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Light pollution at night

Using the 'windscreen wiper' technique to maintain a proper lookout at night

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Last year, the authors published an article highlighting the issues watchkeepers face when maintaining a proper lookout during the day ('Scanning: From screen to screen', *Seaways* November 2022). This article takes the same topic further, exploring the issues faced at night together with suggestions to improve the ability to maintain lookout in the darkness. This research is part of a project funded by Maritime Research and Innovation UK (MarRI-UK) studying Lookout Awareness of Distractions. A key part of this project is the creation of a Distraction Evaluation Ratio (LADDER).

Lookout at night

Maintaining a proper lookout at night presents the watchkeeper with a series of challenges related to 'dark adaptation' that have so far not been sufficiently studied. These challenges are partly due to there being no specific requirements about these matters in the STCW Code – with a resulting lack of guidance, and subsequently training.

The STCW Code states '*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*'. It does not, however, provide guidance on how they should do so.

A basic understanding of the operation of the human eye and how it reacts to light and the visible colour spectrum is essential if watchkeepers are to make the most of their night vision.

The IMO performance standards for Radar, ARPA and ECDIS displays require that the '*information is clearly visible to more than one observer in the conditions of light normally experienced on the bridge of the ship by day and by night*'.

IMO also sets illumination control requirements for Visual Display Units (VDUs) or multi-function displays (MFDs) on the ships' bridge during the day. For example:

- VDU background luminance range must be 15-20cd/m^2 (candela per square metre) (see box, right)
- Display luminance range must be 80-160cd/m^2

IMO does not, however, provide a clear min/max luminance for night usage – precisely where the luminance level causes real problems for maintaining a proper lookout.

Computer screens deployed as MFDs on a ship's bridge typically operate with a peak luminance range of 80-500 cd/m^2. This is far brighter than the permissible level for spotlights (0-20 lux), and will cause light pollution that will affect dark adaptation. Surprisingly, the ability to vary illumination levels is delegated to the watchkeeper, but it is disturbing that they are not educated about the effect of colours and brightness on their vision.

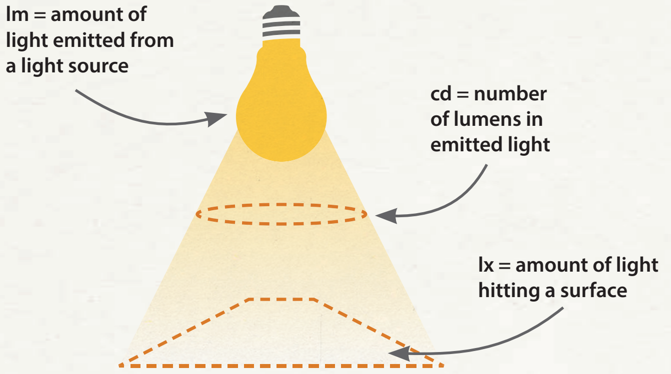
Human eye structure

The vast amount of information received by the human eye is sent to the brain for recognition, processing (in photoreceptor cells), storage and

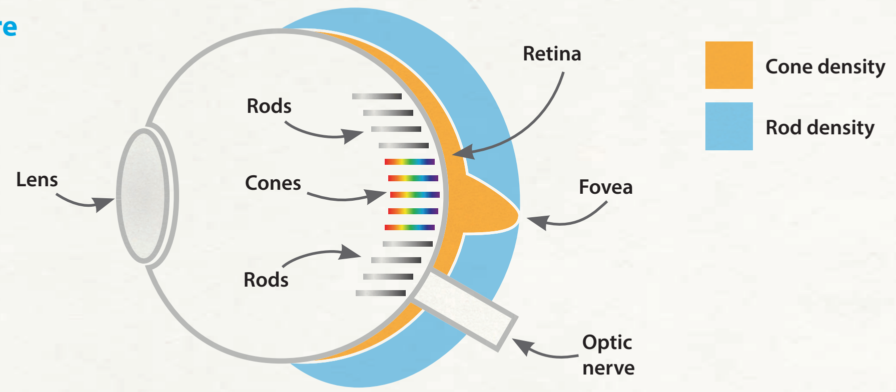
Definitions:

Lumen (lm)	A unit of luminous flux i.e., amount of light emitted from a light source.
Candela (cd)	A unit of luminous intensity i.e., the number of lumens in emitted light.
Lux (lx)	The amount of light hitting a surface i.e., the number of lumens on a specific area of a surface.
Luminance	The amount of light that passes through, is emitted from, or is reflected from a unit area. Measured in candela per square metre (cd/m^2)
Illuminance	Amount of light falling on a surface measured in units of Lux (Lux = lm/m^2)

1 cd/m^2 = 1 Lux = 1 Lumen/m^2



The structure of the eye



action. The rays of light reflected from the objects into the eyes enables them to register the object visually – to see. If there is no light to reflect or if the eyes are unable to capture the reflected light, the eyes do not see. The average luminance at which the eye can see ranges from approximately 0.000001 (10^{-6}) cd/m^2 – a dark night – to approximately 100,000,000 (10^8) cd/m^2 – a bright sunny day.

The retina at the back of the eye is covered by two types of light sensitive photoreceptor cells – cones and rods (see above). There are 5-6 million cones and 80-90 million rods in each eye. The fovea, a small depression within the retina, contains mostly cones, and is the point of sharpest focus. Rods and cones each provide a different type of vision, with cones processing colour vision and bright lights, and rods working better in dim light. This duplex system consisting of cones and rods provides visibility over a large range of ambient light levels.

Photopic vision registers colour, detail and distant objects. It is generated by cones and is available in a luminance range of 10-10^8 cd/m^2. Cones are activated by release of a photopigment known as opsin. They are considered to function in luminance levels of above 3cd/m^2 and reach their peak sensitivity at 555 nanometre wavelength light.

Scotopic vision occurs in luminance levels of below 3cd/m^2 (between 10^{-3} and 10^{-6} cd/m^2), and is generated by rods. Rods provide the best image perception in low light, but they cannot distinguish colours, and vision instead appears in shades of grey.

Obviously, it is not always absolute dark or daylight. In twilight, both rods and cones contribute to vision. This is referred to as '**mesopic vision**', and occurs between luminance levels of between 0.003 to 3 cd/m^2.

Dark and light adaptation

In order to see in the dark, the eye must shift from using cones to rods; a process which takes time. The change from cones to rods is triggered by release of a photopigment known as rhodopsin that helps rods adjust to low light or darkness. This process is known as 'dark adaptation'. It takes approximately 20-30 minutes for rhodopsin to reach its full density at around 10–5 cd/m^2. The magnitude of rhodopsin release is dependent on the light intensity (the lower the light intensity; the greater the amount of rhodopsin released). The dark adaptation process may take longer in some people depending upon the quality of their eyesight, age, fitness, and level of fatigue.

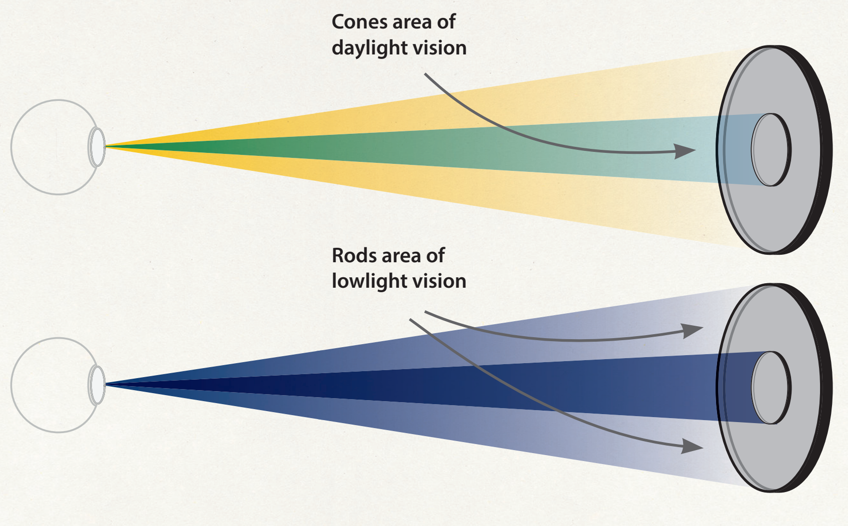
Light adaptation is the reverse process of dark adaptation. If dark-adapted eyes are subjected to a bright light for as little as one second, the rhodopsin begins to decompose, voiding the dark adaptation. It takes 5-7 minutes for cones to adjust fully to the bright light after decomposition of rhodopsin has begun.

The blind spot

The cones are 'unavailable' in darkness, meaning there is an area approximately 5 to 10 degrees wide in the central part of the retina that is 'night blind'. Because of this, the eyes cannot detect an object in darkness if looked at directly. Instead, vision must be off-centred in order to 'spot' an object with rods (see diagram, right). With binocular vision (seeing with both eyes), the blind spot is not an issue since an object is unlikely to be in the blind spot of both eyes simultaneously, but it may remain undetected in monocular vision; for example if the field of view for one eye is obstructed by a bridge window post. The dark adaptation process for watchkeepers must include shifting the vision by 4 – 12 degrees to one side so that rods can be fully utilised, and the blind spot avoided. This is a salient feature of the 'window wiper scan' method.

When dark adaptation is complete, photopic vision is unavailable but peripheral vision remains available and is extremely useful in the detection of faint light sources such as navigational lights of other vessels or dim stars. This function is vital for performing optimum lookout, particularly spotting collision threats from other objects.

Day and night vision



The visible spectrum of light

The various colours used in the MFDs or other lighting on the bridge of a ship also have an impact on dark adaptation (see below). The visible spectrum

Table 1 – Visible Light Spectrum

Colour	Wavelength*** (nanometre)	Frequency* (THz)	Energy** (eV)	Used by Rods or Cones
Violet	400 - 440	668 - 789	3.10	Violet border i.e., the lowest wavelength/frequency limit of visible light.
Indigo	440 - 460	600 - 700	2.48	
Blue	460 - 500	606 - 668	2.75	500nm rhodopsin released at peak sensitivity
Green	500 - 570	526 - 606	2.25	
Yellow	570 - 590	508 - 526	2.14	Most sensitive wavelength for cones 555nm (yellow-green)
Orange	590 - 620	484 - 508	2.06	
Red	620 - 720	400 - 484	1.91	Red border i.e., the highest wavelength/frequency limit of visible light.

* THz – Trillion Hertz
** eV - electron-volt
*** There are no agreed limits for the visible spectrum. The values used here are found in most of the reference materials.

Polishchuk, O. V., Tykhanova, O. (2022) Biophysical aspects of electromagnetic theory of human vision perception of light information in the visible range. Ukrainian Neurosurgical Journal. Vol. 28. pp. 17-24.

Rabia, R. Rizvi, S. S., Riaz, F., Shokat, S. (2018) Designing of Cell Coverage in Light Fidelity. International Journal of Advanced Computer Science and Applications. 9. 10.14569/IJACSA.2018.090308.

of light includes violet, indigo, blue, green, orange, yellow and red (VIBGOYR) colours with wavelengths between 400 to 720 nanometres. A shorter wavelength corresponds to higher frequency and energy in the visible spectrum. Red has the shortest frequency (400-484THz), lowest energy (1.91eV) and a wavelength of 620-720 nanometres, whereas violet has the highest frequency (668-789THz), highest energy (3.10eV) and a wavelength of 400-440 nanometres. Ultraviolet wavelengths (<400 nanometres) fall below the visible spectrum, whereas infrared wavelengths (>720 nanometres) fall above this spectrum. Both are considered invisible to the human eye.

With respect to the visible light spectrum and the photoreceptor cells, three distinct areas need to be considered for maintaining a proper lookout at night:

Dark adaptation: As watchkeepers walk into the wheelhouse at night, their eyes don't see anything at first i.e., total darkness. This is the point at which dark adaptation commences. As explained above, this depends upon successful release of rhodopsin. Rods have a higher sensitivity to blue light of wavelengths 460-500 nanometres or less – meaning that rhodopsin is not released, or begins to break down, if exposed to light of this colour. They have no sensitivity to red light of wavelengths greater than 620 nanometres.

Red wavelength light does not trigger the decomposition of rhodopsin – so if the watchkeepers spend some time in a chart room, for example, illuminated by red light, they will not lose their dark adaptation. Rhodopsin continues to be released to process dark adaptation, and remains at the same saturation level. This however only works with dim monochromatic red light of a single frequency or wavelength and not a white fluorescent lightbulb covered with red liner, coating, or filter.

Light adaptation: When a person moves from darkness into light to focus on e.g., an ECDIS display, the eyes begin the process of light adaptation. If they remain focussed on the ECDIS for approximately 5-7 minutes, the eyes will be fully light adapted, requiring a further 20-30 minutes for the regeneration of sufficient rhodopsin for full dark adaptation. It is therefore vital that watchkeepers are aware of the luminance levels on the bridge and their impact on dark and/or light adaptation.

The IHO specifications for electronic chart content require that '*For the ECDIS this means setting up the display for bright sunlight, when all but the starkest contrast will disappear, and for night when so little luminance is tolerated that area colours are reduced to shades of dark grey (maximum luminance of an area colour is 1.3 cd/m^2 compared with 80 cd/m^2 for bright sun)*'.

The maximum luminance of an area colour of 1.3 cd/m^2 allowed by IHO falls in the mesopic vision range i.e., 0.003 (10^{-3}) – 3cd/m^2. This means even when ECDIS luminance is reduced to the minimum design level, it will still be above the levels required for scotopic vision (luminance $< 0.003(10^{-3})$ cd/m^2), thus the conditions to switch to full dark adaptation are unlikely to be achieved if the ECDIS is used. This is further complicated by the fact that the combined luminance of various MFDs, engine and communication controls and other light pollution caused by accommodation lights etc will increase the prevailing luminance on the bridge (wheelhouse). There is a high possibility that these conditions will never allow watchkeepers to achieve a full dark adaption.

Back scatter of multiple light colours: The IRPCS 'Rule 6 – Safe Speed' requires vessels to consider '*at night the presence of background light such as from shore lights or from back scatter of her own lights*' because it may take longer to distinguish between different colours of light exhibited on shore, requiring more time to understand their position with respect to lights.

Lookout procedures

Watchkeepers must consider the following:

1. Understand the simplified structure of cones and rods to appreciate how eyes are used differently at night than during the daylight.
2. They must treat the eyes as a precise instrument which needs adjustment to the change in illumination.
3. It takes approximately 20-30 minutes to achieve dark adaptation, but once adapted, it takes only one second to lose it, even just by looking at an MFD for a brief period. This may require the dark adaptation process to commence from the beginning i.e., requiring 20-30 minutes for full dark adaptation again.
4. It takes approximately 5-7 minutes for light adaptation. This period should not be overlooked, particularly when inspecting details on ECDIS.
5. The luminance levels for the bridge as well as for each MFD must be 'risk' assessed to ensure they remain within the photopic, scotopic or mesopic vision limits.
6. When maintaining a lookout at night, the window wiper scan method can still be applied and in fact provides a better mechanism to use peripheral vision and avoid the risks resulting from the 'blind spot'.
7. All watchkeepers are recommended to practice the guidance provided to find their own optimum for dark/light adaptation and use of window wiper scan method.

Further reading

Human Performance and Limitation for Mariners – The Nautical Institute

Vision and Decision: a video produced by CHIRP maritime https://tinyurl.com/VisionDecision

The Navigator issue 19: Lookout