DARK ADAPTATION TIME FOR HUMANS, AFTER VIEWING A TARGET ILLUMINATED WITH TWO DIFFERENT TYPES OF LIGHT SOURCES

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Abstract

The differences in scotopic recovery time between LED illuminators and a tungsten-halogen illuminator was investigated. The spectral distribution and the luminous intensity distribution of all the supplied illuminators were measured. The scotopic recovery time was measured, using a low-contrast USAF bar target and a low-level light source for background illumination. We were not able to measure a significant difference in scotopic recovery time, after the target was illuminated with the two light sources. The measured luminance levels in the laboratory are expected to differ substantially to those in the field due to the low reflectance of natural targets. Therefore, laboratory measurements should be complimented by field measurements. Our results, supported by a literature study, highlighted the necessity for further research using the current methods, as well as the validation of results by using an adaptometer.

Keywords: Dark Adaptation, Scotopic Recovery Time, LED, Tungsten-Halogen, Illuminators, Spectral Distribution, Luminous Intensity

1 Introduction

Light Emitting Diodes (LEDs) are revolutionising the illumination industry. The main reason for this is the high efficacy – high visible light output for relatively low energy input, as well as high reliability (LEDs MAGAZINE, 2008). The current ranges of ultra-bright LEDs are making inroads in the portable illuminator (torch) market. Due to increased battery life and reliability most of the illuminator manufacturers are replacing the traditional lamps (e.g. tungsten halogen) with LEDs in their high-end products.

The South African National Defence Force (SANDF) has been mandated to patrol and protect the country's borders, of which a large part consists of wild, uninhabited areas where animals are roaming freely. Sometimes these patrols take place during night time, and illuminators are used to detect and identify possible dangerous animals.

When using bright light sources during night time, the human eye's luminous efficiency may be changed from scotopic to mesopic or photopic. The SANDF requested answers to the following questions:

- Are there any differences in scotopic recovery time when using different types of illuminators?
- If any differences do occur, are these differences significant?

This paper describes the different illuminators and their characteristics, the test set-up in order to test the scotopic recovery time, the measurement results, the conclusions as well as recommendations for future research.

2 Measurements and results

Five different illuminators were used during this investigation. Four of these are equipped with LED light sources, and one is equipped with a tungsten-halogen (TH) source. Three of the illuminators have focus mechanisms, allowing the beam to be focussed to a spot, or to be de-focussed to a wide beam. Measurements were performed to determine the spectral distribution and luminous intensity distribution of the respective illuminators. This was followed by visual experiments making use of observers, the illuminators, low contrast targets and a low-level light source (moon-/starlight simulator).

2.1 Spectral power distribution

The spectral distribution of each of the illuminators was measured, using a PhotoResearch PR715 spectroradiometer (with responsivity over the spectral range 380 – 1068 nm) and a Spectralon white reflectance standard. The reflectance standard was illuminated with the illuminators at an angle of -45^{o} with respect to the normal, and the reflection was measured at an angle of 45^{o} to the normal. The PR715, the reflectance standard and the illuminators were mounted in the same horizontal plane. The spectral power distribution of four of the five illuminators is shown in Figure 1. LED1, LED2 and LED3 are the illuminators with LED light sources, and TH is the illuminator with the tungsten-halogen lamp. From the results obtained it is clear that the spectral power distribution of the three LED illuminators is similar. LED4 (used later in the experiments) was not available during these measurements, but since it is from the same manufacturer, it was assumed to have a similar spectral power distribution.

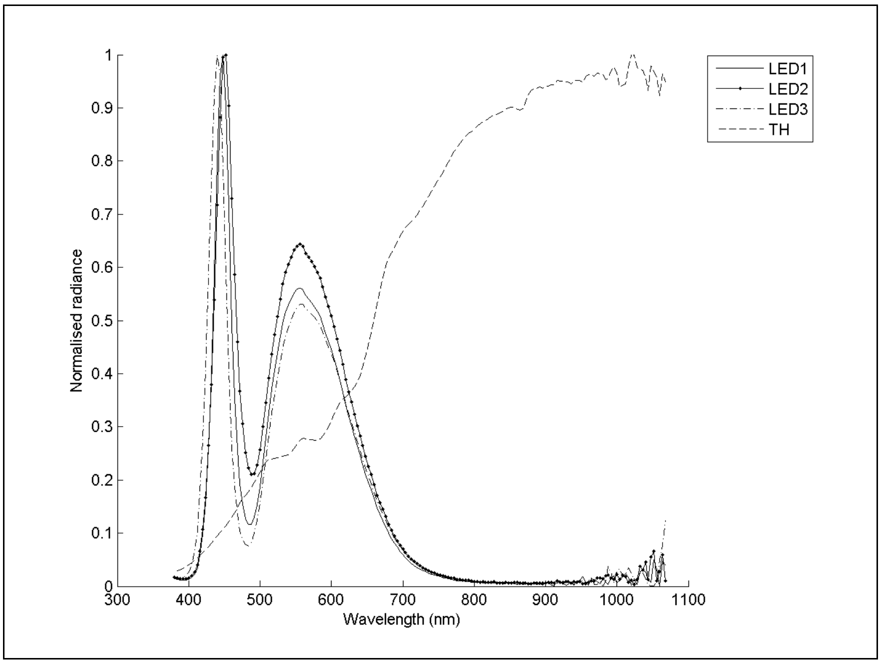

Figure 1. Spectral power distribution of four illuminators

2.2 Luminous intensity distribution

A goniophotometer at the South African Bureau of Standards (SABS) was used to measure the luminous intensity distribution of the illuminators. The illuminators were mounted horizontally in the goniophotometer. Measurements were taken in a horizontal plane between 35º left (-35º) to 35º right (+35º). In the vertical plane the measurements were taken between 45º bottom (-45º) to 45º top (+45º). The data interval was 0,2º from -2º to 2º, a 5º data interval between 5º and 15º and a 10º data interval for the remainder of the angles. In order to simplify the data analysis it was assumed that the luminous intensity distribution is symmetrical around the centre of the beam, therefore the average of the intensity readings in the four quadrants, at each angle, was calculated. This data is presented in Figure 2 and Figure 3. Figure 2 shows the average luminous intensity distribution for the de-focussed illuminators LED1, LED2 and LED4.

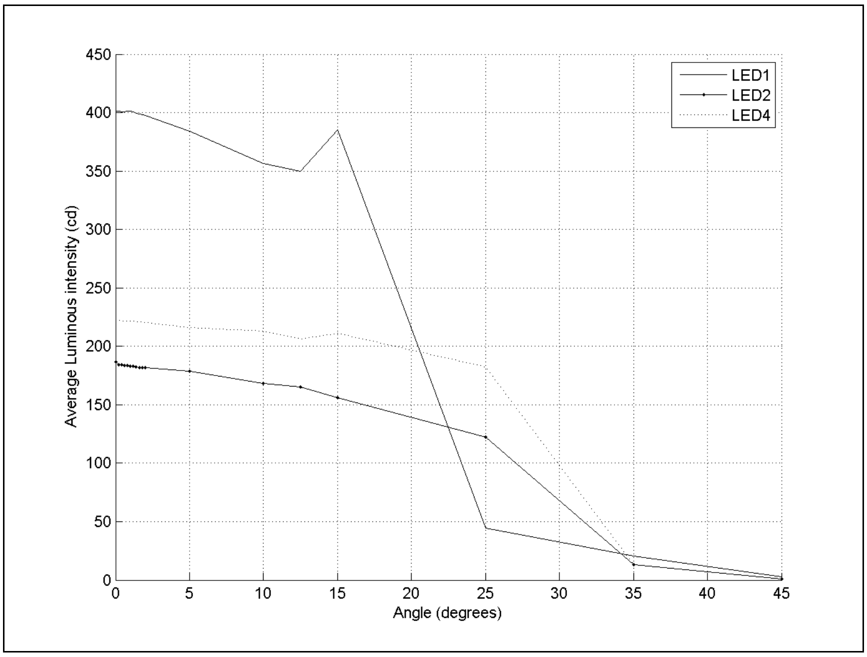

Figure 2. Average luminous intensity distribution – de-focussed (wide)

The average luminous intensity distribution for the focussed beams (LED1, LED2, LED3, LED4 and TH) is shown in Figure 3.

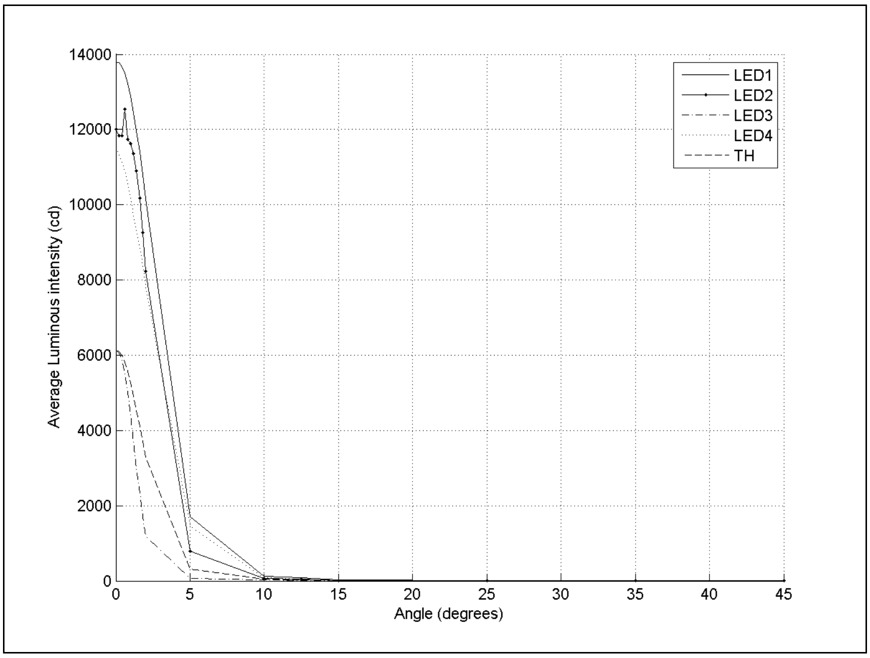

Figure 3. Average luminous intensity distribution – focussed (spot)

2.3 Visual experiments

A similar procedure as described in the manual of the Goldmann-Weekers adaptometer (HS, 19xx) was used to determine the eye's scotopic recovery time. These instruments are used in clinical studies to determine the eye's scotopic recovery time (Peters, 2000; Gaffney, 2011). During these studies a subject's eyes was first allowed to become dark adapted. The subject was then exposed to a high level of illuminance, where-after the subject was presented with low-contrast targets. By monitoring the time required to identify targets with different contrast levels, the scotopic recovery time was determined.

A schematic diagram of our measurement setup is shown in Figure 4. A low-contrast United States Air Force (USAF) Bar Target (Figure 5), which is generally used for determining the optical resolution of a lens system, was used as a visual target (Hopkins, 1970). The target has several horizontal and vertical bar pairs of the same size, called groups (as an example group 0/3 is indicated in Figure 5). These groups are arranged from large to small, and depending on which group can be identified, the resolution of an optical system can be calculated. These targets are available in high-contrast (black bars on a white background), medium-contrast and low-contrast (light-grey bars on a white background).

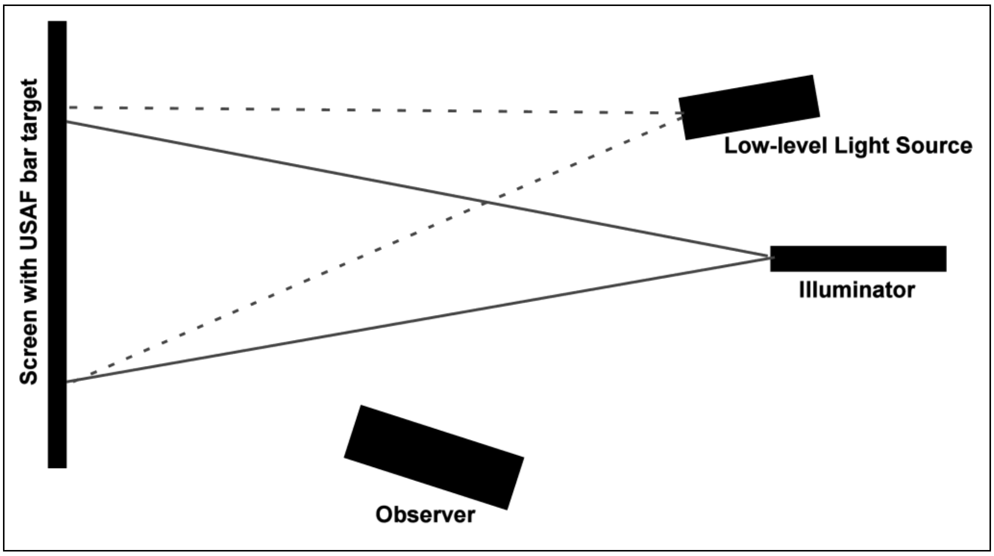

Figure 4. Experimental setup, top view

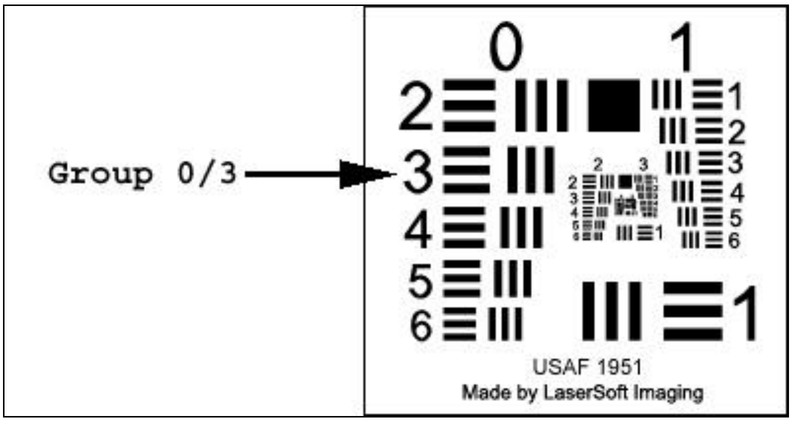

Figure 5. US Air Force bar target

The illuminator was mounted on a movable rail, that allowed for the adjustment of the illuminance levels on the bar target. The distances used during the measurements ranged from 2,5 m to 8,0 m. The illuminators were mounted such that it allowed for easy switching between the different types.

A low-level light source (LLLS), typically used for resolution tests in this laboratory, was used as a background illuminator for the bar target. Starlight conditions were assumed. The low-level light source was adjusted such that the luminance of the bar target was 10^{-4} cd/m^2 (starlight conditions (Burle, 1974)), which is below the scotopic threshold of 0,001 cd/m^2 (CIE, 2010).

An illuminance meter, placed next to the bar target, was used to measure the vertical illuminance levels at the target (the total illumination of the low-level light source and the illuminator). The illuminance meter was also used to measure the illuminance at the observer, whilst facing the bar target.

3.2 Procedure and results

The first step was to determine the illuminance at the bar target for different illuminator distances. This was done for the TH illuminator (chosen as reference) and the LED4 illuminator. The LED4 illuminator was selected since its beam spread closely matched that of the TH illuminator.

The TH illuminator's illuminance was measured at different distances. An illuminance meter, positioned vertically at the bar target, was used. This process was repeated for LED4. However, LED4 has approximately a 2,5 times higher luminous intensity compared to that of TH. This problem was solved by placing a NG11 neutral density filter in the light path. With the combination of the LED4 illuminator and the NG11, the illuminance level at the target was approximately the same than that produced by the TH illuminator. The results of these measurements are illustrated in Figure 6.

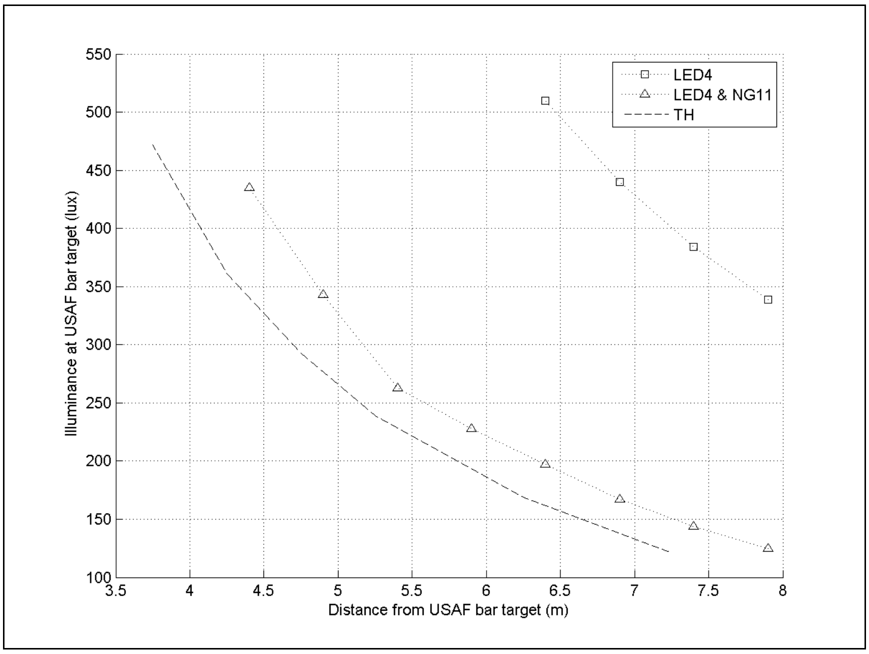

Figure 6. Luminous intensity for TH and LED4, at different distances

Three illuminance settings were selected for the purpose of this evaluation. These were 360 lux, 240 lux and 125 lux. The corresponding distances from the bar target for both TH and LED4 (with NG11 neutral density filter) was in the region of 4,7 m, 5,5 m and 7,1 m. The following procedure was followed:

- The low-contrast bar target was selected for the visual observations.
- The observers were seated one meter from the bar target.
- The LLLS provided the background illumination during the observations.
- The observers' eyes were allowed to become dark adapted with the background illumination switched on (adaptation took approximately 20 minutes).
- The observers were instructed to determine the smallest group they could see on the bar target.
- The bar target was replaced with a white reflective surface, the intention being to move the eye's responsivity from the scotopic to mesopic or photopic region.
- The illuminator mounted on the movable rail was switched on, and the observers were instructed to look at the white reflective surface for approximately 15 seconds.
- The illuminator was switched off, and the white reflective surface was removed.

- The time required for the observer to identify the smallest group on the bar target was recorded as the recovery time.
- This process was performed for both the TH and LED4 (with the NG11 neutral density filter) illuminators, for all three illuminance levels mentioned above.

The luminance of the white reflective surface was determined for the two different light sources, and is shown in Table 1, together with the respective illuminance values.

Table 1. Illuminance of the illuminators and the luminance of the white surface

	Illuminance (lux)	**Luminance of white surface (cd/m^2)**	
		LED4 & NG11	**TH**
1	360	2,5	1,3
2	238	1,9	1,2
3	125	1,5	1,0

The scotopic recovery times for all of the test points were similar. All the observers were able to distinguish the smallest group on the bar target, for both TH and LED4, after approximately 5 seconds.

4 Discussion

The spectral power distribution of the LED illuminators was similar, with peaks at 445 nm and 555 nm. The spectral power distribution of TH showed a typical distribution for this type of lamp.

The luminous intensity distribution as well as the peak values of the different LED illuminators showed a large variation. The focussed versus the de-focussed luminous intensity distribution values also differed dramatically, e.g. maximum luminous intensity value for LED1 is 14 000 cd when focussed, and 400 cd when de-focussed.

During the visual experiments we could not observe any significant difference between the recovery times for LED4 and TH. The illuminance levels on the target were kept at the same level for both types of illuminators. Luminance measurements (Table 1) showed that mesopic conditions existed (as defined by the CIE (CIE 2010)) when the target was illuminated by both types of illuminators.

The results from the measurements and visual experiments showed that more experimental work needs to be done. The exact relationship between the luminance level and the recovery time is still unclear. To address this issue, it will be required to change the luminance levels from low to high levels in small increments, using more observers. This should be done for both types of illuminators, to determine whether or not the spectral content of the lamp has an influence on the recovery time.

Hammond et al (Hammond, 2010) investigated the photostress recovery time of subjects' eyes, using intra-ocular lenses, with and without blue filters. The subjects with blue filtering experienced faster photostress recovery than those without blue filtering. Stringham et al (Stringham, 2008) placed blue-filtering macular pigments in the inner retinal layers of subjects' eyes. Improvements in glare disability and photostress recovery were obtained. The spectral distribution of the LED illuminators (Figure 1) shows a prominent blue peak at 445 nm. When the spectral distribution is weighted with the scotopic efficiency function (shown in Figure 7), it is evident that the peak at 445 nm contributes significantly to the visual response. With reference to Hammond's and Stringham's findings, the question arises whether or not the blue peak of the LED illuminators will significantly affect the scotopic recovery of the eye. This will be the subject of future studies.

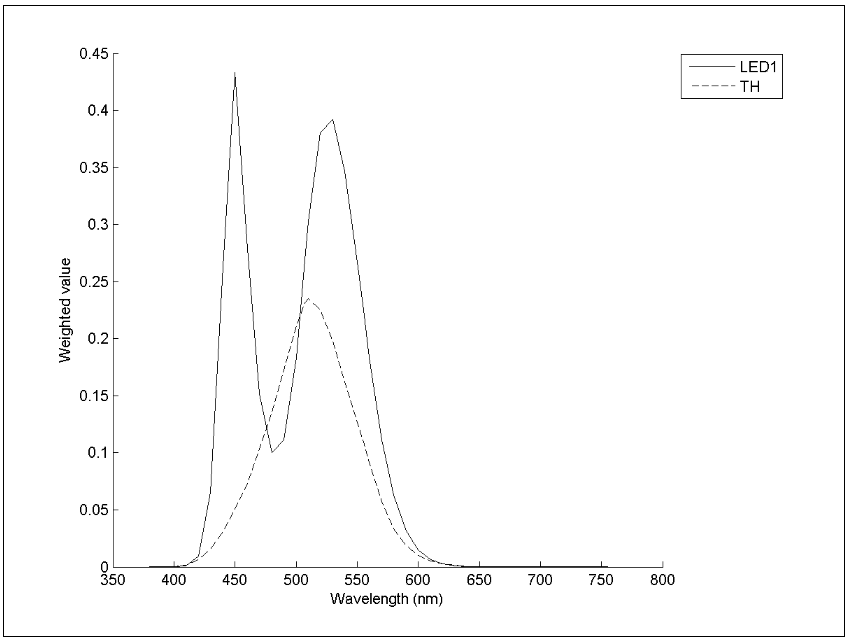

Figure 7. Illuminator scotopic-weighted function

5 Conclusions and recommendations

The results obtained during this study did not provide a clear answer to the research question. However, published articles suggest that the blue content of LED sources could have a negative effect on scotopic recovery time.

Our results highlighted the following areas for further research:

- If possible, the minimum luminance level at which the eye's efficiency is changed from scotopic to mesopic, for both these illuminator types, has to be determined. This will allow us to advise the user on the selection of suitable illuminators, based on the respective luminous intensity values of these illuminators.
- The possible effect of the blue peak on the scotopic recovery of the eye has to be studied. This could aid in determining the suitability for use in the operational environment, using any of the two illuminators studied (and for that matter any other LED-based illuminator that does not have a dominant peak in the blue region).

In order to confirm the results and methods of the current study (and proposed future work mentioned above), it would be beneficial to determine the scotopic recovery time using an adaptometer.

So far, these studies are laboratory-based. The target (USAF bar target) has a relatively high reflectance, resulting in a relatively high luminance value. However, in field applications the targets (e.g. foliage) have a low reflectance that will result in low luminance values. This implies that during illumination, the eye's responsivity is expected to remain in the scotopic region, and therefore no adaptation will be experienced. As a result of this, it will be necessary to perform these measurements with natural targets as well.

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