SURFACE LIGHTNESS AND SIZE AND DISTANCE EFFECTS

by

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INTRODUCTION

The study of color has been a science ever since Sir Isaac Newton succeeded in breaking down day light into its component spectral colors by means of a glass prism. Before that, even from the most remote times, man had associated certain qualities with certain colors. Once it was known that color exists only in light, it was easy to experiment with it.

Color has two main functions in architectural design. The direct effect of it is its pleasantness. There are also various possible indirect effects.

On reviewing the literature on human-reactions to color, Guilford (1934) concluded that there was increasing preference for increasing lightness. In a study by Helson and Lansford (1970), it was found that higher lightness contrast combinations of object and background colors were liked better than either high or low lightness object colors. Cheskin (1947), while describing the preference of colors, wrote that persons of European peasant origin showed a preference for pure, bright colors while their city-bred children generally prefered more neutral and delicate colors. Further, he claimed that Latin people prefer warm colors such as red, yellow and orange, whereas Swedish and Danish people generally like cool colors such as blue, green and purple. It seems that color liking differs in various countries in accordance with the type of civilization or culture.

The terms "cool" and "warm" as used in relation to light do not refer to sensations of temperature but are only visual sensations. Bennett and Rey (1972) conducted an experiment with subjects wearing red, blue, and clear

goggles and concluded that hue produces a strictly intelluctual effect, a belief that one is warmer or cooler but does not affect one's thermal comfort. They report other research to the same effect.

Another indirect use of color is to make the room surface - walls and ceilings appear closer or farther away in order to produce a feeling that the room is smaller or bigger. Today, the greatest ingenuity is directed towards this art of space production to fulfill the needs of people. Most people are inclined to think of the character of a room in terms of the uses to which it is built. The walls of the room can be altered without considerable expense to make the room look bigger or smaller by the application of colors.

In the planning of buildings, the architect is dealing with appearance (size) of space which he encloses by walls and roof. Suppose, for example, that the architect is dealing with a series of three rooms, all communicating with each other through wide openings and that these three rooms are of restricted dimensions. Further, it is desired to minimize the cramped effect. Robertson (1932) says that the architect would like to select colors to produce a reaction in the occupants that three rooms appear larger, which is the most economical approach.

Various design principles are followed by the designers with respect to color and apparent distance and size. One rule of thumb used by designers is that "warm colors" appear to be closer and "cool colors" appear to be farther away. That is, under a restricted area constraint, designers would try to make the room appear larger or smaller through the application of colors. For instance, Leventhal (1936) commented on the effect of color

that red is perceived closest, green somewhat farther away and blue still farther in relation to gray.

This effect of hue on apparent distance and size may be due to the different refractive indices of eye media and that there may be a displacement of the colored (hue) images such that the red has to be farther or closer than the blue in order to seem to be in the same plane. Further if this hue effect holds, it may also be that the same effect would subside as the hue saturation is reduced.

In a second possible color effect, Bennett (1977) writes that, a "too-high" ceiling might be painted a dark color to make it appear closer and that light colored walls are supposed to make the room seem more spacious (walls recede). Two explanations may be given to this tendency of colors with higher reflectance to appear farther than dark ones. On the physical side, the various colors reflect from a constant distance different amounts of light to the retina ranging from 2.3 percent in the case of black to 80 or 90 percent in the case of white. The light is transmitted to retina, and the retina is excited. In turn, the more intensely the retina is excited, the more intense is the visual sensation. This sensation may be interpreted as distance. There is another physical factor which is interrelated with the lightness that is associated with the intensity of the stimulus. There might be irradiation which makes a bright object appear larger by virtue of the "spreading" of light in all directions and with a corresponding loss in sharp definition of its contours.

Some research has been done of the color effect on apparent distance and size and some of the outcomes were contradictory. Since the results

of previous studies on this subject have been inconclusive, the effect of color on apparent distance and size is a challange to scientists, and requires further research.

Color

There are three dimensions to color. "Hue" is the dimension that varies with wavelength of light, distinguishing such entities as red, yellow, orange, green, blue, purple and corresponding to what is sometimes called "color". Another critical aspect of light and one of the dimensions of color is "value", defined as reflectance and related to luminance or brightness or lightness. "Chroma" or "saturation" are terms for the third dimension of color, which varies with the purity or complexity of the combination of wavelengths of light that make up a given color. Highly saturated colors are sometimes called, "rich" colors.

The system of color notation developed by Munsell (1915) identifies color in terms of the three attributes: hue, value and chroma. The hue (H) notation of a color indicates its relation to a visually equally-spaced scale of 100 hues. There are ten major hues (five principal and five intermediate) positioned in ten hue steps apart within this scale as shown in Figure 1. The value (V) notation indicates the lightness or darkness of a color in relation to neutral gray scale, which extends from absolute black to absolute white. The value symbol 0/ is used for absolute black; the symbol 10/ is used for absolute white. The chroma (C) notation indicates the degree of departure of a given hue from neutral gray of the same value. The scale of chroma extends from /0 for a neutral gray out to /10, /12, /14 or further for highly saturated colors.

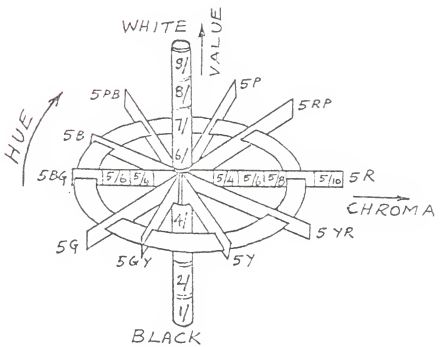

Figure 1. Hue, Value and Chroma Scales Arranged in Color Space.

One of the major problems with color research is that it is difficult to produce color stimuli in which the three dimensions are varied in a controlled fashion without simultaneous or confounded changes in two or three of the dimensions. Many researchers have not been scrupulous about this.

Literature Review

An early study by Luckiesh (1918) on "retiring" and "advancing" (warm and cool) hues, attempted to ascertain the magnitude of this color effect on apparent distance. He used two wooden boxes, each containing a tungsten lamp and each equipped with an aperture covered with opal glass. A red filter of fairly high purity and an opaque card cut to a plain letter "X" form were placed in one box before the diffusing glass. The other box was similarly equipped with a blue filter and a letter "E" cut from an opaque card. The two boxes could be moved to and fro by the observer. The two colored letters which stood out in space in a dark room were adjusted to appear in the same plane, by moving one of the boxes back and forth while the other was kept in a fixed position. The experiment was performed with nine subjects. The result indicated that there was a displacement of the colored images such that the red "X" had to be farther from the observer than the blue "E" in order to appear in the same plane. This hue effect was found to be quite small: 39 millimeters at a 2.5 meters viewing distance (1.4%) and 127 millimeters at a 7.25 meters viewing distance (1.7%). No statistical significance test was performed. Also there is a possibility that luminance and saturation might have been confounded with hue.

Warden and Flynn (1926) studied the hue effect on apparent size using identical cartons, covered with Hering's paper of different hues, arranged

in a series selected by chance. The succeeding arrangements of the cartons were made by a systematic rotation of the cartons from left to right. The color dimensions might have been controlled by the kind of paper used, but no detail information is available. The experiment was carried out with eight arrangements of eight different colored cartons and running six subjects. The subjects were instructed to indicate by numbers opposite the colors the relative size of the different cartons. The amount of hue effect varied considerably from one arrangement to another. It is to be noted here that the color stimuli were produced in which the three dimensions might have not been controlled without simultaneous confounded changes in two or three dimensions. The relative values of the carton sizes were ranked in each arrangement and the combined averages of eight series were computed for each hue. The maximum hue effect was found to be 8 percent. No statistical test was carried out on this result. It may be said that the result is inconclusive due to possible confounding of reflectance and saturation with hue and lack of significance testing. They reported that the amount and definiteness of the hue effect on size is governed by the specific arrangement of the hues. That is, the size perception is dependent upon the total contrast effect of the hues produced by a specific arrangement of hues and not by the individual hue.

Gundlach and Macoubrey (1931) did an investigation to check Warden and Flynn's (1926) results by duplicating their method and using Milton Bradley's color paper. This might have controlled the color dimensions but no information is available on the color characteristics of Bradley's paper. The stimuli were exposed on an openshelf instead of in a glass fronted case.

The total averages of eight arrangements for each hue were calculated and compared. The standard deviations of the distribution of the averages were calculated and found to be quite different from one another. No significance testing was carried out. In contrast to the findings of Warden and Flynn, it appeared in this study that the effect of hue on apparent size is present to a certain degree under every arrangement and was found to be a maximum of 22 percent based on average of eight arrangements. It was concluded that there was a hue effect on apparent size. It was found in this study that while investigating the effect of hue, the influence of reflectance and saturation have been neglected. The result is inconclusive due to possible confounding and lack of significance testing.

Katz (1935), used broad headed nails on a wooden board wrapped with red and blue papers alternately to study the effect of hue on distance. It is understood from the report of this study that the reflectance and the saturation of red and blue papers were not controlled. At a viewing distance of approximately thirty-one inches, the reds appeared nearer than the blues by about one percent of the viewing distance. It may be said that the result could not be generalized due to confounding of saturation and reflectance and due to lack of significance testing.

In another study by Pillsbury and Schaffer (1937), subjects viewed red from neon light and blue from neon and argon under circumstances in which the size of the light was compensated at different distances to give the same retinal image. This was achieved by moving the lights on parallel rails which in turn narrowed the slit through which the lights were seen. It was found for eleven out of fifteen observers that the blue light appeared

nearer by three percent than red. No statistical analysis was presented. Again the result is inconclusive due to the absence of significance testing and possible confounding of luminance and saturation.

Taylor and Summner (1945), performed an experiment with a wooden cabinet painted flat black inside and fit snugly over a Howard-Dohlman depth perception apparatus. The apparatus was illuminated by a 40-watt fluorescent lamp and consisted of a stationary vertical pole and a movable pole. The stationary pole was covered with neutral gray paper tubing and the movable pole was covered with one of six colored paper tubings, with different lightness. These colored tubings were varied on the movable pole in the course of the experiment. Eleven subjects were used and were asked to adjust the position of the movable pole so as to put it in line with the fixed pole kept on the left side and at a distance of 90 incnes. The result was that when the apparent distances of the different colors were held constant, the "bright" colors (higher reflectance - white, yellow and green) were actually farther than they appeared to be by 22 percent, while the "darker" colors (red, blue and black) were actually farther than they appeared to be by only 0.02 percent (compared to gray).

One of the shortcomings of this study is that hue and saturation may be confounded. Also no statistical analysis was presented to reinforce the result. On the basis of the above two points, it may be said that the result is inconclusive.

Another limitation in Taylor and Summner's method may be based on subjects reports that relative distinctness, relative sharpness of the

vertical edges and relative thickness of the poles served as cues in their attempts to equalize the distance of the two poles.

Three years later, Johns and Sumner (1948) repeated the same experiment under identical conditions with two exceptions. The subjects were different and the movable pole to the subject's right eye was constantly covered with the neutral gray paper tubing while the six colored paper tubings were rotated on the stationary pole. They arrived at a result by ranking the means of the distance between the reference pole and the movable pole. At a constant distance "bright" colors (higher reflectances) appeared to be closer than dark colors, with respect to neutral gray. White, yellow and green appeared nearer by only 0.09, 0.06 and 0.05 percent respectively and red, blue and black appeared farther away by only 0.11, 0.13 and 0.11 percent, respectively. The result is inconclusive on the same basis of shortcomings of Taylor and Sumner's study, three years before.

Hanes (1960) carried out two experiments and came up with results partially contrary to the design rules of thumb. In his first experiment, a special depth-perception apparatus was used with painted test materials. This laboratory set-up was intended to measure independently the effects of each of the three color dimensions (hue, brightness and saturation). Results indicated that increasing brightness could cause apparent distance being closer by as much as five to seventeen percent. Hue effects varied between nine and nineteen percent for saturated (strong) hues and between two and three percent for relatively unsaturated hues with red and yellow appearing to advance relative to green and blue. No statistical analysis was presented.

With evidence that color can cause considerable change in the apparent distance of surfaces under laboratory conditions, Hanes conducted his second experiment to test such effects in a more realistic applied situation. He setup a room shell (12 feet long, 22 feet wide and 8 feet high) with a movable end wall on one side and a luminous ceiling to give uniform illumination. The side walls and the fixed end wall were painted a medium gray. Provision was made on the removable wall side for easy transfer of colors (red, yellow, green, blue, black, light gray, white and medium gray) and easy forward-backward movement of those walls. Subjects were seated in a fixed position ten feet from the standard gray wall and asked to make two settings for each of seven colored walls so that the gray stationary wall and the movable colored wall appeared equidistant to the subject. The average distance setting for various hues indicated that hues have a significant effect on apparent distance and that yellow appeared to be closest to the subjects with red and green next, white third, then light gray, blue and black. While considering the lightness dimensions alone, the order from most to least "advancing" was white, light gray and black. This result for lightness was exactly opposite to what is customarily said about the distance effects of black and white. Another finding of Hane's experiment was that the highly saturated colors appeared closer than the medium gray standard.

This study does not present much detail on the control of three dimensions of color. Also no statistical analysis was performed on the results. So the result is inconclusive due to confounding of color dimensions and lack of significance testing.

McCain and Karr (1970) conducted an experiment with two different hues of matched luminance and one year later, repeated the same experiment under six different luminance combination of two hues. Their experimental set up consisted of a depth perception apparatus with a fixed, vertical reference rod and an adjustable vertical rod. Different combinations of white, red and blue were applied to the two rods and subjects viewing the stimuli at a distance of 6 meters, were asked to move the reference rod. The first experiment showed that the red appeared closer by 0.36 percent with respect to blue, and the blue appeared farther away by 1.36 percent. This was found to be true at the five percent significance level. There is a possibility that the advancing effect of the red might have been larger than the actual due to the receding effect of the reference rod blue and a similar reverse effect might have been true when the blue rod was adjusted with respect to the reference red rod.

The second experiment was conducted with 12 subjects. The luminance of the fixed rod and the adjustable rod were varied under each color combination. Red appeared closer and blue appeared farther under various luminance combinations. At equal luminance levels, the red appeared closer by 0.26 percent with respect to the blue and the blue appeared farther with respect to the red by 0.26 percent. This proved to be true at the five percent significance level but the effect of luminance was found to be insignificant. The only shortcoming of this study is that saturation may be confounded with hue.

Thus, there are many conflicting results from various research on perception of surface lightness right from the time the studies on this subject were begun (Table 1). Two out of three studies on hue effect

TABLE 1. Summary of Previous Studies

AUTHOR AND YEAR	OBJECTIVE OF THE STUDY	APPROACH OF THE STUDY	MAGNITUDE OF THE RESULT	STATISTICAL SIGNIFICANCE	CONCLUSIONS
Luckiesh 1918	Hue and Distance	Two wooden boxes. One with red filter and a letter "X" cut from card board. The other one with blue filter paper and a letter "I". Both equipped with tungsten lamp. Adjust and put them in a plane. Luminance and saturation may be confounded.	Red appeared closer by 1.4 percent at 2.5 m viewing distance and 1.7 percent at 7.25 m viewing distance than blue.	Not tested.	Small effect. Inconclusive due to possible confounding and lack of significance testing.
Warden and Flynn 1926	Hue and Size	Eight cartons of 8 different hues placed against black wall of a case. Indicate relative size of each carton. Reflectance and saturation may be confounded.	Average relative size of 8 different hues cartons: Red 4.4 Purple 4.7 Yellow 4.9 White 4.9 Green 4.3 Gray 4.5 Blue 4.8 Black 4.3.	Not tested.	Small effect. Inconclusive due to possible confounding and lack of significance testing.
Gundlach and Macumbrey 1933	Hue and Size	Same method as Warden and Flynn. Reflectance and saturation may be confounded.	Average relative size of 8 different hues cartons: Red 5.12 Purple 4.39 Yellow 3.05 White 3.80 Green 3.92 Gray 5.16 Blue 4.54 Black 6.17	Not tested.	Marked effect. Inconclusive due to possible confounding and lack of significance testing.
Katz 1935	Hue and Distance	Nails on a wooden board covered with red and blue papers. Reflectance and saturation may be confounded.	Red appeared nearer than blue by 12 at 31 in. viewing distance.	Not tested.	Small effect. Inconclusive due to possible confounding and lack of significance testing.
Pittsburg and Schaefer 1947	Hue and Distance	Depth perception apparatus. Red from neon light. Blue from argon & neon. Adjust slit to compensate size of light at different distance to give same retinal images. Luminance and saturation may be confounded.	Blue appeared nearer by 3% than red.	Not tested	Small effect. Inconclusive due to possible confounding and lack of significance testing.

TABLE 1. Summary of Previous Studies (continued)

AUTHOR AND YEAR	OBJECTIVE OF THE STUDY	APPROACH OF THE STUDY	MAGNITUDE OF THE RESULT	STATISTICAL SIGNIFICANCE	CONCLUSIONS
Taylor and Sumner 1945	Reflectance and Distance	Depth perception apparatus. Stationary pole - Gray tubing Movable pole - 6 colored tubing.	White, yellow, green appeared closer by 22% & Red, Blue, Black by 0.02% w.r.t. Gray.	Not tested.	Appreciable effect. Inconclusive due to possible conflicting and lack of significance testing.
Johns and Sumner 1948	Reflectance and Distance	Depth perception apparatus. Stationary pole - 6 colored tubing Movable pole - Gray tubing Hue and saturation may be confounded.	Hues of higher reflectance appeared nearer than dark colors. White 0.09% Green 0.05% Black 0.11% Yellow 0.06% Red 0.11% Blue 0.11%	Not tested	Small effect. Inconclusive due to possible confounding and lack of significance testing.
Hanes 1960 I Expt.	Hue, Reflectance, Saturation and Distance.	Depth perception apparatus.	Hue: - 9-14%. For saturated colors. 2-3%. For unsaturated colors. Red & yellow appeared closer relative to Green and Blue Reflectance: - 5-17%. Effect on apparent distance.	Not tested.	Inconclusive due to lack of specific information and lack of significance testing.
Hanes 1960 II Expt.	Hue, Reflectance, Saturation and Distance.	A room shell 12' L x 22' W x 8' H. Gray - Fixed wall. Different color wall - movable. No precise detail about simultaneous changes of Hue, Reflectance and Saturation.	Hue: - Yellow 3 16%, White 2.0% appeared closer w.r.t. Gray. Reflectance: - White, Light Gray, Blue appeared closer in the descending order. Saturation: - Higher saturated walls appeared closer than Graywall.	Not tested.	Inconclusive due to possible confounding and lack of significance testing.
McCain and Karr 1970	Hue Luminance and Distance	Depth perception apparatus. Movable rod and stationary rod. Saturation may be confounded.	Red appeared closer by 0.36% w.r.t. Blue. Blue appeared farther by 1.36% w.r.t. Red.	Five percent significance level.	Acceptable at 5% significance. But control of saturation might have yielded more reliable result.
McCain and Karr 1971	Hue Luminance and Distance	Depth perception apparatus. Movable rod and stationary rod. 6 levels of luminance. Saturation may be confounded.	Red appeared closer by 0.26% w.r.t. Blue. Blue appeared farther by 0.26% w.r.t. Red at equal luminance levels.	Five percent significance level.	Acceptable at 5% significance. But control of saturation might have yielded more reliable result. Effect of luminance found to be insignificant.

resulted in the conclusion that the red appears closer and the blue appears farther and the other study had a reverse effect. Later, two studies claimed that hues with higher reflectance appear farther than dark colors, but it was disproved by Hane's study. Only the study by McCain and Karr presented statistical tests, however, without taking care of confounding of saturation.

So, these unsteady results of the successive studies and lack of statistical testing of the results certainly inspire more research on this topic to obtain better information.

PROBLEM

Most of the research on color effects on apparent size and distance have used some kind of depth perception apparatus and produced minor conflicting results on distance and size reactions to color. Methodologically, the previous research has been weak in not controlling for simultaneous changes in hue, saturation and brightness and in not determining statistical significance of the results. The purpose of the present research is intended to determine specific color effects due to hue, saturation and brightness on apparent distance and size on a quantitative basis using a scale model of a room.

The three hypotheses in this study are

1. Red appears nearer and blue appears farther
2. The lower the saturation, the lesser an advancing hue appears closer and the lower the saturation, the lesser a receding hue appears farther away, and
3. The lesser the lightness, the nearer a wall appears.

METHOD

Assuming an eight foot ceiling, a scale model of thirty (scale) feet long and twelve (scale) feet wide in size was kept at a distance of ten (actual) feet from the subject's binocular vision. The center point of the end wall was in line with the subject's eyes. A chin rest was provided to insure the consistent position of the subject's face. Masking was installed on the chin rest so that the subject's vision was restricted to see only the model room as shown in Figure 2. The background about the model room was covered with black cloth. Two external 200 watt incandescent light sources were placed in such a way to obtain uniform illumination of 60 foot candles throughout the model room.

Two tasks were used in the experiment.

1. Choosing the appropriate size of a model human figure for each of the seven rooms made up of different color characteristics.
2. Judgment of distance of the human figure from the end wall.

Apparatus

A fixture was designed to produce a perspective view model of a room by inserting the various walls. The ceiling of the model was white with 90 percent reflectance and was maintained unchanged throughout the experiment. "Kmart- Acrylic Latex Flat House Paints" of "pure white" and "anchor black" with hue and saturation at zero were mixed to produce a neutral gray of 15 percent reflectance (and zero saturation). The flooring of the room was painted this gray and maintained constant throughout the experiment.

Figure 2. Experimental Setup of the Scale Room Model and Model Human Figure

The seven sets of side walls and end walls were detachable. Two sets of walls were painted red and blue, using "Kmart-Accent Latex Flat Finish Paints" of "aztec red" and laser blue". The color dimensions of them are shown in Table 2 to study the hue effect. The same hues were desaturated by mixing the gray with the saturated paints to produce red and blue with 15 percent reflectance and /5 chroma. This was to enable the evaluation of the effect of saturation on apparent distance and size of hue effects. With the control of hue and saturation at zero, three wall sets were made up of black with six percent reflectance, white with 90 percent reflectance and neutral gray with 15 percent reflectance in order to study the reflectance effect. The determination of hues and saturation levels were made by comparing the samples of painted material with Munsell colors. The reflectance levels were based on measurements with a photometer.

The figures were cut from a cardboard of 0.1 in. thickness maintaining the height required for a perspective view at two inches from the end wall so that when they were superimposed on the back wall the theoretical size of the (female) figures varied from 5.0 (scale) feet to 5.8 (scale) feet. They were painted neutral gray of 35 percent reflectance to simulate caucasion skin reflectance.

Unlike Hane's (1960) study, there was no contrast between the side walls and the end walls.

TABLE 2. Munsell Notation of Colors Used.

Name of Color Dimensions	White	Neutral Gray	Black	Sat. Red	Unsat. Red	Sat. Blue	Unsat. Blue
Munsell Notation	N 9.5/	N 4.5/	N 2.82/	5R 4.5/10	5R 4.5/5	4 PB 4.5/10	4 PB 4.5/5
Reflectance (%)	90	15	6	15	15	15	15

Tasks

The subjects were asked to perform the two tasks according to the instructions given in Figure 3. Subjects placed their faces against a chin rest facing the model at ten (actual) feet from it. The subjects looked at nine different sizes of human figures at random, under each wall condition. The subjects expressed their evaluation as "too-big", or "too-small" or "just about right" depending on the figure's appearance to them, in proportion to the model room. If more than one figure appeared to be "just about right", they were shown again to the subjects. The subjects chose the most appropriate figure after a thorough look at them. All the information expressed by the subjects was recorded on the data sheet (Figure 4) against the respective color.

After the subject had chosen the appropriate size of the figure to fit the room under each condition, after looking at nine different figure sizes, the selected figure was placed at a distance in the range of two (scale) feet to six (scale) feet from the end wall. The subject's estimation of the distance of the figure from the end wall was noted, along with the actual measurement. This was repeated for another distance in the range of six (scale) feet to ten (scale) feet from the end wall. At the end of the experiment subjects were asked for their comments.

Experimental Design

The subjects were shown the colored walls in random sequence and also the order of the figures was randomized for each subject (Appendix 5). Each subject was shown all the conditions of the experiment.

INFORMED CONSENT AND INSTRUCTIONS FOR SUBJECTS

This study is being done to find whether the three characteristics (hue, brightness and saturation) of color have any significant effect on apparent size and distance.

You are asked to place your face on the chin rest and look at the scale model of a room. The experimenter will provide the room with seven different walls and introduce different sizes of human being figure under each wall condition. You are to say whether the figure appears to be "too-small" or "just right" or "too-big" for the room size, under each condition.

After you choose the right figure for the room model, the experimenter will place the figure at a distance from the end wall. You are to judge the distance between the figure and the end wall, say like 2 ft. or 10.75 ft. etc. This will be repeated again for another distance from the end wall. This brings your task to an end.

There are no dangers and risks involved in the experiment. You can take rest any time you wish. However, if you feel very uncomfortable during the experiment, you are free to stop at any time. I hope that you will complete the experiment so that I can collect all the data and complete my research.

You may feel free to ask any question at any time of your participation. If you have any comments about the procedure and the experiment, please write them at the end of the experiment in the place provided on the data sheet. Now, if you are ready for the experiment please sign the consent form given by the experimenter.

I thank you very much for your cooperation.

Figure 3. Instructions.

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NAME: DATE:

COLOR WALL	SIZE OF THE HUMAN BEING FIGURE. 5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	DIST. BET. FIG AND END WALL	ACTUAL DISTANCES
WHITE											
RED											
UN. SAT. RED											
N. GRAY											
UN. SAT. BLUE											
BLUE											
BLACK											

COMMENTS:

Figure 4. Data sheet.

Subject Recruiting Procedure

An incidental sample of acquaintances of the experimenter participated in this study, from various departments of Kansas State University. Twenty subjects of various color eyes (2 green, 3 hazel, 3 blue, 4 brown, 8 dark brown) and different nationalities participated in this experiment. Each subject was paid $2.50 for performing the task which lasted for about 45 minutes.

RESULTS

Twenty sets of data were collected for distance and size evaluation tasks and are shown in Appendices 1, 2, 3 and 4.

The mean values of the difference between the evaluated and the actual distances due to reflectance and hue-saturation effects are shown in Tables 3 and 4 respectively. The mean values of the figure size chosen by the subjects due to reflectance and hue-saturation effects are shown in Tables 3 and 5 respectively.

The analysis of variance was carried out for each characteristic of color wall conditions. The analysis of variance for the reflection and hue-saturation effects on distance are shown in Tables 6 and 8 and their effects on size are shown in Tables 7 and 9.

The relationship between reflectance and distance and between reflectance and size are plotted in Figures 5 and 6. Also the hue effect on distance and the effect of saturation levels of hue on distance are plotted in Figures 7 and 8. Figures 9 and 10 exhibit the hue effect and size variation due to saturation levels of hue respectively.

TABLE 3. Mean Values - Reflectance.

Color	Reflectance	Mean of Distance (Scaled Feet)	Mean of Size (Scaled Feet)
White	90	-1.45	5.52
Neutral Gray	15	0.57	5.25
Black	6	0.81	5.19

- : Appearing farther than the actual.

+ : Appearing closer than the actual.

TABLE 4. Mean Values - Hue, Saturation and Distance (scaled feet).

Colors Satn. Levels	Red	Blue
Saturated	0.92	-1.61
Unsaturated	0.91	-1.36

- : Appearing farther than the actual.

+ : Appearing closer than the actual.

TABLE 5. Mean Values - Hue, Saturation and Size (scaled feet).

Colors Satn. Levels	Red	Blue
Saturated	5.23	5.42
Unsaturated	5.30	5.27

TABLE 6. Analysis of Variance - Reflectance and Distance.

S. No.	Source	S.S.	df	M.S.	F	$\hat{\alpha}$	Denominator
1.	Reflectance	124.67	2	66.33	39.59	0.000	#7
2.	Subjects	46.46	19	2.44	1.55	0.122	#7
3.	Readings	0.08	1	0.08	0.05	0.826	#7
4.	Refl. and Subj.	99.24	38	2.61	1.66	0.062	#7
5.	Refl. and Read.	10.61	2	5.30	3.37	0.045	#7
6.	Subj. and Read.	35.26	19	1.85	1.18	0.323	#7
7.	Error	59.82	38	1.57			
8.	Total	376.15	119				

TABLE 7. Analysis of Variance - Reflectance and Size

S. No.	Source	S.S.	df	M.S.	F	$\hat{\alpha}$	Denominator
1.	Reflectance	1.17	2	0.58	97.15	0.000	#3
2.	Subjects	0.55	19	0.03	4.82	0.000	#3
3.	Error	0.23	38	0.006			
4.	Total	1.95	59				

TABLE 8. Analysis of Variance - Hue, Saturation and Distance.

S. No.	Source	S.S.	df	M.S.	F	$\hat{\alpha}$	Denominator
1.	Hue	232.08	1	232.08	1744.95	0.000	#3
2.	Saturation	0.54	1	0.54	4.06	0.046	#3
3.	Subjects	2.45	19	0.13	0.97	0.501	#4
4.	Readings	0.15	1	0.15	1.17	0.280	#3
5.	Hue and Satn.	0.66	1	0.66	4.98	0.027	#3
6.	Hue and Read.	0.50	1	0.50	3.80	0.053	#3
7.	Satn. and Read.	0.10	1	0.10	0.75	0.387	#3
8.	Hue, Satn and Read.	0.02	1	0.02	0.18	0.665	#3
9.	Error	17.69	133	17.69			
10.	Total	254.21	159				

TABLE 9. Analysis of Variance - Hue, Saturation and Size.

S. No.	Source	S.S.	df	M.S.	F	$\hat{\alpha}$	Denominator
1.	Hue	0.13	1	0.13	14.13	0.001	#7
2.	Subjects	0.87	19	0.04	5.11	0.000	#7
3.	Saturation	0.03	1	0.03	7.79	0.012	#5
4.	Hue and Subj.	0.17	19	0.009	1.01	0.487	#7
5.	Subj. and Satn.	0.08	19	0.004	0.46	0.950	#7
6.	Hue and Satn.	0.22	1	0.22	24.71	0.000	#7
7.	Error	0.17	19	0.009			
8.	Total	1.67	79				

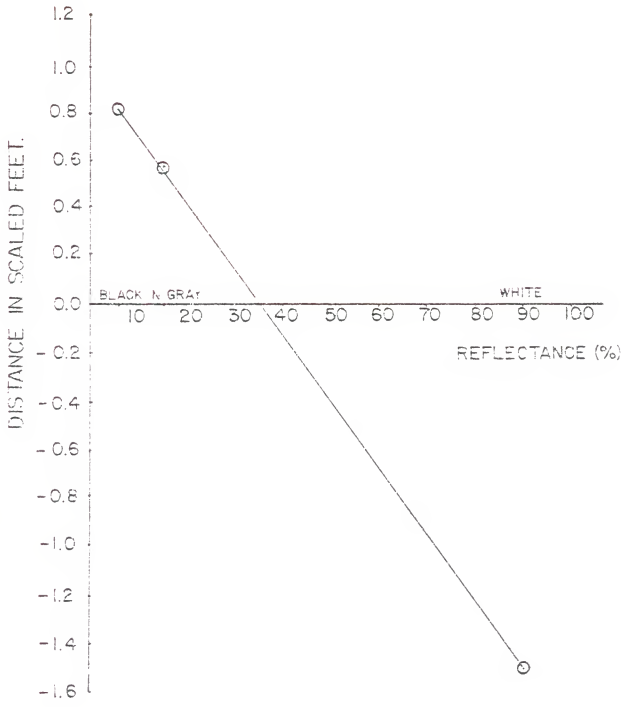

Figure 5. Reflectance Effect on Distance.

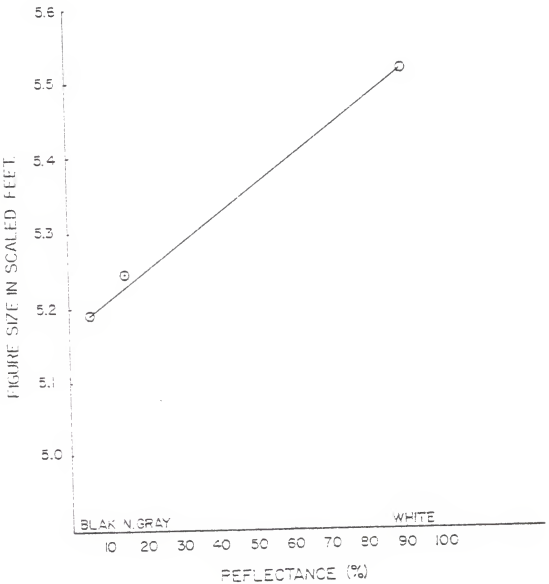

Figure 6. Reflectance Effect on Size.

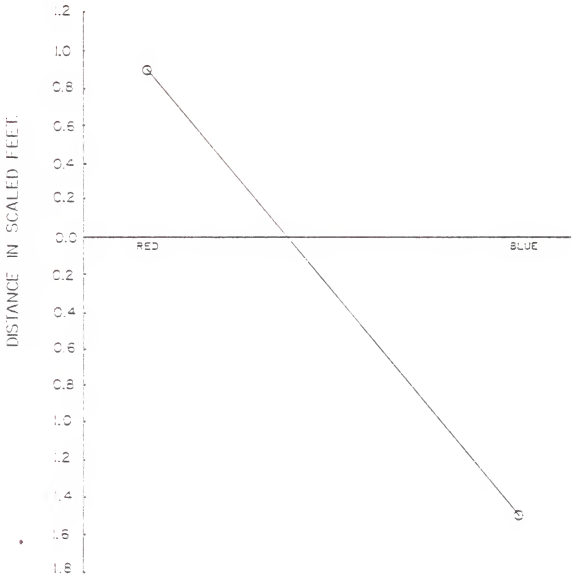

Figure 7. Hue Effect on Distance.

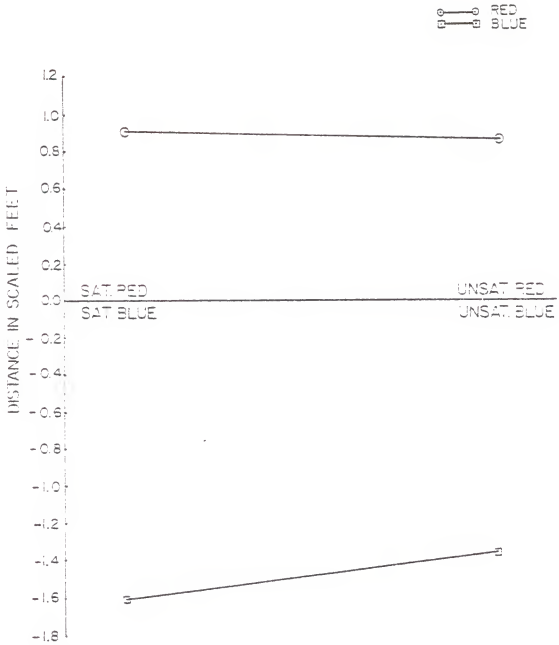

Figure 8. Individual Hues and Their Saturations and Distance.

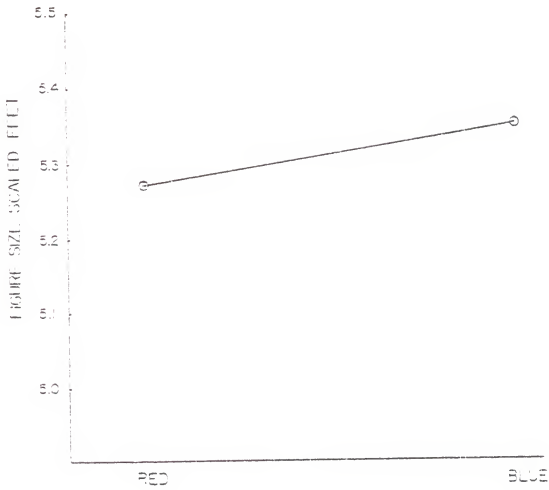

Figure 9. Hue Effect on Size

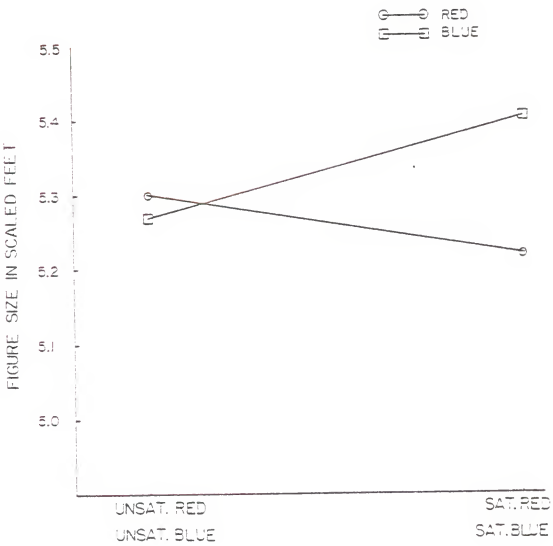

Figure 10. Individual Hues and Their Saturations and Size

DISCUSSION

Reflectance and Distance and Size

The analysis of variance (Table 6) shows that the reflectances are significantly different in terms of distance and the subjects and the interaction between subjects and reflectance are non-significant, at the five per cent significance level. Due to the appropriate direction of differences of means and the significance of F-tests in this and other cases, it was not necessary to perform one tailed t-tests for the directional hypotheses. The apparent distance is influenced by the reflectance of the color being viewed. The direction and magnitude of this effect are shown in Figure 5 and Table 3. It was found that with respect to the actual distance white with 90 percent reflectance appeared to be farthest from the subject by 26.0 percent and as the reflectance is lowered down on the gray scale, the color stimulus was found to be gradually appearing closest by 15.2 percent than the actual distance in the case of black with 6 percent reflectance.

Referring to the Table 7, it can be seen that the reflectance effect on size is significant and its logical explanation may be given as follows with the help of Figure 6. With white which appears to be farther, the model room looks bigger to the subject and the subject selects a figure, bigger by 1.8 percent than the average size, to match the room size. Similarly, with black which appears to be closer, the model room looks smaller and the subject selects a figure, smaller by 3.7 percent than the average size, to match the room size.

Hue and Distance and Size

The analysis of variance (Table 8) shows that hue effect on apparent distance is significant and the subjects and the interaction between subjects and hue are non-significant, at the five percent significance level. That is, red and blue have significantly different effects on distance. The direction and the magnitude may be seen in Figure 7 and Table 4. Red appears closer to the subject by 15.9 percent than the actual distance and blue appears farther by 29.8 percent than the actual distance, at a viewing distance of ten feet. The effect of hue is in line with the findings of previous studies but here the result obtained is statistically significant and without confounding of reflectance or saturation.

As the red appears closer, it makes the room look smaller and the subject selects a figure, smaller by 2.4 percent than the average size, in proportion to the room size. Similarly the size of the figure chosen to fit the blue room is bigger by 3 percent than the average size, due to the receding effect of blue. This is shown in Figure 9 and Table 5.

Saturation and Distance and Size

The saturation effect on distance was found to be significant (Table 8), but the effect was relatively small (Figure 8). By lowering the saturation of red from /10 to /5 chroma, the advancing effect of red reduced from 15.9 percent to 15.3 percent.

Similarly, the receding effect of blue was reduced from 29.8 percent to 23.3 percent by desaturating the blue form /10 to /5 chroma.

Corresponding changes in size due to the saturation levels were also seen (Figure 8). The smallness of the figure chosen was reduced from 2 percent to 1.8 percent as the red is desaturated from /10 to /5 chroma.

That is, as the saturation level decreases, the unsaturated red appears lesser in closeness and the subject choses a figure smaller than that of the saturated red.

The same kind of reverse effect was true for the blue. The size of the figure for the saturated blue was bigger by 3.7 percent than the average size. When the blue was desaturated, the figure chosen was bigger only by 2.4 percent. The direction and magnitude of the saturation effect on apparent size are shown in Figure 10 and Table 5.

General

In this research a full size room was simulated by a scale model room to study the effect of color dimensions individually. It may be hard to believe that a subject could have reasonably selected an appropriate model human figure to match a scale model room. Especially, this might appear to be a guess more than a subjective evaluation when the viewing distance is converted to the scaled feet of 120. But it is interesting to know that in a study conducted by Bennett, Lee, Peterson and Yoon (1978) with five hundred-forty six students serving as judges of the height and weight of a male and a female stimulus person wearing either vertical or horizontal stripes on his clothing at an average viewing distance of 30 feet, judgments in general were quite accurate and the percentage error for the height was very small (0.8%). This supports the present procedure of using subjects' estimations on apparent figure size in the scale model room. The error of judgments might vary depending on the viewing distance by an unappreciable amount, but this is a different issue.

It was found that the effect of reflectance on apparent distance was quite substantial. This result may be very useful to the designers who desire to lower or raise the ceiling or to enlarge or shrink the room size by the application of suitable colored surfaces. This might result in appreciable saving as the above process does not involve any disruption of walls.

Similarly, red and blue have a substantial effect on apparent distance by virtue of which they make the room look smaller or bigger respectively. This finding is a validation of the architectural rule of thumb.

The results due to saturation were statistically significant but the average magnitude of such effect was small and seemingly of little practical consequence.

It is concluded that the experimental control of hue, saturation and reflectance in this study has produced reasonable results on a quantitative basis, taking care of most of the shortcomings of the previous studies.

CONCLUSIONS

From the result of this study the following conclusions can be made for the effect of surface lightness on apparent distance and size.

1. Hues have a significant effect on apparent distance and size. For instance, red appears closer by 15.9 percent and blue appears farther by 29.8 percent than the actual distance. The corresponding effects of red and blue make the room appear smaller or bigger respectively.
2. When the saturation of an advancing hue is reduced, the hue appears less close and when the saturation of a receding hue is reduced, the hue appears less far away. Similarly, the smallness of the stimulus size is reduced due to desaturation of the red and the bigness of the figure size is reduced due to desaturation of the blue.
3. Reflectance influences the apparent distance and size. A color of higher reflectance (white) appears farther away by 26.0 percent making the room look bigger and a color of lower reflectance (black) appears nearer to the observer by 15.2 percent making the room look smaller in size, which is similar to what is customarily said about white and black.
4. The outcome of this study could be used as one of the bases of design to make the rooms look bigger or smaller through an inexpensive design process.

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APPENDICES

APPENDIX 1. Selected Figure Sizes (Scaled Feet).

SUBJECT NO.	WHITE Refl. 90%	NEUTRAL GRAY Refl. 15%	BLACK Refl. 6%
1	5.7	5.4	5.2
2	5.5	5.3	5.1
3	5.5	5.3	5.2
4	5.6	5.3	5.3
5	5.3	5.1	5.1
6	5.4	5.1	5.1
7	5.8	5.3	5.5
8	5.5	5.4	5.3
9	5.4	5.2	5.1
10	5.6	5.3	5.4
11	5.6	5.3	5.3
12	5.6	5.3	5.3
13	5.4	5.2	5.1
14	5.6	5.3	5.2
15	5.6	5.4	5.2
16	5.5	5.2	5.2
17	5.3	5.2	5.1
18	5.5	5.3	5.0
19	5.5	5.1	5.2
20	5.5	5.1	5.0

APPENDIX 2. Evaluated Distance and Actual Distance (Scaled Feet).

SUBJECT NO.	WHITE Refl. 90%				NEUTRAL GRAY Refl. 15%				BLACK Refl. 6%			
	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL
1	3.0	4.0	7.0	8.0	3.5	4.0	9.0	8.0	4.0	4.0	8.0	8.0
2	4.0	4.0	10.0	8.0	3.0	4.0	10.0	8.0	3.0	4.0	9.0	8.0
3	4.0	2.5	8.0	6.5	2.0	4.5	6.0	8.0	3.0	4.0	6.0	7.5
4	3.0	2.5	9.0	8.5	2.5	3.5	6.5	7.5	1.5	4.0	6.0	8.0
5	7.0	5.0	12.0	7.5	2.0	2.5	9.0	6.0	3.0	3.5	5.0	6.0
6	5.0	3.5	10.0	8.0	4.0	3.5	8.0	7.0	3.0	4.0	6.0	6.5
7	6.0	3.5	12.0	9.0	4.0	3.0	7.0	9.0	4.0	4.5	7.0	6.5
8	4.0	4.0	8.5	7.0	2.5	3.0	5.0	6.5	2.0	2.5	6.0	7.0
9	3.5	3.0	14.0	8.5	5.0	4.0	9.0	7.5	2.0	3.0	6.0	7.0
10	4.0	3.0	12.0	9.0	3.0	3.5	7.5	7.5	2.0	3.0	5.0	7.5
11	3.0	3.0	6.5	6.0	4.0	3.5	6.0	10.0	2.0	2.5	6.0	7.5
12	4.0	3.5	10.0	8.0	4.0	4.5	8.0	7.5	3.0	3.5	7.0	7.5
13	4.0	3.0	7.75	6.0	3.0	3.5	7.0	8.0	2.25	4.0	5.0	7.5
14	6.0	3.5	12.0	7.0	5.0	4.0	7.0	10.0	2.0	3.0	5.5	6.0
15	3.0	2.5	8.0	7.5	3.5	4.0	8.0	7.5	3.0	4.0	5.0	6.5
16	4.0	3.0	8.0	6.0	5.0	4.5	13.0	7.5	5.0	4.0	6.0	8.0
17	8.0	3.5	10.0	6.5	3.0	2.5	5.0	10.0	3.0	4.0	6.0	6.5
18	4.0	3.0	10.0	7.5	2.0	3.0	5.5	7.0	3.0	4.0	5.0	8.0
19	4.0	3.5	7.0	7.0	4.0	4.5	8.0	7.5	3.0	3.0	6.0	6.0
20	5.5	4.0	8.0	7.5	2.5	3.0	4.0	9.0	2.0	3.0	5.0	6.0

APPENDIX 3. Selected Figure Sizes (Scaled Feet)

SUBJECT NO.	SAT. RED	SAT. BLUE	UNSAT. RED	UNSAT. BLUE
1	5.4	5.5	5.4	5.2
2	5.3	5.5	5.4	5.3
3	5.3	5.5	5.5	5.3
4	5.4	5.4	5.4	5.3
5	5.0	5.2	5.0	5.3
6	5.2	5.4	5.3	5.1
7	5.6	5.7	5.6	5.6
8	5.3	5.4	5.1	5.4
9	5.1	5.2	5.2	5.0
10	5.2	5.2	5.4	5.3
11	5.2	5.5	5.3	5.3
12	5.3	5.4	5.2	5.3
13	5.1	5.4	5.3	5.3
14	5.3	5.5	5.5	5.4
15	5.3	5.4	5.3	5.4
16	5.1	5.5	5.2	5.1
17	5.2	5.3	5.4	5.1
18	5.1	5.2	5.4	5.3
19	5.2	5.4	5.3	5.4
20	5.2	5.4	5.3	5.2

APPENDIX 4. Evaluated Distance and Actual Distance (Scaled Feet).

SUBJECT NO.	SAT. RED				SAT. BLUE				UNSAT. RED				UNSAT. BLUE			
	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL	EVAL-UATED	ACTUAL
1	3.0	4.0	7.5	8.0	5.5	4.0	9.5	8.0	3.5	4.0	6.5	8.0	5.5	4.0	9.5	8.0
2	3.0	4.0	6.0	8.0	6.0	4.0	9.0	8.0	3.0	4.0	7.25	8.0	5.0	4.0	9.0	8.0
3	3.5	5.0	7.0	7.5	5.0	3.5	10.5	8.5	4.0	4.75	5.0	6.0	4.5	3.0	10.0	9.0
4	3.5	4.5	4.5	6.0	6.5	5.0	10.0	9.0	3.5	4.0	7.5	8.5	4.5	3.0	8.25	7.0
5	2.5	4.0	7.0	8.0	6.0	4.5	8.0	6.5	2.0	3.0	6.0	7.5	4.5	3.0	9.5	8.0
6	2.0	3.0	5.0	6.0	5.5	4.0	9.0	7.5	2.0	2.5	5.0	6.5	3.0	2.0	10.0	8.5
7	1.0	2.5	9.0	10.0	4.0	3.0	9.5	7.5	3.0	4.0	7.0	8.0	5.75	4.5	8.5	7.0
8	2.0	3.5	9.0	9.0	5.0	3.5	7.5	6.0	3.5	4.0	6.0	7.5	6.0	4.5	9.5	8.0
9	3.0	4.5	5.0	6.0	5.0	3.5	9.0	8.0	2.0	2.5	6.0	6.5	5.75	4.5	10.5	9.0
10	5.0	4.0	6.0	7.5	5.0	3.5	8.0	6.0	1.5	2.5	7.0	8.0	6.0	4.5	11.0	9.5
11	4.0	4.5	6.0	7.0	6.0	4.0	8.0	6.5	3.5	4.0	8.0	8.5	4.5	3.0	9.0	7.5
12	3.5	4.0	5.5	6.5	4.5	3.0	8.0	6.0	2.0	3.0	8.0	9.0	5.5	4.0	10.0	8.5
13	3.5	4.5	6.0	7.5	5.0	3.5	8.5	6.5	3.5	4.0	7.5	8.5	5.0	4.0	8.0	7.0
14	4.0	4.0	8.0	8.5	5.0	3.0	8.0	6.5	3.5	4.5	6.0	6.5	4.0	2.5	10.5	9.5
15	2.0	3.0	5.0	6.0	5.0	3.5	8.5	6.5	4.0	4.5	7.0	8.0	4.5	3.5	10.0	8.5
16	4.0	4.5	7.0	7.5	4.5	3.0	10.5	8.5	3.5	4.0	6.0	6.5	5.0	3.5	8.75	7.5
17	3.0	4.0	6.0	8.5	4.5	3.0	7.5	6.0	3.0	3.5	5.5	7.0	4.5	3.0	7.5	6.0
18	4.0	4.5	6.5	8.0	5.5	4.0	8.0	6.5	2.5	3.5	5.0	6.5	3.5	2.5	10.5	9.0
19	2.0	3.0	7.0	8.5	6.0	4.0	9.5	8.0	3.0	4.0	6.0	6.5	5.0	3.5	10.5	9.0
20	2.5	3.0	7.0	8.5	4.5	2.5	9.0	7.5	3.5	4.5	5.0	6.5	5.5	4.0	9.5	8.0

APPENDIX 5. Randomized Sequence of Color Walls and Model Human Figures.

SUBJECT NO.	SEQUENCE								
1.	L.R.	W	L.B.	B	BLA	R	G		
	3	8	7	4	2	5	9	6	1
2.	BLA.	R	G	B	L.R.	W	L.B.		
	6	2	8	7	3	9	5	4	1
3.	R	G	W	BLA.	B	L.R.	L.B.		
	4	9	7	8	3	1	6	2	5
4.	G	LR.	W	R	BLA.	B	L.B.		
	1	9	5	3	4	6	7	5	2	8
5.	L.R.	R	G	B	BLA.	L.B.	W		
	1	2	8	1	9	7	6	3	5
6.	W	L.R.	B	G	R	BLA.	L.B.		
	4	7	5	9	8	3	1	6	2
7.	BLA.	L.R.	W	B	R	L.B.	G		
	5	3	6	7	8	9	4	2	1
8.	L.B.	L.R.	G	B	BLA.	R	W		
	7	2	4	9	6	8	3	1	5
9.	G	B	W	R	BLA.	L.B.	L.R.		
	3	2	4	6	7	8	5	9	1
10.	B	W	R	BLA.	G	L.B.	L.R.		
	1	7	6	9	3	8	4	2	5

SURFACE LIGHTNESS AND SIZE AND DISTANCE EFFECTS

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

This study was an attempt to determine the effect of color characteristics (hue, reflectance and saturation) on apparent distance and size in interior spaces. The task consisted of looking at a scale model room made up of different color characteristics under each condition, chosing the appropriate size of a model human figure to match the room and estimating the distance of the figure from the end wall of the model room.

Twenty subjects were run. Analysis of variance was performed for the color characteristics with the significance level set at five percent.

The result showed that there is a significant effect due to hue, reflectance and saturation. Namely, red appears nearer and blue appears farther. Colors of higher reflectance (white) appear farther and of lower reflectance (black) appear nearer to the observer. Also when the saturation decreases, the effect of a particular hue on apparent distance and size decreases.

The effects of hue, saturation and reflectance in this study suggest that these may be useful tools of the designer.