SCI8102 Research Skills Essay Assignment

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# Is Orange Light a Better Colour than Red for Dark Adaptation?

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# **Table of Contents**

| Abstract               | 3  |
|------------------------|----|
| Introduction           | 3  |
| Materials and Methods  | 12 |
| Results and Discussion | 17 |
| Conclusion             | 27 |
| Appendix               | 28 |
| References             | 31 |

# Abstract

Maintenance of dark adaptation is critical for visual astronomers. Where artificial lighting has been necessary, astronomers have traditionally used red lighting. However there are sound reasons to suggest that this may not be the optimal colour. Previous research in night dark adaptation has all been laboratory based whereas this study tested astronomers using their own environment, via the use of computer images to imitate astronomers' normal sources of artificial light, and stars themselves as the criteria for assessing changes in dark adaptation. In their normal working environment the study revealed that orange is the most appropriate colour for lighting for most astronomers, but there was considerable variation. Variation may reflect the significant variation in the ratio of red and green cone receptors in the retina, in people with normal colour vision. Further the study did not reveal deterioration in dark adaptation as a function of age.

# Introduction

Protection of visual dark adaptation is vital to visual astronomers. They share this need with aviators, mariners and military personnel. Yet there is little scientific data to determine what colour low level artificial lighting is associated with the least interference with dark adaptation. Much has been written about the photochemistry of dark adaptation and re-adaption after exposure to very high power lighting (Adler, 1987; Reuter, 2011; Wandell, 1995), but there is barely any data on the use of feint light sources and how exposure to them impairs vision.

The aim of this paper is to examine the effects of different colours and intensity of light on both visual acuity and maintenance of retinal sensitivity.

Red has traditionally been the lighting colour of choice by visual astronomers, both for navigating safely around their environment, and for chart-reading purposes. But there is no data to confirm that red is in fact the most appropriate colour for this purpose. When asked, astronomers will invariably (and incorrectly) state that night vision retinal receptors can't detect red light. Probably another reason astronomers have used red light, is the historic use of red light in photography dark rooms. Red lighting for dark rooms was not related to visual dark adaption, but rather black and white photography paper was usually made red insensitive, to provide the ability to work in light that would not affect the paper.

In 2016 Robert Dick in Sky and Telescope magazine argued that from a visual physiology perspective, orange may be a better colour for many people, (Dick, 2016), but actual testing was limited to the author. This paper aims to test that hypothesis in the visual astronomy environment.

## **Background Visual Physiology**

Photons are converted to neuronal signals by receptors in the retina of the eye. These receptor cells can be anatomically and functionally divided into rods and cones. The cones can be further divided into blue or "S" (short wavelength) cones, green or "M" (medium wavelength) cones and red or "L" (long wavelength) cones. S cones only comprise 5-6% of total cones, so imaging is done by red and green cones, with S cones only interpreting whether the colour of the object is blue (Solomon & Lennie, 2007).



Figure 1 Anatomy of the eye and retina (Sarno, 2018)

Cones provide us with colour vision and optimally work in daylight light intensity. This is known as photopic vision. At night there is a threshold below which cones cannot detect light.

Rods provide monochromatic vision that is suited to very low light levels as experienced at night. This is known as scotopic vision. During the day there is a threshold at which rods become saturated or "bleached" and cannot transmit data.

Intermediate light levels where both cones and rods operate is known as mesopic vision.



*Figure 2 Functional luminance ranges of rods and cones.* (Dick, 2016)

As rods and cones receive photons and create neural impulses, they are depleted of the photochemicals to do this. As these molecules take time to regenerate, the process is a self-regulating sensitivity mechanism. With exposure to light, the molecules are depleted and the receptor becomes less sensitive. During periods of darkness, the photochemicals are fully regenerated, and sensitivity increases. Cones take 15 minutes to fully dark-adapt, while rods take 30-40 minutes to adapt. The sensitivity of the eye can vary by a factor of 25,000 by this mechanism (Hall, 2011). A fully dark adapted rod can be triggered by a single photon (Reuter, 2011). To further amplify the signal, but prevent excessive noise, rods are interconnected with many rods producing the one signal. The price of this noise reduction mechanism is the loss of visual acuity by rods.



Figure 3 Dark adaption pattern of rods and cones (Hall, 2011)

It is commonly believed that visual astronomy relies solely on rod receptors for vision, however that is not the case. Rod receptors only provide low acuity monochromatic vision in the peripheral visual fields. Colour sensation can only be perceived by cones. Further, central vision falls on the part of the retina called the fovea, which is exclusively populated by cones. Only the fovea has high visual acuity. Off axis or "averted vision" visual acuity decreases by as much as 50% per degree(Anstis, 1974). By 10 degrees off axis where rod receptors are most frequent, visual acuity is less than 20 % of central visual acuity. Therefore sensing high acuity detail, such as planetary detail or separation of close individual stars, is only possible with cones.



Figure 4 Rod and Cone Densities in five subjects vs. angular eccentricity from the fovea. (Wells-Gray, Choi, Bries, & Doble, 2016)



Figure 5 Decrease in Visual acuity vs. angular eccentricity from the fovea by Wertheim (2a) and Polyak (2b) (Harrison, 1953). Given these limitations, rod receptors are limited to detecting the presence of a feint star and also the presence or absence of nebulosity that is not visible in central vision. One significant function of a telescope in visual astronomy is to gather enough light so the eye can operate in the mesopic range of vision.

As we are therefore dependent on cone function in visual astronomy, and the L cone receptor (which for most people comprises the majority of our cone receptors) is sensitive to red light (Figure 7), the use of red light may confer no advantage.



Figure 6 Operating wavelengths of retinal receptors. (Hall, 2011)

Additionally it is often incorrectly inferred from the above diagram that rods are insensitive to red light. However this diagram demonstrates only the frequencies at which each receptor absorbs maximum light, therefore its optimal operating wavelengths. The diagram does not show relative sensitivities, in particular significantly increased sensitivity of rods.

A log scale graph demonstrating relative light sensitivity of rods and cones at different wavelengths is shown in figure 7. This demonstrates that rods are over one hundred times more sensitive than cones in blue green light, while in red light rod sensitivity is similar to L cone sensitivity.



Figure 7 Relative sensitivities of rods and cones. (Davson, 1990)

Green light that is sufficiently bright to read by is likely to saturate rods, but even red light sufficiently bright enough to activate, and therefore deplete of photochemicals in L cones will also activate and deplete photochemicals in rods, therefore affecting rod sensitivity as well L cone sensitivity.

In summary red light might not infer any special visual adaptation protection to cone vision, while green light may lead to loss of rod sensitivity.

In 2016 it was suggested that orange light might be the optimal colour for illumination. Orange light minimizes overstimulation of rod receptors as occurs in the green blue region of the visual spectrum, but stimulates both red and green cone receptors allowing better visual acuity for any given brightness of light(Dick, 2016).

The percentage stimulation of the different receptors by different colours is shown in Figure 9. Maximum stimulation of both red and green cones occurs in the orange region of the spectrum.



Figure 8

Percentage stimulation of cone receptors by different colours. Orange light is the region of maximum stimulation of red and green cones.

(Hall, 2011)

### Age and dark adaptation

The retina is less sensitive at all light levels, and dark adaptation is slower with increasing age. This is true even in the absence of lens or retinal disease. It is thought to be due to a slowing of the regeneration rate for photoreceptor chemicals for vision(Jackson, Owsley, & McGwin Jr, 1999). See figure 9



Figure 9 Time to achieve dark adaption vs. age. (Jackson et al., 1999)

In conclusion there are sound reasons why orange rather than red may be the optimal colour for artificial lighting, where preservation of dark adaptation is vital. There is also the opportunity to see if loss of dark adaptation in this context is age related.

# **Materials and Methods**

The trial is designed to test cone and rod sensitivity to red, orange, green and white light. Blue light was not tested, as blue cones do not contribute to visual acuity.

The prime source of artificial light at night for visual astronomers is their computerized maps, so the trial utilizes laptop computer images I designed, as the light source, and the impact of such exposure on defined feint celestial objects as the way to judge any deterioration in dark adaptation.

Dark adaptation was measured by noting the dimmest stars visible after screen exposure. Star brightness is expressed in magnitudes, where a difference of 5 magnitudes equals a hundred fold difference in brightness (Bennett, Donahue, Schneider, & Voit, 2014). Bright stars (excluding the sun) range in magnitude from Sirius, the brightest star at magnitude -1.46 to Gacrux the 25<sup>th</sup> brightest star at magnitude 1.63. With ideal darkness and sky transparency, and full dark adaption, stars down to a magnitude of around 6.5 can be seen, amounting to 9,096 stars (Hoffleit & Jaschek, 1982).

15 subjects between the ages of 15 and 65, were tested at the Queensland astronomy festival in August 2018. The precise nature or the purpose of the test or possible hypothesis was not explained till after the completion of the trial.

Exclusion criteria were:

- Age under 15 or over 65
- History of retinal disease, cataracts, or diabetes (which is associated with retinal disease).
- Lens or corneal surgery.
- Corrected distant vision less than 6/6
- Corrected reading vision less than 0.5mm at 33.5 cm.
- Colour blindness as tested with Ishishara charts (Panayotov, 2017)
- Variance of greater than 0.5 magnitude below tester's limiting star magnitude.

Each subject gave formal consent prior to medical interview and sight assessment, and was briefed on the testing procedure. Prior to the assessment each subject was taught how to assess limiting magnitude of the night sky using the International Meteor Organization (IMO) test field "L" in the region of the constellations Centaurus and Crux. This procedure involves counting stars within a triangle formed by Beta Centauri (Hadar), Alpha Crux (Acrux) and Gamma Crux (Gacrux) (figure 10).



#### Figure 10

International Meteor Organization Star Field "L," used in study to determine limiting magnitude. 14 stars are visible in this diagram, equating to a limiting magnitude of 6.0 as determined from Table 1. (Goodman, 2014)

As per IMO instructions, the subjects were allowed to identify feint stars by averted vision but only able to include the star in their count, if it was clearly visible with direct vision. This therefore made the star count an assessment of cone function. The star count was then converted to a limiting magnitude, using the following IMO chart.

| Stars | Α   | В   | С   | D   | Е   | F   | G   | Н   | I I | Κ   | L   |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
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| 2     | 2.9 | 1.7 | 2.8 | 2.0 | 2.0 | 3.2 | 2.1 | 2.7 | 1.9 | 2.7 | 1.3 |
| 3     | 3.0 | 3.0 | 3.3 | 3.0 | 2.3 | 3.7 | 2.2 | 3.0 | 2.9 | 3.4 | 1.6 |
| 4     | 3.8 | 4.6 | 3.9 | 3.8 | 3.8 | 3.8 | 2.6 | 3.0 | 4.7 | 4.4 | 1.7 |
| 5     | 5.0 | 4.9 | 4.3 | 5.0 | 4.0 | 4.5 | 3.3 | 5.2 | 5.2 | 5.8 | 4.3 |
| 6     | 5.2 | 5.0 | 4.4 | 5.1 | 4.0 | 4.6 | 4.4 | 5.8 | 5.6 | 5.8 | 4.6 |
| 7     | 5.6 | 5.1 | 4.5 | 5.3 | 4.3 | 4.8 | 4.8 | 6.0 | 5.8 | 5.9 | 4.6 |
| 8     | 5.6 | 5.3 | 4.8 | 5.8 | 5.5 | 5.1 | 5.4 | 6.4 | 5.9 | 5.9 | 4.6 |
| 9     | 5.8 | 5.4 | 5.5 | 5.8 | 5.5 | 5.2 | 5.4 | 6.6 | 5.9 | 6.0 | 4.7 |
| 10    | 5.8 | 5.5 | 5.5 | 5.8 | 5.8 | 5.5 | 5.5 | 6.8 | 6.1 | 6.0 | 4.9 |
| 11    | 6.0 | 5.7 | 5.7 | 6.2 | 5.8 | 5.7 | 5.5 | 7.1 | 6.4 | 6.1 | 5.5 |
| 12    | 6.0 | 5.8 | 5.7 | 6.4 | 6.4 | 5.7 | 5.6 | 7.3 | 6.5 | 6.4 | 5.8 |
| 13    | 6.1 | 6.1 | 5.7 | 6.5 | 6.4 | 5.8 | 5.7 | 7.3 | 6.6 | 6.4 | 5.8 |
| 14    | 6.4 | 6.2 | 5.7 | 6.5 | 6.5 | 6.0 | 5.9 | 7.4 | 6.7 | 6.6 | 6.0 |
| 15    | 6.4 | 6.3 | 5.8 | 6.7 | 6.5 | 6.2 | 6.1 | 7.4 | 6.8 | 6.6 | 6.2 |
| 16    | 6.5 | 6.3 | 6.0 | 6.8 | 6.6 | 6.3 | 6.2 | 7.4 | 6.8 | 6.7 | 6.2 |

Table 1

International Meteor Organization Star field count vs. limiting magnitude. (Matys, 2008)

As an assessment of peripheral rod vision, the subjects were taught how to identify the Coal Sack nebula, which is inside star field "L," and its precise shape as a circular object with a triangular extension (known as the "beak of the Emu," in Australian Aboriginal astronomy).

### Test apparatus

The test apparatus consisted of a Power-Point presentation of Jaeger near vision charts (figure 11).

#### Read from a distance of 14 inches

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tions of the earth. The principal conquests of the Romans were achieved the republic; and the emperors, for the most part, were satisfied with pre-g those dominions which had been acquired by the policy of the seate, the emulations of the consuls, and the martial enthusiasm of the people. The first centuries were filled with a rapid succession of triumples; but it was

# No. 4. .75M

reserved for Augustus to relinquish the ambitious design of subduing the whole earth, and to introduce a spirit of moderation into the public councils. Inclined to peace by his temper and situation, it was very easy for hin to discover that Rome, in her present exalted situation, had much less to hope than to fear from the chance of arms; and that, in the prosecution of

# No. 5. .75M

the undertaking became every day more difficult, the event more doubtful, and the possession more precarious, and less beneficial. The experience of Augustus added weight to these salutary reflec-tions, and effectually convinced him that, by the prudent vigor of

#### No. 4. 1.25M

his counsels, it would be easy to secure every concession which the safety or the dignity of Rome might require from the most formidable barbarians. Instead of exposing his person or his legions to the arrows of the Parthians, he obtained, by an honor-

### No. 7. 1.50M

able treaty, the restitution of the standards and prisoners which had been taken in the defeat of Crassus. His gen erals, in the early part of his reign, attempted the reduction of Ethiopia and Arabia Felix. They marched near a thou-

# No. 8. 1.75M

sand miles to the south of the tropic; but the heat of the climate soon repelled the invaders, and protected the unwarlike natives of those sequestered regions

No. 9. 2.00M The northern countries of Europe scarcely deserved the expense and labor of conquest. The forests and morasses of Germany were

No. 10. 2.25M

filled with a hardy race of barbarians who despised life when it was separated from freedom; and though, on the first

No. 11. 2.50M

attack, they seemed to yield to the weight of the Roman power, they soon, by a signal

Figure 11 Jaeger near vision chart (This is lower resolution than the actual chart). (Bagi, 2018)

The charts were identical with black font on different backgrounds.

The backgrounds were in four colours, red orange, green and white. Their creation and settings are in Appendix 1.

This created forty charts as shown in Figure 13. These were each labelled 1 to 10, E.g. r3, w4. The brightness of each chart was measured at the test distance with a lux meter (Digitech model QM 1587).

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Figure 12 PowerPoint overview of test panels.

# **Test protocol**

Each subject was dark adapted outdoors for a minimum of thirty minutes, during which they were taught how to count stars in star field "L." At the completion of dark adaptation they assessed their count, and excluded from the study if it varied by more than 0.5 magnitude from the author.

Each subject was then shown a dim red Jaeger chart at a distance of 33.5 cm (14 inches) from the forehead to screen on the same MacBook (Pro Retina laptop with Intel Iris Graphics 6100 1536 MB built 2015 serial number C02P74A9FVH5). Screen brightness setting was set at 8/16. Subjects were allowed to scroll through the increasingly bright charts till they could comfortably read out loud the second paragraph of the chart (0.5mm lettering). At the completion of one minute of reading, the screen was turned off. One minute, and four minutes later, they undertook a star count by direct vision, and noted the ability to perceive the Coal Sack nebula and its triangular extension.

Once full dark adaptation was restored, the process was repeated in orange, green, white, and finally with the screen set to bright (4lux) red. This final setting was achieved using red screen "R10" with the brightness setting at 9/16.

# **Results and Discussion**

# Brightness required to read

The brightness required to read the second paragraph of the chart is displayed in Graph 1. Error bars of one standard deviation are displayed.



# **Brightness required to read chart**

Graph 1 Screen brightness to read second paragraph of chart.

It can be seen that a significantly brighter screen was required to read in red than in any other colour. This is consistent with the fact that dim red light may not activate our M cones and therefore we need more red light to compensate (Dick, 2016).

# Impact on perceived visual magnitude

The deterioration in visual magnitude detectable one minute and four minutes after cessation of light is displayed in Graph 2 and 3. Error bars of one standard deviation are displayed.







#### Colour

Graph 3 Loss of cone sensitivity vs. colour of screen 4 minutes after light cessation

Overall, exposure to any of the screens, even at a brightness level far above that normally used, had only small and temporary effects on dark adaptation. Orange light was associated with the least loss of dark adaptation both at one minute and four minutes. Red was the colour that had the next least impact. White and green light, even though the brightness was less than red, had greater impact, with white light having the most impact at four minutes. Bright red was as damaging as green and white at one minute, and, while recovery from bright red was better than for green and white at four minutes, bright red light had greater impact than dim red or orange. This implies that even red light, if sufficiently bright will impact cone vision.

To put this in perspective, the following graph plots the cumulative number of stars visible to the naked eye vs limiting magnitude.



Graph 4 Number of stars visible to the naked eye vs. magnitude. (Lomb, 2011)

As the average limiting magnitude when fully dark adapted in this study was 5.8, the impact on exposure to the different colours at 1 minute, from graph 2, can be converted to number of stars visible using the above graph.





The colour of light to which visual astronomers are exposed has a meaningful impact on the number of stars that can be seen in the short term after light cessation. This would be particularly relevant where frequent referral to computer maps is required.

It is worth noting that night vision goggles, as worn by aviators and military personnel produce a green image. As the least brightness is required in green, this may be an advantage in preserving battery life. While these devices improve night visibility dramatically, it is also at the portion of the spectrum that is most damaging to our inherent night vision.

# Impact on Rod vision as determined by perception of nebulosity and nebulosity detail.

The deterioration in detection of nebulosity is displayed in Graph 4 and 5.



Light colour vs ability to detect nebulosity at 1 minute





Light colour vs ability to detect nebulosity at 4 minutes

Graph 5 Loss of rod sensitivity vs. colour of screen four minutes after light cessation

Overall exposure to any of the screens, even at a brightness level far above that normally used, had only small and temporary effects on ability to detect nebulosity but a greater impact on the ability to detect detail within that nebulosity. Orange light was associated with the least effect at one minute, though probably not significantly different to red both at one minute and four minutes. White and green light, even though the screen brightness was less than red, had greater impact. Bright red was as damaging for impairing the detection of nebulosity detail. This implies that even red light, if sufficiently bright may have subtle impact on rod vision.

In conclusion the data suggests dark adaptation is reasonably resilient to a one minute exposure of light, and that orange light is associated with the least loss of both rod and cone dark adaption.

## Visual impairment vs. age

The youngest six subjects (aged 15 -34) were compared to the oldest 6 subjects (aged 51-65) in graph 6. There was no clear correlation between degree of visual impairment and age. This is in contrast with the evidence that dark adaptation time increases with age.

Possible explanations for this observation could be due to the small group size or the nature of the testing procedure. Other studies showing a loss of dark adaption with age has been derived by exposure to extremely bright light sources to induce complete rod bleaching prior to testing, (Jackson et al., 1999; Reuter, 2011) and may not be applicable to this assessment.



# Decrease in magnitude vs colour and age

Co

Decrease in magnitude vs. age

# Data variability

Variability of the above results could be due to several mechanisms.

Precision of measuring instruments.

The lux meter used was not of high-end accuracy in very low light levels. Its accuracy is rated at +/-5% at the range used.

Discreteness of brightness options.

The brightness levels available were in discrete steps rather continuously variable. (Attempts to build a continuously variable device were expensive time consuming and ultimately proved unsatisfactory).

Subjectivity of end points.

The star count method is the standard in use in practical astronomy but is subjective, and in discrete steps. Dark adaption studies in laboratories use correct analysis of object orientation as a non-falsifiable end point. Commonly in laboratory experiments on visual acuity and adaption, subjects are required to describe the correct orientation of a broken ring, known as the three up one down Landolt ring test.



Figure 13 Landolt rings (Millodot, 2009)

However presently there does not exist a laboratory device that works at the required low light levels.

**Biological variability** 

The exclusion criteria attempted to minimize biological variation due to known lens or retinal disease, either genetic or acquired. Further accuracy would be possible but prohibitively expensive, e.g. retinal scanning, estimation of lens density (Sample, Esterson, & Weinreb, 1989).

The invention of adaptive optics ophthalmoscopes (based on adaptive optics telescopes) has, in recent years allowed us to directly determine the ratio of red, green and blue cones in live human subjects (Williams, 2011). Blue cones in most subjects comprise only 5-6% of total cones, Surprisingly, while most people have around 70% red cones, they may comprise as little as 37% or as much as 92% of the cone population in people with normal colour vision.



Figure 14 Blue green and red cone mosaic of ten subjects with normal colour vision. (False colour added in original paper for clarification, dark lanes are due to overlying blood vessels). (Williams, 2011)

This could explain variations in red vs. orange illumination requirements and variations in time to dark adapt in response to different colours (Danilova, Chan, & Mollon, 2013). Those with a preponderance of green cones would need much less illumination in orange, (which contains green in its creation), than red (that contains minimal green), while those with a preponderance of red cones would have more similar required brightness levels. Expressed as a ratio of red to orange brightness levels, a person with a high ratio of green cones would have a ratio well above one, as the addition of some green to create orange rather than red would significantly increase acuity and therefore decrease the illumination level required in orange. For a person with very few green cones the addition of green to create orange may make little or no difference. Therefore you would expect their ratio to be around one. For the majority of people with about 70% red cones the ratio would be above one, but not dramatically so. Graph 7 supports this theory. Most required a brighter red screen but some required a brighter orange screen while two needed significantly less illumination in orange than red. Whether this represents noise in the data, or is indicative of their red/green cone ratios would require further study and adaptive ophthalmoscopy of each subject.



# **Brightness ratio red/orange**



Spectral analysis of screens.

While the screens created were subjectively indicative of typical screen colours, it would have been desirable to have a spectral analysis of each screen colour. Unfortunately the equipment to do this was not available.

# Conclusion

While further and more refined testing is warranted, if the findings of this pilot study are confirmed, contrary to common belief, orange is the optimal colour for most people for preserving dark adaptation. It is however variable from person to person. For visual astronomers this is useful information and the implementation of orange rather than red lighting would seem appropriate. In other careers such as aviation maritime and military operations, where safety demands optimal dark adaptation, further study of this finding, and possibly the need for individual assessment could be warranted.

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# **Appendix 1**

# **Creation of test screens.**

1. Screen colour

The background colours were created on Adobe acrobat using the RGB colour sliders as follows.

# Method

In acrobat reader click "preferences," scroll to "accessibility," click "page background," scroll to "RGB sliders," click settings icon, tick 8-bit (0-255) and tick "Adobe RGB 1998".

The slider values were;

| Red background    | Red 255, | Green 0,   | Blue 0.   | (Hex colour FF0000) |
|-------------------|----------|------------|-----------|---------------------|
| Orange background | Red 255, | Green 128, | Blue 0.   | (Hex colour FF7F00) |
| Green background  | Red 0,   | Green 255, | Blue 0.   | (Hex Colour 00FF00) |
| White background  | Red 255, | Green 255, | Blue 255. | (Hex Colour FFFFFF) |

Each created colour was saved to the palette at the bottom of the colours page. See figure 11

|   | Pref                    | erences  |
|---|-------------------------|--|
| tegories:   | Document Colors Options |  |
| Commenting<br>Documents<br>Full Screen<br>General<br>Page Display | Replace Document Colors | <ul> <li>High-contrast color combination: Green text on blac</li> <li>ound: Document Text: </li> <li>Last or line att</li> </ul> |
| 3D & Multimedia   |                         | s well as text   |
| Accessibility   | RGB Sliders             | S Well as text.  |
| Adobe Online Services   | Ded                     | Show color value as:   |
| Email Accounts  | Red 254                 | Floating point (0.0–1.0)   |
| Forms   |                         |  |
| Identity  | Green                   | Display P3   |
| Internet  | 128                     | sRGB IEC61966-2.1  |
| JavaScript  | Blue                    | ACES CG Linear (Academy Color Encoding System AP1)   |
| Language  | 0                       | ✓ Adobe RGB (1998)   |
| Measuring (2D)  |                         | Color LCD  |
| Measuring (3D)  | Hey Color # 55750       | Device RGB   |
| Measuring (Geo)   | Hex Color # FF/F0       | Display  |
| Medadring (Geo)   |                         | EPSON Standard RGB - Gamma 1.8   |
| Multimedia (legacy)   |                         | EPSON PJ   |
| Multimedia Trust (legacy)   |                         | Generic RGB  |
| Reading   |                         | HD /09-A ed<br>ROMM RGB: ISO 22028-2:2013 ++1-   |
| Reviewing   |                         | Rec. ITU-R BT.2020-1   |
| Search  |                         | Rec. ITU-R BT.709-5  |
| Security  |                         | SD 170M-A<br>SMPTE RP 431-2-2007 DCI (P3)  |

Figure 11 Creation of background colour "orange."

2. Screen brightness

Ten versions of increasing brightness, but constant saturation and hue, of each colour chart were created as follows:

Method

The above colours charts were saved. In acrobat reader click "preferences," scroll to "accessibility," click "page background," scroll to "RGB sliders," select previously saved colour. Scroll to "HSB sliders" leave hue and saturation as set and vary only the brightness slider in 10 percent increments. See Figure 12



Figure 12 Brightness adjustment

Note: The above techniques were noted to change the background colour and brightness of any pdf. document except the page of the document that was open.

## Screen vs. lux value

With the test computer (MacBook pro13 inch Retina display) set at a screen brightness level of 8/16 bars, the brightness of each panel at the assessment distance of 33.5cm (14 inches) was assessed using a Digitech lux meter. See (Figure 14)

|                    |     | Lux Va | lues  |       |
|--------------------|-----|--------|-------|-------|
| brightness setting | Red | Orange | Green | White |
| 1                  | 0   | 0.1    | 0.1   | 0.1   |
| 2                  | 0.1 | 0.2    | 0.2   | 0.3   |
| 3                  | 0.3 | 0.3    | 0.3   | 0.5   |
| 4                  | 0.4 | 0.5    | 0.4   | 0.8   |
| 5                  | 0.7 | 0.7    | 0.6   | 1.2   |
| 6                  | 0.9 | 1      | 0.9   | 1.7   |
| 7                  | 1.3 | 1.4    | 1.2   | 2.3   |
| 8                  | 1.7 | 1.9    | 1.4   | 3.2   |
| 9                  | 2.2 | 2.4    | 1.9   | 4     |
| 10                 | 2.7 | 3.1    | 2.4   | 5.1   |
|                    |     |        |       |       |

Figure 14

Lux values of test screens

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