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Analysis and Optimisation of Best Practice for Proper Lookout at Night

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ABSTRACT: A significant proportion of accidents appear to be caused by a lack of maintaining a 'proper lookout' on a ship's bridge. The root cause for these accidents could be the result of watchkeeper's lack of awareness of requirements to maintain a proper lookout. This paper utilises the authors' proposed definition of this term and then discusses the outputs from a study on improving watchkeeper behaviour carried out in ship bridge simulators, using eye tracking devices. The study involves applying the proposed method of carrying out visual search scans together with underlining distractions caused by Multifunction Displays (MFDs) found on modern ship bridges. Based on the findings, the paper evaluates the impact of the proposed scan method for maintaining a proper lookout, reduction in distractions caused by MFDs and discusses how it is almost impossible to achieve a complete dark adaptation with the presence of MFDs and other lighting on modern ship bridges. This research offers a solution to control these risks through risk assessment, together with training and education for watchkeepers to overcome these issues. This study is expected to contribute significantly to improving watchkeeper's behaviour in maintaining lookout and application of the proposed scan method.

1 INTRODUCTION

Rule 5 – 'Lookout', of the International Regulations for Preventing Collisions at Sea (IRPCS), 1972 requires the ship's Officer of the Watch (OOW) and accompanying members of the bridge team to maintain an efficient lookout at all times [50]. Various reasons including poor design of controls and interfaces) such as Multifunction Displays (MFDs) appear to interfere with this function [40]. The UK's Marine Accident Investigation Branch [43] states that 65% of the vessels involved in collisions contravened the IRPCS lookout rule, whilst 19% of the watchkeeping officers of the vessels, involved in these collisions, lacked Situational Awareness (SA). The European Maritime Safety Authority indicates that from 2014 to 2021, a total of 563 lives were lost with 6,155 injuries caused mainly from ship collisions, of which 59.6% of accidents were due to human action and 68.3% of the contributing factors were related to human behaviour [10]. According to the Marine Australian Transport Safety Bureau (ATSB) investigations of 41 collisions over 26 years identified consistent failure to maintain a proper lookout [1].

These statistics lead to a fundamental but un-answered question i.e., 'are the lookouts actually doing their job as required by IRPCS?' The accident reports suggest otherwise; therefore, the effectiveness of technology on ship's bridge needs to be assessed from the user perspective. For example, MFDs are now widely used on ship's bridges to show navigational and collision avoidance information. They vary in shape and size but are usually rectangular in shape with Graphical User Interface (GUI) showing different objects in various colours, displayed in multiple pages accessible through soft buttons [3]. This requires more interaction time and effort from the user than when MFDs did not exist.

Although a lack of user input into the MFD design and the resultant design induced errors appear to cause some problems [41], the watchkeeper as a weak link also needs to be investigated to ensure such errors can be avoided. At the end of the day, modern MFDs on the bridge are meant to facilitate watchkeepers, therefore we must know their weaknesses and find ways to work around them. This is similar to the case of the human circadian low where humans increase awareness to mitigate possible adverse consequences.

This paper examines factors contributing to watchkeepers' ability to maintain a high level of SA and the impact of MFD design on maintaining an effective lookout at night. The authors also believe that there is a lack of appreciation of the need to maintain a proper lookout amongst OOWs that need to be addressed to improve their behaviour. Based on these, this paper utilises the authors' definition of proper lookout [34] together with an effective scan pattern that can be used for optimised visual searching, avoiding distractions caused by MFDs. The impact of illumination on dark adaptation and validation of the need to raise watchkeepers' awareness to improve night watchkeeping is also presented.

2 STCW REQUIREMENTS FOR LOOKOUTS

The STCW Code is a mandatory device that defines training standards for OOWs and others who are tasked as a lookout. The conduct of bridge watchkeeping and the training for all involved in performing watchkeeping duties is therefore internationally aligned to the standards prescribed in the STCW Code. For lookout duties, the Code [22] specifically uses the phrase 'a proper lookout is maintained at all times…'. It goes a step further by using the phrase 'keep a proper lookout by sight and hearing' for competence required for non-OOW ratings forming part of a navigational watch. In explaining the criteria for evaluating this competence, the Code requires that 'sound signals, lights and other objects are promptly detected and their appropriate bearing in degrees or points is reported to the officer of the watch'. The Code elaborates these two phrases further on the exact requirements but does not define the term 'proper lookout' leaving a gap that, in the authors' view, is the main culprit in causing underlying issues connected to a lack of maintaining a proper lookout. In order to fill this gap, the authors defined proper lookout as [34]:

'The application of due diligence to improve situational awareness by:

1. Sight - Through systematic visual search scans of the environment around own vessel.
2. Hearing - Through a quiet wheelhouse with access to outside sounds.
3. All available means such as Radar, AIS and other bridge equipment.'

This proposed definition not only encompasses the IRPCS requirements but also provides reference to a visual scanning approach for maintaining a lookout as established through the research presented in this paper. The research methodology consisted of using Eye Tracking Devices (ETDs) in ship bridge simulators after providing guidance on scan patterns to participants to capture potential improvements in their lookout behaviour. This paper discusses the findings considering existing research and provides suggestions to improve lookout procedures.

3 SITUATIONAL AWARENESS

Through an efficient visual search, watchkeepers feed information to their brain to become aware of objects in the ship's surroundings. This is referred to as Situational Awareness which is the cognitive process of knowing what is going on around a ship to understand danger so that measures could be taken to avoid it [13].

Multitasking is intrinsic to navigational watchkeeping where maintaining an efficient lookout is a sub-task, yet instrumental in developing fully informed SA. It must therefore encompass perception, comprehension and projection of a threat's location and movement in relation to own ship, as shown in Figure 1 [11, 46].

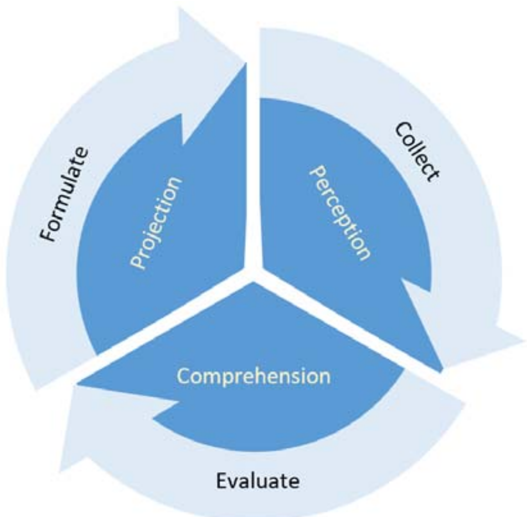

Figure 1. Three Level SA Model [34]

In essence, the OOW perceives and comprehends the current situation, and runs mental predictive models about the likely outcomes [20] with respect to collision avoidance. Any shortfalls in perception or comprehension can easily lead to a lack or inappropriateness of SA [6], which is a more serious issue than the judgemental errors for poor decisions leading to accidents i.e., inefficient lookout is directly proportional to lack of attention or vice versa. This could be linked to distractions on the bridge or after long periods of inactivity [59] due to lack of traffic in the vicinity of the ship. Surprisingly, the UK's Maritime and Coastguard Agency [45] recognises Global Maritime Distress and Safety System (GMDSS) equipment, completion of administrative tasks [47] on bridge and routine testing of bridge equipment as ‘distractions’ to the watchkeeping officers’ primary duty of keeping a proper lookout. However, no one appears to propose a solution to overcome them albeit recognising that these distractions potentially lead to low levels of SA [42]. This is where the solutions presented in this paper are not only relevant but fill in a long standing, vital, yet fundamental gap in maritime watchkeepers’ skills.

3.1 *Visual searching and distractions*

The basic rules for the safety of navigation remain the same despite the introduction of significant automation on ship’s bridge [17]. The well-known four stages of passage planning, i.e., appraisal, planning, execution, and monitoring are still utilised by the modern navigator. The first stage feeds into the second and the second into the third stage and so on. The task-demand from the watchkeeper increases in high traffic density or during coastal navigation when monitoring the progress of a vessel that is following a well appraised, planned and executed passage plan. This stage therefore requires an increased focus and attention as a ‘slight’ loss of attention may lead to a loss of SA.

In essence, SA feeds from maintaining a proper lookout which is a simple ‘visual search’ exercise. To ensure that a watchkeeper’s attention is suitably focused to identify any potential hazards, watchkeepers need to establish their own ‘visual search technique’ which is a basic procedure facilitating the maintenance of effective lookout across the necessary area, whilst overcoming any potential distractors.

To gauge user input into designing navigational and collision avoidance information displayed on MFDs, a questionnaire-based survey was conducted as part of this MarRI-UK funded research. This questionnaire was distributed amongst experienced OOWs and Masters which showed only 10.4% of (67) watchkeepers will visually check their vessel’s surroundings to verify the position of other vessels with only 4.5% indicating that they will verify visibility when taking over the watch. These statistics evidence that the modern watchkeeper does not understand the significance of lookout by sight, let alone the added complications for maintaining a lookout at night or indeed the impact of MFDs on their ability to maintain lookout. They not only need to understand it but must also appreciate the significant differences for maintaining a night lookout.

The watchkeepers’ primary task is to perform a visual search in addition to maintaining an auditory attention to any sounds that may need their response. In addition, they also need to look at the equipment via the MFDs to monitor various elements for safe navigation. Regardless of where the watchkeeper needs to look, the visual search requires [61] the watchkeeper to recognise a particular object amongst other visible objects or features. This recognition requires focused attention entwined with SA, attention-related errors and other factors that contribute to the safe navigation.

Visual search is a natural process one goes through in daily life wherein the individuals actively scan the environment to locate a particular object, also referred to as a visual stimulus, among irrelevant features, referred by some researchers as the distractors [5]. For example, the search for a desired product on the shelf in a supermarket qualifies as a visual search where all other undesired products are the distractors. The visual search for the desired product is controlled by directing the attention focus whilst scanning the products, ignoring undesired products. This is the very principle that the watchkeepers need to apply to their visual search when maintaining a lookout on the bridge of a ship.

The eyes are considered a gateway to the brain [58] and act as the prime source for updating an OOW’s SA. However, the background scatter of lights in the coastal areas, partitions in the bridge windows, clouds in the sky, all act together in most cases to camouflage a watchkeepers view. Furthermore, the human eye naturally tends to focus somewhere, even when there is nothing to focus on such as featureless sky – a perceptual process [58] known as ‘selective attention’ i.e., the ability to focus on some sensory inputs while tuning out others. If no stimuli challenge the vision to attract focus, the eyes naturally revert [14] to a relaxed intermediate focal distance of 3 to 10m, a phenomenon known as empty-field myopia.

This highlights two important factors that impact upon OOW’s ability to maintain SA as needed for Endsley’s [11, 12] SA model. i) the watchkeeper is looking without seeing anything [60] and, ii) watchkeepers can miss something important, despite looking outside the window, because they selectively attend to only one aspect of the scene visible to the eye [57]. This limitation comes into effect when the watchkeeper is actually looking outside the window but what about when they are not? Similarly, there is a tendency for attention to drift to internal thoughts (mind wandering), which can also distract from the primary task. Under non-demanding conditions, the issue of attentional control also creeps in [53]. This could be significant when there is less traffic around the ship causing the watchkeepers to be bored which may turn their attention to MFDs simply as a means to escape the boredom, i.e., when people are bored, they actively seek sources of distraction as a deliberate strategy. There remains therefore a need to evaluate the impact of illumination at night, particularly to dark adaptation, when looking at MFDs on the bridge.

Reaction Time (RT) to an auditory or visual stimulus [62] is the interval between the presentation of a stimulus, and a voluntary response such as the press of a response key. When our nervous system i.e., the eyes in the case of a watchkeeper, recognise the stimulus, the information is relayed to the brain [31] which releases instructions via the spinal cord for hands, fingers, or other body parts to react. Our ‘sensory memory’ holds the information captured via eyes for 1 to 4 seconds from where it is transferred into Short Term Memory (STM) [64, 39]. The STM can hold this information for 6-12 seconds. It is this duration which defines whether the OOW will deal with the information received, manipulate it mentally and take the required action. However, if a distraction triggers another event, then this information may be lost leading to an inaction by the watchkeeper.

The human brain's STM [58] is a 'limited capacity system' where two operations requiring it will interfere with each other e.g., a distraction caused by an alarm when the watchkeeper is trying to focus on the lookout function. So, the OOW is almost always faced [40] with a daunting task of having to focus on one task whilst deliberately and actively inhibiting or ignoring other tasks which can literally be considered as distractions in this context. They thus require a continuous mental effort [64] to shift focus to avoid exceeding their mental capacity for retaining and recognising hazards in the STM, process them and take appropriate actions.

Each navigational task [42] performed by a watchkeeper requires substantial multiple sources of information to be processed. Based upon an individual's cognitive ability, they can probably choose the source of this information but if overwhelmed by the visual or audible information stimuli, the decision-making is almost always likely to be affected [8], leading possibly to human error. Hofheimer [19], refers to it as 'fleeting attention span' and explains it as 'lapses in the ability to concentrate on a stimulus or task and sustain the requisite degree of focused attention to persevere with information processing or task attainment'. This error is deemed to be the result of an incorrect decision, improperly performed action, or a lack of action [54]. If it can be trapped, the probability to lead to accidents can be reduced. Regardless of what nomenclature is used for distractions that push the watchkeepers away from their primary task, they must overcome them, and a potential solution is the scan method proposed in this paper.

3.2 *Window wiper scan method*

The eye can only fully focus and recognise an object when it is viewed in its central Field of Vision (FOV) which results in clear, sharply focused messages being sent to the brain. The central FOV extends from right in front of the eyes to approximately 2.5° either side. This 5° monocular field of view for each eye provides a total binocular field of view of 10° with both eyes. In comparison, peripheral vision extends to approximately 100°-110° on either side of the eye (Figure 2) which is considered extremely useful in identifying objects that may pose a collision threat. The objects that appear to have no relative motion are unlikely to pose any threat, therefore even if they are not detected through peripheral vision, they will be picked up when the eyes gain focus in any given block.

By contrast, any visual information that is processed through peripheral vision will be of less detail. As the eyes can only fully focus on this narrow viewing area, effective scanning is best accomplished with a series of short, regularly spaced eye movements that bring successive sections of the area to be scanned into the central visual field. The two photoreceptor cells in human eye i.e., cones and rods. The cones, located in the centre of retina recognise colour and detail of the object when light is reflected from it. The rods provide peripheral vision with their functionality ceiling to luminance levels equivalent to a night with overcast sky and without moonlight. For a normal eye, the foveal vision provides a 20/20 visual acuity with the peripheral vision acuity in the region of 20/200 [55]. Despite a significant reduction in visual acuity, peripheral vision assists in detecting large objects or objects in motion without providing details for shape and colour of the object.

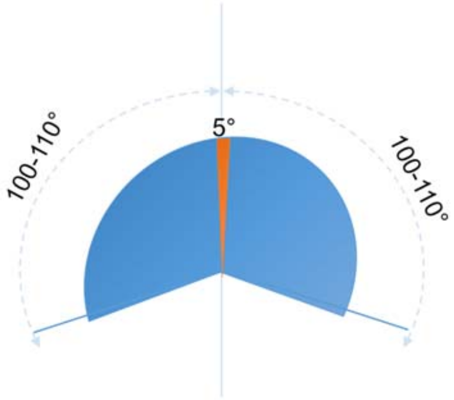

Figure 2. Human Eye Central and Peripheral Vision Field [34]

To scan effectively a watchkeeper must know how to make the best use of their eyes' natural capabilities and train themselves to do this repeatedly. This idea was proven in 1980's when video gamers trained to use efficient visual scanning patterns showed better performance than those who received random pattern training or no training at all [36]. Likewise, airline pilots have a long history of using recommended visual scan methods for keeping an effective lookout.

Scanning the visual field is a key factor in collision avoidance and should be a continuous process used by the watchkeepers to cover all areas visible from the bridge. The proposed scan method is based on the premise that traffic detection can best be conducted by focussing on a series of fixed points in space. When the head is in motion, vision is blurred, and the brain does not register potential targets. Unless a series of fixations is made, there is little likelihood that a target will be effectively detected. To be most effective, a watchkeeper's vision should be shifted and refocused at regular intervals but care should be taken when refocusing because the eyes may require several seconds to refocus, particularly when switching between places of different illumination levels.

A scan of the visual horizon should be broken down into approximately 10°'blocks', to ensure that the field of central vision focusses on each sector in turn before moving on to the next, spending no more than 4 seconds on each. Watchkeepers are used to time measurement for recognising maritime lights at night. For example, if a light with characteristic of flashing 6 seconds (Fl. 6s) is found on chart, they will locate this light on the horizon and mentally count 'and one, and two, and three,… and 6' to measure the 6 second interval. In application therefore, the bridge window is to be divided into blocks, each of which is to be methodically scanned for traffic in sequential order. This should be performed as follows (Figure 3):

1. Start in the centre block of the visual field (towards the bow of the vessel).

2. Vision is moved to the port side of the vessel, focusing for a period of no more than four seconds on each 10° block. The brain is naturally trained to process vision from left to right [15], hence scan commences towards the left shoulder.
3. After reaching the last block on the port side, vision should resume its journey back to the centre block, again scanning each 10° block on the port side for no more than four seconds in each block.
4. Repeat on the starboard side of the vessel. Vision is moved from the centre block of the visual field to the starboard side in blocks of 10°, focusing for a period of no more than four seconds on each 10° block.
5. After having scanned each 10° block of the window, vision should be switched to the instrument panel within the bridge. Starting in the middle (in line with the bow), the equipment should be scanned to port employing the same block approach that was utilised to look out of the window.
6. Then in blocks back to the centre.
7. From the centre (in line with the bow), the equipment should then be scanned to starboard, employing the block scan approach.
8. Then in blocks back to the centre.
9. Once an appropriate amount of time has been spent viewing the instrument panels inside the bridge, the external scan process should be resumed.

Searching in sectors of 10° and focusing in each sector for no more than 4 seconds means spending a maximum of 84 seconds (1m 24s) to scan back and forth across a 210° field of view in the visual screen areas and 6 MFDs x 4 seconds each requiring 24 seconds maximum. This time sharing gives a ratio between visual screens and MFDs of 3½:1 which falls in the same range as used in the aviation industry (3-6:1) between visual screens and MFDs [15]. The watchkeeper should remain constantly alert to all traffic within their field of vision. This means periodically scanning the entire visual field outside the vessel by going out on to the bridge wing to look astern. In addition, watchkeepers should consider blind spots caused by fixed structures within the bridge such as posts or window struts and take appropriate action to avoid these masking their view of other vessels.

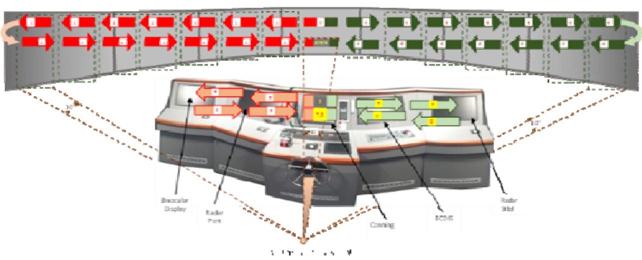

Figure 3. 'Windscreen Wiper' Scanning [33]

4 LOOKOUT AT NIGHT

Maintaining a proper lookout at night presents very different but understudied challenge for the maritime watchkeeper, commonly known as 'dark adaptation' or adjustment to 'night vision'. The IMO [22] requirements in STCW Code with reference to dark adaptation state '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'.

Neither the Code specifies how this is to be achieved nor do the watchkeeping industry practices make allowances for this due to a lack of research-based evidence. Unfortunately, it has been left to the interpretation of legislatures to devise standards and guidance for watchkeepers and bridge equipment display manufacturers. As a consequence, whilst there is some general guidance about it, seafarers are not taught about the science behind dark adaptation and consequences of not following a scientific approach to it. Literature review reveals a major flaw in shipboard systems in this aspect which is the lack of detailed assessment of the impact of lighting and displays, particularly the MFDs on watchkeeper's ability to achieve and maintain dark adaptation. For example, the IMO performance standards for Radar, ARPA and ECDIS [23, 24, 25, 27, 28, 29] 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'. The classifications societies may apply these rules with their own twist, but IMO requirements are the minimum. To control lighting on the bridge of the ship including that from Visual Display Units (VDUs) or MFDs, IMO [26] provides various requirements. For example, during the day, the VDU background luminance range is 15-20cd/m2 (candela per square metre) with display luminance range of 80-160cd/m2. But IMO does not provide a clear min/max luminance at night which is where the luminance level causes real problems for maintaining a proper lookout. The IMO only requires:

– 'a satisfactory level of lighting … to complete such tasks as maintenance, chart, and office work satisfactorily, both at sea and in port, daytime, and night-time.
– Visual alarms on the navigating bridge should not interfere with night vision.
– All information should be presented emitting as little light as possible at night.
– Displays should be capable of being read day and night'.

These requirements however specify that at night on bridge, continuously variable red or filtered white light and on chart table filtered white or spotlights are provided for illumination from 0 – 20 lux.

Surprisingly, these requirements evidence that the watchkeeper is delegated the ability to control variation of these lights but it is disturbing that they are not educated about the effect of colours and brightness on their vision. Keeping in view that the typical computer screens, which may be deployed on ship's bridge for office work or may even be the MFDs for bridge equipment, operate with peak luminance range of 80-500 cd/m2 [16], thus these are far brighter than the permissible level (0-20lux) for spotlight, hence will cause light pollution that will affect dark adaptation.

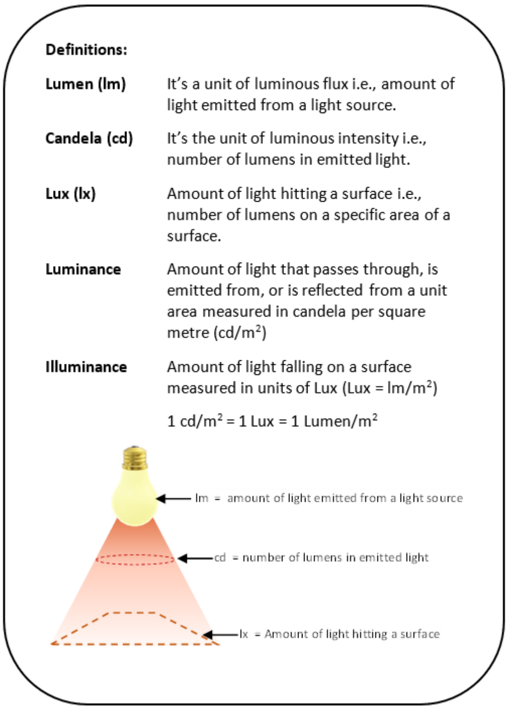

Figure 4. Illumination Terminology

In order to understand the function of eyes, two aspects of human vision need to be understood; i) the structure of human eye and,– ii) the characteristics of the light that when reflected from objects and received by eyes provide vision. These are discussed in the remaining sections.

4.1 *Human eye structure*

The human eye receives vast amount of information and sends it to the brain for recognition, processing, storage and action. The eyes capture this information via the rays of light reflected from the objects the eyes see. If there is no light to reflect or if the eyes are unable to capture the reflected light, the eyes do not see. When light is reflected from various objects and received by human eye, the collected information must be processed within the eye's photoreceptor cells. The average luminance at which the eyes can see ranges from approximately 0.000001 (10-6) cd/m2 on dark nights to approximately 100,000,000 (108) cd/m2 during a bright sunny day [4].

The basic structure of the eye is shown in Figure 5. The eyes contain two types of photoreceptor cells in the retina - cones and rods [7]. Each eye is estimated to have 5-6 million cones and 80-90 million rods. The fovea, a small depression within the retina, contains mostly cones in the central part which is also referred to as the point of sharpest focus.

Cones recognise colour (certain frequencies of light which are not present in darkness), detail (when bright light is reflected from any object e.g., sun, moon or artificial light) and distant objects to provide vision known as 'photopic vision' available in luminance range of 10-108 cd/m2 [49]. The cones are activated by release of a photopigment known as Opsin and are further divided into three sub-types based on their colour-sensing ability for red, green, and blue colours. A mixture of these colours gives the human eye an ability to distinguish thousands of different colours. Cones are considered to function in brightness level equivalent [2] to that of 50% moonlight at night or above about 3 cd/m2 luminance [37] and reach their peak sensitivity [56] at 555 nanometre wavelength light.

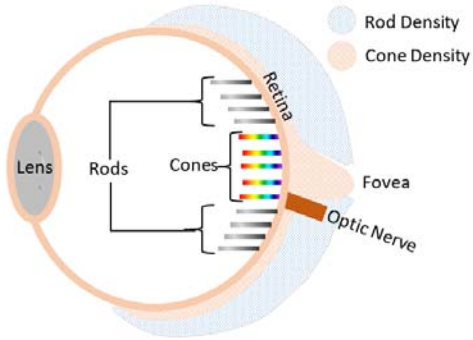

Figure 5. The Structure of an Eye [35]

In the absence of luminance level of 3 cd/m2 [4] or more, the second type of cells i.e., rods provide vision, known as 'scotopic vision', available in luminous range [4, 49] of 10–3-10–6 cd/m2. Rods are designed for the best image perception in low light, but they cannot distinguish colours i.e., even the coloured objects are seen but in shades of grey. This duplex system consisting of cones and rods allows the eye to provide visibility over a large range of ambient light levels.

In order to see in the dark, eyes need to shift their focus from using cones to rods which takes time. When switching from seeing bright light to darkness, a photopigment [38, 2] [64] known as rhodopsin is produced that helps rods' adjustment to low light or darkness. Rhodopsin is produced according to the light intensity which takes approximately 20-30 minutes to reach its full density at around 10–5 cd/m2. This process is known as 'dark adaptation' which may take longer in some people depending upon the quality of their eyesight, age, fitness and level of fatigue [30]. Regardless of these variable factors, research-based evidence suggests that the adjustment to night vision cannot complete in less time than 20-30 minutes even though scotopic vision starts improvement from approximately 5-10 minutes into the process of dark adaptation.

When eyes are subjected to a bright light for more than one second, the rhodopsin is decomposed voiding the dark adaptation but at the same time, waiting for light adaptation. It takes 5-7 minutes for cones to adjust fully to the bright light after decomposition of rhodopsin – a phenomenon referred to as 'light adaptation'.

A third function to be considered is the simultaneous functionality of both rods and cones such as in twilight conditions – a phenomena known as 'mesopic vision' where both rods and cones contribute to vision between luminance levels of between 0.003 (10-3) to 3 cd/m2 [4]. At night when the brightness is at low level, but it is not absolute dark, some objects can still be seen due to the contrast between the object such as the navigational lights of another ship and the background darker sea/ocean over lighter sky.

In darkness, the cones are 'unavailable' for vision through an area approximately 5 to 10 degrees wide, therefore the vision must be off centred to 'spot' an object with rods in the regions shown in Figure 5. This is because the central part of retina cannot detect an object if looked at directly due to the night blind spot in the rods area of vision. In the context of binocular vision (seeing with both eyes), 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 e.g., if one eye's field of view was obstructed by a bridge window post. Therefore, a process that must form a part of dark adaptation [48] for watchkeepers is to shift the vision by 4 – 12 degrees to one side so that rods can be fully utilised, and a blind spot avoided. Furthermore, the head should remain in continual motion as explained in the 'window wiper scan' method, to overcome any issues of missing object detection due to the blind spot.

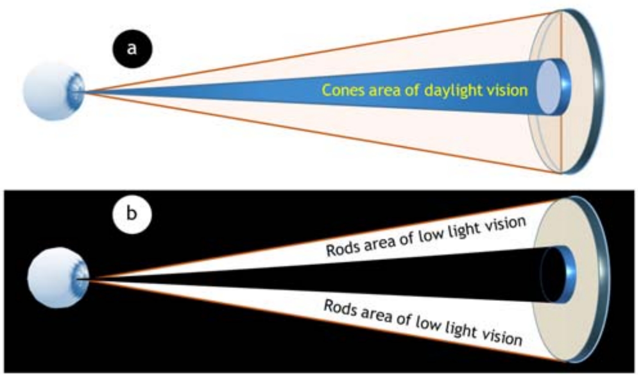

Figure 6. Day and Night Vision [35]

When dark adaptation is complete, the photopic vision is unavailable but peripheral vision is available and 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 collision threats from other objects. In essence, the lookout or visual search at night is entirely dependent upon peripheral vision due to foveal night blind spot discussed previously. The watchkeeper must therefore look between 5-10° either side of the object which together with binocular vision provides an overall arc of 100-110° on either side of the eye. This can only be achieved if the watchkeeper does not search for objects in the foveal region but scans the areas adjacent to it. This is where the authors' proposed 'window wiper scan' pattern becomes more useful as the head/eyes are moved in 10-degree blocks allowing the peripheral vision to scan each block to detect objects, both stationary and moving.

4.2 *The visible spectrum of light*

A further area to consider for dark adaptation is the impact of various colours used in the MFDs or other lighting on the bridge of a ship. The main component that makes it is possible to see things is the light. The literal meaning of the word 'photo' is 'light' which stimulates the photoreceptors (cones and rods). The visible spectrum of light includes violet, indigo, blue, green, orange, yellow and red (VIBGOYR) colours with wavelengths [18] between 400 to 720 nanometres (table 1). A shorter wavelength corresponds to higher frequency and energy in the visible spectrum e.g., red colour has the shortest frequency (400-484THz), lowest energy (1.91eV) and a wavelength of 620-720 nanometres whereas violet colour 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 and are considered invisible to human eye. However, some of us may continue to see some colours in both the ultraviolet and infrared wavelengths but prolonged exposure to these may damage the eye.

With respect to the visible light spectrum and the photoreceptor cells (rods and cones), three distinct areas need to be considered from a watchkeeper's perspective, particularly when maintaining a proper lookout at night:

1. Dark adaptation: As watchkeepers walk at night into the wheelhouse, their eyes don't see anything i.e., total darkness. This is the time at which dark adaptation commences which depends upon successful release of rhodopsin which reaches its peak sensitivity when exposed to wavelengths of around 500 nanometres [32] which corresponds to blue-green light wavelengths. Rods have a higher sensitivity to blue light of wavelengths 460-500 nanometres or less, no sensitivity to red light of wavelengths greater than 620 nanometres.
   In order to facilitate a quicker adaptation to darkness [7], the watchkeepers are recommended to spend some time, for example, in chart room illuminated by red light. This is because the red wavelength light offers biological benefits in terms of not triggering the decomposition of rhodopsin. This however only works with dim monochromatic (single frequency or wavelength) red light and not a white fluorescent light bulb covered with red liner, coating, or filter. As rods are not sensitive to red light wavelength, rhodopsin continues to be released to commence dark adaptation and remains at the same saturation level if the eyes are exposed to the same level of red light. Therefore, the use of red light (or red goggles) is recommended for many control spaces, e.g., in ship's bridges, submarines, aircrafts and so on where the operators can continue to be 'darkness' adapted whilst performing their tasks. In case of ship's bridges, then the same approach can be adapted to provide a better night vision.

Table 1. Visible Light Spectrum (Adapted from [51, 52])

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.

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

2. Light adaptation: When a person moves from darkness into light, even if that means focusing on an MFD e.g., ECDIS display using multiple colours, the eyes begin light adaptation which means rhodopsin will start to decompose [49]. If this focus remains on the MFD for approximately 5-7 minutes, the cones will adjust fully to the MFD colours, thus requiring a further 20-30 minutes for the regeneration of rhodopsin to dark adaptation.

Whilst the foregoing is a basic concept to understand the extreme situations for dark and light adaptation, there is however an intermediate function that assists in transition between dark and light adaptation. This is pupil dilation i.e., the increase in pupil diameter (to 8mm) with a decreasing brightness and the reverse process of decreased diameter (to 2mm) with reducing brightness by up to about four times than normal diameter [4]. Although the change in rod and cone sensitivity happens gradually over several minutes but the pupil dilation is much quicker. Despite the known changes in pupil diameter, the effect is minimal and hence not considered in this paper from a watchkeeper's perspective.

Based on the foregoing discussion, it is vital that watchkeepers always compare the luminance level on bridge to see its impact on dark and/or light adaptation. In a study carried out by Wynn et al. [65], luminance levels (see Table 2) from various MFDs on the bridges of a RoPax and an oil tanker were recorded at night. The IHO [21] 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/m2 compared with 80 cd/m2 for bright sun)'. For RoPax, it is clearly evident that the EDCIS luminance was higher than the minimum allowed but not set by the watchkeeper. On this basis, it is only fair to assume that the watchkeeper was either not aware of this option in ECDIS and by extension, for other MFDs or they did not apply this due to a lack of awareness of the impact on their dark adaptation.

Table 2. Luminance Level on Real Ships [65]

	RoPax Tanker Luminance (cd/m^2)	Luminance (cd/m^2)
ECDIS	5.8	-
Radar 1 Output	0.72	1.37
Radar 2 Output	0.21	1.15
Engine Controls	2.4	0.14

Further, the maximum luminance of an area colour of 1.3 cd/m2 allowed by IHO falls in the mesopic vision range i.e., 0.003 (10-3) – 3cd/m2 meaning that despite the watchkeepers adjusting the ECDIS luminance to the minimum design level, it will still be above the Scotopic vision luminance (< 0.003(10-3) cd/m2), thus they will never have the conditions to switch to full dark adaptation. This is further complicated by the fact that the combined luminance for various MFDs, engine and communication controls and other light pollution caused by accommodation lights etc will increase the prevailing luminance on the bridge (wheelhouse), thus the possibility of never achieving a full dark adaption remains quite high.

3. Back scatter of multiple light colours: The IRPCS 'Rule 6 – Safe Speed' require 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 that may confuse the watchkeeper, requiring more time to understand their position with respect to those lights.

When the vision shifts from photopic (cone based) vision to scotopic (rod based) vision, the blue and green lights appear relatively brighter (when placed in proximity and looked at simultaneously with 15-20° off-centred vision) as compared to yellow or red lights. This phenomenon is known as Purkinje shift [9]. However, red light appears brighter when the eyes are fixating centrally.

Relating the Purkinje shift to the IRPCS Rule 6 requirement, the watchkeepers must be able to see the link between some lights, particularly the shore lights of different colours appearing and disappearing with the shift from central to peripheral vision. Thus, they must keep this in mind when looking out at night.

5 LOOKOUT PROCEDURES

In order to rank 'visual search' high in OOW's priorities, they must first mentally accept its significance. They then need to be trained in establishing their own 'timesharing technique' to share their focused attention between looking outside of the bridge windows and on the other tasks within the bridge that require focusing on MFDs. A minimum ratio of 3:1 (in favour of visual scanning out of the windows) must be maintained in open sea conditions, but this may vary based on factors such as the area of operation e.g., proximity to coastline or traffic density etc. Obviously, if higher focus is needed on navigation in coastal areas, additional person to assist in maintaining proper lookout will be required. Similarly, where the traffic density requires more focus on maintaining visual lookout, then an additional OOW may need to be called upon to monitor ship's progress as per the passage plan. In essence, the manning level on the bridge can be determined from the amount of time needed for maintaining a proper lookout.

The watchkeeper should remain constantly alert to all traffic within their field of vision. This means periodically scanning the entire visual field outside the vessel by going out on to the bridge wing to look astern. In addition, watchkeepers should consider blind spots caused by fixed structures within the bridge such as posts or window struts and take appropriate action to avoid these masking their view of other vessels.

To summarise the techniques for maintaining a proper lookout at night, the following must be considered by all watchkeepers:

1. The watchkeepers must 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 allows for avoidance of missing potential threats from being visually spotted.
3. It takes approximately 20-30 minutes for dark adaptation, but once adapted it takes only one second to lose it even if just because of looking at an MFD for a brief period. This will 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 during the day or at night, the window wiper scan method can still be applied and in fact provides a better mechanism to use peripheral vision.
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.

6 CONCLUSION

The maritime watchkeepers' primary task is to maintain a proper lookout at all times, but this term is neither suitably defined in the STCW Code nor any guidance on its accomplishment is provided by regulators, leaving a skill gap that prevents the watchkeepers from attaining a full SA. This appears to result from a lack of research on this topic combined with the fact that the modern bridges now have a larger number of MFDs drawing watchkeepers focus away from their primary task of maintaining a lookout. A definition of proper lookout has been presented for inclusion in the STCW Code.

In line with the proposed definition of 'proper lookout', a window wiper scan method that can be used to divide the time shared between looking outside vs. looking at MFDs to maintain a ratio of at least 3:1 is presented. This approach however needs to be applied at a wider level wherein the maritime watchkeepers' training includes a support system for the simulator instructors and assessors to train and assess their lookout behaviours at an early stage in watchkeepers' career.

A further area of improvement for watchkeepers is a lack of awareness with dark adaptation at night and the light pollution caused by MFDs and other lights on the bridge. The researchers believe that currently there is no risk assessment approach to gauging the impact of lighting on night watchkeepers. Finally, a list of recommendations is provided for watchkeepers to follow and maintain a proper lookout.

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