Effects of ambient illumination on text recognition for UI development

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Abstract

In this research, the effects of illumination intensity on character recognition performances has been assessed for LCDs. Measuring how the minimum acceptable contrast ratio in the content changes as the device is moved from an indoor office illumination to a (simulated) outdoor level. The data collected during the research has been applied to an evaluation tool to assess the performances of a colour combination under various lighting conditions. The underlying equation is made available for further development and improvement of light aware UI in mobile applications. The collected data points out how the W3C 7:1 contrast ratio threshold is not sufficient to ensure legibility during outdoor/mobile use. A value of 18:1 is the suggested guideline for the minimum W3C contrast ratio high illumination.

1 Introduction

Ambient illumination conditions (chromaticity, directionality and intensity of the of the light source) have a measurable effect on psychophysics performances such as visual abilities and workload (Lee et al., 2011), (Lin et al., 2008) affecting legibility, response time (Humar et al., 2008), (Lin and Huang, 2013) and colour discrimination (Baah et al., 2012). While the impact of light chromaticity (Humar et al., 2014), (Lin, 2003) on visual performance has been intensively studied, ambient illumination has not. When considered as a variable, it is often limited not to exceed to indoor conditions (rarely exceeding 500lux) (Lin and Huang, 2006). Consequently, guidelines of visual accessibility often do not aid the UI design effectively outside this range. The W3C contrast ratio (W3C, 2018), part of the WCAG guidelines (W3C, 2008) is an example, as it does not consider ambient illumination as a variable in the "Success Criteria". A high ambient illumination can significantly reduce the effective ambient contrast ratio (Chen et al., 2017) of a monitor and the perceived contrast. Specifics "low light" or "night" versions of multiple software have been developed to reduce this usability issue, with inverted polarity and a different contrast ratio such as the Android "Night mode" (Wagoner, 2016) matching the interface to the overall ambient brightness (Baumann and Thomas, 2001). Only recently this is translating into light aware UIs (*Examples of Light-Aware User Interfaces*, n.d.) that "adapt" to different illuminance conditions adjusting the graphical elements.

1.1 Variables

-**Ambient illumination**, (illuminance and chromaticity).

-**Ambient Illuminance**, 300/500 lux (office work), 2000/1000 lux (precision work), up to 10000 lux (outdoor, clear day). Illuminance in the experiment was limited by the light source and reached a maximum value of 5500 lux.

-Chromaticity can have a measurable impact on visual performance (Lin and Huang, 2013), (Tseng et al., 2010) but since the stimuli material variated only in luminance (chromatically neutral) the effect of the chromaticity of the illumination was expected to be minimal. The illumination had a fixed white point of 3400K for the duration of the experiment, defining a display viewing condition as a mixed adaptation state (Katoh, 1995), (Katoh, 1998). The display peak white resulted as the dominant adapted white point in the dim ambient illumination of the lowest test setting, but as the ambient illumination intensity increased the observer adapted to the warmer white point of the fluorescent tube.

-The **polarity** between text and background colours can affect the text recognition performances (Buchner and Baumgartner, 2007). Positive polarity has better performances in proofreading, independently from luminance, chromatic contrast ratio and lighting conditions without a significant effect on effort and strain on the subjects. Inverted polarity can be preferable in the dark as it matches to a higher degree the ambient luminance reducing glaring (Baumann and Thomas, 2001). During the study, the polarity was kept to positive.

-Background hue/Text hue and the consequent chromatic contrast, was fixed, working only on a different luminance.

-Luminance contrast is the variable of interest for the "design choice" in question (difference in luminance between the text and background colours). The minimum contrast at which the text is distinguishable (and readable) has been measured at increasing ambient illuminations. The relative difference in luminance is expressed either as "contrast ratio" or as "contrast". For patters with an equal presence of bright and dark features, contrast is defined as the difference between the luminance divided by their sum "Michelson contrast"(Barten, 1999), (Michelson, 1927). Weber contrast is to be used when small features are positioned on a uniform background (i.e. for letter stimuli), and the background luminance is dominant. Weber contrast is defined as the difference between the text and background luminance divided by the background luminance (Pelli and Bex, 2013). The W3C contrast ratio scale will be used as reference (W3C, 2018) as a recognised tool for web development and accessibility.

-The **typeface** of choice was Microsoft's Times New Roman, chosen as in is a common benchmark for legibility evaluation (Hall and Hanna, 2004), (Lin and Huang, 2006). Font size was set at 0.4 degrees of visual angle (24 arc-minutes), 0.3°to 2°is repeatedly referred (Ojanpää and Näsänen, 2003) as the optimall size range (Legge and Rubin, 1986), (Legge et al., 1987).

-Recognition time was used to evaluate the threshold at different contrast ratio and ambient illuminations. The stimuli design requires three to four saccades and fixations; it includes four letters positioned at an angular distance of 2°from each other. A target threshold of 800ms can be hypothesised, considering a standard value of 150 ms per regular saccade (Yang and Mcconkie, 2001), (Fischer and Ramsperger, 1984), and was the expected value for a subject with normal visual acuity.LCD variables:

-Display white point luminance: maximum intensity of light emitted from the screen (white colour) divided by the area in a given direction (cd/m2 or Nits).

-Brightness, perception elicited by the test patch, the relation between its luminance and the perceived brightness follows a power law, Stevens's brightness law (Rudd and Popa, 2007). The reference exponent for a 5° target in the dark is 0.33(Rudd and Popa, 2007).

-Display black point luminance: minimum intensity of light emitted by the screen (cd/m2 or Nits), in the sRGB standard it is set to 0.2 cd/m2

(IEC, 1999), (approximation for a dim lit room). In LCDs, the black point luminance depends on the amount of backlight that is effectively blocked by the panel (Chen et al., 2017). In this study, the display black point luminance was considered as measured in a dark room, separate from the reflected ambient light.

-**Contrast ratio** (LCD) is the ratio of the luminance of the brightest colour (white) to that of the darkest colour (black) that the system is capable of producing at the same time.

-**Brightness setting**: fixed to the maximum available value ensuring not to cause discomfort at the lowest considered ambient Illumination.

-The **luminous reflectance**: (Chen et al., 2017) normalised value (0-1) of the proportion of ambient light reflecting off the display (i.e. 0.1 for a matte display or 0.047 for an iPhone 7 glass display). Surface material and anti-glare treatment will influence the final ambient contrast ratio. A measure of the light reflecting from the display is obtained multiplying the ambient illumination per the luminous reflectance, also referred to as flare. In the sRGB specification, it is assumed to be 0.2 cd/m2 in a dim viewing environment (IEC, 1999).

2 Methods

2.1 Subjects

Twenty-six (half females) students between 22 to 30 years old, from the NTNU campus in Gjøvik, participated in the experiment. A short pre-test interview was used to rejected participants with low uncorrected vision.

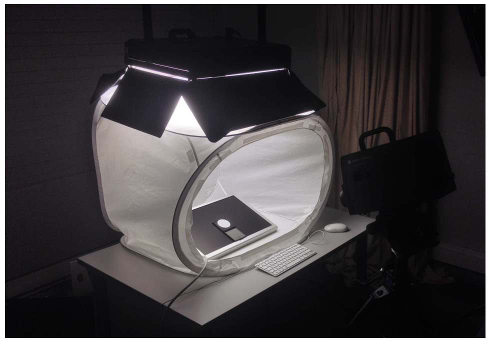

Figure 1: The setup was measured using a Konica Minolta CS-2000 Spectroradiometer (Ltd, 2018) at the viewing distance of 70cm.

2.2 Apparatus

The experiment used the open source software package "PsychoPy" (Peirce, 2018), (Peirce, 2008) for neuroscience and experimental psychology. Thanks to the built-in capabilities of PsychoPy to accept data about screen resolution, dimension and viewing distance, the stimuli elements can be defined as device independent (drawn in degrees of viewing angle). The stimuli software is presented by a Raspberry Pi 3 Model B (Foundation, 2018*a*).

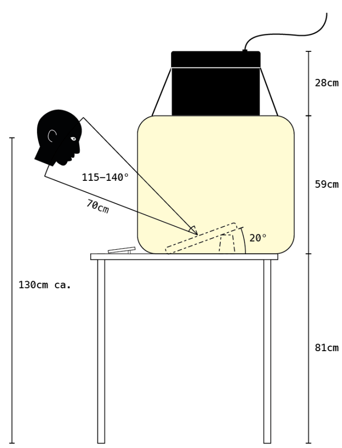

Figure 2: Side measurements of the setup, viewing angle is slightly dependant from the subject height (limited adaptability of the sitting position).

The chosen display is a matte 20" Apple Cinema Display, with a viewing angle of 178°horizontal and vertical, brightness (luminance) of 250 cd/m^2, contrast ratio of 400:1, response Time of 14 ms, pixel Pitch of 0.258 mm and pixel Density of 99.06 ppi. The setup was measured using a Konica Minolta CS-2000 Spectroradiometer (Ltd, 2018) at the viewing distance of 70 cm. The light source allowed for ninety steps, from ambient illuminance of 85 lux to 5500 lux.

The display was mounted tilted 20°from the horizontal plane and placed inside a lightbox to obtain a uniform illumination and a diffuse flare, fig.2 and fig.1. In this configuration, the contrast ratio and maximum display luminance were reduced to 96.6:1 and 97.5 cd/m^2. The performance of the display can be evaluated using the ambient contrast ratio (ACR) measure, defined as (Chen et al., 2017) 1.

$$ACR = \frac{OnLum + ambLv \times Rl}{OffLum + ambLv \times Rl} \tag{1}$$

Where OnLum and OffLum are the measured "Display white point luminance" and "Display black point luminance" (cd/m^2) with no ambient illumination, $ambLv$ is the ambient luminance (cd/m^2 converted from illuminance lux) and Rl is the panel "luminous reflectance". The ambient contrast ratio was measured and computed for each of the contrast ratio pairs, including absolute black and white (-1,+1) fig.3, Rl can be computed as per the formula to an approximated value of 0.118 that can be used to simulate the ACR at higher ambient illumination.

2.3 Stimuli

The stimuli consist of four randomly selected lowercase letters positioned on the vertex of a square having side 2°(ca. 2.4cm.). Four levels of luminance contrast (neutral grey palette) with positive polarity have been selected, see tab.1, the

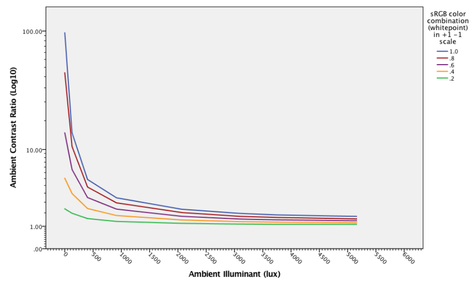

Figure 3: Ambient contrast ratio as measured with the the Konica Minolta CS-2000 for each of the contrast ratio pairs (see stimuli).

normalised values of +-0.8 (W3C contrast of 13.9) were excluded.

Table 1: Table of the test colour pairs
Table of the colour pairs applied to text and background during the test: normalised text colour (from -1 to +1), sRGB text colour, sRGB background colour, W3C contrast ratio.

norm. txt	sRGB txt	sRGB back	c.ratio
-1	0	255	21
-0.6	51	204	7.8
-0.4	76.5	178.5	4
-0.2	102	153	2

2.4 Procedure

Each participant has been instructed to focus on the centre of the display; a fixation point would appear for one second, decreasing in size, before the four letters were shown. The letters were visible for a variable duration, and the participants instructed to write down the four letters, after they had disappeared, using the keyboard in no particular order, guessing if necessary.

The test was divided into four steps, randomly sequenced, corresponding to the four ambient illuminations, foe each all four contrast ratios were tested, in-between the participants were invited to rest. The experiment was limited to approximately thirty minutes per subject. The test followed on a staircase procedure to eliminate the response time from the measurements of the recognition time. The adaptive psychophysical procedures (Treutwein, 1995) calculates the average threshold while variating the stimuli intensity(time duration the letters were visible) depending on the previous responses of the subject (correct/incorrect recognition). The parameters of the staircase procedure were selected to balance precision and overall test duration (30'): four reversal, one up/two down with a decreasing step size of 0.2, 0.1 and 0.05, the initial stimuli intensity was 1000ms.

2.5 Metodological issues

The expected result for a two-down/one-up sequence is a 80.35% correct point (A., 1998), (Pelli and Bex, 2013), still it has to be noted that the reduced number of trials effects this value (Rose et al., 1970), (Wales and Blake, 1970).

A procedural error was not identified during the pre-testing phase and has to be accounted for: the randomised selection of the four letters allowed for the same letter to appear multiple times, this has been reported as making the task perceptibly easier. Since the letter sequence was not saved by the software it is impossible to evaluate this phenomenon.

3 Data Analysis

3.1 Overview

The twenty-six subjects produced in total 4332 data-points and 353 approximated thresholds. The mean recognition threshold is the minimum time needed to recognise all four letters successfully with a confidence level of 80.35%. In fig.4 the threshold is compared with the ambient illumination, this is a device dependent relation as the shape of the trend is strongly dependent to the perceived ambient contrast ratio (see Apparatus) of the particular LCD screen and room conditions.

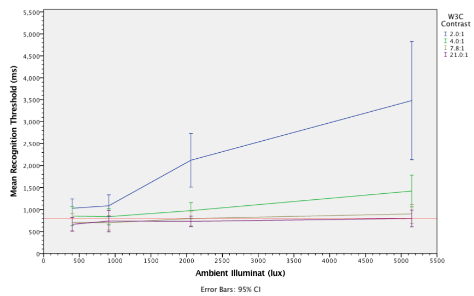

Figure 4: Plot of the mean computed threshold for a given room illumination level (lux) divided per W3C contrast ratio of the stimuli material.

The recognition threshold grows as the contrast is reduced, showing how this affects the ability of the subjects to recognise the letters reliably. The uncertainty in the data grows proportionally with the ambient illumination level, as the consistency across subjects lowers with the contrast. The same trend is observable in fig.5, this plot is device independent: the same ACR can be the result of different displays, colours and ambient illumination. The data covers a limited range: from ACR of 5:1 at 400lux (W3C contrast ratio of 21:1) to about 1.1:1 at 5100lux (W3C contrast ratio of 2.0:1).

In fig.5 it is also possible to identify the ACR at which the recognition time rises over the 800 ms target (c.a. 2.5:1) and then rapidly increases as the ACR is further reduced, again the uncertainty grows considerably as the contrast ratio approaches 1:1. Considering the W3C contrast ratio scale as an independent variable it is possible to evaluate the 7:1 threshold set by the W3C specifications (W3C, 2018). The trend defined by the mean recognition time for the 7.8:1 measurements (the closest to the W3C threshold) overlaps the 21:1

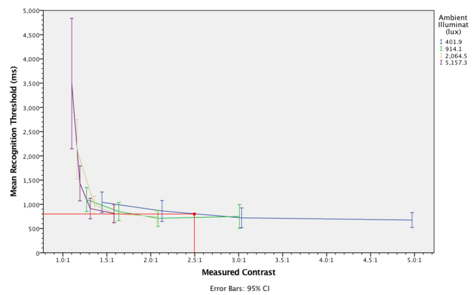

Figure 5: Plot of the mean computed threshold per a given ambient contrast ratio divided by ambient illumination level (lux), notice how the contrast ratio range was covered varying both illumination and software stimuli contrast ratio.

series up until c.a. 2000 lux ambient illumination. This confirms the validity of the W3C scale in a typical indoor illumination (¡2000lux), since the recognition time has been measured only on subjects with normal visual acuity this does not guarantee the accessibility requirements for low vision subjects.

3.2 Discussion

The following psychometric function describes a measure of reading performances that is device independent (relation between the recognition time and ACR).

The formula has limited reliability as for the following parameters:

-**ACR** the collected data reaches only 5:1. The Reading performances seem to stabilise as the contrast ratio surpass 2:1, this behaviour has been observed before (Lin, 2003), with measurements up to 6:1.

-**Font size and Family**, considerably larger or smaller text would potentially move the threshold(Lee et al., 2011).

-**Screen DPI** as well a display technology (LCD, OLED) are a confounding variables (Ziefle, 1998), (Ziefle, 2001).

-**Reading Task** It is not possible to directly infer from the results of a single letter recognition task the expected sustained reading performance in the same conditions.

3.3 Synthesis

$$meanRecTime = 779.245 + \frac{7.4605 \times 10^9}{(Eacr/0.4192372)^{15.311} + 1} \tag{2}$$

The reaction time equation eq.2, plotted in fig.6, is an interpolation produced through data fitting from the discrete points of mean computed threshold per a given ACR fig.5. The sigmoidal equation takes as input the effective ACR. The value of $Eacr$ is calculated through adaptations of the ACR equation for LCDs (Chen et al., 2017).

-Effective ambient contrast ratio equation eq.3

$$Eacr = \frac{effLvMax + ambLv \times Rl}{effLvMin + ambLv \times Rl} \tag{3}$$

The ambient illuminance (lux) is converted to ambient luminance (cd/m^2) as $ambLv$, Rl is the display specific luminous reflectance. The value of $effLvMax$ and $effLvMin$ are computed as a linear interpolation between the maximum and minimum display luminance, the parameter controlling the interpolation is the relative luminance. The relative luminance is calculated from the sRGB values that are first linearised (as per sRGB specification) from gamma-compressed RGB (standard $gamma$ in the experiment was = 2.2) and then fed into the luminosity function eq.4, eq.5, (W3C, 2018).

-Relative Lumiance eq.4

$$rLv = 0.2126 * R' + 0.7152 * G' + 0.0722 * B' \tag{4}$$

-Effective Luminancee eq.5

$$effLv = dispMax * rLv + dispMin * (1 - rLv) \tag{5}$$

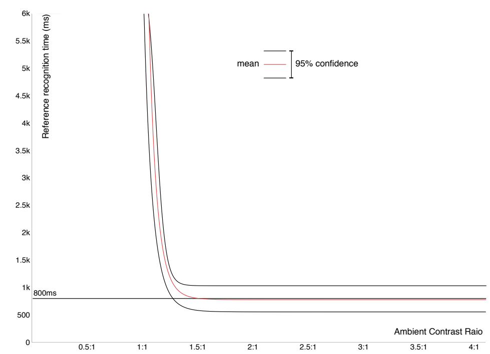

Figure 6: Plot of the three sigmoidal equations representing expected response time within two standard deviations (95%).

4 Application

The psychometric function is a proof of concept of how a light aware interface could react to the settings and sensors of the device, i.e. ambient light sensor, brightness settings, head position tracking.

To make the underlying relations understandable and usable for designers or developers, it was decided to prototype an interactive interface that would present the data dynamically. The interface should take as inputs all the independent variables and outputs a reference value to assess the expected reading performances. The system diagram is described in fig.7, following the procedure described in the previous chapter.

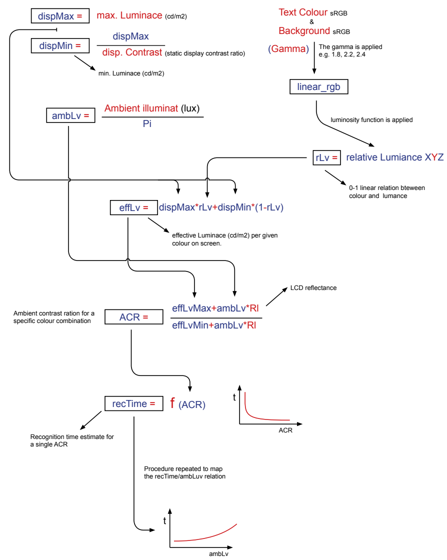

Figure 7: Logical diagram of the back-end of the web interface.

4.1 Interface

Two prototypes were developed, the first in Python and the second rewritten in JavaScript fig.8, using D3 and Function Plot (Bostock, 2018), (Poppe, 2017) to visualise the mathematical relations.

The interface is composed of four main elements: the first graph, in the top-left corner fig.8, represents the final estimated mean recognition time (red line) as well as the 95% probability area (grey patch) as measured during the data collection. These values are plotted against the ambient illuminant intensity as it changes. The bottom graph represents the effective ACR as it changes at different illuminant levels. Both graphs are controlled from the top right panel. The variables are specifications of the LCD (white point luminance cd/m2, static contrast ratio, black point luminance cd/m2 and reflectance) as well as a pair

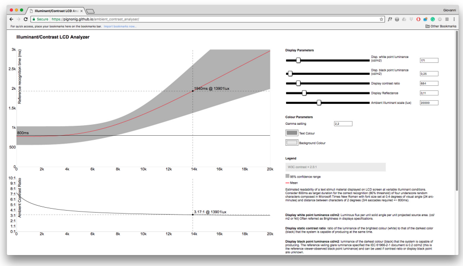

Figure 8: Second implementation of the interface, rewritten in JavaScript thanks to D3 and Function Plot (Bostock, 2018), (Poppe, 2017), available on GitHub(Pignoni, 2018).

of selectable sRGB colours.

The display specification can often be retrieved either from the manufacturer or independent reviewers, such as Displaymate (Displaymate, 2018), maximum luminance and contrast ratio are common specifications, black point luminance is often not reported but the static contrast ratio can also be used. Reflectance is also often not reported and if impossible to measure it can be approximated to 10% for a matte display or 5% for a modern glass covered smart-phone (Chen et al., 2017). The reference value of 800ms is included to visualise where the reading performance will deviate from the standard value, the W3C contrast ratio is included as a further reference.

4.2 Considerations

The result application is not yet a foolproof tool for colour evaluation, the preferred application of these results is the back-end of a software or OS. Hopefully, this and other work will increase interest over light aware User Interfaces making the adoption of such technologies more common in the future. The last revision of the web application is hosted on GitHub ad retrievable at pignonig.github.io/ambient_contrast_analyser/.

5 Conclusion

Further research would be needed to understand how the equation should perform at an ambient contrast ratio of more than 5:1, as well as to understand the relation of the ACR with other independent variables (such as character size and visual acuity). The area of interest at low ACR plotted in fig. 4 and 5 shows how the W3C 7:1 contrast ratio threshold is not sufficient to ensure legibility during outdoor/mobile use. A value of 18:1 is the suggested guideline for the minimum W3C contrast ratio, considering the maximum contrast (black on white) as the best solution in complex lighting conditions and the most resilient to flares.

6 Acknowledgements

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References

A., G. P. M. (1998, 'Forced-choice staircases with fixed step sizes: asymptotic and small-sample properties', *Vision Research* **38**(12), 1861–1881.

Baah, K. F., Green, P. and Pointer, M. (2012), 'Colour perception with changes in levels of illumination', *Color Imaging XVII: Displaying, Processing, Hardcopy, and Applications*.

Barten, P. (1999), Contrast sensitivity of the human eye and its effects on image quality, PhD thesis, IPO : Instituut voor Perceptie Onderzoek.

Baumann, K. and Thomas, B. (2001), *User interface design for electronic appliances*, Taylor & Francis.

Bostock, M. (2018), ‘Data-driven documents’. **URL:** *d3js.org/*

Buchner, A. and Baumgartner, N. (2007), ‘Text – background polarity affects performance irrespective of ambient illumination and colour contrast’, *Ergonomics* **50**(7), 1036–1063.

Chen, H., Tan, G. and Wu, S.-T. (2017), ‘Ambient contrast ratio of lcds and oled displays’, *Optics Express* **25**(26), 33643.

Displaymate (2018)**URL:** *http://www.displaymate.com/mobile.html*

Examples of Light-Aware User Interfaces (n.d.). **URL:** *msdn.microsoft.com/en-us/library/windows/desktop/dd318924(v=vs.85).aspx*

Fischer, B. and Ramsperger, E. (1984), ‘Human express saccades: extremely short reaction times of goal directed eye movements’, *Experimental Brain Research* **57**(1).

Foundation, R. P. (2018*a*), ‘Raspberry pi 3 model b’. **URL:** *www.raspberrypi.org/products/raspberry-pi-3-model-b/*

Hall, R. H. and Hanna, P. (2004), ‘The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention’, *Behaviour and Information Technology* **23**(3), 183–195.

Humar, I., Gradis ar, M. and Turk, T. (2008), ‘The impact of color combinations on the legibility of a web page text presented on crt displays’, *International Journal of Industrial Ergonomics* **38**(11-12), 885–899.

Humar, I., Gradisar, M., Turk, T. and Erjavec, J. (2014), ‘The impact of color combinations on the legibility of text presented on lcds’, *Applied Ergonomics* **45**(6), 1510–1517.

IEC (1999). **URL:** *webstore.iec.ch/publication/6169*

Katoh, N. (1995), 'Appearance Match between Soft Copy and Hard Copy under Mixed Chromatic Adaptat', *Recent Progress in Color Processing* **7**(4), 110.

Katoh, N. (1998), 'Effect of ambient light on the color appearance of softcopy images: Mixed chromatic adaptation for self-luminous displays', *Journal of Electronic Imaging* **7**(4), 794.

Lee, D.-S., Ko, Y.-H., Shen, I.-H. and Chao, C.-Y. (2011), 'Effect of light source, ambient illumination, character size and interline spacing on visual performance and visual fatigue with electronic paper displays', *Displays* **32**(1), 1–7.

Legge, G. E. and Rubin, G. S. (1986), 'Psychophysics of reading iv wavelength effects in normal and low vision', *Journal of the Optical Society of America A* **3**(1), 40.

Legge, G. E., Rubin, G. S. and Luebker, A. (1987), 'Psychophysics of reading—v. the role of contrast in normal vision', *Vision Research* **27**(7), 1165–1177.

Lin, C.-C. (2003), 'Effects of contrast ratio and text color on visual performance with tft-lcd', *International Journal of Industrial Ergonomics* **31**(2), 65–72.

Lin, C.-C. and Huang, K.-C. (2006), 'Effects of ambient illumination and screen luminance combination on character identification performance of desktop tft-lcd monitors', *International Journal of Industrial Ergonomics* **36**(3), 211–218.

Lin, C.-C. and Huang, K.-C. (2013), 'Effects of ambient illumination conditions and background color on visual performance with tft-lcd screens', *Displays* **34**(4), 276–282.

Lin, C. J., Feng, W.-Y., Chao, C.-J. and Tseng, F.-Y. (2008), 'Effects of vdt workstation lighting conditions on operator visual workload', *Industrial Health* **46**(2), 105–111.

Ltd, K. M. S. S. P. (2018), 'Cs-2000 spectroradiometer'. **URL:** *http://sensing.konicaminolta.asia/products/cs-2000-spectroradiometer/*

Michelson, A. A. (1927), *Studies in optics*, The University of Chicago Press.

Ojanpää, H. and Näsänen, R. (2003), 'Effects of luminance and colour contrast on the search of information on display devices', *Displays* **24**(4-5), 167–178.

Peirce, J. (2018), 'Psychopy'. **URL:** *http://www.psychopy.org*

Peirce, J. W. (2008), 'Generating stimuli for neuroscience using psychopy', *Frontiers in Neuroinformatics* **2**.

Pelli, D. G. and Bex, P. (2013), 'Measuring contrast sensitivity', *Vision Research* **90**, 10–14.

Pignoni, G. (2018), 'Lcd iluminant contrast analyser'. **URL:** *pignonig.github.io/ambient_contrast_analyser/*

Poppe, M. (2017), 'Function plot'. **URL:** *mauriciopoppe.github.io/function-plot/*

Rose, R. M., Teller, D. Y. and Rendleman, P. (1970), 'Statistical properties of staircase estimates', *Perception & Psychophysics* **8**(4), 199–204.

Rudd, M. E. and Popa, D. (2007), 'Stevens's brightness law, contrast gain control, and edge integration in achromatic color perception: a unified model', *J. Opt. Soc. Am. A* **24**(9), 2766–2782. **URL:** *http://josaa.osa.org/abstract.cfm?URI=josaa-24-9-2766*

Treutwein, B. (1995), 'Adaptive psychophysical procedures', *Vision Research* **35**(17), 2503–2522.

Tseng, F.-Y., Chao, C.-J., Feng, W.-Y. and Hwang, S.-L. (2010), 'Assessment of human color discrimination based on illumination color, ambient illumination and screen background color for visual display terminal workers', *Industrial Health* **48**(4), 438–446.

W3C (2008), 'Understanding techniques for wcag success criteria'. **URL:** *www.w3.org/TR/2016/NOTE-UNDERSTANDING-WCAG20-20161007/understanding-techniques.html*

W3C (2018), 'G17: Ensuring that a contrast ratio of at least 7:1 exists between text (and images of text) and background behind the text'. **URL:** *www.w3.org/TR/WCAG20-TECHS/G17.html*

Wagoner, A. (2016), 'Night mode is back and its here to stay'. **URL:** *www.androidcentral.com/night-mode-back-and-we-hope-its-here-stay*

Wales, R. and Blake, R. R. (1970),'Rule for obtaining 75% threshold with the staircase method', *Journal of the Optical Society of America* **60**(2).

Yang, S.-N. and Mcconkie, G. (2001),'Eye movements during reading: a theory of saccade initiation times', *Vision Research* **41**(25-26), 3567–3585.

Ziefle, M. (1998), 'Effects of display resolution on visual performance', *Human Factors: The Journal of the Human Factors and Ergonomics Society* **40**(4), 554–568.

Ziefle, M. (2001), 'Aging, visual performance and eyestrain in different screen technologies', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* **45**(3), 262–266.