ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
ID: TG-20170816160928

Original scientific paper

THE IMPACT OF THE TEXT AND BACKGROUND COLOR ON THE SCREEN READING EXPERIENCE

Anja ZORKO, Snježana IVANČIĆ VALENKO, Mario TOMIŠA, Damira KEČEK, Darijo ČEREPINKO

Abstract: Everyday use of modern technologies implies the need for an optimization of readability and legibility parameters used for the reading of text on screen. A lot of research on readability and legibility in printed materials and digital media has been conducted. It has been noted that the rules for the optimal readability and legibility do not apply equally to both mediums. The choice of proper typeface and font size, foreground and background colour, line spacing, sentence length, and text difficulty have the biggest role in text legibility. There is a tendency in our speaking area to read black text on a white background, which is a standard colour combination in printed materials. Furthermore, many studies have concluded that the above mentioned colour combination is one of the best when it comes to achieving optimal text readability and legibility. The purpose of this study was to test the readability and legibility of text on a computer screen by taking into consideration the different colour combinations of text and background. The factors listed above were used to define the text sample. In this research, for each of the five groups tested, the colour of the text and background were varied, while the content and other parameters of the text sample were constant.

Keywords: colour; eye tracking; legibility; readability; reading speed; text

1 INTRODUCTION

Colour has been studied for many years in many aspects, such as physics, psychology, art and graphic design. The term colour, when referred to as a physically measurable stimulus defines colour as the dominant light wavelength of the visible part of the spectrum which causes colour perception. Colour can also be defined by its abstract nature as a sensory experience that is generated by the stimulation of the visual system with specific electromagnetic radiation. [1]

The human perception of colour begins when electromagnetic radiation stimulates the cones present in the eyes. A different stimulation of red, green and blue cones generates the experience and perception of different colours. The digital, on-screen display, uses the additive colour mixing technique and RGB colour space. The RGB colour space is very much like the human colour perception; it also uses three components for colour building. In the RGB colour space, colour is defined by a red, green and blue component and each of them can be defined in the range from 0 to 255, which means in 256 different values. Colour can also be written in a hexadecimal system. The first two digits define the value of red; the next two value of green and the last two values define the blue colour component. [2]

Regardless of the aspect in which colour is studied, it is ubiquitous and indispensable in everyday life. The current lifestyle, ever-present technology and the existence of the Internet greatly affect our way of spending time. Either for work or leisure, most of that time is spent in front of a screen, computer, mobile or tablet. Therefore, for overall health perseverance, it is important to know what effect colour can have on text readability and legibility, as well as whether it affects the eye strain.

Previous research shows that specific text and background colour combinations can affect text readability and legibility. The readability of printed materials has been thoroughly examined and documented; research shows that a combination of black text on a white background (positive text) is more readable than a combination of white text on a black background (negative text). Previous research also show that a slightly coloured paper does not affect text readability, but the brightness contrast between the foreground and background colours do affect it; the greater the contrast, the better the readability. [3]

Beside the general guidelines, previous research has given specific colour combinations that are now considered optimal for readability enhancement (black text on white background and black text on yellow background) and some which are not recommended for use (as shown in Fig. 1, green text on an orange background and red text on a green background). [1] [3]

Figure 1 Best and worst foreground and background colour combinations for printed materials

2 READABILITY AND LEGIBILITY

Čerepinko [4] defines legibility as an optical and visual characteristic of character and readability as an optical and visual characteristic of blocks of text and its defining of how difficult a character is for reading. The readability of text refers to its content and represents the objective difficulty of reading which can be measured with various formulas. The ease of reading also depends on the competence and reading abilities of the reader itself.

While analysing the readability research, Dillon [5] states that the speed of reading, accuracy of reading, fatigue, understanding of the read text and personal preferences can be researched. According to Dillon, measuring the speed of reading to define text readability is one of the most common methods. It can be carried out in two ways. The first way is by defining the length of text that is going to be read and then measure the time required to read it for every subject. Other option is to limit the time of reading and measure the length of read text in a limited time. The process of reading depends on many factors of which the most significant are the content suitability of the text, age and readers' education [6]. An average reader, in a text that is suitable for his or her age and education level, fixates on 1.2 words in one gaze. For a more complex text and less known topics, a number of fixated words drops down below 1 and vice versa, while a simpler text generates a greater number of fixated words. [7]

Previous research show that the readability of a text depends on a number of factors, the appearance and size of the typeface, proper character combining, the medium on which it is printed and the method with which the text is printed. Thereby, the optimal amount of characters in a line (60 to 70 characters in printed materials and 40 for the digital screen) has been previously defined. [8] The influence of contrast on readability and legibility has also been previously researched [9]. The serif typefaces proved to be more readable for printed materials, while the sans serif fonts proved to be more readable for the technologies that display text on digital screens (tablet, personal computer) [10], and they are preferred by the majority of readers.

3 W3C CONSORTIUM AND WEB CONTENT ACCESSIBILITY GUIDELINES

The World Wide Web Consortium (W3C) guidelines are often used while preparing materials for digital devices. "W3C is international community whose mission is to define open standards to ensure the long-term growth of the Web." [11]

W3C has defined some web content accessibility guidelines (WCAG 2.0). Those guidelines contain recommendations on how to arrange web content so that it is accessible and equivalent to a greater number of users. Guidelines are separated by categories such as visibility, usability, intelligibility, robustness. That clear difference between the foreground and background colour can help improve readability, and it is mentioned under the visibility guidelines. To get a better overall content accessibility, it is recommended to have a greater colour contrast.

Minimal contrast is defined in two categories:

- Level AA - contrast ratio at least 4.5:1
- Level AAA - contrast ratio at least 7:1 [12]

The colour and brightness contrast can be used to define the colour of text and colour of the background. The brightness contrast or reflection can be defined as a ratio of the amount of light reflected from the object in contrast to the light shining on the object. [13] W3C defines brightness contrast as a difference of value between the brightness values of text according to the brightness values of the background. The values 125 and greater are defined as positive and acceptable. The colour contrast is defined as a physical value of the colour, the difference between colours in a defined colour space. According to the W3C guidelines, the difference between two colours should be 500 or more. [3][12]

4 RESEARCH METHODOLOGY

The purpose of this study was to examine the influence of different foreground and background colour combinations on the screen reading experience. At the beginning of the research, it was necessary to define the textual sample, typeface, and colour combinations. 100 students from the University North, the Multimedia, Design and Application Department were tested.

4.1 Sample definition

According to Brangan's research of readability formulas, for the purpose of this experiment, a textual sample of a difficult (LIX=46; bordering medium) reading difficulty was used. The text reading difficulty was measured by using the LIX formula (1) adjusted for the Croatian language:

$$LIX = A/B + (C \times 100)/A + 2 \quad (1)$$

where A is the number of words, B is the number of sentences and C represents the number of long words (eight or more characters). According to the LIX formula, the text reading difficulty is measured by the following scale: <24 very easy, 25-34 easy, 35-44 medium, 45-54 difficult, >55 very difficult. [14]

Sheedy et al. have been researching the typeface influence on the legibility of textual characters and words on a digital screen, and according to that research, Arial and Verdana are the most legible, and Times New Roman and Franklin the least [15]. For this reason, the typeface used for the sample in this research is a sans serif typeface Verdana, font size 27 pt, arranged in one column.

Fig. 2 shows the sample used in this research. The sample is copied from the "Grafički dizajn i komunikacija" book by the authors Tomiša and Milković, and it is a segment from the chapter about colour spaces. [16]

> Pri radu s bojama na ekranu važno je pravilno izabrati pozadinsku boju jer je to uglavnom najveća površina gdje je prisutna jedna boja. Treba uzeti u obzir kriterije poput karaktera boje, svjetline i ostalih elemenata boje. Važno je znati unaprijed koji se efekti žele postići. Pozadinska boja rijetko je jedina boja na ekranu. Obično se kombinira sa slovnim znacima, simbolima, slikama i logotipima. Takvi različiti elementi međusobno djeluju i omogućuju jedni drugima kontraste u kvaliteti i kvantiteti.

Figure 2 Textual sample used in this research

For research purposes, two best and two worst colour combinations were chosen, as defined by the previously mentioned research (Fig. 1). A black text on a white background and a black text on a yellow background were chosen as the best colour combinations, and a green text on an orange background and a red text on a green background as the worst. For the fifth test group, a black text on a cream background was chosen because that is the colour combination that imitates the colours of printed books. [3][1][17]

Since those colours have generally been defined in the CMYK colour space (research was done for printed materials), for the needs of this research, precise colour tones have been selected from the web safe colour palette. The web safe colour palette defines colours which should be used for web designated materials. The usage of safe colours should ensure that the same colour looks identical on most digital devices independent of the device characteristics and applications that are used. [1]

The enclosed Tab. 1 shows an overview of the chosen colours and their RGB and hexadecimal values.

Table 1 Overview of the chosen colour values

Colour	RGB colour code			Hexadecimal colour code
	Red	Green	Blue	
white	255	255	255	FFFFFF
cream	255	255	204	FFFFCC
yellow	255	255	0	FFFF00
orange	255	153	0	FF9900
red	255	0	0	FF0000
green	0	128	0	008000
black	0	0	0	000000

Tab. 2 shows samples used in this research, as well as the colour contrast, brightness contrast and tone difference values. Values have been calculated with an application available on the snook.ca1 website. The application uses the WCAG 2.0 formula for contrast calculations. It is possible to precisely define the wanted colours of the text and background, and the application then calculates the contrast values and verifies whether those values are acceptable considering the W3C guidelines. [12]

Table 2 Samples and their colour contrast, brightness contrast and tone difference values

Colour of text	Colour of background	Sample	Colour contrast	Brightness contrast: (>= 125)	Tone difference: (>= 500)
black	white	SAMPLE	21	255	765
black	cream	SAMPLE	20.43	249.18	714
black	yellow	SAMPLE	19.56	225.93	510
green	orange	SAMPLE	2.4	90.92	280
red	green	SAMPLE	1.28	1.11	383

After reading the sample, the reading habits on digital screens and the subjective reading difficulty were tested by using the prepared survey. The reading difficulty was evaluated by using the Likert scale from 1 to 5, where 1 defined hard to read and 5 easy to read.

4.2 Devices used in research

The textual samples used for this research were shown on a Samsung LCD screen, S22A350H model. The screen size was 21.5 inches and the aspect ratio was 16:9. The subject's distance from the screen was in the range from 50 to 80 centimetres, which is the distance suggested as the most favourable for longer viewing and reading on a digital screen. The specified distance was optimal according to the eye tracking device specifications and the monitor visual angle which was 170°/160°. [18][19]

The subject reading measuring was accompanied by the eye tracking technology which allows us to measure the point of gaze and fixation points while watching the screen. The device used was the Gazepoint GP3 Desktop eye tracking device and the accompanying Gazepoint Analaysis 3.5.0 software.

5 RESULTS AND ANALYSIS OF THE RESEARCH

The empirical analysis of this research was based on the results obtained from the measurement conducted among the students of the University North, the undergraduate interdisciplinary professional study of the "Multimedia, Design and Application" Department. The descriptive and inference statistic methods have been used in the data analysis. Students have been analysed based on gender, age and year of enrolment.

Of a total of 100 subjects, 52 were male and 48 female. On the basis of age, subjects were separated into three age groups. The first group included students younger than 21, the second included students from the age 21 to 25 and the third included students aged 26 and older. The first group was more numerous than the other two (58% of the examinees), while the third group consisted of only 7% of examinees. A bit more than half of the interviewed students were enrolled in first year (52%), while only two students were enrolled in their third year of college.

Within the inferential statistic, the distribution of the reading time data obtained by the research was examined. The distribution of the reading time data, which was tested with the Kolmogorov–Smirnov test, statistically significantly differs from the normal distribution. Therefore, for the testing of the statistically significant differences between the samples, a nonparametric Kruskal–Wallis test was used. In the cases of the statistically significant differences between the samples, multiple comparisons test was used to determine the statistically significantly different samples. The differences confirmed at $p<0.05$ were considered statistically significant. For the graphical representation of the reading time data distribution, the Box and Whisker Plots were used. The statistical analysis was performed by using the Matlab 7.0 mathematical software.

In Tab. 3 the descriptive statistics of the text reading time and the results of the Kruskal–Wallis test are shown.

Table 3 Descriptive statistics and results of the Kruskal-Wallis test for the text reading time

GROUP	Mean (s)	Median (s)	Kruskal-Wallis test	
			H	*p*
G1	31.60	32	11.53	0.02
G2	29.35	28		
G3	31.40	32		
G4	29.55	29.50		
G5	29.20	28		

As shown in Tab. 3 and Fig. 3, the shortest average reading time was determined for the group G5, 29.20 seconds. Group G1 had the longest average reading time of 31.60 seconds. The biggest mean value of 32 seconds was identified for the groups G1 and G3, while the lowest mean value was identified for the groups G2 and G5. From Tab. 3 it can be seen that there is a statistically significant difference in times of reading (p=0.02). By using the multiple comparisons test, it has been confirmed that the groups G1 and G5 are statistically significantly different.

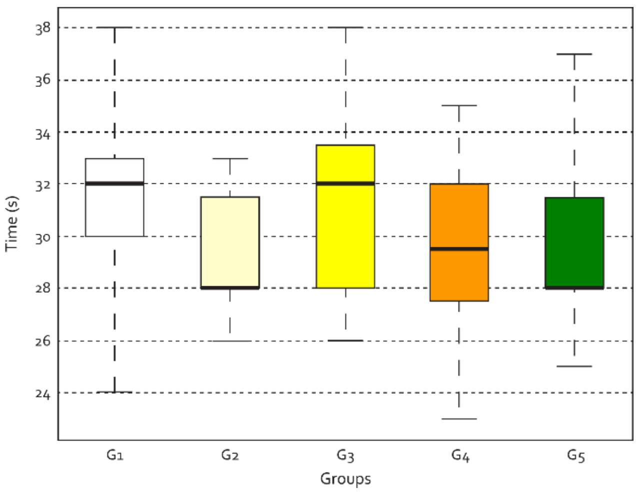

Figure 3 Time taken to read the text sample

The ratio of the number of mistakes was tested for all five groups. From a total of 100 students that were included in the research, 43 of them read the textual sample without a mistake. Group G4 had the largest percentage of students that read the sample without a mistake (55%). That percentage was just slightly lower in group 1, where 50% of the students read the text without a mistake. Group G3 was the group where the least number of students read the text without a mistake, only 30%. In 37% of the readings, there was one mistake, two mistakes in 33%, three mistakes in 12%, four in 11% and five mistakes occurred in 7% of the readings. Group G3 had the largest number of students that made one mistake during the reading (six students), and in group G4 only two students made one mistake.

Tab. 4 shows the results of the tests, the longest, shortest and average time of reading, as well as the total number of mistakes for every group of examinees. From the results shown, it can be concluded that the combination of the black text on a white background is the most readable combination of colours. The mentioned colour combination was shown to the group G1 and that group also had the least number of total mistakes.

The sample shown to the group G3 (a black text on a yellow background) stands out as the worst colour combination for text readability. Group G3 had the largest mean value of reading time (Tab. 3) and the biggest total number of mistakes (Tab. 4). Fig. 4 also shows the deviation in the heat map of the group 4 in relation to the other four.

Groups G4 and G5, which had combinations of colour defined as the worst for readability, produced unexpected results. [17] The total number of mistakes in the mentioned groups was lower (Table 4) than the total number of mistakes for the groups G2 and G3 which had the best colour combinations. Group G5 also had the shortest average time of reading.

Table 4 Results of measurement, times of reading and a total number of mistakes

	G1 black text white background	G2 black text cream background	G3 black text yellow background	G4 green text orange background	G5 red text green background
longest time of reading (s)	38	33	38	35	37
shortest time of reading (s)	24	26	26	23	25
average time of reading (s)	31.5	29.6	31.2	29.6	29.2
total number of mistakes	18	28	31	23	24

Since measurements were recorded by an eye tracking camera, the results of the research are also visible with the help of heat maps that show the points of interest for the subjects. The areas at which the subjects looked the most are coloured in warm colours and the least viewed areas are coloured in blue.

As it is visible from the examples in Fig. 4, heat maps of all five samples were similar, only the group G3 showed some deviation. The sample 3 had a black text on a yellow background. The results of the measurements show that the group G3 also had the most number of total mistakes. It can be assumed that the above mentioned colour combination is the most tiring and there is no tendency of fixation as there is on the other four maps.

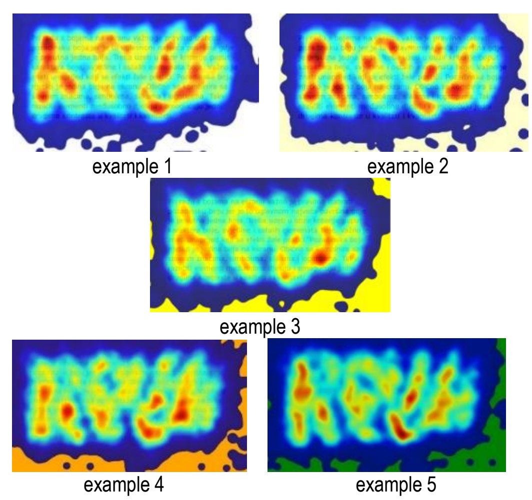

Figure 4 Overview of heat maps

6 CONCLUSION

According to previous research about the influence of colour on the readability of printed materials, it was confirmed that the combination of a black text and white background is one of the most readable and a combination of a red text on a green background is the least readable [17].

The purpose of this research was to determine the foreground and background colour influence on the readability on a digital screen. The results obtained in this research are similar to those obtained for the readability on printed materials. A black text on a white background came out as the most readable colour combination. The group that read above the mentioned sample had the least total number of mistakes, although the average time of reading was the longest, 31.5 seconds. That does not mean that the mentioned combination is not a good colour combination because the average time of reading for all groups was between 29.2 and 31.5 seconds. In a survey that was carried out just after testing, the respondents also declared that the black foreground-white background colour combination is the least stressful for the eyes.

A black text on a yellow foreground has proven to be the least readable colour combination. The results of these colour combination readings have the biggest total number of mistakes and the least percent of students (30%) read this sample without mistakes.

Unsuspected results were obtained for the fourth and fifth sample, a green text on an orange background and a red text on a green background. Even though on printed materials those combinations have proven to be the least readable, this research shows they are good for reading on a digital screen. It is interesting that the total number of mistakes was lower for those samples than for the second and third (black-cream, black-yellow) samples. It can be assumed that it is due to the fact that those samples had a lower colour contrast which can be seen in Tab. 2.

Given the fact that this is only the start of a possibly large field of research, a recommendation for future experiments would be to increase the amount of colour combinations and the number of respondents tested in order to determine if there is (and what it would be) any specific effect causing the differences between the same combinations of colours in the different media (screen and print).

Note: This research was presented at the International Conference MATRIB 2017 (29 June - 2 July 2017, Vela Luka, Croatia).

7 REFERENCES

[1] Žufić, J.; Kalpić, D.: Boja i efikasnije e-poučavanje, Metodički obzori: časopis za odgojno-obrazovnu teoriju i praksu, Vol. 4 (2009)1-2 No. 7-8 (2009) 57-72
[2] Kodner, J.; Nonaka, A.; Wilson, J.; Brajnard, D.; Ungar, L.: Determining the Readability of Colored Text, Univ. of Pennsylvania Philadelphia
[3] Tinker, M. A.: Experimental Studies on the Legibility of Print: An Annotated Bibliography, Reading Research Quarterly, Vol. 1, No. 4 (1966) 67-118
[4] Čerepinko, D.: Optimizacija grafičkih parametara korisničkoga sučelja za 'tablet novine', Doktorska disertacija, Grafički fakultet Sveučilišta u Zagrebu, 2014.
[5] Dillon, A.: Reading from paper versus screens: a critical review of the empirical literature, Ergonomics, Vol. 35, No. 10 (1992) 1297-1326
[6] Just, M. A.; Carpenter, P. A.: A theory of reading: From eye fixations to comprehension, Psychological Review, Vol. 87, No. 4 (1980) 329-355
[7] Furlan, I.: Čitanje u svjetlosti teorije informacije, Pedagogija, Vol. 4 (1963) 596-612
[8] Rabinowitz, T.: Exploring Typography, Clifton Park, NY: Thomson/Delmar Learning, 2006
[9] Legge, G.: Psychophysics of Reading, Mahwah, NJ: Lawrence Erlbaum Associates, 2006
[10] Čerepinko, D.; Keček, D.; Periša, M.: Text Readability and Legibility on iPad with comparison to Paper and Computer Screen, Tehnički vjesnik Vol. 24, No. 4 (2017) 1197-1201
[11] https://www.w3.org/ (Accessed: 4.04.2017)
[12] https://www.w3.org/TR/WCAG/#visual-audio-contrast (Accessed: 4.04.2017)
[13] York, J.: Legibility and Large-Scale Digitization, Hathi Trust Digital Library, 2008.
[14] Brangan, S.: Razvoj formula čitkosti za zdravstvenu komunikaciju na hrvatskom jeziku, doktorska disertacija, Zagreb, Medicinski fakultet Sveučilišta u Zagrebu, 2011
[15] Sheedy, J. E.; Subbaram, M. V.; Zimmerman, A. B.; Hayes, J. R.: Text legibility and the letter superiority effect, Human Factors: The Journal of the Human Factors and Ergonomics Society, Vol. 47, No. 4 (2005) 797-815
[16] Tomiša, M.; Milković, M.: Grafički dizajn i komunikacija, Veleučilište u Varaždinu, 2013., ISBN 978-953-7809-19-5
[17] Zjakić, I.; Milković, M.: Psihologija boja, Veleučilište u Varaždinu, 2010., ISBN 978-953-95000-1-4
[18] http://www.samsung.com/us/computer/monitors/LS22 A350HS/ZA-specs (Accessed: 27 April 2017.)
[19] http://narodnenovine.nn.hr/clanci/sluzbeni/2005_ 06_69_1354.html (Accessed: 6 April 2017.)

Authors' contacts:

Anja ZORKO, Teaching Assistant
Snježana IVANČIĆ VALENKO, Lecturer
Mario TOMIŠA, Ph.D, Associate Professor
Damira KEČEK, Senior Lecturer
Darijo ČEREPINKO, Ph.D, Assistant Professor

University North,
104. brigade 3, 42000 Varaždin, Croatia
anja.zorko@unin.hr,
snjezana.ivancic@unin.hr,
mario.tomisa@unin.hr
damira.kecek@unin.hr
darijo.cerepinko@unin.hr