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THE SCIENTIFIC APPLICATION OF LIGHT AND COLOR TO THE DENTAL ENVIRONMENT

Wm. Ralph Sellers, Lieutenant Colonel, USAF, DC
John M. Young, Colonel, USAF, DC
Joseph M. Powell, Lieutenant Colonel, USAF, DC

August 1978

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This final report was submitted by personnel of the Dental Investigation Service Branch, Clinical Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order DSB38100.

This technical report has been reviewed and is approved for publication.

WM. RALPH SELLERS
Lieutenant Colonel, USAF, DC
Project Scientist

JOHN M. YOUNG
Colonel, USAF, DC
Supervisor

ROBERT G. MCIVER
Brigadier General, USAF, MC
Commander

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Wm. Ralph Sellers, Lieutenant Colonel, USAF, DC
John M. Young Colonel, USAF, DC
Joseph M. Powell Lieutenant Colonel, USAF, DC

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This report was compiled to provide guidance in using light and color scientifically in the dental environment. Visible light and the contiguous infrared and ultraviolet regions of the electromagnetic spectrum have measurable physiologic effects on man. Also, component wavelengths of visible light (color) appear to have definite psychological manifestations. Specific applications of light are recommended for the various divisions of USAF dental facilities.

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CONTENTS

THE SCIENTIFIC APPLICATION OF LIGHT AND COLOR TO THE DENTAL ENVIRONMENT

INTRODUCTION

The design and construction of an Air Force dental facility is a monumental undertaking. Literally thousands of decisions must be made by a cadre of specialized personnel: architects, engineers, health facility officers, administrators, and dentists. In cases such as the selection of the air-conditioning system, hard data exist on comfort ranges, flow rates, air-exchange rates, and condensor capacity; so the decision-making process can be technically quantified, equated, and the outcome predicted. On the other hand, the selection of interior colors, and to a lesser extent the application of light, has traditionally been placed more in the realm of the artist; in this case, the interior designer. Often the selection of a particular color becomes a matter of personal taste, and no real consideration is given to the functional properties of light and their effects upon man. Yet, as the scientific body of knowledge expands, it becomes apparent that the light energy which has illuminated man's evolution for some 3 million years does have biological effects and that these effects may be given useful purpose, just as other forms of electromagnetic energy are used by man.

The purpose of this paper is to review the nature of light, with particular interest in the biological effects of light components, and then to apply this knowledge to the selection of light and color in the Air Force dental facility.

PHYSIOLOGY OF VISION

The general physiology of the eye is well described in standard reference texts. Only those aspects of special interest to this paper will be considered here.

The eye is able to adjust itself to various intensities of light by a process known as adaptation. This is accomplished by the iris, a pigmented, muscular tissue which contains circular muscle fibers that constrict and radial fibers that dilate the pupil. Adaptation to bright light by pupillary constriction is a fairly rapid reaction, requiring only 1-2 minutes for completion; however, for the pupil to dilate and adapt to darkness requires 5 times longer.

Accommodation is the process whereby the curvature of the crystalline lens is increased, or made more convex, in order to focus an image on the retina. As the ciliary muscle contracts, the lens bulges forth and becomes more spherical. The act of focusing on a near object requires both accommodation of the crystalline lens and convergence, or medial rotation, of the eyeballs on a vertical axis. Convergence is controlled by the eye's extrinsic musculature. The act of seeing, then, requires that considerable work be done. Ganong (5) states that the ciliary body is one of the most used muscles in the body.

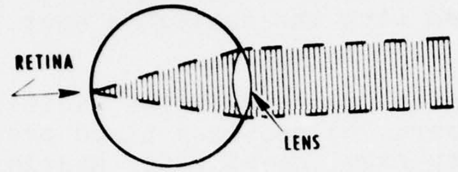
The color of an object affects the eye's accommodation (Fig. 1). Yellow is perfectly refracted by the resting lens, so light converges directly on the retina without accommodation taking place. Red, however, is only slightly refracted by the resting lens, so the lens must become more convex to focus the image on the retina. At the other extreme, blue is strongly refracted by the lens, so the image is formed in front of the retina and is in poor focus. This same optical geometry also affects the perceived size of a colored object. Since to be in focus the image of a red object must be brought closer to the lens, a red object will appear larger than a blue one. This gives rise to the artistic rule that warm colors advance and cool colors recede. In addition, objects of sufficiently high brightness produce a diffuse radiation pattern on the retina, which causes them to appear larger. Thus, yellow will appear larger than white, red, green, blue, and black, in that order. In a like manner, pastels will appear larger than pure color (3).

Apparently, then, color and light can become tools to affect factors such as image size, visual acuity, and fatigue. Later sections of this report will deal more specifically with this application.

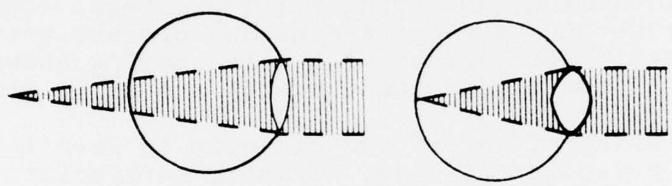
BIOLOGICAL EFFECTS OF LIGHT AND COLOR

The biological effects of light are well demonstrated in the plant and animal kingdom. The lowly amoeba, without any specialized photosensitive organelles, reacts to light through the innate sensitivity of its protoplasm. Bird migration depends more on the duration of daylight than on temperature. The pineal organ of frogs and lizards responds to light (3). The human pineal gland is thought to be vestigial; however, light does penetrate the human skull and reach the neuroaxis (4).

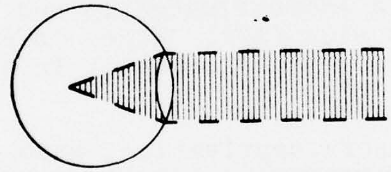
Wurtzman (17) is of the opinion that light is secondary only to food as the most important environmental input in controlling bodily functions. In humans, light has been



YELLOW – PERFECTLY REFRACTED UPON THE RETINA BY THE RESTING LENS.



RED – THE LENS MUST BE MADE MORE CONVEX TO FOCUS THE IMAGE ON THE RETINA



BLUE – SHARPLY REFRACTED SO THAT THE IMAGE IS PRODUCED IN FRONT OF THE RETINA. THE EYE CANNOT ACCOMMODATE

Figure 1. Accommodation of the crystalline lens while viewing color.

shown to dilate blood vessels, increase circulation, and increase hemoglobin and protein production (3). Interestingly, blind human females reach puberty at an earlier age than do females of normal vision (6). Metzger applied a light stimulus to human subjects whose arms were outstretched in front of the body: under the influence of red light, the arms moved apart; of green light, the arms moved together. Remarkably, this phenomenon occurred with the subject's eyes tightly sealed (3).

Red has been shown to have a definite exciting influence on the cerebellum. Gerard (6) recorded blood pressure, palmar conductance, respiratory rate, heart rate, muscle tension, eye blinks, and brain waves in human subjects exposed to various colors. In general, red increased all recorded parameters and proved more disturbing. Blue, on the other hand, had a relaxing, calming, and tranquilizing effect. Hack (7) believes that blue may be a depressant and prefers green for a peaceful effect. Fere agrees with this, having shown less autonomic arousal and muscle tension with the color green (3).

The stimulating effect of red can also be seen in patients with cerebellar disease. Tremor, torticollis, and Parkinsonian phenomenon may be decreased if the patient is both protected from red colors and wears eyeglasses with green lenses (2). Of special interest, psychological tests have shown that time is overestimated in red light and underestimated in green and blue (12). Also, infants have been shown to cry less and have less activity in nurseries illuminated with blue light (3).

In studies on sensory deprivation, Hebb has demonstrated that an organism needs varying cyclical stimuli in order to remain alert and sensitive to the environment (14). At the end of 5 days in a monotonous environment devoid of visual and tactile stimuli, subjects were bored, restless, and unable to concentrate. Straight edges appeared rounded, objects seemed to float in space, and mental tests showed that intelligence had deteriorated.

Jaensch believes that the response to form is an intellectual process, whereas the response to color is impulsive and emotional (3). Attraction to warm colors is viewed as a childlike response and is associated with extroverts and the brunette-complexion type. Attraction to cool colors is considered to be a more mature response associated with the introvert and the blonde-complexion type. Thus, coolness signifies withdrawal into self; warmness, an outward drive for contact with the external environment. Further, extroverts show a decided preference for abstract, colorful, nonobjective or surrealistic art, whereas introverts prefer realistic use of color and traditional or period styles that "make sense."

In the electromagnetic spectrum, the infrared and ultraviolet regions (immediately adjacent to visible light) are also important from a health standpoint. Russian scientists working in polar regions have described a sunlight-deficiency disease consisting of imbalanced homeostasis, nervous disorders, vitamin D deficiency, and lowered resistance to disease. Ellinger reports that ultraviolet radiation of the floors and upper air in barracks housing naval recruits reduced infectious respiratory disease by 19.2% and streptococcus infection by 24% (3). In a separate study, he showed that ultraviolet-irradiated subjects were able to increase work output by 60% under laboratory conditions. Also, Bergen (1) demonstrated that workers became less fatigued under a full-spectrum light source than one of partial spectrum.

Investigations into the biological effects of light continue. Already the selective amplification of wavelengths at the chlorophyll absorption peak (red) have greatly increased yields in greenhouse tomatoes, and eliminating the ineffective green and yellow allows energy conservation. By using blue incandescent light in the breeding pens of chinchillas, ranchers can skew the sex ratio of offspring as much as 70% in favor of female breeding stock (13).

Applying scientific data to the use of light and color in the dental environment is of primary interest to us and will now be considered.

RECEPTION ROOM

The color and light requirements of the reception area and waiting room have special significance. Dental patients exhibit a high degree of anxiety and apprehension over their impending dental appointment (11); therefore, the entire tone of the reception and waiting area should be one of pleasantness and relaxation. The correct use of color and light can do much to promote this effect. Since a sense of privacy is desirable in waiting areas, the light should be more subdued. Incandescent lighting is preferred in sources such as table and floor lamps (12). For objects to have a normal appearance at low light levels, a warm tint to the light source is desirable (Kruithoff's rule). The pink tints common in beauty parlors are especially good for enhancing flesh tones and making the patient "look good" (3). Variable-intensity overhead lighting may be useful in adjusting the mood of the reception area to the outside environment. During early morning hours or on cloudy, cold, or inclement days, higher light levels help to provide a cheery contrast; whereas on warm, sunny days, lower light levels provide a welcome feeling of coolness and relaxation (12).

Large areas of warm color (e.g., walls) should be avoided since they may increase the patient's anxiety level as well as the perceived passage of time. Red is especially noted for its arousing effects on the autonomic nervous system. To provide a relaxing, calming, and soothing color environment, which will also tend to decelerate the passage of time, cool colors should be selected. Certain shades of blue can produce these effects; however, large expanses of deep blue should not be used because the eye has difficulty in focusing this color. It becomes uncomfortable to look at, imparting a cold, bleak look. Also, its retiring property is disconcerting in that it makes objects appear smaller. On the other hand, blue may be used to good advantage on smaller areas such as privacy partitions. Green is the color of choice for large areas; it has much of the soothing effect of blue without its disadvantages.

Soothing, tranquilizing surroundings aimed at calming the anxious dental patient should not be overdone. The human eye becomes bored with monotonous, unvarying schemes of light and color. Bright, warm, cheerful colors such as yellow, as well as touches of red, may be used for accent. The levels of light may be increased to illuminate art objects and magazine tables, and be reduced over more secluded areas such as waiting room chairs. Spotlighting will emphasize objects of interest such as sculptures and murals. The interplay of directional lighting will produce a three-dimensional highlight-and-shadow effect and greatly enhance visual and mental comfort. Sole dependence upon ceiling-mounted light sources can result in excessive flat lighting and destroy the beauty of form (3). With proper application of color and light, the dental waiting room can be a pleasant and relaxing sanctuary for the dental patient.

DENTAL TREATMENT ROOM

The dental treatment room requires greater care in illumination and color than any other division of the dental facility. The dentist is performing detailed hand-eye coordinated tasks in a small, confined space with poor reflectance (the oral cavity) and, in many situations, must execute difficult shade-matching procedures that require great color discrimination. If the light in a dental operatory does not contain the full color spectrum, all colors will not be seen (1). Color is not a constant property of matter, but rather is a manifestation of absorbed and reflected light as perceived by an observer. Spectral energy distribution, Kelvin temperature, and color-rendering index become important criteria in the usefulness of light for dental shade matching (10). If these factors are not considered, two colors can appear to be the same in the dental operatory and yet exhibit gross color mismatch in daylight or under domestic light conditions. Metamerism is frequently encountered in dentistry because the chromogenic pigments in artificial teeth are not identical spectrophotometrically to the pigments found in natural teeth (10). Preston (12), therefore, recommends that the Kelvin temperature of a dental light used for critical shade matching be about 5500, that the spectral-energy distribution curve closely approximate standard daylight, and that the color-rendering index be above 90. A study published in January 1977 favored the Verd-A-Ray critiColor and the General Electric Chroma 75 as the best full-spectrum fluorescent light sources available for dental illumination (1).

The level of illumination required in the dental treatment room is quite high. Not only do finely detailed extraoral procedures demand high light levels, but the constant shift of the dentist's visual fix between the intensely lighted oral cavity (1000-2000 fc) and the lower ambient levels of the room may induce severe adaptation fatigue. This problem is compounded as levels of intraoral illumination rise. The intensity of dental operatory lights has been increased, dual operating lights are advocated by several authorities, and adjunctive fiber-optic illumination in dental handpieces is becoming popular (8). The ideal ratio of intraoral to extraoral illumination is considered to be 3:1; however, ratios as high as 10:1 are acceptable and even recommended from a standpoint of energy conservation (8, 12). Preston (12) believes that 2100-3200 lux (200-300 fc) at a distance .76 m (30 in) above floor level represents the best compromise. This level can be attained in a 3- x 3-m (10- x 10-ft) room, by twelve 1.2-m (4-ft) fluorescent tubes (12). The all-luminous ceiling or recessed-fixture installation is preferred (8). Luminous ratings of fluorescent luminaires are based on measurements made with new tubes; both intensity and light quality decay with time. Old fluorescent tubes will appear dimmer and take on a yellowish tint and should be replaced long before they burn out. The manufacturer's recommendations are helpful in determining replacement time (9).

The recumbent dental patient is an important consideration in the design of overhead lighting. Eggcrate-type diffusers, which permit the patient to stare directly through the grid into the light source, are not suitable for dental use. Acrylic diffusers that permit at least 90% light transmission and do not alter spectral characteristics are much preferred because they scatter light evenly throughout the room and reduce glare. Careful selection of the diffuser is important, for efficiency varies greatly from one manufacturer to the next; light-transmission levels as low as 60% have been reported. In addition, the diffuser should be easy to clean since dirt accumulation can significantly reduce its transmissivity (12).

The reclined position of the dental patient also influences color selection for the floor covering. Since the floor represents background (visual surround) for the dentist with a visual fix on the mouth, a relatively light-colored floor covering will help reduce adaptation fatigue (8).

Ambient light derived from reflecting surfaces can influence critical shade discrimination, especially if these surfaces are either large or near the view of the operator. Vivid hues of high chroma will absorb specific wavelengths of incident light, so the light reflected will not be full spectrum and will modify the color of any object it strikes (12). For example, a bright green-yellow wall can arouse the complementary color, red-violet, in a tooth under observation. The American Society for Standard Testings and Materials recommends a neutral light-gray color (Munsel N7/-N9) as an ideal background for areas of critical shade matching (10). Birren (3) cautions that the brightness of walls and ceilings is significant because illumination may be rapidly lost if the surrounding surfaces are dark and nonreflective. The following brightness values (Munsel) have been recommended for the dental treatment room (8):

Ceilings - white or off-white	9 or higher
Walls	8 or higher
Cabinets	8 or higher
Counter tops - nonglare surface	7 or higher
Floors	6 or higher

The selective absorption of daylight through transluscent draperies can be especially deleterious to critical shade matching (10). The influence of inconstant daylight (morning, high noon, evening) and the need for full-length drapes can be eliminated by using eye-level windows with large overhanging eaves (18). (See Figures 2 and 3.) Color accents can be used on fixtures and cabinets to avoid monotony.

This by no means minimizes the importance of windows to provide an exterior gaze in each dental treatment room. Wells (15) reported on particularly noteworthy research concerning the effects of various physical environmental factors on approximately 2500 office workers. He discovered that employees exhibited a strong subjective preference for

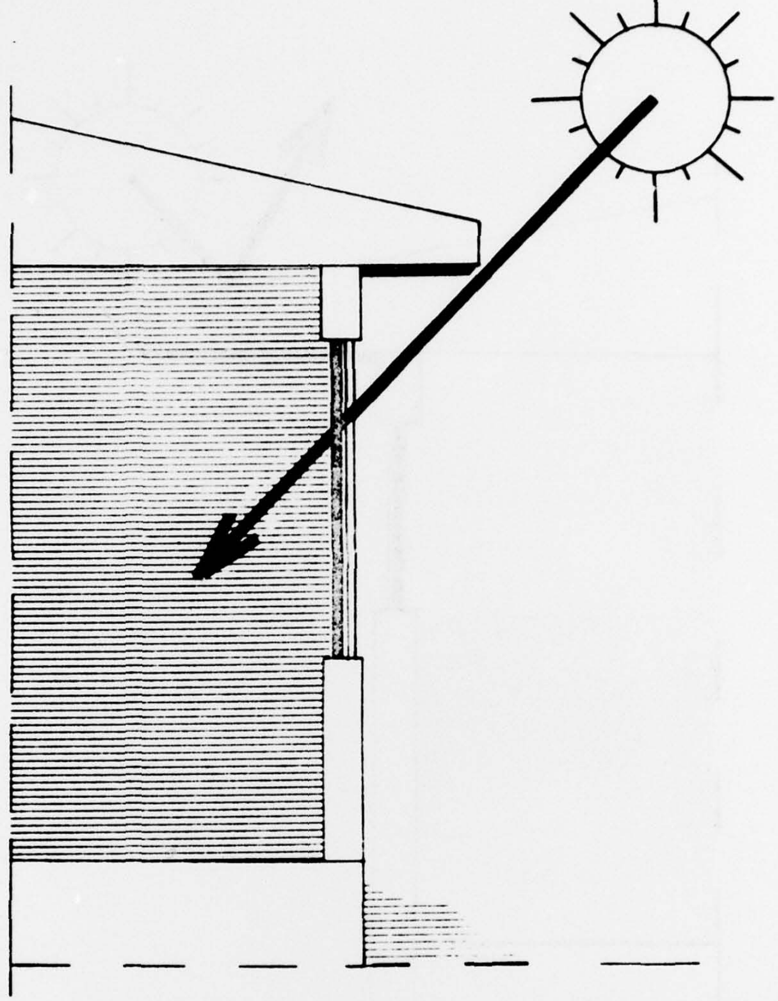


Figure 2. Direct sunlight, particularly when filtered through colorful window draperies, can severely affect shade discrimination.

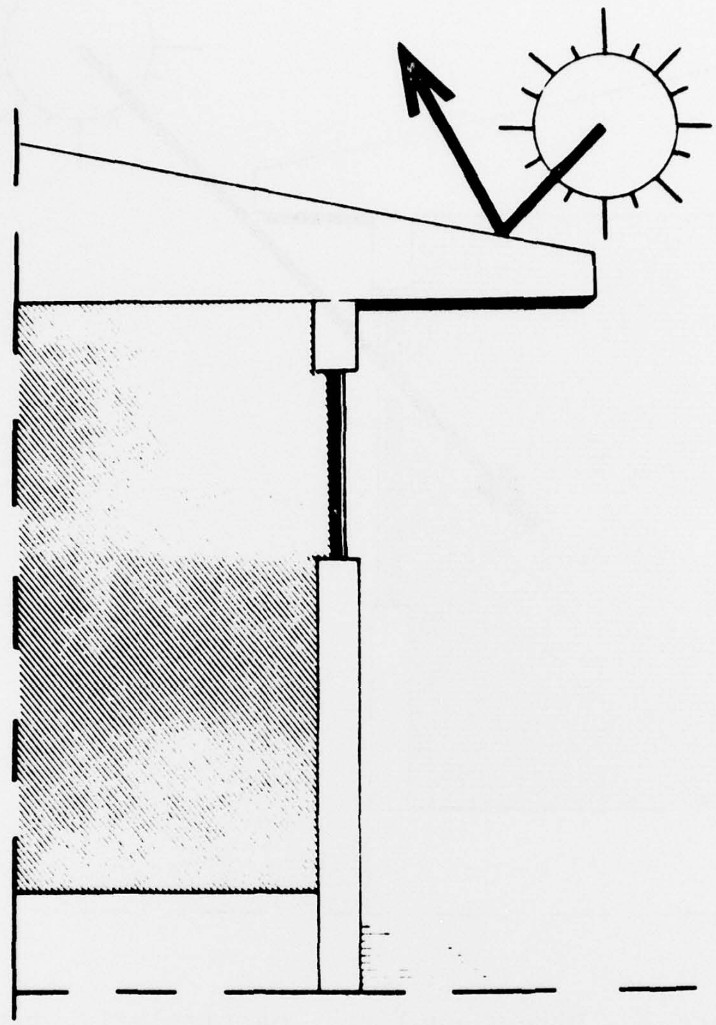


Figure 3. The use of eye-level windows and overhanging eaves to combat the effect of direct sunlight.

windows and daylight. This finding was supported by Secrist (13) who determined that of a group of 54 environmental variables, desk location near an office window was subjectively rated as the single most important factor affecting worker performance.

The strict color standards discussed above particularly apply to prosthodontic operatories and dental laboratory areas in which a great deal of critical shade matching is performed.

In general-dentistry rooms or specialty operatories where the need for critical shade selection is less frequent, more vivid background colors may be used and a dimmer switch (or double switching of overhead lights) installed to nullify light during shade selection (8, 10, 12). If a way to reduce light intensity is not provided, the chroma of large surfaces should be held to 4 or below since saturated room colors can significantly alter critical shade discrimination (8).

In surgical dental-treatment rooms, a special tone of blue-green is preferred for walls and tile splashboards. Surgical blue-green reduces glare in the field of view, provides better contrast, aids the acuity of the surgeon's eye, and complements the reddish tint of blood and soft tissue (3).

LABORATORIES

In critical shade-matching areas of the dental laboratory, such as the ceramic section, the light and colors should be as identical as possible to those in the prosthodontic dental-treatment rooms (see Dental Treatment Room section). This allows the dental technician to reproduce the exact shade selected by the dentist. Desk-top color-corrected light sources identical to the dental operatory light are available for laboratory use to avoid metameric mismatches (10). Dental laboratory work is of a highly detailed and minute nature, and additional task lighting is essential. The combination light consisting of a circular color-corrected fluorescent light with a center blue-daylight incandescent bulb is most effective. Task lighting should be supplemented by relatively high levels of ambient light. All-luminous ceilings that provide about 3200 lux (300 fc), measured .76 m (30 in) from the floor, are very useful. In addition, 300-W spotlights focused over the vibrator and investing units help eliminate blocking shadows and provide good visibility in these critical areas. Optical-gray work surfaces with approximately 30% reflectance will help reduce eye fatigue and are much preferred to the glossy white or black colors frequently encountered (12).

BUSINESS OFFICE

The front desk and record area should be well illuminated to promote effective and efficient work. Levels of approximately 1000 lux (100 fc) at the work surface are about optimum and may be best provided by full-spectrum fluorescent ceiling fixtures (9). The beneficial effects of light on factors such as fatigue and work production may then be realized. If these higher levels of illumination are coupled with warm luminous colors, personnel activity will be directed outward (centrifugal action) to the incoming patients and the short monotonous tasks such as scheduling appointments, answering the telephone, and filing. Excessively bright surrounding walls should be avoided as they interfere with the worker's ability to concentrate; the reflectance constricts the pupils and produces a fatiguing glare which handicaps work performance. Levels of approximately 40%-60% reflectance are appropriate. The personnel's visual comfort can be considered also when the work surface is selected. Desk tops of a warm pearl gray (optical gray) with about 30% reflectance have been shown to reduce eye-blink rate and lessen retinal and convergence fatigue, and subjectively judged to be pleasant (3).

PRIVATE OFFICE

In the private office, the worker must be able to concentrate on mental problem solving and creative thought. Light and color here should produce a visual effect (centripetal) that directs the subject's attention inward and maximizes concentration upon the task at hand (3). The desk area is of central emphasis when the general lighting is indirect and subdued and desk lamps are used to increase lighting for task performance. Walls should be of the cooler hues (gray, blue, green, and turquoise), with decreased brightness. This will be less disturbing and emphasize the centripetal effect (3). An off-color wall in a bright accent color and located behind the desk, out of the worker's view, may be added for decorative interest.

CONFERENCE ROOM-LIBRARY

In most dental facilities, the conference room and library are apt to be combined. Since dental libraries are used on an occasional, short-duration basis, light and color should be selected more for the conference setting. Here a stimulating effect is desirable. The outward, centrifugal effects of warm tones such as red, orange, and pumpkin may be put to good use. Substantially more variety and adventure may be employed to provide sensory stimulation and help hold interest. Lights should be able to be dimmed to allow presentation of slides and movies. Slightly higher levels of illumination over the audience will allow notes to be made during such presentations and will help offset the somnific effect of a darkened room. Conference tables and reading areas are best illuminated to a level of 750-1000 lux (70-100 fc) (9).

CORRIDORS

Corridors in larger dental facilities represent a special and easily solved color and lighting problem. A hallway stretching out before the eye requires light and color that conjure up the image of a footpath. Semi-spotlight ceiling fixtures which are evenly spaced and project their beam down onto the floor help to establish a continuous row of lights that are easy for the eye to follow (12). Walls and ceilings may be done in white and pastel shades with sufficient reflectance to enhance lighting and conserve energy; however, the use of a darker floor covering helps to create the desired footpath effect.

The proper ratio of hallway illumination to that of adjacent work areas is important since the pupil reacts quickly to light but adapts slowly to darkness. A level 1/3 to 1/5 that found in adjacent areas will permit easier adaptation of the eye to the transition from work area to the less illuminated corridor (9).

CONCLUSION

This report has presented ways in which color and light may be reasonably applied to the dental environment. Hopefully, it will be of some help to those responsible for the design of Air Force dental facilities. The authors have made a concerted effort to be objective; yet, as is true of any scientific approach, great care must be exercised in applying tentative, working conclusions based upon experimental data--for the scientist does not accept absolute truth. For example, the color red has been consistently shown to have a stimulating effect upon man in a number of carefully controlled studies. Before we assume that all red is stimulating, however, we should realize that the red selected by a research psychologist to produce maximum measurable effect is "blood" red. The deep-rooted psychological associations with this color in an animal with the phylogenetic history of man is obvious. On the other hand, red is also the color of a pumpkin, and man is hardly aroused to any comparable extent by this innocuous fruit. Nonetheless, the interpretive use of light and color based upon scientific experimentation is always preferred to the alternative--the dogma of personal taste.

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GLOSSARY OF TERMS

Angstrom (Å) - a unit of wavelength of light equal to 10^{-10}m (10^{-1} nm).

Brightness - the subjective or sensory measurement of visible light coming from a reflecting-surface source.

Candela (cd--replaces the "international candle") - unit of luminous intensity equal to 1/60 the luminous intensity of 1 cm^2 of a blackbody surface at the solidification temperature (2046 K) of platinum.

Candlepower - the luminous intensity of a light source, in a given direction, expressed in terms of the candela. Formerly expressed in terms of the international candle; now, metallic platinum, which emits 60 candela/cm^2 at 2046 K is used as the standard (see "candela").

Color - when only part of the visible spectrum is seen by an observer, it will be perceived as color. The average wavelength of the spectral color components of white light are:

violet	410 nm	Cold
blue	470	
green	530	
yellow	590	
orange	610	
red	670	Warm

Color-Rendering Index - an industrial standard used to compare the color-rendering ability of a light source to a standard reference source rated at 100.

Color Temperature - when a standard blackbody is heated, it begins to radiate incandescent light: at 1800 K, it will appear red; at 2800 K, red-yellow; at 5000 K, white; and at 8000 K, pale blue. The color temperature of a light source is the temperature (K) at which the color of the source (same hue and saturation) would be evoked by the radiant energy of a blackbody.

Fluorescent Light - visible light produced where a mercury vapor arc excites luminescent phosphors located in the wall of a containing tube.

Footcandle (fc) - a measure of illuminance, or the amount of light falling on a unit surface area. Example: A screen placed 1 ft from a source of 1 candlepower will be illuminated 1 fc. (1 fc = 1 lumen/ft^2 -- expressed metrically in lux, which equals 1 lumen/m^2, 1 fc = 10.76 lux.)

Incandescent Light - visible light produced by the thermal excitation of a filament.

Infrared - that part of the electromagnetic spectrum immediately above red (780-10^5 nm).

Kelvin Temperature - temperature scale found by adding 273 to the Celsius temperature. At 0 (-273°C), all molecular motion ceases.

Kruithoff Rule - a principle stating that for colors to have a normal appearance, the light source should be given a warm tint (pink, orange, or yellow) at low levels of illumination (under 320 lx, or 30 fc), and increasingly cooler tints as the level of illuminance is increased.

Light - that part of the electromagnetic spectrum visible to the eye. The wavelength of visible white light ranges from 397 to 723 nm.

Lumen (lm) - unit of luminous flux (flow of light energy). The amount of light emitted per second in a unit solid angle by a uniform-point source of 1-cd intensity (1 lm = cd·sr); i.e., the amount of light falling per second on unit area placed at unit distance from such source. (1 lumen = 4π candlepower)

Luminous Flux - time rate of flow of light; total visible-light energy emitted by a source per unit time (usually measured in lumens).

Lux (lx) - practical unit of illumination in the metric system. It is equivalent to the metercandle and is the unit of illumination on a surface that is everywhere 1 m from a uniform-point source of 1-cd intensity (the illumination on a 1-m^2 area on which there is a uniformly distributed flux of 1 lumen); equal to 1 lm/m^2.

Metamerism - the phenomenon of having two objects match under one light source, but not under another source because of incongruence in spectral energy distribution curves. For example, a restoration may match the shade tab under a color-corrected dental light, but exhibit gross mismatch under an uncorrected fluorescent source with a high peak in the blue range.

Munsell Color System - a system of color designation based upon the basic color of an object (hue), the relative amount of saturation of the color present (chroma), and the relative lightness or darkness (value).

Neutral Gray - an achromatic color completely devoid of hue or chroma.

Refraction - the bending of a light ray, due to a change in its velocity as it passes through a transparent medium. Since shorter wavelengths travel at lower velocity in media, violet is refracted to a greater extent than red.

Spectral Energy Distribution - the relative amount of each wavelength of component color emitted by a light source. Comparing the SED curve of an artificial light source to standard daylight is useful in determining color quality.

Ultraviolet - that part of the electromagnetic spectrum immediately below violet (10-380 nm).