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STANDARDIZING SHIPBOARD LIGHTING: LIGHT FIXTURES AND LIGHT BULBS ON U.S. NAVY SHIPS

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SUMMARY/RECOMMENDATIONS

The intent of this investigation was to determine if light levels varied significantly depending upon the light bulb/fixture configuration. Three light bulb types and four fixture designs were evaluated at the HLW (maintenance level) and LLW (night time) lighting conditions. Two results found in this study are critical to the standardization of shipboard lighting. First, is that the Daylight bulb should be eliminated from the stock system. The light levels produced by this light bulb are significantly lower than the other two bulbs for all conditions. Using the Daylight light bulb at the HLW level would provide significantly lower light levels than recommended to conduct equipment maintenance. Whereas, at the LLW level, the Daylight light bulb provides insufficient light to carry out routine watch-standing duties efficiently. In addition, the Daylight bulb cannot be used interchangeably with the Coolwhite or White light bulbs to provide a uniform light field. The lower intensity and spectral characteristics (bluish-gray light) of the Daylight light bulb provide a significant disruption in an otherwise homogenous light field composed of Coolwhite or White light bulbs.

The second recommendation would be to discontinue the use of the clear fixture lens. This lens does not provide a homogenous field of light. The initial density values of the LLW filter have been designed using the opaque diffusers which provide additional attenuation of illumination. Use of the clear diffuser in the LLW condition would provide a light field significantly more intense than recommended levels thus disrupting the dark adaptation process. Although the clear diffuser is not used on submarines, its use on surface ships should be examined carefully.

Standardizing Shipboard Lighting: Light Fixtures and Light Bulbs on U.S. Navy Ships

Over the past decade a great deal of concern has been raised regarding appropriate ambient lighting for night-time illumination in operational areas on submarines. Red lighting was first used in World War II to promote dark adaptation for the men in diesel powered submarines which were required to surface or come to periscope depth regularly at night. However, with the advent of nuclear powered submarines this need was all but eliminated. Yet, the red lighting system was retained primarily for dark adapting the periscope operator in case of an emergency which could cause an unanticipated need to surface at night.

Dissatisfaction with the red lighting system caused the crews of many ships to alter the lighting within their work environment. Some would extinguish all lighting, and some tried a white light configuration in which the overhead lights in the vicinity of the visual display equipment were turned off, while lights away from the visual display equipment remained on. There were many complaints of eye strain, fatigue, and headaches. In addition, watch-standers reported that working under red ambient illumination was also fatiguing, made focusing difficult, and significantly impaired their ability to identify color-coded information from charts. These complaints led to the discovery by one crew of an alternative light filter for submarines that was available through the Navy stock system.

The alternative was a blue filter which appeared to address some of the problems expressed by the operational forces (Letter from CO, USS Greenling SSN 614, 1980). Their choice of lighting was supported by research quoted in the NAVSEA lighting manual which contained a chapter on blue illumination for radar system display consoles (see NAVSEA Lighting Manual, chapter 12). The rationale for the use of this lighting was that performance on perceptual tasks could be improved if the visible spectrum were divided in half based upon relevant/irrelevant information. A short wavelength (blue) was used for general room (non-relevant) illumination while a longer wavelength (amber) was used for display (relevant) illumination. The division was achieved by placing an amber filter over the display screen; this technique effectively split the visual spectrum by limiting the output of the display to long wavelengths and by not transmitting any of the blue ambient illumination to the display phosphor. A major drawback of this configuration was that intensity of the displays needed to be increased in order to penetrate the filter thus reducing the life of the cathode ray tube (CRT). The initial at-sea test of blue lighting was reported to have lowered recognition differential (NRD), thus improving target detection performance, which prompted an official test installation on another submarine (see letter from COMSUBLANT). Soon word spread through the submarines in the local area, and many changed to blue ambient illumination since the filters were available in the GSA catalogues. There were fewer reports of eye strain under blue light, as compared to red, but this was due to the fact that the transmittance of the blue filter was greater, thus allowing more light into the compartment (Kinney, Luria, and Ryan, 1982). However, because the blue filter provided more light it therefore failed to meet the initial objective of chromatic illumination which was to facilitate the dark adaptation process. In fact, blue light is by far the worst chromatic illumination to use if dark adaptation is required because it effects the visual receptors (rods) responsible for night vision. During this same time period, NSMRL staff members were investigating the optimum lighting conditions for watch-standing in sonar (Kinney, Luria, Neri, Kindness, and Schlichting, 1981). The men surveyed reported liking the blue lighting and voiced complaints about red lighting. Soon after a message was sent from COMSUBLANT (1982) and COMSUBPAC (1981) directing all submarines to convert their lighting systems in the sonar room to use blue filters.

Additional problems led to the desire for a new ambient lighting system that would address the operational performance problems while facilitating the dark adaptation process. A long series of studies was conducted and indicated that problems associated with red light could be alleviated, if not eliminated, by substituting white light of generally comparable brightness (Kinney, Luria, and Ryan, 1982). These results have been reported in a series of manuscripts (Kobus and Luria 1985, Luria and Kobus, 1983). The substitute lighting system, referred to as Low Level White (LLW) lighting, was comparable to red lighting, and better than the blue lighting for all operational tests while facilitating the dark adaptation of shipboard personnel. In addition, crews which used LLW lighting reported reduced levels of watch-standing fatigue, enhanced detection of information on video displays, and no interference with the ability to identify color-coded information. These results were demonstrated not only in the laboratory but also through extensive testing in the fleet (Kobus and Luria, 1985, 1989). The results of these studies indicated that using low level white lighting indicated an increase in detection and classification performance (Luria and Kobus, 1983), was less detrimental to dark adaptation (Luria and Kobus, 1984), did not degrade visibility through the periscope (Luria and Kobus, 1985), improved the capability to use color-coded information (Benson, Ghirardi, Kobus, Luria, Lambert, Massey, Oswald, and Plath, 1987) and enhanced detection of colored targets on CRT's (Neri, Luria, and Kobus, 1984; Neri, Luria, and Kobus, 1986). In addition, the at-sea survey of LLW lighting (Kobus and Luria, 1985) indicated that 7 of 8 crews strongly preferred LLW lighting, because they experienced less fatigue, enhanced sonar performance, and felt better under stressful conditions. These same crews requested that they be allowed to retain the handmade LLW lighting filters until they were available through the GSA system.

Although the specifications have long been developed and published (Luria and Kobus, 1986), it was not until January of 1991 that the LLW filter was officially adopted by the Submarine force as the standard for night-time ambient illumination. The LLW lighting filters, consisting of replacement neutral density film sleeves, have been manufactured by hand until a source can be provided.

The results of the LLW research program have indicated that LLW lighting can reduce eye strain, headaches, and fatigue among sonar operators, and at the same time enhance their performance. In addition, these results have been extended to the control room and have demonstrated enhanced performance of navigation, fire control and ship control personnel. Furthermore, the use of LLW has also provided a very tangible benefit to the Navy by eliminating the need to redesign the Steering Control Panel/ Ballast Control Panel (SCP/BCP) on Trident submarines. These systems were developed using different colors to code the various indicators to allow for maximum discriminability. Using chromatic ambient illumination eliminated the operator's ability to distinguish between the indicators. Using LLW lighting allowed operators to take full advantage of the color-coding capability of the systems while maintaining dark adaptation (see Benson et al, 1986, for a complete description of Trident submarine lighting problems). After careful consideration of the advantages that LLW lighting provided, the operational forces requested that the filters be installed on a permanent basis (Letter from CO, USS William H. Bates, 1986). COMSUBDEVRON TWELVE (1985) recommended that all sonar rooms be converted to LLW lighting, and COMSUBLANT requested the density specifications of the filters. This data was used to develop an A&I (alteration & installation) change which made LLW filters available to the fleet (Luria and Kobus, 1986). In the Spring of 1991 LLW lighting filters were installed in the sonar and control room of all submarines.

Although modifications were made to standardize night-time ambient illumination on submarines, additional problems were reported. Light diffusers were different depending upon the location of the light and the class of ship. Different types of diffusers (also referred to as fixture lenses) were available. These differences affect the transmittance properties of the fixture. To further complicate matters different types of light bulbs were used throughout a compartment. In fact, any one of three separate light bulbs could be purchased through GSA contract using the <u>same</u> stock number. One major concern was that the light bulbs appeared to vary in the amount of energy transmitted. The intent of the present study was to investigate systematically the various light fixtures and types of light bulbs currently available in the fleet for standardizing shipboard lighting systems. An evaluation was conducted to determine if significant illuminance differences were provided between the various configurations and to make recommendations for the operational standardization of shipboard lighting.

METHOD

Materials

Four different configurations of overhead light fixtures available for installation on submarines were used in this experiment: 20-watt fixture with three bulbs (T-20), 20-watt with two bulbs (D-20), 8-watt with three bulbs and clear lens diffuser (T-8c), and 8-watt with three bulbs and opaque (milky-white) lens diffuser (T-80). Three types of light bulbs are also found on submarines and were tested: Cool White (CW), White (W), and Daylight (DL). Two levels of light intensity were tested: High Level White Light (HLW) and Low Level White Light (LLW). In the HLW condition, light was unfiltered. LLW lighting was provided by using neutral density filters (sleeves over bulbs) which allowed 2.5 percent transmittance of that of an unfiltered bulb (see Luria and Kobus, 1986). Two layers of neutral density photographic film were used to construct filters of 1.5 +/- 0.02 density. In the present study, fixtures with three bulbs were configured so that only the middle bulb was fitted with a filter, leaving the two outer bulbs unfiltered. Fixtures with two bulbs were configured so that only one bulb was filtered. Each fixture (T-20, D-20, T-8c, and T-8o) was tested with each bulb type (CW, W, DL) and light intensity (off, filtered, unfiltered), generating a mixed factorial design for the 20 watt and the 8 watt fixtures (Fixture (2) by Bulb (3) by Light level (2)).

A power supply box was fitted with a three-way toggle switch. The switch could either be selected to provide LLW, no light (off), or high level white (HLW) lighting. Illuminance was measured using a Minolta Model T-1M Illuminance Meter with remote sensor attachment. The sensor was affixed to a 1.25 in. diameter cardboard disk. The disk/sensor assembly sealed the end of a 5 inch tube (1.25 in diameter), so that the sensor was inside the tube and faced the open end (see Figure 1). The tube limited the angle of incidence of light falling on the sensor to 15.52 degrees. The inside and base of the tube were covered with a black, flat finish paint to minimize reflection. A foam-rubber ring was attached to the open rim of the tube to serve as a light seal between the fixture lens and the sensor. The center of each fixture lens was marked by a circle of 1.5 in. into which the open end of the sensor tube was placed for each measurement.

Insert Figure 1 about here

Procedure

Light readings were recorded using each type of light fixture and each level of lighting. The testing procedure was completed as follows: With the power supply box in OFF position, the open end of sensor tube was placed within the circle on the fixture lens. The light meter was then used to measure illuminance of the extinguished light. This procedure was used as a baseline measure to control for other light sources in the room penetrating the fixture lens, adding to the total light source. All measures were recorded at the end of a seven second sampling period. The power supply switch was then moved to the LLW and HLW positions, respectively, to record illuminance values.

This cycle of events was repeated once every five minutes for two hours and thirty minutes, to generate a total of 30 sets of readings (i.e., a set of readings comprised of one reading each for OFF, LLW, and HLW) for each bulb/fixture configuration.

RESULTS/DISCUSSION

The means and standard deviations were computed from 30 measurements and expressed as a function of light level, fixture type, and light bulb type. Measurements recorded during the OFF condition were treated as baseline levels of ambient light and subtracted from the HLW and LLW values to control for subtle changes in light levels within the testing room. The illuminance values adjusted for ambient light were then analyzed in separate Analyses of Variance (ANOVA's) depending upon fixture type and/or type of diffuser. Table 1 displays the calculated means and standard deviations for all configurations.

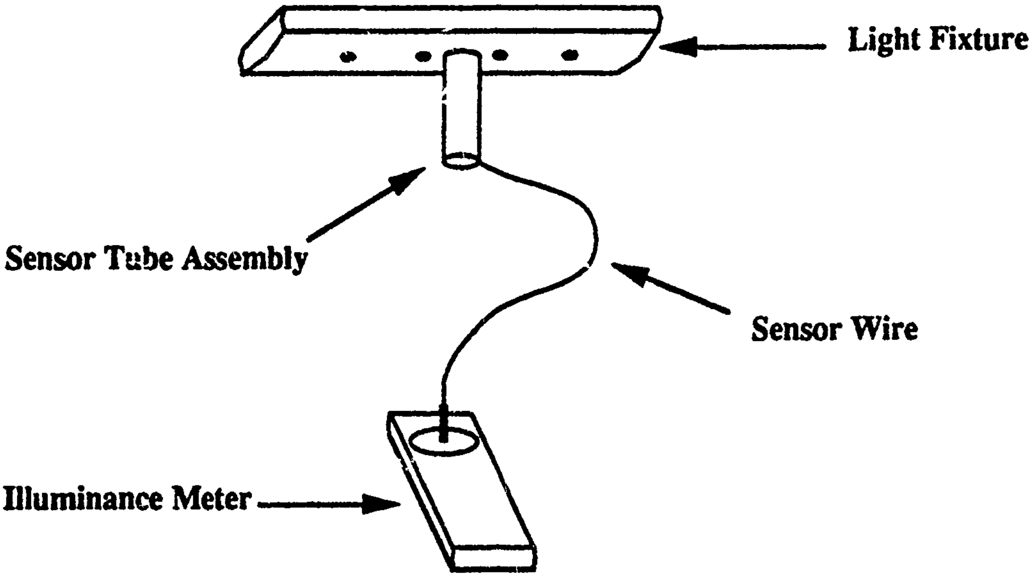

Figure 1. Schematic of the sensor tube assembly, illuminance meter and light fixture as they appeared during the measurement procedure.

Table 1. Descriptive Statistics for all Lighting Configurations.

Configuration	OFF		LLW		HLW	
	Mean	SD	Mean	SD	Mean	SD
TRIPLE-20						
Cool White	0.077	0.007	0.413	0.015	7.726	0.193
White	0.076	0.007	0.411	0.010	7.486	0.112
Daylight	0.075	0.006	0.360	0.014	6.750	0.123
DOUBLE-20						
Cool White	0.120	0.029	0.335	0.035	7.827	0.585
White	0.125	0.015	0.323	0.014	7.509	0.585
Daylight	0.098	0.003	0.288	0.005	6.783	0.271
TRIPLE-8 (CLEAR)						
Cool White	0.053	0.011	0.600	0.053	2.728	0.084
White	0.056	0.013	0.607	0.028	2.682	0.086
Daylight	0.049	0.008	0.592	0.005	2.445	0.075
TRIPLE-8 (OPAQUE)						
Cool White	0.101	0.016	0.375	0.013	8.174	0.088
White	0.063	0.009	0.366	0.012	8.328	0.121
Daylight	0.088	0.015	0.349	0.012	7.556	0.087

TWENTY-WATT FIXTURE

Two types of 20 watt lighting fixtures are available on submarines. One fixture has a three bulb configuration in which the center bulb serves to provide night-time ambient illumination. The analysis for the 20 watt fixtures evaluated differences in fixture type (Three bulb, Two bulb), bulb type (Cool White, White. Daylight), and light level (LLW, HLW). The analysis indicated that the two fixtures were not significantly different. However, the type of bulb used ($F(2,348)=124.8$, $p<.0001$) was highly significant. Significant differences also existed for level of lighting ($F(1,348)=64122.7$, $p<.0001$). Differences in the LLW condition (T-20 = .318 fc ; D-20 = .201 fc) are probably due to the placement of the light meter probe. One should note that the light level appears higher than the recommended (0.1 fc) level for night-time ambient illumination. However, illuminance is a distance dependent measurement and current values are taken at 5" from the light source rather than the recommended "desk top level." A light level by fixture interaction ($F(1,348)=5.67$, $p < .018$) was also statistically significant and appeared to be due to the fact that the light meter probe was placed along the center of the light fixture. Although the number of bulbs differed between the two fixtures the illuminance levels were almost identical (see Figures 2a and 2b).

Insert Figures 2a and 2b about here

Figures 2a and 2b illustrate the main effects as well as the interactions for both HLW and LLW data. The difference between light levels was not of particular interest in this study as an independent measure. Obvious differences were found to be highly statistically significant (HLW condition higher). However the interaction between light level and bulb type was of particular interest ($F(2,348) = 106.9$, $p < .0001$). These results indicated that the Daylight bulb was significantly less intense than the Coolwhite ($p<.001$) or White ($p<.001$) Light bulbs.

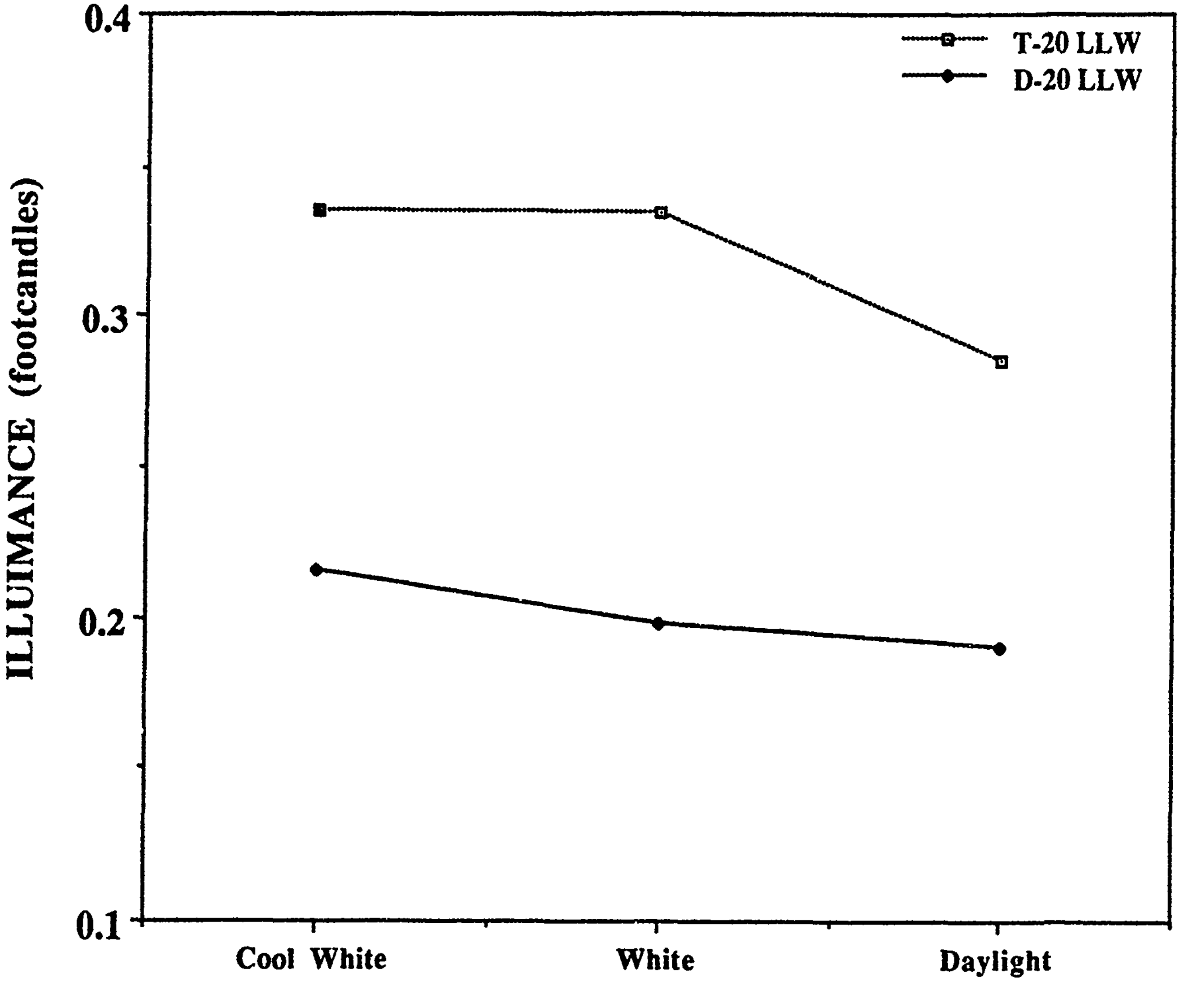

Figure 2a. Illuminance (fc) under LLW from 20-watt fixtures as a function of bulb type.

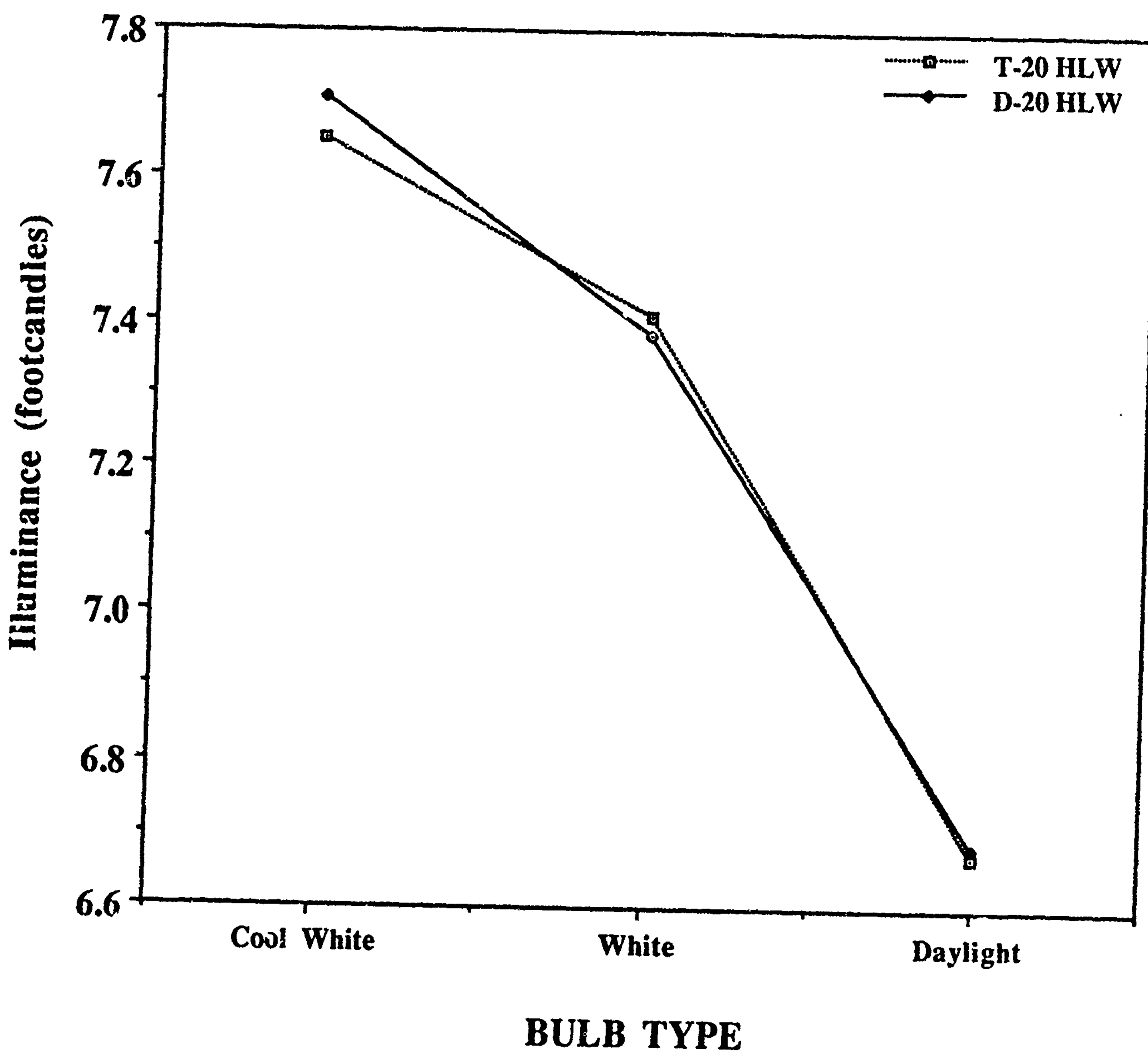

Figure 2b. Illuminance (fc) under HLW from 20-watt fixtures as a function of bulb type.

EIGHT-WATT FIXTURE

The analysis for the 8-watt fixture evaluated differences in bulb type (Cool White, White, Daylight), type of diffuser (clear, opaque), and light level (LLW, HLW). The 8-watt fixtures selected for testing were both available for shipboard use through the GSA catalog. Only the 8-watt fixtures with the opaque diffusers are currently installed on submarines. However, it should be noted that the 8-watt fixture with the clear lens diffuser is used on surface ships. The overall analysis revealed that the type of diffuser significantly effected the intensity of ambient light levels ($F(1,348) = 123810.3, p < .0001$). In addition, the analysis revealed that light bulb type ($F(2,348) = 528.4, p < .0001$), and light level ($F(1,348) = 445111.5, p < .0001$) were highly statistically different.

Insert Figures 3a and 3b about here

Of particular interest were the differences found between diffuser and bulb types. The difference found between light levels was expected and analyses were conducted to determine if light levels interacted with one of the other variables. The opaque filters provided significantly higher light levels in the HLW condition but significantly lower intensity levels for the LLW condition (see Figures 3a and 3b). This was demonstrated by a significant interaction (fixture x light level) ($F(2,348) = 455.9, p<.0001$). The most striking result was the marked attenuation of illuminance from the fixture with the clear lens (T-8c). This result seems somewhat counter intuitive. However, the intent of the opaque diffuser is to distribute light equally across the fixture, generating a homogenous field of light. The clear lens, however, allowed light to pass straight through with little change in direction. The markedly low illuminance values during the HLW condition measured from the fixture with the clear lens can be accounted for by a "dark" region at the center of the fixture from which the illuminance measurements were taken.

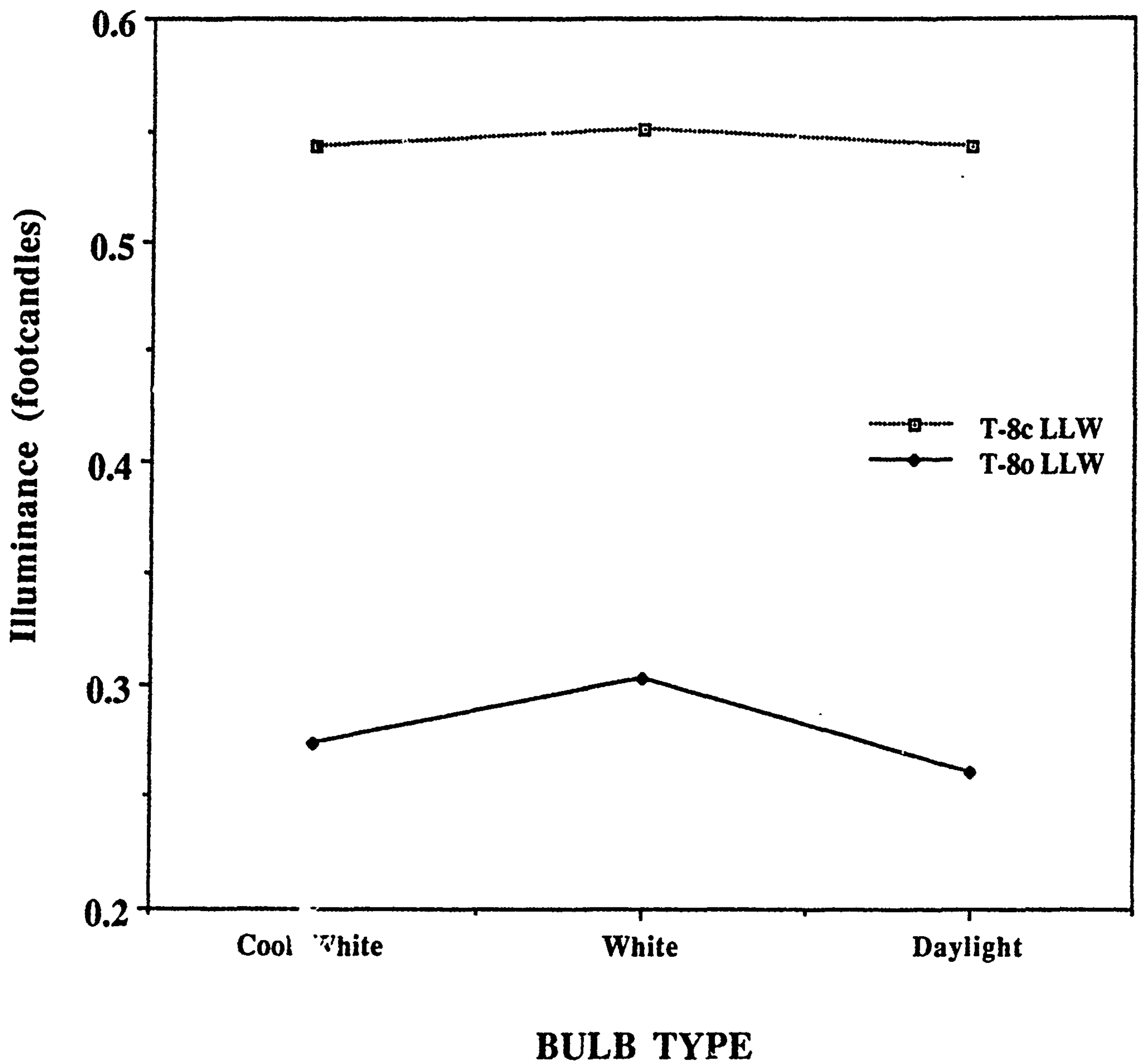

Figure 3a. Illuminance (fc) under LLW from 8-watt fixtures as a function of bulb and lens types.

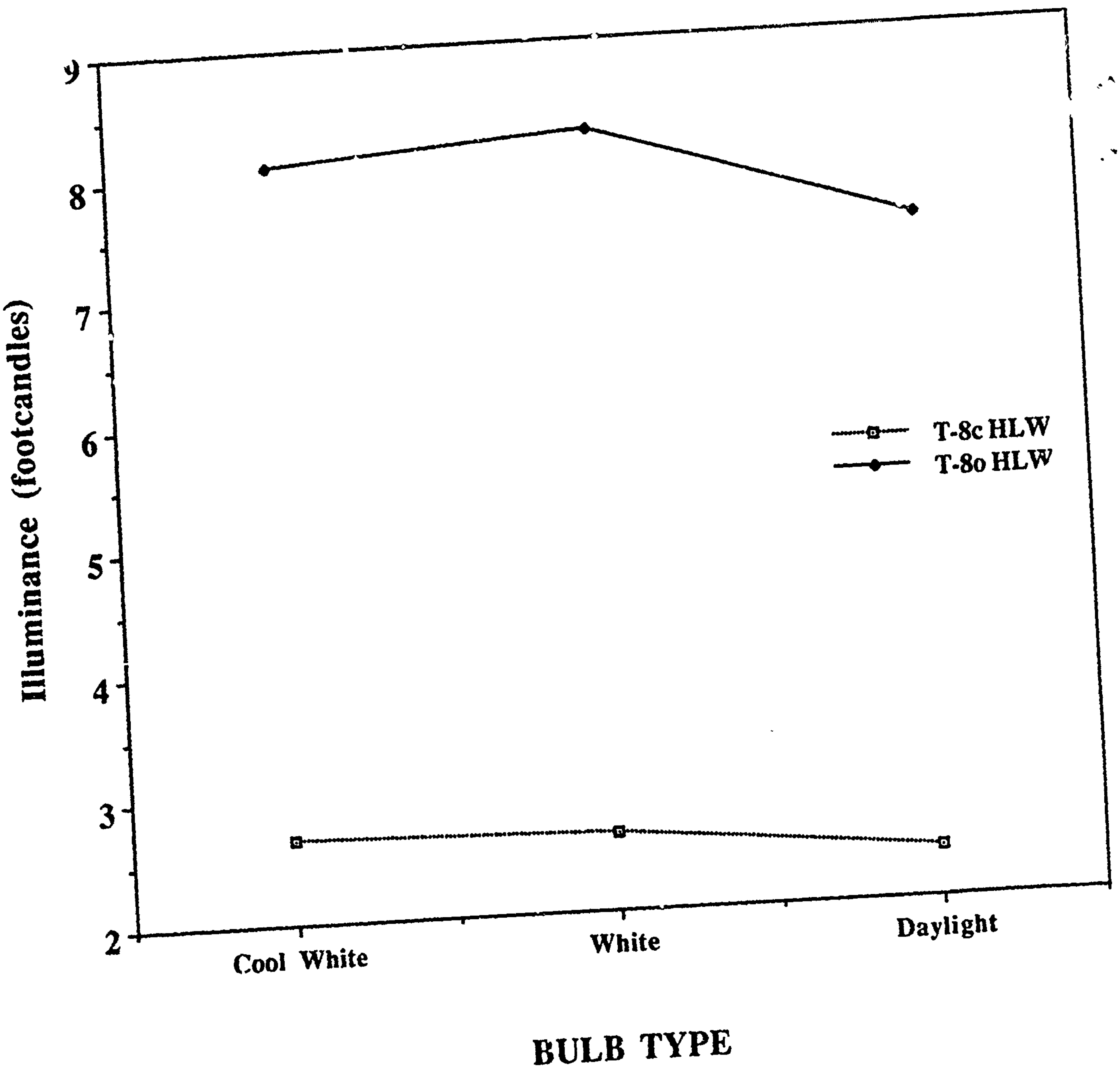

Figure 3b. Illuminance (fc) under HLW from 8-watt fixtures as a function of bulb and lens types.

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