness and Orientation. *American Journal of Psychology*, vol. 82, no. 3, 1969, pp. 359-366.

Bellizzi, J. A., Crowley, A. E., and Hasty, R. W.: The Effects of Color in Store Design. *Journal of Retailing*, vol. 59, no. 1, 1983, pp. 21-45.

Bennett, C. A., Perecherla, A., Chowdhury, Z. K., Prabhakaran, R., and Gettu, S. N.: Three Comparisons of Incandescent and Fluorescent: Color or Luminaire? *Proceedings of the Human Factors Society - 29th Annual Meeting*, 1985, pp. 594-597.

Bennett, C. and Rey, P.: What's So Hot About Red? *Human Factors*, vol. 14, no. 2, 1972, pp. 149-154.

Berlin, B. and Kay, P.: *Basic Color Terms: Their Universality and Evolution*. University of California Press, (Berkeley:), 1969.

Bernardo, J. R.: What Color Reveals: A Therapist's Point of View. *Color Research and Application*, vol. 8, no. 1, 1983, pp. 5-11.

Berry, P. C.: Effects of Colored Illumination Upon Perceived Temperature. *Journal of Applied Psychology*, vol. 45, no. 4, 1961, pp. 248-250.

Birren, F.: Color and Human Response. *Color Research and Application*, vol. 8, no. 2, 1983, pp. 75-81.

Birren, F.: *Color Psychology and Color Therapy*. McGraw-Hill Book Co., Inc., (New York:), 1950.

Birren, F.: The Effects of Color on the Human Organism. *American Journal of Occupational Therapy*, vol. 13, 1959, pp. 125-129.

Birren, F.: *Light, Color and Environment*. Van Nostrand Reinhold, Co., (New York:), 1982.

Birren, F.: The Practical Application of Light and Colour to Human Environments. *Colour 73: The Second Congress of the International Colour Association*. Adam Hilger, (London:), 1973, pp. 179-189.

Blue Is Beautiful. *Time*, September 17, 1973.

Bluth, B. J.: *Soviet Space Stations As Analogs*. NASA NAGW-659, Washington, D.C., 1986.

Boynton, R. M.: Human Color Vision. Holt, Rinehart and Winston, (New York:), 1979.

Brill, M., Margulis, S. T., Konar, E., and BOSTI.: Using Office Design to Increase Productivity. Volume I, 1984.

Brill, M., Margulis, S. T., Konar, E., and BOSTI.: Using Office Design to Increase Productivity. Volume II, 1985.

Brou, P., Sciascia, T. R., Linden, L., and Lettvin, J. Y.: The Colors of Things. Scientific American, vol. 255, no. 3, September, 1986, pp. 84-91.

Brown, B. B.: Specificity of EEG Photic Flicker Responses to Color as Related to Visual Imagery Ability. Psychophysiology, vol. 2, no. 3, 1966, pp. 197-207.

Bullough, E.: On the Apparent Heaviness of Colors. British Journal of Psychology, vol. 2, 1907, pp. 111-152.

Bullough, E.: The Perceptive Problem in the Aesthetic Appreciation of Single Colours. British Journal of Psychology, vol. 2, 1908, pp. 406-463.

Burton, C. M.: A Design Proposal for Improving Four Health Care Environments. Unpublished Paper, 1985.

Caldwell, J. A. and Jones, G. E.: The Effects of Exposure to Red and Blue Light on Physiological Indices and Time Estimation. Perception, vol. 14, 1985, pp. 19-29.

Carterette, E. C. and Symmes, D.: Color As an Experimental Variable in Photic Stimulation. Electroencephalography and Clinical Neurophysiology, vol. 4, no. 3, 1952, pp. 289-296.

Chapanis, A.: Color Names for Color Space. American Scientist, vol. 53, no. 3, 1965, pp. 327-345.

Chongourian, A.: Color Preference and Cultural Variation. Perceptual and Motor Skills, vol. 26, 1968, pp. 1203-1206.

Chongourian, A.: Color Preferences: A Cross-Cultural and Cross-Sectional Study. Perceptual and Motor Skills, vol. 28, 1969, pp. 801-802.

Coates, D.: Understanding Aesthetics: From Old Shoes To a Teacup. ID Magazine, September/October, 1979, pp. 32-35.

Connor, M. M., Harrison, A.A. and Akin, F.R.: Living Aloft: Human Requirements for Extended Spaceflight. NASA SP-483, Washington, D.C., 1985.

Coules, J.: Effect of Photometric Brightness on Judgments of Distance. Journal of Psychology, vol. 50, no. 1, 1955, pp. 19-25.

Courtney, A. J.: Chinese Population Stereotypes: Color Associations. Human Factors, vol. 28, no. 1, 1986, pp. 97-99.

Digerness, B.: Color It Productive. Administrative Management, December, 1982, pp. 46-49.

Egusa, H.: Effects of Brightness, Hue and Saturation on Perceived Depth Between Adjacent Regions in the Visual Field. Perception, vol. 12, no. 2, 1983, pp. 167-175.

Eysenck, H. J.: A Critical and Experimental Study of Color Preferences. American Journal of Psychology, vol. 54, 1941, pp. 385-391.

Erwin, C. W., Lerner, M., Wilson, N. J., and Wilson, W. P.: Some Further Observations on the Photically Elicited Arousal Response. Electroencephalography Clinical Neurophysiology, vol. 13, 1961, pp. 391-394.

Fanger, P. O., Breum, N. O., and Jerking, E.: Can Colour and Noise Influence Man's Thermal Comfort. Ergonomics, vol. 20, no. 1, 1977, pp. 11-18.

Farrell, R. J. and Booth, J. M.: Design Handbook for Imagery Interpretation Equipment. Boeing, February, 1984

Flynn, J. E. and Spencer, T. J.: The Effects of Light Source Color on User Impression and Satisfaction. Journal of Illuminating Engineering Society, April, 1977, pp. 167-179.

Flynn, J. E., Hendrick, C., Spencer, T., and Martyniuk, O.: A Guide to Methodology Procedures for Measuring Subjective Impressions in Lighting. Journal of Illuminating Engineering Society, January, 1979, pp. 95-110.

Flynn, J. E., Spencer, T. J., Martyniuk, O., and Hendrick, C.: Interim Study of Procedures for Investigating the Effect of Light on Impression and Behavior. *Journal of Illuminating Engineering Society*, October, 1973, pp. 87- 94.

Gerard, R. M.: Color and Emotional Arousal. *The American Psychologist*, 1959, p. 340.

Gerard, R. M.: Differential Effects of Colored Lights on Psychophysiological Functions. Unpublished Ph.D. dissertation, UCLA, 1958.

Glass, R. A.: Color Perception Under Energy Efficient Lights. Light, Health, and Design Conference. Health Facilities Design Division. (Ottawa, Canada:), 1981, pp. 131-159.

Glass, R. A., Howett, G. L., Lister, K. and Collins, B. L.: Some Criteria for Colors and Signs in Workplaces. U. S. Department of Commerce, NBS, Washington, D. C., April, 1983.

Goldstein, K.: Some Experimental Observations Concerning the Influence of Color on the Function of the Organism. *Occupational Therapy*, vol. 21, 1942 pp. 147-151.

Goodfellow, R. A. H. and Smith, P. C.: Effects of Environmental Color on Two Psychomotor Tasks. *Perceptual and Motor Skills*, vol. 37, 1973, pp. 296-298.

Gotz, K. and Gotz, K.: Color Preferences of Art Students: Surface Colors: I. *Perceptual and Motor Skills*, vol. 39, no. 3, 1974, 1103-1109.

Gotz, K. and Gotz, K.: Color Preferences of Art Students: Surface Colors: II. *Perceptual and Motor Skills*, vol. 41, 1975, pp. 271-278.

Grandjean, E. Fitting the Task to the Man: An Ergonomic Approach. Taylor and Francis, Ltd., (London:), 1980.

Granger, G. W.: An Experimental Study of Colour Preferences. *Journal of General Psychology*, vol. 52, 1955, pp. 3-20.

Green, R. R. and Goldfried, M. R.: On the Bipolarity of Semantic Space. *Psychological Monographs*, vol. 79, 1965, Whole #599.

Greene, T. C. and Bell, P. A.: Additional Considerations Concerning the Effects of 'Warm' and 'Cool' Colours on Energy Conservation. *Ergonomics*, vol. 23, no. 10, 1980, pp. 949-954.

Guilford, J. P.: The Affective Value of Color as a Function of Hue, Tint and Chroma. *Journal of Experimental Psychology*, vol. 17, 1934, pp. 342-370.

Guilford, J. P. and Smith, P. C.: A System of Color Preferences. *American Journal of Psychology*, vol. 62, 1959, pp. 487-502.

Gunderson, E. K. E. and McDonald, B. W.: Measurement of Habitability. E. C. Wortz and M. R. Gafvert, eds., *Proceedings of the 28th Annual Conference CCAIA*. (Monterey:), 1973, pp. 122-129.

Gurovskiy, N. N., Kosmolinskiy, F. P., and Mel'nikov, L. N.: *Proyektirovaniye usloviy zhizni i raboty kosmonavtov*, 1980. Translation, *Designing the Living and Working Conditions of Cosmonauts*. NASA TM-76497, Washington, D. C., 1981.

Haines, R. F.: Color Design for Habitability. E. C. Wortz and M.R. Gafvert, eds., *Proceedings of the 28th Annual Conference CCAIA*. (Monterey:), 1973, pp. 84-106.

Hammes, J. A. and Wiggins, S. L.: Perceptual Motor Steadiness, Manifest Anxiety and Color Illumination. *Perceptual and Motor Skills*, vol. 14, 1962, pp. 59-61.

Hanes, R. M.: The long and short of color distance. *Architectural Record*, April, 1960, pp. 254-256;348.

Hard, A.: NCS: A Descriptive Color Order and Scaling System With Application for Environmental Design. *Man-Environment Systems*, vol. 5, 1975, pp. 161-167.

Hard, A. and Sivik, L.: Outlines of a Theory of Colors in Combination. *Man-Environment Systems*, vol. 9, 1979, pp. 217-228.

Hayward, D. G.: The Psychology and Physiology of Light and Color as an Issue in the Planning and Managing of Environments: A Selected Bibliography. *Council of Planning Libraries, Exchange Bibliography No. 288*, 1972.

Helson, H., Judd, D. B., and Warren, M. H.: Object-Color Changes From Daylight to Incandescent Filament Illumination. *Illuminating Engineering*, April, 1952, pp. 221-23.

Helson, H. and Lansford, T.: The Role of Spectral Energy of Source and Background Pleasantness of Object Colors. *Applied Optics*, vol. 9, 1970, pp. 1513-1562.

Hogg, J.: A Principal Component Analysis of Semantic Differential Judgments of Single Colors and Color Pairs. *Journal of General Psychology*, vol. 80, 1969, 129-140.

Hogg, J., Goodman, S., Porter, T., Mikellides, B. and Preddy, D. E.: Dimensions and Determinants of Judgments of Colour Samples and a Simulated Interior Space by Architects and Non-Architects. *British Journal of Psychology*, vol. 70, 1979, pp. 231-242.

Hopson, J., Cogan, R., and Batson, C.: Color Preference as a Function of Background and Illumination. *Perceptual and Motor Skills*, vol. 33, no. 2 part 3, 1971, pp. 1083-1088.

Houghton, F. C., Olson, H. T. and Suci, J.: The Sensation of Warmth as Affected by the Color of the Environment. *Illuminating Engineering*, December 1940, pp. 908-914.

Howett, G. L.: Linear Opponent-Color Model Optimized for Brightness Prediction. U. S. Department of Commerce, NBS, Gaithersburg, Md., 1985.

Humphrey, N. K.: Colour and Brightness Preferences in Monkeys. *Nature*, vol. 229, 1971, pp. 615-617.

Humphrey, N. K.: The Colour Currency of Nature. T. Porter and B. Mikellides, eds., *Color For Architecture*. Van Nostrand Reinhold, Co., (New York:), 1976, pp. 95-98.

Humphrey, N. K. and Keeble, G. R.: Do Monkeys' Subjective Clocks Run Faster in Red Light Than in Blue? *Perception*, vol. 6, 1977, pp. 7-14.

Hurvich, L. M.: *Color Vision*. Sinauer Associates, Inc., (Massachusetts:), 1981.

Inui, M.: Colour in the Interior Environment. *Lighting Research and Technology*, vol. 1, no. 2, 1969, 86-94.

Inui, M.: Practical Analysis of Interior Color Environment. Building Research Institute, Occasional Report No. 27, (Tokyo:), 1966.

Inui, M.: Proposed Color Ranges For Interiors. Building Research Institute, Occasional Report No. 28, (Tokyo:), 1967.

Inui, M. and Miyata, T.: Spaciousness in Interiors. Lighting Research and Technology, vol. 5, no. 2, 1973, pp. 103-111.

Jacobs, K. W. and Hustmyer, F. E.: Effects of Four Psychological Primary Colors on GSR, Heart Rate and Respiration Rate. Perceptual and Motor Skills, vol. 38, 1974, pp. 763-766.

Jacobs, K. W. and Suess, J. F.: Effects of Four Psychological Colors on Anxiety States. Perceptual and Motor Skills, vol. 41, 1975, pp. 201-210.

Johns, E. H. and Sumner, F. C.: Relation of the Brightness Differences of Colors to Their Apparent Distances. Journal of Psychology, vol. 26, 1948, pp. 25-29.

Judd, D. B.: Choosing Pleasant Color Combinations. Lighting Design and Application, August, 1971, pp. 31-41.

Judd, D. B.: A Flattery Index for Artificial Illuminants. Illuminating Engineering, vol. 42, 1967, pp. 593-598.

Judd, D. B. and Nickerson, D.: Relation Between Munsell and Swedish Natural Color System Scales. Journal of the Optical Society of America, vol. 65, no. 1, 1975, pp. 85-90.

Kaiser, P. K.: Physiological Response to Color: A Critical Review. Color Research and Application, vol. 9, no. 1, 1984, pp. 29-36.

Kearney, G. E.: Hue Preferences As A Function of Ambient Temperatures. Australian Journal of Psychology, vol. 18, no. 3, 1966, pp. 271-275.

Kelly, K. L. and Judd, D. B.: Color: Universal Language and Dictionary of Names. National Bureau of Standards, Spec. Publ. 440, 1976.

Kidger, N. The Salyut 6 Space Station. Spaceflight, vol. 21, no. 4, 1979, pp. 178-183.



Kitayev-Smyk, L. A.: Optical Illusions in People in Weightlessness and With the Combined Effect of Weightlessness, Angular and Coriolis Accelerations. Problems of Space Biology, vol. 7, 1967, pp. 180-186.

Kitayev-Smyk, L. A.: The Question of Adaptation in Weightlessness. B. N. Petrov, B. F. Lomov and N. D. Samsonov, eds., Psychological Problems of Space Flight. NASA TM-75659, October, 1979, pp. 204-233.

Kitayev-Smyk, L. A.: Study of Achromatic and Chromatic Visual Sensitivity During Short Periods of Weightlessness. Problems of Physiological Optics, vol. 15, pp. 155-159, (N72-15028 06-04).

Kleeman, W.: The Challenge of Interior Design. CBI Publishing Co., Inc. (Boston:), 1981.

Konovalov, B.: New Features of Salyut 7 Station. USSR Report #17, August, 1982, pp. 6-8.

Kron, J.: Home-Psych: The Social Psychology of Home and Decoration. Clarkson N. Potter, Inc., (New York:), 1983.

Kuller, R.: Architecture and Emotion. B. Mikellides, ed., Architecture for People. Studio Vista, (London:), 1980a, pp. 87-100.

Kuller, R.: Differing Demands on Interior Space in Navel Environments. Conflicting Experiences of Space, Proceedings of the 4th I.A.P.C., Volume II, (Louvain-la-Neuve:), 1979, pp. 645-654.

Kuller, R.: The Function of an Interior As a Function of Its Colour. B. Honikman, ed., Proceedings of the Architectural Psychology Conference at Kingston Polytechnic. Kingston Polytechnic and RIBA Publications, (London:), 1970, pp. 49-53.

Kuller, R.: Non-Visual Effects of Daylight. I. J. Krochman, ed., Proceedings of the Symposium on Daylight: Physical, Psychological and Architectural Aspects. Commission International De L'Eclairage, (West Germany:), 1980b, pp. 172-181.

Kuller, R.: Non-Visual Effects of Light and Colour: Annotated Bibliography. The Swedish Council for Building Research, (Stockholm:), 1981.

Kuller, R.: Seeing Red. Working Environments, 1985.

Kuller, R.: The Use of Space - Some Physiological and Philosophical Aspects. P. Korosec-Serfaty, ed., Appropriation of Space. Proceedings of the Strasbourg Conference, CIACO, (Louvain-la-Neuve:), 1976, pp. 154-163.

Kunishima, M. and Yanse, T.: Visual Effects of Wall Colours in Living Rooms. *Ergonomics*, vol. 28, no. 6, 1985, pp. 869-882.

Lin, A. C. and Bennett, C.: Lamps for Lighting People. *Lighting Design and Application*, vol. 13, no. 2, 1983, pp. 42-44.

Livesey, P. J.: Learning and Emotion: A Biological Synthesis. Vol. 1. Lawrence Erlbaum Associates (Hillsdale, N.J.), 1986.

Luckiesh, M.: On "Retiring" and "Advancing" Colors. *American Journal of Psychology*, vo. 29, 1918, pp. 182-186.

Luria, S. M. and Kobus, D. A.: Red Light. White Light. Proceedings of U. S. Naval Institute, August 1985, pp. 123-126.

Mikellides, B.: Conflicting Experiences of Color Space. J.G. Simon, ed., Conflicting Experiences of Space. Proceedings of the 4th I. A. P. C., Vol.II, (Louvain-la-Neuve:), 1979, pp. 679-703.

Minato, S.: Color in Industrial Design. F. W. Billmeyer and G. Wyszecki, eds., AIC Color 77, Proceedings of the Third Congress of the International Colour Association. Adam Hilger Ltd. (Bristol:), 1977, pp. 199-207.

Mogensen, M. F. and English, H. B.: The Apparent Warmth of Colors. *American Journal of Psychology*, vol. 37, 1926, pp. 427-428.

Mount, G. E., Case, H. W., Sanderson, J. W. and Brenner, R.: Distance Judgment of Colored Objects, *Journal of General Psychology*, vol. 55, 1956, pp. 207-214.

Murray, D. C. and Deabler, H. L.: Colors and Mood Tones. *Journal of Applied Psychology*, vol. 41, 1957, pp. 279-283.

Nakashima, T.: Contributions to the Study of the Affective Processes. *American Journal of Psychology*, vol. 20, 1909, pp. 157-193.

Nakshian, J. S.: The Effect of Red and Green Surroundings on Behavior. *Journal of General Psychology*, vol. 70, 1964, pp. 143-161.

Nassau, K.: *The Physics and Chemistry of Color: The Fifteen Causes of Color*. John Wiley and Sons, (New York:), 1983.

Neri, D. F., Luria, S. M., and Kobus, D. A.: The Detection of Various Color Combination Under Different Chromatic Ambient Illuminations. *Aviation, Space, and Environmental Medicine*, June, 1986, pp. 555-560.

Newsome, R. L.: Food Colors. *Food Technology*, July, 1986, pp. 49-56.

Norman, C.: Mexico Acts to Protect Overwintering Monarchs. *Science*, vol. 233, 19 September, 1986, pp. 1252-1253.

Norman, R. D. and Scott, W.A.: Color and Affect: A Review and Semantic Evaluation. *Journal of General Psychology*, vol. 46, 1952, pp. 185-223.

Nourse, E. W. and Welch, R. B.: Emotional Attributes of Colour: A Comparison of Violet and Green. *Perceptual and Motor Skills*, vol. 32, 1971, pp. 403-406.

Oberg, J. E.: *Red Star in Orbit*. Random House, (New York), 1981.

Osgood, C. E., Suci, G. J., and Tannenbaum, P. H.: *The Measurement of Meaning*. University of Illinois Press, (Urbana:), 1957.

Oyama, T. and Nanri, R.: The Effects of Hue and Brightness on the Size Perception. *Japanese Psychological Research*, vol. 2, no. 1, 1960, pp. 13-20.

Payne, M. C.: Apparent Weight As a Function of Hue. *American Journal of Psychology*, vol. 74, 1961, pp. 104-105.

Payne, M. C.: Color As an Independent Variable in Perceptual Research. *Psychological Bulletin*, vol. 61, no. 3, 1964, pp. 199-208.

Paznik, M. J.: Ergonomics Does Pay. *Administrative Management*. August, 1986, pp. 16-24.

Pedersen, D. M., Johnson, M. and West, J. H.: Effects of Room Hue on Ratings of Self, Other and Environment. *Perceptual and Motor Skills*, vol. 46, 1978, pp. 403-410.

Pellegrini, R. J., Schauss, A. G., and Miller, M.: Room Color and Aggression in a Criminal Detention Holding Cell: A Test of the "Tranquilizing Pink" Hypothesis. *Orthomolecular Psychiatry*, vol. 10, no. 3, 1981, pp. 174-181.

Petrov, Y. A.: Habitability of Spacecraft. M. Calvin and O. G. Gazenko, eds., Foundations of Space Biology and Medicine, Vol. III. NASA Scientific and Technical Information Office, (Washington, D.C.), 1975, pp. 157-192.

Pillsbury, W. B. and Schaefer, B. R.: A Note on Advancing-Retreating Colors. American Journal of Psychology, vol. 49, 1937, pp. 126-130.

Pinkerton, E. and Humphrey, N. K.: The Apparent Heaviness of Colors. Nature, vol. 250 (5462), 1974, pp. 164-165.

Plack, J. J. and Shick, J.: The Effects of Color on Human Behavior. Journal of Association for the Study of Perception, vol. 9, no. 1, 1974, pp. 4-16.

Porter, T. and Mikellides, B.: Color for Architecture. Van Nostrand Reinhold Co., (New York:), 1976a.

Porter, T. and Mikellides, B.: Color in Architecture. Architectural Design, vo. 10, 1976b, pp. 614-618.

Ramkumar, V. and Bennett, C. A.: How Big Is Dark? Proceedings of the Human Factors Society -23rd Annual Meeting, 1979, pp. 116-118.

Red is Sexy, Yellow...? Time, September 24, 1979.

Reddy, T. V. and Bennett, C. A.: Cultural Differences in Color Preferences. Proceedings of the Human Factors Society - 29th Annual Meeting, 1985, pp. 590-593.

Renner, L.: Loud or Soft, Every Color Has Its Say. Orlando Sentinel, July 22, 1984.

A Reporter At Large - Life In a Space Station I. The New Yorker, August 30, 1976, pp. 34-65.

A Reporter At Large - Life In a Space Station II. The New Yorker, September 6, 1976, pp. 34-69.

Rice, A. H.: Color: What Research Knows About the Classroom. Nation's Schools, vol. 52, 1953, pp. 1-8;64.

Rogers, J.: Environmental Needs of Individuals and Groups. E. C. Wortz and M. R. Gauert, eds., Proceedings of the 28th Annual Conference CCAIA. Monterey, California, 1973, pp. 54-62.

Rohles, F. H. and Laviana, J. E.: Indoor Climate: New Approaches to Measuring How You Feel. Proceedings of the CLIMA 2000, World Congress on Heating, Ventilating, and Air Conditioning. Copenhagen, vol. 4, 1985, pp. 1-6.

Rohles, F. H. and Milliken, G. A.: A Scaling Procedure for Environmental Research. Proceedings of the Human Factors Society - 25th Annual Meeting, 1981, pp. 472-476.

Rohles, F. H. and Wells, W. V.: The Role of Environmental Antecedents on Subsequent Thermal Comfort. ASHRAE Transactions, vol. 83, 1977, pp. 21-29.

Rohles, F. H., Bennett, C. A., and Milliken, G. A.: The Interaction of the Visual and Thermal Environments on the Comfort and Acceptance of Indoor Space. Institute for Environmental Research, Report No. 80-04, Manhattan, Kansas, 1980.

Rohles, F. H., Bennett, C. A., and Milliken, G. A.: The Effects of Lighting, Color and Room Decor on Thermal Comfort. ASHRAE Transactions, vol. 87, no. 11, 1981, pp. 511-527.

Rosenfeld, A. H.: The Archaeology of Affect. National Institute of Mental Health, Rockville, Maryland, 1976.

Sanders, C. L.: Color Preferences for Natural Objects. Illuminating Engineering, vol. 54, 1959, pp. 452-456.

Schachter, S. and Singer, J. E.: Cognitive, Social and Physiological Determinants of Emotional State. Psychological Review, vol. 69, no. 5, 1962, pp. 379-399.

Schaie, K. W.: Scaling the Associations Between Colors and Mood Tones. American Journal of Psychology, vol. 74, 1961, pp. 266-273.

Schauss, A. G.: Tranquilizing Effects of Color Reduces Aggressive Behavior and Potential Violence. Orthomolecular Psychiatry, vol. 8, no. 4, 1979, pp. 218-221.

Sharpe, D. T.: The Psychology of Color and Design. Littlefield, Adams and Co., (New Jersey:), 1981.

Siple, P. and Springer, R. M.: Memory and Preference for the Colors of Objects. *Perception and Psychophysics*, vol. 34, no. 4, 1983, pp. 363-370.

Sivik, L.: Color Meaning and Perceptual Color Dimensions: A Study of Color Samples. *Goteborg Psychological Reports*, vol. 4, no. 1, 1974a.

Sivik, L.: Color Meaning and Perceptual Color Dimensions: A Study of Exterior Colors. *Goteborg Psychological Reports*, vol. 4, no. 11, 1974b.

Sivik, L.: Measuring the Meaning of Colors: Problems of Semantic Bipolarity. *Goteborg Psychological Reports*, vol. 4, no. 13, 1974c.

Sivik, L.: Measuring the Meaning of Colors: Reliability and Stability. *Goteborg Psychological Reports*, vol. 4, no. 12, 1974d.

Sivik, L.: Studies of Color Meaning. *Man-Environment Systems*, vol. 5, 1975, pp. 155-160.

Sivik, L. and Hard, A.: Color-Man-Environment: A Swedish Building Research Project. *Man-Environment Systems*, vol. 9, no. 4 and 5, 1979, pp. 213-216.

Sivik, L. and Hard, A. Methodological Studies of Color Changes Due to Distance and Lighting: Direct Assessment Using the Natural Color System. F. W. Billmeyer and G. Wyszecki, eds., *AIC Color 77, Proceedings of the Third Congress of the International Colour Association*. Adam Hilger Ltd., (Bristol:), 1977, pp. 362-364.

Skylab Experience Bulletin No. 18: Evaluation of Skylab IVA Architecture. Johnson Space Center, Houston, Texas, December, 1975, JSC-09552.

Slatter, P. E. and Whitfield, T. W. A.: Room Function and Appropriateness Judgments of Colour. *Perceptual and Motor Skills*, vol. 45, 1977, pp. 1068-1070.

Smets, G.: Time Expression of Red and Blue. *Perceptual and Motor Skills*, vol. 29, 1969, pp. 511-514.

Smets, G.: A Tool for Measuring Relative Effects of Hue, Brightness and Saturation in Color Pleasantness. *Perceptual and Motor Skills*, 1982, pp. 1159-1164.

Srivastava, R. J. and Peel, T. S.: Human Movement As a Function of Color Stimulation. Environmental Research Foundation, Topeka, Kansas, 1968.

Stanwood, L.: Specifying Color. Construction Specifier, June, 1983, pp. 50-55.

Stark, G. M., Saunders, D. M. and Wookey, P. E.: Differential Effects of Red and Blue Coloured Lighting on Gambling Behavior. Current Psychological Research, vol. 2, 1982, pp. 95-100.

Styne, A. F.: Lighting and Colour in Architectural Space. IES Lighting Review, December, 1979, pp. 142-144.

Sucov, E. W.: A Review of Research on the Psychological Influence of Color on People. Westinghouse Research Laboratories, (Pittsburgh, Pa.), 1973.

Taylor, I. L. and Sumner, F. C.: Actual Brightness and Distance of Individual Color When Their Apparent Distance Is Held Constant. Journal of Psychology, vol. 19, 1945, pp. 79-85.

Tedford, W. H., Bergquist, S. L. and Flynn, W. E.: The Size-Color Illusion. Journal of General Psychology, vol. 97, no. 1, 1977, pp. 145-149.

Thorne, J.: We're Learning to Put Color's Power to Work. Seattle Times, September 7, 1980.

Tiedje, B.: Spaciousness: The Reality and the Illusion. Unpublished Masters Thesis, Department of Architecture, University of Washington, Seattle, Washington, 1986.

Tinker, M. A.: Effect of Stimulus Texture Upon Apparent Warmth and Affective Values of Colors. American Journal of Psychology, 1938, pp. 532-535.

Tuan, Yi-Fu: Topophilia: A Study of Environmental Perception, Attitudes and Values. Prentice-Hall, Inc., (Englewood Cliffs, N.J.), 1974.

U. S. Navy Shipboard Color Coordination Guidance Manual, NAVSEA 0929-002-7010, Man Factors, Inc., 1975.

Walton, W. E., Guilford, R. B., and Guilford, J. P.: Color Preferences of 1279 University Students. American Journal of Psychology, vol. 45, 1933, pp. 322-328.

Walters, J., Apter, M. J. and Svebak, S.: Color Preference, Arousal, and Theory of Psychological Reversals. *Motivation and Emotion*, vol. 6, no. 3, 1982, pp. 193-215.

Washburn, M. F.: A Note on Affective Value of Color. *American Journal of Psychology*, vol. 22, 1911, pp. 114-115.

Washburn, M. F. and Grose, S. L.: Voluntary Control of Likes and Dislikes: The Effects of an Attempt Voluntarily to Change the Affective Value of Colors. *American Journal of Psychology*, vol. 32, 1921, pp. 284-289.

Washburn, M. F., McLean, K. G. , and Dodge, A.: The Effect of Area on the Pleasantness and Unpleasantness of Colors. *American Journal of Psychology*, vol. 46, 1934, pp. 638-640.

Wexner, L. B.: The Degree to Which Colors (Hues) Are Associated with Mood Tones. *Journal of Applied Psychology*, vol. 38, 1954, pp. 432-435.

White, W. J.: Effects of Transient Weightlessness on Brightness Discrimination. *Aerospace Medicine*, April, 1965, pp. 327-331.

Whitfield, A.: Individual Differences in Evaluation of Architectural Colour: Categorization Effects. *Perceptual and Motor Skills*, vol. 59, 1984, pp. 183-186.

Whitfield, T. W. A. and Slatter, P. E.: Aesthetic Aspects of Colour in Buildings: Recent Empirical Developments. *Planning Outlook*, Spring, 1978a, vol. 21, no. 1, pp. 31-34.

Whitfield, T. W. A. and Slatter, P. E.: The Evaluation of Architectural Interior Color As a Function of Style of Furnishings: Categorization Effects. *Scandinavian Journal of Psychology*, vol. 19, 1978b, pp. 251-255.

Whitfield, T. W. A. and Wiltshire, T. J.: The Influence of Contextual Variables on Colour Selection for Buildings. *Color 77. The Third Congress of the International Colour Association*, Rensselaes Polytechnic Institute, Adam Hilger, (Bristol), 1977, pp. 391-393.

Wilson, G. D.: Arousal Properties of Red vs. Green. *Perceptual and Motor Skills*, vol. 23, 1966, pp. 947-949.



Wilson, N. J. and Wilson, W. P.: The Duration of Human Electroencephalographic Arousal Responses Elicited by Photic Stimulation. *Electroencephalography and Clinical Neurophysiology*, vol. 11, 1959, pp. 85-91.

Wineman, J. D.: Color in Environmental Design: Its Impact on Human Behavior. In *Environmental Design: Research Theory and Applications*, EDRA 10, 1979, pp. 436-439.

Wise, J. A.: The Quantitative Modelling of Human Spatial Habitability. NASA Grant No. NAG 2-346, 1985.

Wise, J. A. and Hogan, T.: Interior Geometry and Spatial Disorientation in Zero-G: A Mental Rotations Approach, In Preparation.

Wise, J. A. and Rosenberg, E.: The Effects of Interior Treatments on Performance Stress in Three Types of Mental Tasks, In Preparation.

Woodson, W. E.: *Human Factors Design Handbook*. Mc-Graw Hill Book, Co., (New York:), 1981.

Wright, B.: The Influence of Hue, Lightness, and Saturation on Apparent Warmth and Weight. *American Journal of Psychology*, vol. 75, 1962, pp. 232-241.

Wright, D.: The Perception of Light and Colour. W. W. Dawson and J. M. Enoch, eds., *Foundations of Sensory Science*. Springer-Verlag, (Berlin:), 1984, pp. 229-258.

Wright, B. and Rainwater, L.: The Meanings of Color. *Journal of General Psychology*, vol. 67, 1962, pp. 89-99.

Xu, H.: Color-Rendering Capacity of Illumination. *Journal of the Optical Society of America*, vol. 73, no. 12, 1983, pp. 1709-1713.

Zajonc, R. B.: Feeling and Thinking: Preferences Need No Inferences. *American Psychologist*, vol. 35, no. 2, 1980, pp. 151-175.



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16. Abstract The purpose of this study was to review the literature on environmental color to enhance habitability in the design of Space Station interiors. The investigators reviewed approximately 200 studies to determine the relative contributions of the three dimensions of color (hue, saturation, and brightness or lightness) to responses to environmental colorations. Implications of the study for color usage in novel settings and locales include: 1) There are no "hard-wired" linkages between environmental colors and particular judgmental or emotional states; 2) Perceptual impressions of color applications can, however, affect experiences and performances in settings; 3) Color behavior studies cannot yet specify an optimal color scheme, but instead must consider differing objectives, the relative importance of each, and design features such as the coordination of geometry, color, texture, etc.; 4) Some color-behavior effects are governed by low-level retinal and limbic mechanisms as well as by cognitive processes; and 5) Colors should first be specified in terms of what they are to do instead of what they are. Some exercise of choice is therefore needed to establish a sense of personal competence in the setting, since color must be ultimately accepted by the people who are to live with it. Note: Empirical research is now in progress within the NASA/ARC Habitability Research Program to validate the conclusions from this literature review.					
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