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Research Article

Hiding from the Enemy: An Assessment of Perception of Polychromatic Light in a Simulated Tactical Environment

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ABSTRACT

Background: Proper tactical lighting is crucial for the success of medical providers in the setting of Special Operations Medicine (SOFMED). Previous research has explored the efficacy of the use of lights of different hues of monochromatic and polychromatic light. The purpose of this study is to explore the illuminance of different hues of light and how they are perceived by observers in low-light conditions. This study is a preliminary exploration aimed at identifying an ideal light source to balance both a provider's visual capability and the possibility of perception by enemy combatants in a tactical operational setting.

Materials and Methods: A PubMed search on 09/20/2021 using terms: tactical lighting, special forces, military medicine, surgical lighting, and illumination revealed 32 peer reviewed papers. The papers pertinent to tactical lighting were only 25. To further examine the question of tactical lighting, twenty-two medical students taking part in a surgical skills and simulation event were enrolled in an institutional review board-approved study. Participants were brought to a darkened warehouse and visually adjusted to a dark setting. They were told that they would see either white, red, blue, and red/green lights on the floor in a doorway leading to a separate room. Each participant was then asked to individually report when they could differentiate the color of light they perceived as a researcher in the adjacent room approached the previously designated doorway with either a white, red, blue, or red/green standardized flashlight. Once reported, the researcher would stop and the distance from the doorway was measured. Farther distances from the doorway indicated easier perception while smaller distances indicated the light color was more difficult to perceive.

Results: Red light was the most difficult to perceive from a distance, followed by white light. The blue and red/green lights were statistically no different and more easily perceived than red and white.

Conclusions: Considering the aspect of minimizing enemy detection only, the red light setting on the standardized flashlight would be recommended for routine operations, being the most difficult to perceive from a distance. However, based on earlier

studies, the benefits of the improved performance of red/green light in combat casualty care may outweigh its increased perceptibility by the enemy. More research is needed to investigate the perception of light in realistic tactical environments rather than in a controlled laboratory setting.

INTRODUCTION

The human eye registers visual input over a wide range of color and illuminance (measured in lux: a unit of how much light falls on a given area) due to the sensitivity of the photoreceptors; rods and cones. The detection limit of the eye changes in Low-Light Environments (LLE) due to the retinal cones' insensitivity to light at lower lux, which can be measured objectively by slowly increasing the luminance a light source emits in a dark room. Luminance is measured in candelas, which is a measure of intensity of light coming from a specific object in a given direction. It has been well established that retinal rods significantly increase in sensitivity to illuminance compared to cones in LLE after about 5-10 minutes, creating a perceivable discrepancy between photopic (light), mesopic (dusk) and scotopic (night) vision. The adjustment of our eyes' sensitivity to light from photopic to scotopic vision is known as dark adaptation and is accomplished via four main factors: intensity of pre-adapting light, the size and position of the retina, the wavelength of emitted light, and rhodopsin regeneration.

The main light-sensitive organ in the body is the retina composed of rods and cones. Cones are normally one of the three types, each with different pigment, namely: S-cones (Blue, or short-wavelength), M-cones (Green, or medium-wavelength) and L-cones (Red, or longer-wavelength). Each cone is therefore sensitive to visible wavelengths of light of different frequencies. Because humans usually have three kinds of cones with sensitivities to different wavelengths of light, humans have trichromatic vision. The "green" and "red" cones are mostly packed into the fovea centralis. By population, about 64% of the cones are red-sensitive, about 32% green sensitive, and about 2% are blue sensitive. The "blue" cones have the highest sensitivity and are mostly found outside the fovea. Alternatively, rods are most sensitive to light and dark changes, shape and movement and contain only one type of light-sensitive pigment. Rods are not good for color vision. Rod cells have a peak sensitivity to light when it travels at a wavelength of 498 nm, roughly halfway between the peak sensitivities of the blue and the green cones.

The perception of the various colored light sources is most likely a reflection of the individual sensitivities of the cones in LLE. These are functional in photopic and mesopic vision, but not in scotopic vision [1]. The transition from photopic to scotopic vision is known as dark adaptation and requires 30 minutes for a retinal rod cells to completely adjust, while the reverse process requires only two minutes to readapt [1-3]. In LLE, rods are significantly more active than cones, allowing for the detection of light that has a shorter wavelength (498 nm) and better discriminates green and blue. Adaptation to a LLE is especially pronounced when using longer wavelengths where rod-cone breaks aren't seen, such as in extreme red (680nm) [4,5].

Visualization and light perception in LLE can be a two-edged sword both within and outside of the surgical operating theater, especially among tactical Special Operations Medicine (SOFMED) units. Poor lighting can lead to poor visualization of key landmarks during surgical intervention, which is broadly accepted as leading to poorer outcomes. Though operating in LLE is generally not relevant in the civilian medical sector, improper use of surgical lighting has been shown to cause burns [6-9], serve as a major source of contamination of the surgical field [10], obscure visualization of operating screens by lowering contrast [10-12], interfere with pulse oximetry [13], and even cause cases of retinal toxicity in prolonged retinal surgery [14].

From a tactical perspective, the proper use of lighting should maximize a medical provider or law enforcement officer's visual capability while minimizing the ability of others, including enemy combatants, to perceive tactical lighting at a distance [15]. There is currently no consensus among SOFMED operators as to which light is superior in this regard [16], and to our knowledge, very little research exists in either the civilian or military sectors due to its specialized application. However, recent studies suggest red/green polychromatic light is superior to red light regarding visualization of important landmarks during surgical intervention [17]. The purpose of this study is to evaluate the perception of various hues of light at a distance in LLE to better understand which colors, if any, may provide a reduction in visualization by enemy combatants. We hypothesized that red and red/green polychromatic light will be harder to detect at a distance than white light of a similar luminance.

METHODS

A PubMed review using the keywords: tactical lighting, special forces, military medicine, surgical lighting, and illumination revealed 32 peer reviewed papers. The papers pertinent to tactical lighting were only 7, a majority of which were works previously done by authors AL, RE, and CC. Therefore, to further examine the implications of light hue observation, First-Light T-MAXLE light sources were used. It contains white, red, green, blue, and combined red/green light settings with three different intensities per setting (low, medium, high). A convenient sample of 22 healthy medical students participating in a surgical simulation course volunteered as subjects for this study. IRB approval was received through the Rocky Vista University Institutional Review Board.

Table 1: Illuminance of the different colored light sources measured at 50 cm.

Light Color (Low Setting)	Illuminance (lux)	Illuminance Relative to White Light (Low)
White	**212**	100%
Red	1	0.53%
Blue	2	0.88%
Red/Green	23	1.51%
Light Color (Med Setting)	**Illuminance (lux)**	**Illuminance Relative to White Light (Low)**
White	469	220.75%
Red	14	6.40%
Blue	30	14.05%
Red/Green	25	11.84%
Light Color (High Setting)	**Illuminance (lux)**	**Illuminance Relative to Low White Light**
White	742	349.29%
Red	116	**54.39%**
Blue	169	**79.75%**
Red/Green	209	**98.61%**

As an analog to perception of light from a distance in a LLE, we designed the experiment to take place in a dark warehouse. To ensure the illuminance of the light was quantitatively equal, we measured and compared the illuminance of each color setting (White, Red, Blue, Red/Green) at various light intensities (high, medium, low) with a digital luxmeter (Table 1). As the relative comparison of lux between the various settings was the primary goal, a fixed distance of 50 cm between the luxmeter and light source was chosen. This is primarily due to the limitations of precision seen in the luxmeter at greater distances. The luxmeter was calibrated in total darkness and several measurements were taken at each setting and intensity.

After determining the illuminance of each intensity and color setting, we decided to use low-white light as a standard with approximately 212 lux at 50cm. With the limitations of the available settings of the T-Max LE light, low-white light was most similar to high-red (116 lux; 54%), high-blue (169 lux; 80%), and high-red/green (209 lux; 99%) at the same distance. These four color-intensity settings were used for each of the four trials.

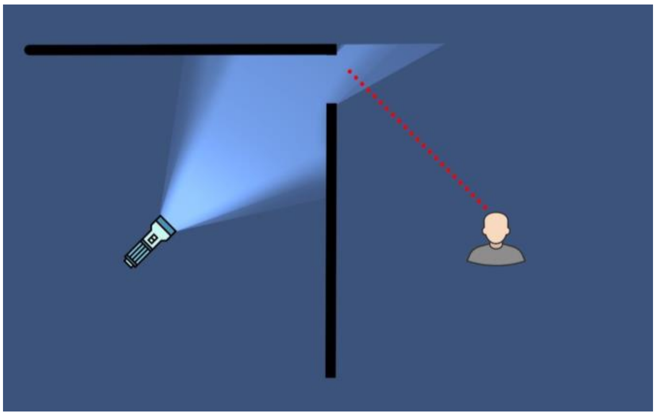

Figure 1: Diagram of study conditions. Subjects stood 2 meters away from the door and were asked to identify when they first perceived the light coming through the doorway. Researchers approached from approximately 15 meters away at the same angle (not drawn to scale).

To evaluate light perception, each subject was brought into the warehouse and placed in line approximately 2 meters and at a 45-degree angle from the doorway (Figure 1). Lights were turned off and a participant was allowed 5 minutes to adjust to LLE. Researchers with the standardized flashlight and at the aforementioned settings pointed the light at the ground near the doorway and walked towards the doorway from 15 meters at a 45-degree angle at approximately 1 meter/second. This approach was chosen to both simulate a semi-austere, light-controlled environment and to accommodate testing in an enclosed space. The test site did not allow for the light approach toward the subject from a greater distance.

The researcher stopped moving when the subject stated they perceived the light source on the floor and the distance from the doorway to the researcher was measured. The premise of the study assumes that a greater distance between the researcher and the door indicates more easily perceived light. Conversely, smaller distances meant the light was more difficult to perceive.

The participants were evaluated in groups of four to six individuals. After being evaluated for one color hue, the subject went to the back the group and waited with their eyes closed for testing with the next hue. This was done to find a balance between allowing time for the participants' vision to adjust back to LLE and decreasing the total time for each individual spent testing. Each subject participated in 4 trials with each trial using a different color. After returning to the back of the line, participants were instructed to close their eyes to maintain dark adaptation while waiting for their next trial. Each trial used a pseudorandomized order of colored light. Each participant was tested at low-white, high-blue, high-red, and high-red/green after the subjects' eyes were adjust to LLE.

RESULTS

Mean distances at which the different light hues were perceived were calculated (Table 2). Red light required the closest proximity to the door for perception by the test subjects, with the ranked order: red, white, red/green, and then blue light. Statistical significance was tested using statistical software by six separate, two sample t-tests between each respective color-intensity setting (Table 3). Each t-test was significantly different from one another with the exception of the blue versus red/green combination.

Table 2: Mean values (meters) and standard deviations of the distance at which the light was perceived.

	Red	White	Blue	Red/Green
Mean Distance (m)	1.458	3.011	4.540	3.990
Std Dev	0.811	0.667	1.541	1.891

Table 3: Two sample t-tests comparing pairs of each light source.

Color Combination	t-value	p-value	Statistically Significant
High-Red vs Low-White	-6.937	<0.01	YES
High-Red vs High-Blue	-8.301	<0.01	YES
High-Red vs High-Red/Green	-5.772	<0.01	YES
Low-White vs High-Blue	-4.159	<0.01	YES
Low-White vs High-Red/Green	-2.29	0.03	YES
High-Blue vs High-Red/Green	1.058	0.30	NO

DISCUSSION

According to research done by Van Buren, et al., there are three major elements of an ideal light source that contribute to success in SOFMED in LLE. First, an ideal light source should allow for maximized visual capability for the provider. Second, the source should permit quick adaptation back to a dark environment after the light is turned off. Third, the ideal light should minimize detection of the provider by enemy combatants to avert compromising the provider or casualty in the field [17]. The aim of our study was to further describe and identify important aspects of the third element of tactical lighting: the perception of that light in LLE from a distance by possible enemy combatants. We found that red light was the most difficult to perceive. However, because the illuminance reading taken from the flashlights high-red setting was only approximately 50% that of the low-white reading, we cannot necessarily conclude that a red light with similar luminance as a low-white luminance would decrease chances of being visualized by a dark-adapted foe. However, while red light was most difficult to perceive, it has drawbacks that must be balanced with the other elements of tactical lighting.

For example, while our study did not examine the first element of tactical lighting outlined above, previous studies have examined how different light sources affect visual acuity. A recent study has concluded that polychromatic light sources such as red/green/yellow and red/green are superior sources of light compared to colored (nonwhite) monochromatic light sources for the purpose of maintaining visual acuity and color-vision perception [18]. Specifically, this study showed red-green light-emitting diodes to be significantly better than a blue light for military first responders assessing acute trauma [8]. In addition, the polychromatic light sources showed no statistical difference when compared against white light [15,17]. The finding that red-green light may be a superior source of tactical lighting in terms of visual acuity but may also be more readily perceived at a distance highlights the importance of balancing the different elements of tactical lighting.

In this respect, it seems that the first and third elements of tactical lighting may be in direct opposition to one another. Per civilian protocol in modern surgical suites, it seems that the best visual acuity would be obtained using an ensemble of bright white lights such as those found in a modern civilian surgical suite. However, even surgical suite lighting still proves insufficient at times. A report by Knulst, et al. [11] indicated that during a typical surgery taking place in an operation suite, an action to improve or change the lighting took place every 7.5 minutes, illustrating the deficits surgeons face with adequate lighting even in well-lit conditions [12]. The recent development of eye-tracking medical headlamps and in-vivo laparoscopic cameras is promising [19,20], but the technology to limit the distance light travels to be perceived by another onlooker hasn't been established.

Another drawback we face with proper tactical light selection appertains to the second element of an ideal light source: the preservation of night vision. Monochromatic and polychromatic light of different hues help to preserve night vision once the light has been turned off in comparison to white light [17]. In order to entirely preserve night vision and to completely avoid the possibility of detection, providers would ideally be able to work in complete darkness. This is unreasonable for both the safety of the patient and provider. Therefore, it is easy to see how the pursuit of only one element of tactical lighting could be irrelevant. Our finding that red light may be most difficult to perceive at a distance must be considered with this information. Each element must be considered together as part of a larger goal.

There are limitations to this study. The study is a preliminary investigation examining the varied perception of different light hues. Due to the closed environment in which the study was conducted, these results may differ from those obtained in more realistic settings such as having a light approach an observer in an outdoor environment on a moonless night. Further studies will investigate lighting in this setting. Additionally, this study did not consider variable visual acuity and color perception among subjects and the necessary time for subjects' eyes to completely adjust to the dark. Consideration of these factors may also be an area for additional research.

CONCLUSION

Tactical lighting has changed since the days of the halogen-bulb surgical headlamp [11]. Choosing a light source is based on a balance of several factors and is highly mission specific. The improved visual capability and preservation of night vision of the red/green light may outweigh its increased visibility in most situations. Regardless, care should be taken to maximize the delivery of healthcare services with minimal risk to both provider and patient.

This study aimed to test various hues of lights in a controlled laboratory setting to evaluate differences in perception from observers. We found that when using the First Light T-Max LE at the settings described above, the red light was most difficult to observe followed by white, red green and blue light. However, we also recognize that this information must be taken in context of the other necessary elements of selection of an ideal tactical light such as identification of blood, instruments, and performing instruments, which are easier done in red-green light [18]. Further studies are necessary to investigate perception of tactical lighting in more realistic operational settings.

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