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Night-time Lookout Duty: The Role of Ambient Light Levels and Dark Adaptation

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The aim of this research was to clarify and quantify the demands of the working environment and watch-keeping regime for large commercial ships in relation to dark adaptation. The night lookout task requires the identification of the relatively bright navigational lights of other ships against the dark background of the sky and sea. The probability of detection is determined by the ambient lighting conditions on the bridge and the dark adapted state of vision. Light levels were such that threshold sensitivity (after 15 minutes) was reduced by around 2 log units in comparison to complete darkness. This has implications for the effective range of navigational lights at sea as defined in regulations. The intensity and position of navigation lights on larger vessels is such that the sensitivity of the eye under typical bridge conditions is likely to be sufficient for their visibility to be acceptable. This may not be the case for less well lit small craft.

KEY WORDS

1. Dark Adaptation. 2. Maritime. 3. Lighting. 4. Lookout.

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1. INTRODUCTION.

A recent report by the Marine Accident Investigation Branch (MAIB, 2007) into the loss of a sailing yacht believed to be in a collision with a larger vessel identified three key factors that could have reduced the Lookout's [dark adapted] night vision, and in turn contributed to the failure of the Lookout to detect the presence of the yacht. These were:

- An insufficient period of dark adaptation to the night watch environment.
- Light pollution in the wheelhouse.
- The wearing of photochromic lenses at night.

The aim of this research was to clarify and quantify the demands of the working environment and watch-keeping regime for large commercial ships in relation to dark adaptation[1].

Current legislation (International Maritime Organization, 2010) states with respect to dark adaptation:

> *"The relieving officer shall ensure that the members of the relieving watch are fully capable of performing their duties, particularly as regards their adjustment to night vision. Relieving officers shall not take over the watch until their vision is fully adjusted to the light conditions".*

However, these regulations fail to specify either a time period that is sufficient for dark adaptation to occur, or the means by which night vision should be evaluated.

The role of the Lookout is to support the Officer of the Watch (OOW) by keeping lookout for other ships, navigation marks, floating debris and other potential dangers to navigation that may cross the ship's path. The lookout task is primarily a visual search task that involves the active scanning of the visual environment for the navigation lights of other ships, which may appear as no more than specks of light on the horizon (Robinson and Thomas, 1986). The lookout task is predominantly reliant on positive contrast, as the Lookout must identify the relatively bright navigational lights of other ships against the dark background of the night sky or the sea. Several factors influence the probability that a Lookout will detect a target object at sea including, the luminance of the background, the luminance of the target, atmospheric conditions, target size, distance to target and the threshold of *illuminance* at the eye of the observer [i.e., the Lookout]. The threshold of illuminance at the eye is determined by the ambient lighting[2] conditions on the bridge and the dark adapted state of the Lookout.

1.1. *Dark Adaptation.* Human vision involves the capacity of the eye to adapt to variations in ambient illumination. The eye can function from very dark to very bright levels of light; its capabilities reach across more than 10 orders of magnitude (Hill and Chisum, 1964). The average luminance of the visual scene that can be accommodated ranges from roughly 0·000 001 cd/m^2 (candela per square metre) on a very dark night to around 100 000 cd/m^2 on a bright sunlit day (Boyce, 2003). Dark adaptation is the improvement of visual sensitivity that occurs when the ambient light level is decreased (Barlow, 1964). It is reliant on a number of complex processes that involve the sequential progression of anatomic, photochemical and neurophysiological events (Norton et al., 2002). These include increased photosensitivity of the retina, conversion from cone to rod vision and a shift in the neural pathways within the retina (Lamb and Pugh, 2006).

The time course of dark adaptation is dictated primarily by the duplex anatomic structure of the retina and the extent to which rods, cones, or both are influenced by the adapting light. Under reduced illumination (ambient luminance below 0·03 cd/m^2), only rod cells are functional and this is termed scotopic vision (Curcio et al., 2000). As the light increases, rod function starts to decrease and the cones begin

[1] The Maritime and Coastguard Agency has recommended that photochromic lenses should not be worn for lookout duties at night (MCA, 2007) and, as such, this issue was not considered.

[2] Ambient light includes both naturally occurring light such as, moonlight, light pollution from the deck lights and the lights of other ships and shore lighting, among other sources.

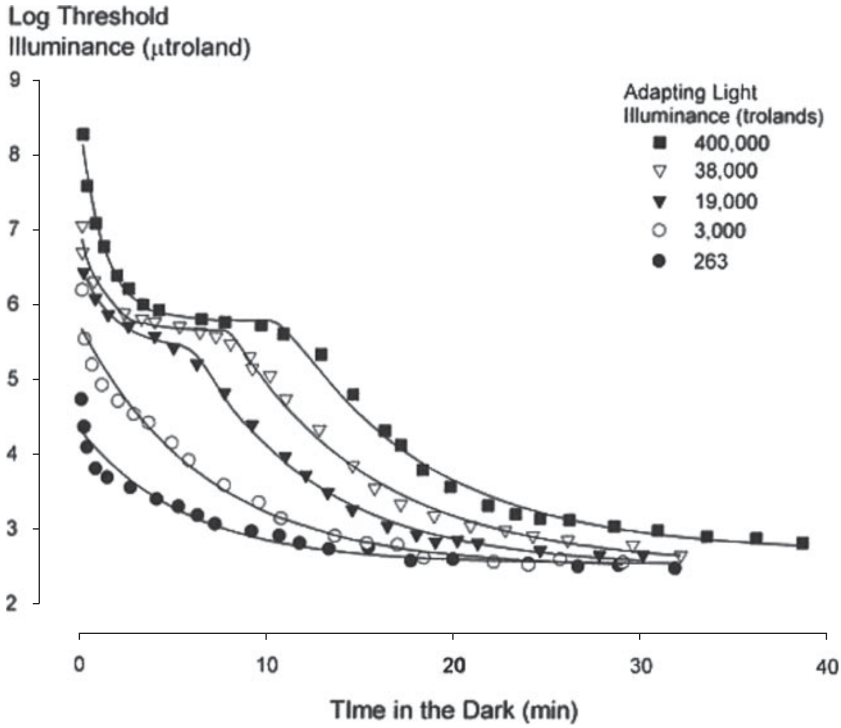

Figure 1. Dark adaptation curves following different levels of pre-adapting luminance (Hecht et al., 1937); Reprinted from The Psychophysical Measurement of Visual Function Norton et al., Adaptation to Light and Dark, 2002).

to operate. Once luminance increases sufficiently, so that only cones are functioning, the visual system is operating in the photopic range. The transition between photopic (cones) and scotopic (rods) vision is gradual; both the rods and cones, as well as the adaptive mechanism of each system interact in the mesopic range (Fisher et al., 1970).

Figure 1 illustrates the classic Dark Adaptation Curve (DAC) reported by Hecht et al., (1937), who observed a two stage decrease in visual threshold with time after initial pre-adaptation to a very bright light source. The first phase of the curve reflects the fact that, after exposure to bright light, the cone system is more sensitive to subsequent test lights, while the rods are relatively insensitive to such stimulus. As such, the cone system is the active system in determining the threshold for the detection of stimulus light during this phase. Depending on the strength of the initial light source, the first phase may take around 5 to 10 minutes to complete, approaching a minimum threshold in the mesopic range.

After around 5–10 minutes in the dark, the rod-cone break occurs, i.e. the sensitivity of the rod pathway improves to the point where the rod system becomes the more sensitive of the two (Rushton, 1961). This is reflected by the second phase of the DAC, wherein the rods require around 30 to 45 minutes to effectively reach their maximum sensitivity (absolute threshold) of around 10^{-5} cd/m^2 (Tipton, 1984). Decreasing the intensity of the light level prior to adaptation reduces the initial threshold of detection and decreases the time taken to reach both the rod-cone break, and the minimum detection threshold (Figure 1).

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Fundamental differences exist between experimental laboratory studies that measure light threshold of the dark adapted eye (Fisher et al., 1970) and substantial variations can occur with small changes in stimulus dimensions. In any determination of a DAC, the actual level of threshold sensitivity will depend upon the size, duration and wavelength of the pre-adapting light source (Barlow, 1957; Hecht et al., 1935; Hecht et al., 1945; Rushton, 1961; Wolf, 1945). Particularly relevant in the examination of the lookout task is the intensity of the initial source. It is highly unlikely that the bridge crew will, immediately prior to commencing night time lookout duties, be exposed to a light source comparable to those used in the laboratory study of dark adaptation (Spillman et al., 1972). They are far more likely to adapt from much lower levels of light.

2. METHODS.

2.1. *Ship Visits.* The following ship visits were undertaken during this investigation:

2.1.1. *Visits Onboard Two Roll-On, Roll-Off and Passenger Ferries (RoPax).* A return journey onboard two separate RoPax vessels was undertaken to observe the activities associated with maintaining a safe navigational watch at night. Both vessels had forward located closed bridges. The vessels observed shuttle between ports, on relatively short routes with a typical turnaround time of four hours and operate a '6 hours on, 6 hours off' watch rotation.

2.1.2. *Two Nights Visit Onboard an Oil Tanker.* A one-way journey onboard an oil tanker, which was a much larger vessel that makes far longer voyages than either of the RoPax ferries and as such operates a traditional four-hour watch rotation. The oil tanker has an aft (rear) located bridge with open bridge wings; selection of this design was deliberate in order to ensure differences in bridge activities between different ship types were captured.

2.2. *Measurement of Ambient Light Levels on the Bridge.* A lighting assessment was conducted to determine the amount of light the bridge team are exposed to under normal operating conditions including, naturally occurring light (e.g., moonlight) the light emitted from onboard equipment and any significant sources of light that the OOW and Lookout may be exposed to within the operational bridge environment. Measurements of *illuminance*, the total luminous flux incident on a surface area, were taken on every workstation on the bridge. At each site, the horizontal illuminance was measured at desk height using a calibrated Minolta T1 illuminance meter. Measurements were made on the RoPax vessels while the moon's phase was the Last Quarter and on the tanker while the moon's phase was the First Quarter. Spot measurements were made of representative conditions in the corridors and cabins adjacent to the bridge. Measurements of *luminance*, the amount of light reflected or emitted from a surface, were taken from the key workstations within the operator's field of view. Measurements were taken using a calibrated Minolta LS110 Luminance meter. Luminance measurements were taken from the operator's standing position in front of the equipment controls and focused on a particular target or portion of a target.

2.3. *Spatial Link Analysis.* A spatial link analysis was conducted in order to examine the movement of the bridge team during night-time navigation and, in particular, exposure to any light source that could affect visual performance both on

Table 1. Luminance measures of the key workstations on the RoPax Bridge.

Target	Luminance (cd/m^2)
ECDIS (ECS)	5·8
Radar 1: Background	0·1
Radar 1: Output	0·72
Radar 2: Background	0·16
Radar 2: Output	0·21
Engine controls	2·4
NAVTEX (LCD blue display)	0·56

and off the bridge. Four samples of 30 minutes, taken from video footage recorded during the ship visits, were analysed to illustrate the topographical relationship between the bridge crew, items of equipment on the bridge and the different areas of the bridge. This analysis considered only the basic physical relationships between system components; every time two items are linked a line is drawn between them, thus the more frequently two components are linked, the greater number of lines are drawn between them. This approach provides valuable information on the work areas most frequently used by the bridge team. These diagrams do not represent the sequence of interactions as many of the activities occur in parallel.

3. RESULTS.

3.1. *Ro Pax Bridge*. The average illuminance on the RoPax bridge was 0·15 lux; the minimum illuminance value measured in the area was 0·02 lux. The average illuminance in the cabins was 165 lux. The average illuminance in the corridor leading to the bridge was 82·6 lux. The chartroom onboard the RoPax vessel was separate from and located at the rear of the bridge and was fitted with a window, so that during the day natural daylight illuminated the chartroom and the OOW could look out while attending to tasks in the chartroom. However, this is impractical at night, as the light from the chartroom would flood the bridge causing adaptation to occur; therefore 'blackout' curtains were used to shield the bridge from light within the chartroom. Due to the availability of an Electronic Chart Display and Information System (ECDIS) on the bridge, visits to the chart room were infrequent. The OOW entered the chartroom occasionally to manually fix the ship's position relative to the passage plan, and to update the deck log.

The chartroom was lit by a 60 W incandescent bulb, kept on during the voyage, located to the side of the chart. The illuminance levels beneath the lamp were the highest (580 lux). In the centre of the chart table the levels were lower (288 lux). The average of all the illuminance measurements taken in the chartroom was 146·6 lux; the minimum illuminance value measured in the area was 35 lux. Table 1 indicates that most of the measured illuminances were very low, which was a direct effect of the low ambient lighting on the bridge and the night time settings applied to the equipment displays.

3.2. *Tanker Bridge*. The average illuminance on the bridge was 0·05 lux; the minimum illuminance value measured in the area was 0·01 lux. The average illuminance in the cabins was 125 lux. The average illuminance in the corridor leading to the bridge was 110 lux. The chartroom onboard the tanker was integral to the

Table 2. Luminance measures of the key workstations on the Tanker Bridge.

Target	Luminance (cd/m^2)
Radar 1: Background	0·01
Radar 1: Output	1·37
Radar 2: Background	0·01
Radar 2: Output	1·15
Engine controls	0·14
Internal communications	0·25

bridge. During the day, the chartroom was an open sided workstation, effectively a desk in the middle of the bridge. At night 'blackout' curtains were used to cordon off the chartroom area creating a separate room within the bridge. The tanker operated with traditional paper charts, which meant that visits to the chart room were more frequent than on either of the RoPax vessels. In addition to the ship's charts, navigational aids such as satellite positioning system and Loran-C positioning system were located in the chartroom. The OOW frequently entered the chartroom to manually fix the ship's position relative to the passage plan, and to update the deck log.

The chartroom had two table lamps, both fitted with 40 W incandescent bulbs that were kept on during the voyage. The illuminance levels beneath the lamps were the highest (82 lux). In the centre of the chartroom the levels were lower (65 lux). The average of all the illuminance measurements taken in the chartroom was 56·5 lux; the minimum illuminance value measured in the area was 21 lux. Table 2 indicates that most of the measured luminances were very low, which in common with the RoPax bridge is a direct effect of the low ambient lighting on the bridge and the night time settings applied to the equipment displays.

3.3. *Spatial Link Analysis.* Figure 2 illustrates the topographical relationship between the bridge crew, other system components (i.e., items of equipment on the bridge) and different areas of the RoPax bridge (represented alphabetically). Figure 3 shows the movement of the tanker bridge team during 30 minutes of observation. The thickness of the lines and the associated numbers reflect the extent of the bridge teams' interaction with the different sections of the bridge.

Table 3 shows the total amount of time spent in the chartroom during the four 30-minute sample observation periods. Note that the tanker operated a three-man bridge team and it was the junior officer that made visits to the chartroom, not the OOW. One possible explanation for the differences observed is that the RoPax vessels were fitted with ECDIS as part of the integrated bridge system, reducing the need to refer to papers charts and in turn the need to enter the chartroom.

4. DISCUSSION.

4.1. *The Dark Adaptation Curve.* It is clear that the Lookout's task is not well modelled by considering the dark adaptation function usually obtained in the laboratory or clinic, and to do so can easily give rise to incorrect interpretations because it is taken out of context. The starting point of the Lookout's adaptation was lower than that used in the laboratory (i.e., a bright light) and the end point was

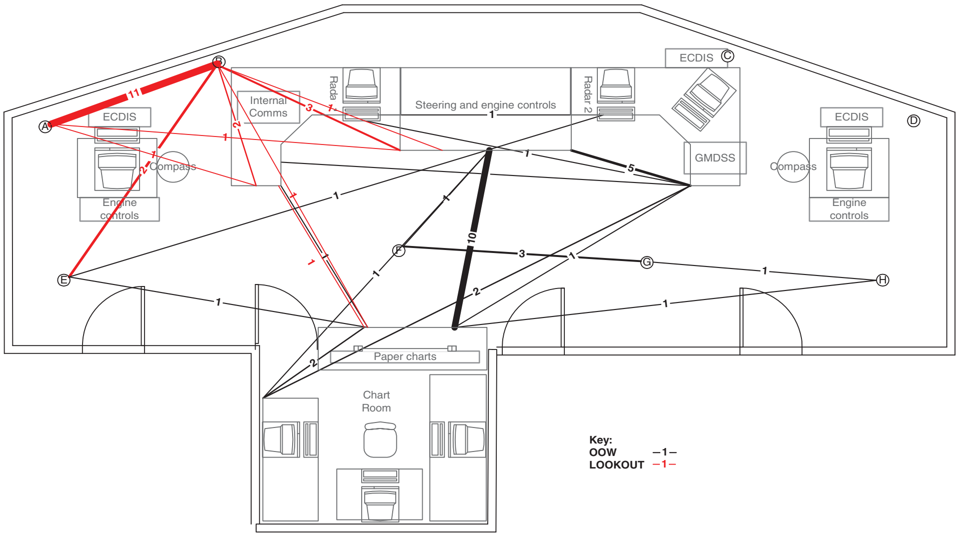

Figure 2. Movement of the RoPax bridge team during 30 minutes of observation.

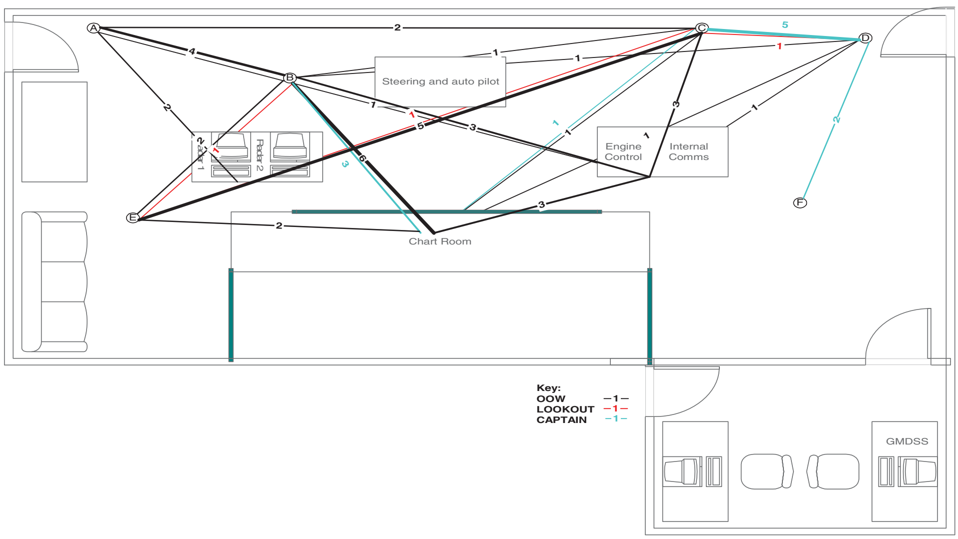

Figure 3. Movement of the tanker bridge team during 30 minutes of observation.

greater than total darkness. It is clear from the visits to the ships that the data in the literature does not allow us to model mathematically the Lookout's task with any precision. Consequently, recommendations about the time the Lookout should adapt before starting their duties are based on an approximation to broadly comparable data.

For example, during an examination of night time driving performance, Plainis et al., (2005) examined the time course of dark adaptation to mesopic levels of

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Table 3. Total time (minutes) spent in the chartroom during 30 minutes of observation.

	Night 1		Night 2	
	1	2	3	4
RoPax	4·24	13·55	8·55	1·09
Tanker	20·19	27·53	16·20	27·48

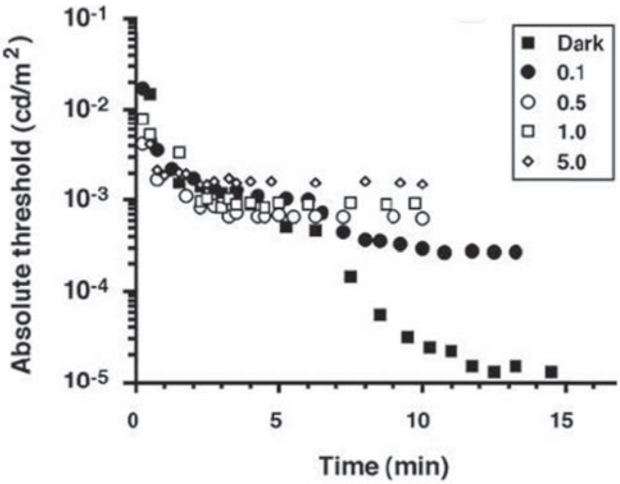

Figure 4. Dark adaptation curves for four mesopic levels of background luminance (measured in lux) compared with the classical DAC (filled squares), (adapted from Plainis et al., 2005).

illumination. Figure 4 shows retinal adaptation at a range of ambient light levels after exposure to a 3200 cd/m^2 light source for one minute (again this is much brighter than levels observed onboard the ships visited), in comparison to total darkness. It is clear that the retinal adaptation curve alters markedly with ambient lighting. In total darkness there is a clear rod-cone break, which occurs at around the 7 minute mark and the rods require around 15 minutes to reach the absolute threshold of around 10^{-5} cd/m^2. However, at upper mesopic levels (5·0 lux) only a single curve is observed, which undergoes a monotonic increase in sensitivity that can be attributed to cone mediated vision. Similarly, at 0·5 lux no break is evident, suggesting that the rod recovery is desensitised by the cone system, which dominates at these levels. If the ambient illuminance is decreased to 0·1 lux (low mesopic levels), the rod-cone break is present and a second, rod-dominated phase of adaptation can be distinguished, representing the switch between cone and rod-mediated vision.

At the light levels observed on the ship visits (0·1 lux), the rod-cone break is delayed compared with that for absolute darkness. Under these conditions, the rods would be sensitive enough to detect the test light at around 8 minutes, after which, significant improvements in threshold sensitivity occur. However, threshold sensitivity under mesopic light levels (after 15 minutes) is reduced by around 2 log units in comparison to complete darkness. As a consequence, the Lookout would never be fully dark adapted, and would therefore need less time after entering the bridge to reach a steady state of adaptation.

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A further difficulty in trying to extrapolate from laboratory studies of dark adaptation to the context of the ship's bridge is that, in the former case, after exposure to a bright light, the person is put into a totally dark environment, whereas the bridge is not in complete darkness. A key factor in determining the ambient light level on the bridge is the level of moonlight, which will vary depending on the phase of the moon, influencing the dark adaptation of the Lookout. This may also affect the contrast between target objects and the background (i.e., the night time environment), making objects more difficult to detect. Where no moon is present it may be possible that the bridge team will operate in near total darkness (scotopic vision). However, the average illuminance on the RoPax bridge was 0·15 lux, while the average illuminance on the tanker bridge was 0·05 lux, which suggests that mesopic, rather than scotopic, vision may be of primary importance on the bridge because some light is often present during night operations (Miller and Tredici, 1992). There is a common misconception that only the rods are used at night and only the cones are used during the day. Actually, both rods and cones function over a wide range of light intensity levels and at intermediate (mesopic) levels of illumination, they function simultaneously (Figure 1). Neither the rods nor the cones operate at peak efficiency in this range, but both actively contribute to visual perception (Nakagawara et al., 2006).

The current 15 minute recommendation for dark adaptation (International Chamber of Shipping, 2007; International Maritime Organization, 2008) is sufficient, given that watchkeepers are not likely to be adapting from bright light levels. However, it would be useful to reinforce this guidance, as the length of handovers observed during the ship visits were shorter than the recommended 15 minutes. Furthermore, on some large vessels, crew alternate periods on the bridge with periods of safety checks and fire watches in other parts of the vessel, some of which will be brightly lit. It should be noted that the same period of dark adaptation would be required every time the Lookout returns to the bridge. The illuminance levels on the bridge observed during the ship visits were within the recommended limits defined in guidance on ergonomics criteria for bridge design (International Maritime Organization, 2000), which suggests a fundamental understanding of best practice associated with blackout procedures (i.e., radars and console lights appropriately dimmed and the chartroom curtained off, avoiding contamination from residual light).

4.2. *The Impact of the Chartroom on Dark Adaptation.* During normal bridge operations, the need to enter the chartroom is considered the most significant factor affecting dark adaptation (as shown by the spatial link analysis). The average illuminance in the RoPax chartroom was 146·6 lux, while the average illuminance in the tanker chartroom was 56·5 lux. The IMO Guidelines on ergonomics requirements for bridge layouts (International Maritime Organization, 2000) state that:

> *"A satisfactory level of lighting should be available to enable bridge personnel to complete such tasks as maintenance, chart and office work satisfactorily, both at sea and in port, daytime and night time."*

In addition, the lighting required on the bridge should be designed so as not to impair the night vision of either the OOW or the Lookout through glare, reflection or flicker.

All information should be presented emitting as little light as possible at night, and red or filtered white light (i.e., a white lamp with a red filter attached) should be used to maintain dark adaptation whenever possible. Adjustable lighting (continuously variable between 0 and 20 lux) should be provided for controls and visual displays, including display, control and panel labels and critical markings, which must be read at night or under darkened conditions. The range of the dimming control should permit the displays to be legible under all ambient illumination conditions.

Although the ships visited were very good at following the blackout procedures and maintaining appropriate light levels on the bridge, it appears that less consideration is given to light levels in the chartroom. The illuminance readings in the chartroom were significantly higher than recommended and would cause the eye to readapt to light, even if exposure to the light was brief. Light levels on the RoPax vessels were approximately seven times the recommended maximum and approximately three times the recommended maximum in the tanker chartroom. This suggests that the number and duration of visits to the chartroom may be a significant issue in terms of dark adaptation. However, this effect may be mediated by the fact that the Lookout remained on the bridge while the OOW was in the chartroom, meaning that at least one member of the bridge team was adapted to the ambient conditions at all times during the watch.

The bridge teams on the RoPax vessels made far fewer visits to the chartroom (approximately five per sample) in comparison to the bridge team on the tanker (approximately 12 visits per sample). Furthermore, when the same sample footage was used to calculate both total and average time spent in the chartroom, results indicate that the duration of visits was far greater for the tanker bridge crew (an average of 2 minutes 17 seconds per visit) than the bridge crews on the RoPax vessels (an average of 1 minute 29 seconds per visit). The longest time period spent in the chartroom, during observation on the RoPax vessels, was 3 minutes and 58 seconds, compared to 13 minutes and 52 seconds on the oil tanker.

The use of ECDIS reduces the need to use paper charts and therefore should reduce the need for the bridge team to visit the chartroom. Further research would be needed to quantify the impact of ECDIS on the frequency and length of visits to the chartroom. Also, further research would be needed to assess the impact of the significant minority of vessels that will not be required to carry ECDIS. In addition to the use of ECDIS there are other navigational techniques (e.g., radar parallel indexing, plus clearing bearings and ranges) which can reduce the need to visit the chartroom and hence can be employed in the management of dark adaptation. Consideration could be given to promoting their use in this context, particularly on those classes of vessels not required to carry ECDIS.

4.3. *Luminous Range of Navigational Lights.* Given the observation that illuminance levels onboard the bridge fall in the mesopic range, it is important to determine the necessary luminous range of a navigational light, in order for it to be seen by the mesopic adapted eye and within the conditions set out in the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS, 1972). The luminous range of a light is defined as the maximum distance at which a light can be seen, as determined by the luminous intensity of the light, the meteorological visibility, and the sensitivity of the eye of an observer (i.e., as determined by the ambient light level on the bridge to which the observer's eyes are adapted). The further the observer is from a light the more its beam has spread out so less light will enter the eye. In addition, any haze in the air will attenuate the beam. This can be expressed in

Table 4. Nominal range calculation for night time background luminance values.

	Conditions		
Background lighting	None	Minor	Substantial
Illuminance (lx)	2·00E-07	2·00E-06	2·00E-05
Transmissivity (per NM)	0·80	0·80	0·80
Visibility (NM)	13	13	13
Range (NM)	Intensity (cd)		
1	0·9	9	90
2	4·3	43	430
3	12	120	1,200
4	27	270	2,700
5	52	520	5,200
6	94	940	9,400

mathematical terms using Allard's Law (International Association of Marine Aids to Navigation and Lighthouse Authorities, 2008). A selection of figures derived from the formula is given in Table 4.

The figures highlighted in the third column of Table 4 are the minimum levels of luminous intensity (cd) required to satisfy the requirements specified in the COLREGS Rule 22 (visibility of lights), at the ambient light levels observed during the ship visits. These figures reflect the fact that visual sensitivity is around two log units poorer under low mesopic conditions than under scotopic conditions (see first column, Table 4).

Anecdotal reports from experienced mariners suggest that when observing the navigation lights of one commercial vessel from another commercial vessel it is not unusual to be able to see the lights of the other vessel well in excess of the minimum ranges specified in the COLREGS. They reported that under favourable circumstances it is possible to see the lights of other commercial vessels at up to twice the specified minimum. It is not known whether this is because the manufacturers of navigation lights fitted to commercial vessels exceed the minimum specifications set out in the COLREGS or due to the relative heights they are fitted at and observed from in commercial vessels. Experienced mariners have also indicated that the problem of observing navigation lights of other vessels from the relatively lofty height of a commercial vessel's bridge becomes greater as the other vessels become smaller (and closer), with the navigation lights of leisure craft being notoriously difficult to see.

The specification of navigation lights contained in the COLREGS has evolved over centuries from the days of sailing ships when vessels observed each other from similar heights and travelled at much lower speeds. The present regulations make some attempt to overcome the disparity between the sizes of vessels (and allow for heeling and rolling motion) by specifying a vertical arc through which navigation lights must be visible; the lights of sailing vessels are required to have 50% intensity at the limits of the vertical arc. This could make the detection of sailing vessels' navigation lights particularly difficult if they are heeled over by the effects of the wind.

Another possible constraint is the limited electrical power on leisure craft, and particularly small sailing craft. As a result, navigation lights designed for leisure craft may just meet the minimum specifications in the COLREGS. This is particularly pertinent when it is further considered that background lighting levels on the bridge mean that the Lookout will be operating almost exclusively in the mesopic range of dark adaptation, and that in order for navigation lights of other vessels to be seen at the minimum specified range their intensity may need to be increased by 2 log units (Table 4). These factors, together with the effects of heeling, mean that the lights of a small sailing vessel are unlikely to be reliably detectable at the specified minimum range under the measured ambient bridge lighting conditions, even by an observer who is fully adapted to these conditions.

It is therefore reasonable to conclude that the configuration and specification of navigation lights relating to small craft may need to be reassessed with a view to improving their minimum detection range in representative operating conditions. Alternatively, consideration could be given to moving the lookout position from the bridge to a location where the level of dark adaptation is in the scotopic region. In practice this would entail a return to posting a lookout on the forward main deck section of the vessel. However, this presents its own problems; as this is an exposed position there will be occasions when adverse weather and sea conditions make this lookout position untenable. Therefore, some protection from the elements would need to be provided so that the Lookout is operating in a safe comfortable environment that enables them to concentrate on the lookout task.

Furthermore, certain types of vessel may not be able to find a suitable location that is in the scotopic vision regime due to the proximity of deck lighting. There will also be manning issues to consider if the OOW is not to be left as the only person on the bridge at night. Even if the separate lookout position is only required in near coastal waters, to be effective a substantial number of the world's merchant fleet would be affected and this would require international agreement to alter the appropriate international conventions.

5. CONCLUSIONS.

Under laboratory conditions, very bright pre-adapting lights are used, and it can take up to 40 minutes for the eye to adapt to complete darkness. However, it is highly unlikely that the bridge crew will, prior to commencing night time lookout duties, be exposed to comparably bright pre-adapting lights. Lighting levels on the bridge are such that only partial dark adaptation occurs. As a consequence, the Lookout's eyes would never become fully dark adapted, and it would therefore take less time after entering the bridge for the eyes to reach a steady state of adaptation. Adaptation to lighting conditions on the bridge will normally be achieved in 15 minutes. The intensity and position of navigation lights on larger vessels is such that the sensitivity of the human eye under measured ambient conditions is likely to be sufficient for their visibility to be acceptable. This may not be the case for less well lit small craft.

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REFERENCES

Barlow, H. B. (1957). Increment thresholds at low intensities considered as signal/noise discriminations. *Journal of Physiology*, **136**, 469–488.

Barlow, H. B. (1964). Dark adaptation: A new hypothesis. *Vision Research*, **4**, 47–58.

Boyce, P. R. (2003). *Human Factors in Lighting*. Taylor & Francis, London.

COLREGS (1972). *The Convention on The International Regulations for Preventing Collisions at Sea 1972 (with amendments adopted from December 2009)*. International Maritime Organization, London.

Curcio, C. A., Owsley, C. and Jackson, G. R. (2000). Spare the Rods, Save the Cones in Aging and Age-Related Maculopathy. *Investigative Ophthalmology Visual Science*, **41**(8), 2015–2018.

Fisher, K. D., Carr, C. J., Huff, J. E. and Huber, T. E. (1970). Dark Adaptation and Night Vision. *Federation Proceedings*, **29**(5), 1605–1638.

Hecht, S., Haig, C. and Chase, A. M. (1937). The Influence of Light Adaptation on the Subsequent Dark Adaptation of The Eye. *The Journal of General Physiology*, **20**, 831–850.

Hecht, S., Haig, C. and Wald, G. (1935). The Dark Adaptation of Retinal Fields of Different Size and Location. *The Journal of General Physiology*, **19**(2), 321–337.

Hecht, S., Hendley, C. D., Ross, S. and Richmaond, P. (1945). *Influence of Exposure to Intense Sunlight on Subsequent Night Vision*. Camp Lejune: North Carolina: Medical Field Research Laboratory, M&S Research Project X-442, AV-233-W.

Hill, J. H. and Chisum, G. T. (1964). Flashblindness: A Problem of Adaptation. *Aerospace Medicine*, **35**(9), 877–879.

International Association of Marine Aids to Navigation and Lighthouse Authorities (2008). *Marine Signal Lights: Part 2 – Calculation, Definition and Notation of Luminous Range*. Recommendation E-2000-2.

International Chamber of Shipping. (2007). *Bridge Procedures Guide*. Marisec Publications, London.

International Maritime Organization. (2000). *Guidelines on Ergonomic Criteria for Bridge Equipment and Layout*. MSC/Circ.982.

International Maritime Organization. (2008). *Night-Time Lookout – Photochromatic Lenses and Dark Adaptation*. MSC.1/Circ.1280.

International Maritime Organization. (2010). *Standards of Training, Certification and Watchkeeping [STCW] A-VIII/2 Part 3–1, Paragraph 19*. International Maritime Organization, London.

Kemp, J. (1995). The Evolution of Navigation Lights for Ships. *The Journal of Navigation*, **48**, 256–267.

Lamb, T. D. and Pugh, E. N. Jr. (2006). Phototransduction, Dark Adaptation, and Rhodopsin Regeneration, The Proctor Lecture. *Investigative Ophthalmology Visual Science*, **47**(12), 5138–5152.

MAIB (2007). *Report on the investigation of the loss of the sailing yacht Ouzo and her three crew, South of the Isle of Wight during the night of 20/21 August 2006*., Marine Accident Investigation Branch Report No. 7/2007. Published 12 April 2007.

MCA (2007). Night-time lookout – *Photochromatic Lenses and Dark Adaptation, MGN 357 (M+F)*. Department of Transport, Maritime and Coastguard Agency, Southampton.

Miller, R. E. I. and Tredici, T. J. (1992). *Night Vision Manual for the Flight Surgeon*. Brooks Air Force Base: Texas: Armstrong Laboratory).

Nakagawara, V. B., Montgomery, R. W. and Wood, K. J. (2006). *Aircraft Accidents and Incidents Associated with Visual Disturbances from Bright Lights During Night-Time Flight Operations*. Federal Aviation Administration, Washington D.C.

Norton, T. T., Corliss, D. A. and Bailey, J. E. (2002). Adaptation to Light and Dark. In: T.T. Norton, D.A. Corliss, and J.E. Bailey (Eds.), *The Psychophysical Measurement of Visual Function*, Chapter 4, 75–104. Woburn, MA: Butterworth Heinemann.

Plainis, S., Murray, I. J. and Charman, W. N. (2005). The Role of Retinal Adaptation in Night Driving. *Optometry & Vision Science*, **82**(8).

Robinson, N. P. and Thomas, D. B. (1986). The Visual Tasks on the Ship's Bridge. *Vision in Vehicles, Proceedings of the Conference on Vision in Vehicles, Nottingham, 9–13 September 1985*, (Edited by A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith and S .P. Taylor). Amsterdam, North-Holland.

Rushton, W. A. H. (1961). Dark-Adaptation and the Regeneration of Rhodopsin. *Journal of Physiology*, **156**, 166–178.

Spillman, L., Nowlan, A. T. and Bernholz, C. D. (1972). Dark Adaptation in the Presence of Waning Background Luminances. *Journal of the Optical Society of America*, **62**(2), 177–181.

Tipton, D. A. (1984). A Review of Vision Physiology. *Aviation, Space, and Environmental Medicine*, **55**(2), 145–149.

Wolf, E. (1945). Effects of Exposure to Ultra-Violet Light on Subsequent Dark Adaptation. *Proceedings of the National Academy of Science and the United States*, **31**, 349–355.