A novel approach to study the effect of font/background color combinations on the text’s recognition efficiency on LCDs

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Abstract

With the popularization of cell phones, laptops, and tablets, Liquid Crystal Displays (LCDs) have become one of the main types of User Interface (UI) in the modern world. While LCDs are widely used for retrieving text information, the impact of text formatting on the legibility is often overlooked. With the goal of improving recognition efficiency (RE) on LCDs, this paper studies the impact of font/background colors on RE of texts being presented on LCD. For this purpose, difference between font/background color combinations, Primary Color Difference (PCD), is introduced that brings efficient RE assessment under wider spectrum. Accordingly, a testing platform is designed in C#.NET that captures participants’ response time to different font/background color combination stimuli. Based on the results, black background and green font color outperform other tested colors especially when the PCD is maximized. In correspondence to results, Implications for using research outcome in prototype LCDs are suggested.

Keywords: Human Computer Interaction, User Interface, Recognition Efficiency, displays, text color

1. Introduction

User interface (UI) is a media that handles the interactions between human and machines where the UIs are widely divided into physical and computerized interfaces [1, 2, 3]. In recent years, the use of personal electronic devices such as laptops, cell phones, and tablets have become more prevalent than ever. A study in 2010 shows that US students spend more than 20 hours per week using cellphones only for texting and calling [4]. Moreover, with the rise of technology, computers and other electronic devices have being widely used as a displaying, controlling, modifying, and monitoring terminals in many industries from healthcare to nuclear power plants the distributed
control systems. For all of the electronic devices a human-computer interface (HCI) is used as the primary user interface that act as a bridge between the machine and human. Typical HCIs can vary from simple indicator lights, buzzers, or speakers, to more complex Liquid Crystal Displays (LCDs), Light Emitting Diode (LED) displays, or any combinations between them. Among current HCIs, electronic displays such as the LCDs are the most commonly used HCI in various machines and devices being used by majority of people everyday.

While the use of electronic devices have soared in last few years, the importance of HCI readability is often overlooked. For instance, many healthcare institutes and hospitals are using electronic health record (EHR) and Electronic Medical Records (EMR) systems to store and retrieve patients’ medical history and information. EHR systems are widely adopted in recent years transitioning from paper-based documentations to a computer-based media. EHR and EMR resulted to a growing number of information being presented on LCDs in the health care operations. A proper design of the way information being displayed on LCDs (e.g., the background, font size, font type, and font color) could decrease the human errors for information retrieval and prevent fatal misjudgments. With a general goal of improving the human-computer interaction efficiency, this paper studies the relationship between the visual performance of LCDs and the text presentation legibility, to be specific, the font and background color combination.

One important indication of visual performance of certain text presented on LCDs is its Recognition Efficiency (RE). The text’s RE is further related to its readability or legibility. Readability is the reader’s ability to recognize the form of a word or a group of words for contextual purposes, while the legibility is the reader’s ability to recognize the form of single word without contextual purposes. In a common sense, the more legible words or texts are being presented, the higher their RE is.

In this paper, we examine legibility of texts for different sets of font and background colors with series of non-meaningful and randomly composed three-letter word stimuli for eliminating the learning effect of the participants. Unlike previous studies that only experimented a limited number of font and background color, in order to assess a wider range of font and background color combinations, Primary Color Difference (PCD) is utilized. Using PCD, we are able to generalize our results while preserving our design of experiment framework relatively feasible.
The rest of the paper is organized as follows: In section 2, a review of literature regarding recognition efficiency, color definitions in LCDs, and font/background color assessments for both reflectors and luminophor materials are provided. In section 3, the primary color difference method and the underlying hypotheses of the research are further explained. Experimental design steps, preparation, setup, and protocols are discussed in section 4, followed by descriptive and statistical data analysis using analysis of variance and response surface method. In section 6, discussion of the research highlights, insights, and primary outcomes are further explored. Finally, the conclusion remarks and recommendations for future research are summarized in Section 7.

2. Background

2.1 Text Recognition Efficiency

The texts’ RE has been confirmed to be influenced by factors such as luminance, font size, font style, interletter spacing, letter case, and text layout by previous researches[12, 13, 14, 15, 16, 17]. For example, luminance was found to have major effects on the RE [18, 19, 20]. Researchers such as Lin [21] not only found that the combination of luminance and contrast ratio had a significant effect on RE, but also pointed out the two factors might have some correlations that merit further study. The font type is another factor that may influence the RE, and for different types of languages the influences may be different. Researchers studied on English characters [22, 23] found that there was no significant effect of commonly used font types on RE while researches on Chinese characters indicated that significant effect was found between these two factors [24, 25, 26, 27, 28]. Besides, the combination of font size and font type may also influence the RE [29]. Furthermore, Ling and van Schaik [30, 31] found that the way in which the text is presented on webpages (i.e. font type and line length) have a significant impact on the RE of the text. They later found that the line spacing and text alignment for text presented on webpages have a significant influence on the text’s RE[32].

Besides of the above-mentioned factors, one feature that can impact the RE but often overlooked in previous research is the colors in the displays (both font color and background color). Yussof, Abas [33] drew a conclusion that the background color gives affection to RE of
texts on e-books. This conclusion was also supported by Bonnardel, Piolat [34] research on the website design. Zhao el. al.[35] found that the yellow-highlighted background is superior to the non-highlighted background while text on computer screen is being magnified and presented to readers. They indicated that yellow could be a reasonable choice of background color for a magnifier when the text is black. Some researchers also pointed out that inappropriate use of color could result in poor performance and a higher incidence of visual discomfort [36].

2.1 The influence of colors on the RE

Before looking further into the effect of colors on the RE, it is necessary to clarify the definition of colors in this research. A useful way to define colors is using the widely accepted concept of “primary color”, which defines any observable color by the combination of the three primary colors. Note that the primary colors are primarily defined based on the physical properties of the material and there are different primary color sets for reflector materials (such as papers) and luminophore materials (such as LCDs as examined in this paper). For colors on reflectors, the three main colors are “Red, Yellow and Green” while for colors on luminophore the three main colors are “Red, Green and Blue”, or RGB. Because our target is LCD, a typical kind of luminophore, we use RGB as our color definition scale plate.

In order to produce full color spectrum in LCDs, each of main colors in RGB can get 256 different values (indicated by consecutive integers from 0 to 255). Therefore, colors on LCDs can be defined by its three RGB values, respectively. For instance, pure black can be defined as Red=0, Green=0, Blue=0 or (RGB=0, 0, 0); Pure white can be defined as Red=255, Green=255, Blue=255 or (RGB=255, 255, 255). The black and the white are the two extreme cases of colors. Other colors’ RGB values fall between 0 and 255. For example, the sky blue can be defined as (RGB=0, 155, 255).

If we are able to make a general rank about the virtual performance of font/background color combinations, our goal to compare the RE under different font/color combinations would be realized. In other word, we should get a complete ranking of the RE for all the possible color combinations. However, the number of colors defined by RGB could be more than 16 million (256×256×256), let along the combination between any two of them (more than 200 trillion
combinations). Thus it is necessary to find a more efficient way to check RE of colors rather than enumerate all the possibilities. Unlike previous studies in the effect of font/background color combinations literature that simply hand pick several color combinations, this research introduce a framework that is more generalized by checking more color combinations with less experiments.

2.2 The impact of Font/Background color on RE

Previous studies have conducted many research to study the relationship between the text’s RE and the font/background color combinations [6, 30, 37, 38, 40, 41, 42]. The first known experiments to study the font/background color combinations was conducted in 1912 by Le Courier [43]. The author performed an experiment in which letters were printed on paper posters under different font/background color combinations. Each poster contained two rows of letters. All posters were exposed to sunlight and participants were asked to rank the legibility of the letters. The ranking of 13 font/background color combinations was then listed in a table, which is known as Le Courier legibility table as shown in Table 1. Based on Le Courier Table, the higher the legibility was ranked, the better texts’ RE would be. It was determined that the most legible color combination was black letters on yellow background [43] [Le Courrier, 1912]. But further research was needed given the original ranking and lack of detail about the experiment [38]. Later on between 1928 and 1963, Tinker and Paterson [44, 45, 46] carried out similar studies of legibility and readability on reflectors surfaces. Authors studied the legibility of text under 10 font/background color combinations and discovered a different legibility ranking, compared with Le Courier’s table (Table 1). Yet, this discrepancy is not surprising. Even today, researchers can hardly come to an agreement about which color combination is statistically better than others under different experimental conditions.

A very important shortcoming of previous studies is that because luminophore’s physical properties are different from reflectors (such as papers), conclusions from previous studies can hardly be directly extended into the context of luminophore such as LCDs. For instance, some researchers reported that the visual performance was slower with electronic display compared to paper material [47, 48]. Also, they pointed out that electronic displays might lead to visual fatigue and strain more quickly and frequently [49]. In 2008, Humar et al. [6] performed an experiment
similar to Le Courier’s but on CRT screens rather than on paper posters with the purpose examining the visual performance of webpages [6]. They examined font/background color combinations set similar to Le Couriers, and discovered a new ranking for CRT screens, as listed in Table 2. Although earlier researchers failed to identify specific color combination that performs a better readability on electronic displays, they revealed that the font/background color combination is an important factor that affects RE [50, 51].

| Font Color | BK | G | R | B | W | BK | Y | W | W | R | G | R |
|------------|----|---|---|---|---|----|---|---|---|---|---|---|
| Background Color | Y | W | W | W | B | W | BK | R | G | BK | Y | R | G |
| Le Courier Ranking | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Humar Ranking | 7 | 5 | 1 | 10 | 6 | 4 | 11 | 8 | 3 | 13 | 2 | 9 | 12 |

Note: “R”= Red, “G”= Green, “B”= Blue, “BK”= Black, “W”=White, and “Y”=Yellow.

Finally, the methods used by previous researchers can be classified into three main categories with respect to measurement of the participant’s visual performance [6] [Humar et al., 2008]. The first method is called visual search tasks [20, 51, 52]. One example of this method is asking participants to either identify misspelled words or find special words from non-meaningful paragraphs. The second method is to measure the recognition time for certain stimuli (characters, words or sentences) [18, 29, 42, 53]. The third method is to measure participant’s accuracy in words recognition tasks. The stimuli were shown to the participants either for a very short time or in a relatively small font size and the participants were asked to identify as many as possible stimulus during the task [41, 54, 55]. The first and third methods, namely visual search tasks and word recognition have similar realizations with the fact that the participant memory retention, previous experience, and instantaneous concentration have important impact on the results. As a result, in this study, we have adopted to use the second method by measuring the recognition time for each stimulus, striving the decrease participants’ characteristics impacts and reducing the risks of skewed results, which will be elaborated in the following parts. Our general goal is to find a more efficient way to examine the effect of the font/background color combinations on the RE and to
tell from statistical perspective which color combination is better than the other.

3. Methods

3.1 The Primary Color Difference

As we mentioned earlier in Section 2.1, colors on luminophore materials can be defined by the three primary colors of Red, Green, and Blue (RGB) with each ranging from 0 to 255. Given any two colors, we could further define their Primary Color Difference (PCD) as the absolute difference between each of their three primary colors respectively: namely the ΔRed (ΔR), the ΔGreen (ΔG) and the ΔBlue (ΔB) (Δ represent absolute difference). Correspondingly, the value of the ΔR, the ΔG or the ΔB for any two given colors will remain between 0 and 255.

As a result, we could adopt the concept of the PCD to define the font/background color difference. For example, the orange color font (RGB=255, 100, 0) on pure white background (RGB=255, 255, 255) can be defined as ΔR=0 (255–255), ΔG=155 (|100–255|) and ΔB=255 (|0–255|), or (ΔRGB=0, 155, 255). But the reverse is not necessarily true. A PCD of (ΔRGB=0, 155, 255) could represent the color combination of any pair of colors with the same primary color difference. For instance, the PCD of the sky blue font (RGB=0, 155, 255) on pure black background (RGB=0, 0, 0) is also (ΔRGB=0, 155, 255).

3.2 Study hypotheses

In this paper, we study the font/background color by focusing only on their PCD values regardless of what color combination it may represent for. One of our hypotheses is that although certain PCD value can stand for many font/background color combinations, these combinations that share a same PCD value may have certain color properties in common and results in the similar RE. If this hypothesis is proved true, we could realize one of our goals to find a more efficient method to study colors rather than enumeration.

As we could tell from previous studies, text’s visual performance, or the RE, under different font/background color combinations is different from one to another. For instance, pure black
text on pure white background is easier to read for majority of people than yellow text on white background [56]. Thus, another hypothesis is that there must be some relationship between the PCD value and the RE.

3.3 Measurement of the RE

In this research, a design of experiment framework is used to measure participants’ RE to certain stimuli under different font/background color combinations. Participants were requested to respond to the font stimulus shown on the screen as fast as they can. Similar to previous studies, we define the RE by participants’ average Response Time (RT) to the target stimuli.

However, interpreting RE using RT can come with discrepancies. Since RE is a “subjective” concept, it is extremely hard to establish one-to-one correspondence between each REs and their RTs. One possible reason for this discrepancy is that human ability to mentally processing the environmental stimulus is different from one to another. Furthermore, the attitude of different individuals is also different and no evidence show that such a bias has no effect on RE. For example, individuals who show a greater preference to green color may have a quicker response to greens. To better address this problem, we use random sampling in selecting the participants in terms of their gender, ethnics and backgrounds, and tested each stimulus several times to reduce noises on the RT.

Moreover, people’s RE for certain stimulus may change with time and their living environment. One possible explanation is that people's mental and physical status will change with time. Besides of these subjective factors, environmental factors such as light, temperature and noise may also have significant effect on people’s RE to certain stimuli. Accordingly, in this study, all environmental factors are fixed for all participants to achieve results focused on font/background color effects on RE and RT.

Another major difficulty of this type of researches is measuring RT accurately. The average RT in our experiments were less than a second for the given stimuli. Besides, it was hard to accurately determine when or whether a participant recognizes the stimulus. Recognition is a mental process and it's hard to be observed or recognized.
In order to overcome major shortcomings of previous researches while addressing all difficulties in capturing RTs, we wrote a computer program in C#. Net to assist the experiment in order to record RT with high accuracy and stability. The computer program enabled us to control variables easily. More details about the program will be explained in Section 4.2.

4. Data Collection and Experimental Design

4.1 Participants

The invitations for participating in LCD recognition efficiency experiment were distributed among graduate students of Northeastern University, Boston, USA. The only requirement for participating in the experiment was having normal vision or corrected to normal vision. Among students that were interested in participating in the experiment, 11 qualified invitees are selected randomly. Participants were asked to sign the consent form prior to the experiments providing information about their age, ethnicity, and eyesight vision. All participants were students at the time of experiment with the average of 25 years old. 54% of participants were male and 45% of participants were female. Participants had different ethnicities and were from countries such as China, USA, Iran, Saudi Arabia, France, and Mexico.

4.2 Testing Platform

In order to record subjects’ RT to stimuli accurately, a computer program is written in Microsoft Visual Studio C# platform, providing a structural procedure to measure RT. The program enable us to control variables by changing the text's font/background color regarding to its RGB values. A graphical user interface is designed to help participants getting familiar with the stimuli and main experiment. Figure 1 shows the interface of the program.

As shown in Figure 1, Nine (9) stimuli each consist of three letters are mapped to a numeric keypad as the target text. To minimize the learning effect of participants by predicting the stimulus without reading it completely, these nine stimuli share some similar characters such as same starting or ending character. ATS is mapped to 1, OTR represent number 2 in the keypad, OPS is mapped
to number 3 and so forth, as shown in Figure 1. During the experiment, these stimuli will be randomly and individually being presented to participants in certain font/background colors. The testing program was also tested to verify its user friendliness. A systematic approach to collect the data (in terms of RT) was approved.

**Figure 1** The interface of constructed stimuli for capturing participant response time

4.3 Testing Procedures

The application is programmed in a way that during each run of the test, only one font/background color combination is shown to the participant. The program will run to show participants one of the nine stimuli under the assigned font/background color combination and collect the participants RT to these stimuli. We replicated the testing procedure several times to achieve accurate results for each font/background color combination.

The testing process is shown in Figure 2 as an example of font/background color combination as green/black. First, a crosshair cue appears in the center of the screen for 200
milliseconds to indicate the position that stimulus will appear. Then, a randomly selected stimulus of green appears at the same position 200 milliseconds after the crosshair hide. In each experiment, a participant will be asked to press the space button on the keyboard as soon as recognizing the stimuli. Once the participant pressed the space button, the stimulus text disappears, living only the background. The time interval from the stimulus appear on display to the participant press space button, is recorded as the response time (RT). After the participant pressed the space button, the program waits until participant enter the stimulus mapped number to check recognition correctness. For example, if the participant recognized the “RAP” stimulus, he/she should press the mapped number button “7” in the keyboard; if the participant recognized the “ROT”, he/she should press the number button “8”, and so forth.

The testing procedure will be repeated with a different font and background color and a new randomly selected stimulus, until enough data being collected. It has been asked from participants to avoid guessing the stimulus. However, if a participant responds to more than 5% of stimuli wrong, the collected data in this run will be discarded and the participant will be given a 10 minutes break. Stimulus words combinations were selected in a way that participants could not easily guess the stimulus word unless he or she recognizes all its three letters. For instance, two of the nine stimuli start with letter “R”, two of them start with letter “S”; two of the nine stimuli end with letter “P”, two of them end with letter “T”.
Figure 2 Experiment process using the designed computer program. The black squares represent the LCD display at each stage of the experiment.

4.4 Experiment setup and protocols

Prior to performing any experimental design, careful considerations of factors that might affect test results are inevitable[57]. Environmental conditions, experiment conditions, and instruments
 accurateness are examples of conditions and factors that should be controlled.

Environmental factors such as light intensity and audible noise were stabilized during the experiments by controlling the laboratory conditions. The experiment instruments, screen size, screen type, screen resolution, computer hardware specifications, keyboard type, chair and table type, and height kept similar for all participants.

In order to select LCD displays’ type and specifications, most prevalent displays’ settings were considered. LCD displays with 1920×1080 resolution and screen refresh rate of 60Hz, diagonal viewing Size of 24 inches with preset display area (H×V): 20.9×11.7 square inches were used during the experiments.

The laboratory conditions such as distance of participants to the display, display’s angle, position of display, and keyboard were consistently controlled. In order to verify the relative position between participants and the display, all participants were required to sit straight comfortably on an adjustable rotary chair in front of the display. The subjects were also required to adjust the display and the chair properly that make sure their sight lines are as perpendicular to the center of the display plane as possible. The ergonomic designs suggest 50 to 70 centimeters distance between eyes and screen and 10 to 20 centimeters lower than user eyesight. Participants were given the chance to get familiar with the testing software and the procedure before the test.

4.5 Experimental design

The study was conducted with the principals of Design of Experiments (DOE) as a fractional factorial design, shown in Table 2. As previously described, there are two main factors, background and font colors. The first factor is “background color” with 2 levels that are the white (RGB=255, 255, 255) and the black color (RGB=0, 0, 0). The second factor is “font color” with 9 levels defined by the primary color difference (PCD) that are: three ∆Rs (∆R=250, ∆R=180, ∆R=110); three ∆Gs (∆G=250, ∆G=180, ∆G=110); and three ∆Bs (∆B=250, ∆B=180, ∆B=110). For each combination of background and font color, the test was repeated 10 times. That means each participants were asked to perform 18 experiments (2×9) with 10 replications each (18×10=180 experiments in total). Each test takes between 5 to 10 seconds and the whole testing per each participant (180 experiments) takes between 20 to 40 minutes. After each 60 experiments,
participants were asked for a 10 minute break before proceeding to the next wave of experiments.

In order to decrease the impact of participant's fatigue on the results, the sequence of stimuli that is tested for each participant is not the same. For instance, while participant 1 may have been tested black background and $\Delta R=110$ (test#1) in his first experiment, participant 2 may have this test as his 50th experiment. Moreover, Instead of repeating each font/background color 10 times consecutively, the test is repeated randomly. For instance the black background and $\Delta R=110$ (test#1) for participant 1 is tested as his 1st, 15th, 45th, 87th, 90th, 128th, 151th, 169th, 177th, and 178th experiment. Therefore, the fatigue impact is distributed evenly among all stimuli.

Table 2 Design of experiment tests. Combination of font and background color resulted 18 tests. Each test is repeated 10 times by each individual.

| test # | Background color | Font color | $\Delta$Red | $\Delta$Green | $\Delta$Blue |
|--------|------------------|------------|-------------|--------------|-------------|
|        | Black            | White      | 110         | 180          | 250         |
| 1      | 1                | 0          | 1           | 0            | 0           |
| 2      | 1                | 0          | 0           | 1            | 0           |
| 3      | 1                | 0          | 0           | 0            | 1           |
| 4      | 1                | 0          | 0           | 0            | 1           |
| 5      | 1                | 0          | 0           | 0            | 1           |
| 6      | 1                | 0          | 0           | 0            | 1           |
| 7      | 1                | 0          | 0           | 0            | 1           |
| 8      | 1                | 0          | 0           | 0            | 1           |
| 9      | 1                | 0          | 0           | 0            | 1           |
| 10     | 0                | 1          | 1           | 0            | 0           |
| 11     | 0                | 1          | 1           | 0            | 0           |
| 12     | 0                | 1          | 0           | 1            | 0           |
| 13     | 0                | 1          | 0           | 0            | 1           |
| 14     | 0                | 1          | 0           | 0            | 1           |
| 15     | 0                | 1          | 0           | 0            | 1           |
| 16     | 0                | 1          | 0           | 0            | 1           |
| 17     | 0                | 1          | 0           | 0            | 1           |
| 18     | 0                | 1          | 0           | 0            | 1           |

According to Fisher et al. [58], any experiments conducted under statistical Design of Experiments (DoE) framework have to follow three principals (i.e. randomization, replication, and blocking) in order to achieve a reasonable and valid finding [58, 59]. Randomization is the process
of assigning individuals randomly to one or group of experiments. In our experiments the order of allocating font/background color was randomized. A proper randomization approach helps “averaging-out” impacts of extraneous factors that might present. Replication decrease impacts of variability by repeating each factor combination independently. It also helps obtaining an approximation of experimental error. For this purpose, the experiment for each font/background combination was repeated 10 times although the actual text stimuli were different during the replication process. Finally, blocking, a design technique that arranges experimental units into a group to improve comparison precision and eliminate known variation, was implemented. We used blocking to group results by participants. Since participants may have faster/slower reactions to the same stimuli in comparison to others, by grouping each participant, a set of relatively homogenous experimental conditions were compared.

5. Data Analysis

By the time that all participants completed the experiments, 1980 response time dataset corresponding to fractional factorial design are collected. In order to analyze the dataset, descriptive analysis, Factorial Analyses of Variances (ANOVA), and Response Surface Methods (RSM) are conducted to compare response time to each combination of font/background color.

All analysis was performed with Minitab 15 and R-Studio. ANOVA results revealed that not only the main factors (i.e. font and background color) have significant effects on text's legibility, interactions between factors do too.

5.1 Descriptive Analysis

The average response time and the standard deviation for each experiment is provided in Table 3, based on the test numbers (Test#) in Table 2. There are significant differences between the results of different experiments. For instance, test # 1 which represent black background and ∆Red equals to 110, has the mean response time of 332.51 milliseconds and standard deviation of 72.45, while the response time for test# 16 (white background with ∆blue=110) is 984.44 milliseconds and standard deviation of 64.40.
### Table 3
Mean response time and Standard deviation (in milliseconds) for each test case.

| Test # | Mean response time (milliseconds) | Standard deviation of response time |
|--------|-----------------------------------|------------------------------------|
| 1      | 332.51                            | 72.45                              |
| 2      | 313.51                            | 95.31                              |
| 3      | 254.36                            | 83.99                              |
| 4      | 288.13                            | 83.42                              |
| 5      | 256.05                            | 84.20                              |
| 6      | 219.127                           | 82.23                              |
| 7      | 814.61                            | 229.67                             |
| 8      | 532.18                            | 206.22                             |
| 9      | 414.21                            | 124.30                             |
| 10     | 525.74                            | 218.37                             |
| 11     | 407.08                            | 128.97                             |
| 12     | 367.80                            | 106.32                             |
| 13     | 282.59                            | 79.35                              |
| 14     | 255.60                            | 68.03                              |
| 15     | 210.28                            | 93.88                              |
| 16     | 984.44                            | 64.40                              |
| 17     | 958.74                            | 100.85                             |
| 18     | 866.845                           | 199.44                             |

In order to get more in depth analysis from the experiments dataset, box-plot analysis for each color is provided in Figure 3. Each color is grouped based on the $\Delta$ values into 250, 180, and 100. According to the figures, the green font color outperforms red and blue, both in terms of median response times and inter-quartile range. The blue font color, as oppose to the green, has a high response time and the difference between values of $\Delta$ ($\Delta=250$, $\Delta=180$, $\Delta=110$) is remarkably more than the red and the green.

**Figure 3** Box-plot analysis of font color response time in milliseconds. The response times are grouped...
Similar analysis has performed on the background colors (black and white), as shown in Figure 4, providing histogram and box plot, accordingly. Based on the results, majority of response times for black background falls between 200 to 400 milliseconds with few responds higher than 1 second. In contrary, the white background has a smoother distribution and most of the response times is between 100 to 500 milliseconds, but number of responds that take 1 second or more, is notably higher than black background.
Figure 4 Box-plot and histogram analysis of background color response time in milliseconds.

While the analysis provide useful insights about the performance of font and background colors, the interaction effects between different combination of font and background colors are not emphasized. For this purpose, in Section 5.2, ANOVA results pertaining to interactions between the factors of the design of experiment is provided.

5.2 Statistical analysis for main factors

Font/background colors as the main factors of our factorial design framework were compared by Factorial Analyses of Variances (ANOVA). There was a significant difference between two background colors (ANOVA, F= 911.55, p = 0.00) as well as between different font colors (ANOVA, F= 3385.06, p = 0.00).

In addition to main factors, $\Delta$ values were compared. Through grouping font colors by their $\Delta$ values (i.e. $\Delta=250$, $\Delta=180$, $\Delta=110$) rather than $\Delta$Rs, $\Delta$Gs, and $\Delta$Bs we were able to further express impacts of $\Delta$ values on the legibility. Results show that there was a significant difference between $\Delta$ values (ANOVA, F= 263.50, p = 0.00), though F-value was comparatively lower. However, the corresponding R-Sq was high (R-Sq = 83.28%) to assure the data was fitted well to ANOVA statistical model.
Figure 5 depicts mean response time (in milliseconds) for each factor. Green had least response time followed by red and blue. Also response time to black background color was less than white.

**Figure 5** Mean response time (in milliseconds) for each font color, background color, and the difference ($\Delta$)

5.3 Statistical analysis of interactions between factors

It has been confirmed that the interactions between the factors of an experiment make response value (here RT) among levels of different factors to be different [58, 59]. In other words, interaction is the failure of one factor to generate same impacts on the response value at different levels of another factor.

Hence, we analyzed all possible interactions of factors to interpret significant changes in response time. Figure 6 illustrates all possible interactions among levels of font and background colors.
colors, and Δ considering its values as an independent factor. The interaction plot between background and font color is shown at the top right. At the experiments that the font color was green, the response time was similar regardless of background color, but when the font color was Blue or red, the interaction between factors led to different response time when levels of one factor changed. The interactions between Δ values and font colors are shown in middle right. In all delta values, green font color had least response time following by red and blue respectively. Δ values and font colors had not significant interaction and the previous trend were remained unchanged. Also, there was not a significant interaction between background color and Δ values on response time as shown in middle top of the Figure 6.

Figure 6 Pairwise Interactions impacts between font color, background color, and Δ on Response time (in milliseconds).

5.4 Response Surface Methodology

While the design of experiment results provide useful insights about the impact of
font/background color on RT and how the interaction between these colors can affect the recognition efficiency, it is only limited to the colors provided. In order to generalize the results, a method that furnish the continuous color spectrum rather than given discrete points (i.e. 110, 180, 250) were required. Response Surface Methodology (RSM) provides deeper explorations among associated control variables to one or more response of interest. In general, RSM includes a group of statistical and mathematical techniques used in building an unknown functional relationship between response variables and a number of input variables. Fitting response curve to the levels of a factor can be beneficial to interpret that relationship, predict response value with different combinations of design factors, and determine the optimum setting of variables to minimize (or maximize) response value.

Figure 7 shows how changing font colors and Δ values concurrently, might affect response time for each background. Note that minimum response time achieved when font color is between green and red. When the font color is blue, by increasing Δ value, the response time can be decreased consistently while in black background, but Δ values does not impact the recognition efficiency of blue in white background. While in the black background, the best response time area achieved by Δ values above 235, the best response time in white background corresponds to Δ values between 220 to 250 intervals. Additionally, the black background provides a more consistent platform where for the majority of font and Δ combinations, the response time is lower than 300 milliseconds. On the contrary, the white background recognition efficiency is more sensitive to the font and Δ combinations, resulting higher response time with small modifications to the combination of font and Δ.

This is a good expansion of our results since Δ values as well as font colors can be inferred as continuous variables.

Figure 7 Response Time contour plots for each background color based on Δ and font colors. Font colors codes are 1= Green, 2= red, 3=Blue.
6. Discussions

Results has proven that the background/font color combination has a significant effect on the RE. Based on the results, black background outperforms the white background in terms of the RE. Moreover, when maximizing the $\Delta G$ value the RE could be greatly increased, but in the similar level the impact of $\Delta R$ is relatively small, with inverse impact of $\Delta B$ while at the same level. Thus the effect of PCD on the RE can be shown as “$\Delta G>\Delta R>\Delta B$”. Moreover, font/background color combinations with a higher PCD value of either $\Delta G$, $\Delta R$ or $\Delta B$ shows a better performance of the RE compared with those color combinations with a less PCD value. According to the provided statistical analysis, the font color, background color, and PCD values, as well as the interactions between these factors have significant effect on the Recognition Time (RT).

Some of the research outcomes can be intuitively shown in Figure 8 (in example text “Hello”).
In this example graph, each row indicates a certain PCD value (ΔR, ΔG and ΔB of either Δ=250, 180 or 110). The left half of the graph is on black background and the right half is on white background. According to our conclusions, the text “Hello” on black background is generally more distinguishable than that on white. Besides, in general, texts with its ΔG maximized are more distinguishable than those with ΔR maximized or those with ΔB maximized. For each of the three PCD groups in the graph, the texts on the first row are more distinguishable than the texts on the following rows while the upper group (ΔG) shows a more clear of such trend (ΔG>ΔR>ΔB). Font with the ΔG maximized with Δ=250 is most distinguishable while font with the ΔB maximized with Δ=110 is least distinguishable. These subjective intuitions is in accordance with our statistical results.

**Figure 8** An illustration to primary color difference of font/background colors with two backgrounds (black and white) and three levels of difference (250, 180, 110), in the green, red, and blue respectively. For instance when (ΔG=250), the PCD provide a green color on black screen and purple color in white screen.

One inference from the conclusion is that the RE of the text on certain background colors can be maximized when increasing both the ΔG and the ΔR simultaneously but further research is required that confirms this hypothesis with more color combinations.
7. Conclusions and Future Research

In this study, the effect of font/background color combination on the Recognition Efficiency (RE) is examined. One of the contributions of this study is using a new concept of Primary Color Difference (PCD) between the two colors in studying the virtual performance of the user interface. Unlike prior studies such as Humar [6] and Zhao et al.[35] that verifies the legibility of limited colors, we examined a wider color combination spectrum using PCD. Most importantly, this study offers a realizable way to maximizing the RE for any given color combination.

After reviewing the pertaining literature, we conducted the experiments with a reduced full factorial design with 2 factors: background colors with 2 levels (White and Black), and font colors with 9 PCD values between a given background color and the font colors ($\Delta R=250/180/110$, $\Delta G=250/180/110$, $\Delta B=250/180/110$). Results has proven that the background/font color combination has a significant effect on the RE. The results of this study can be easily extended to prior research. For instance, Zhao et al.[35] indicated that yellow could be a reasonable choice of background color when the font color is black font for a text on computer screen being magnified and presented to the readers. The yellow color code is (255, 255, 0) and the black color code is (0, 0, 0). Therefore, the PCD is (255, 255, 0). Our results shows that in order to increase recognition efficiency, “$\Delta G>\Delta R>\Delta B$” should be maximized, which is in accordance with the yellow background and black font color ($\Delta G=255$, $\Delta R=255$, $\Delta B=0$).

Similar to any human factor studies, this study comes with some limitations. First, all of the participants were students between age of 19-28 years old and the number of participants were limited due to the timeframe of the project. In order to overcome this limitation, each participants performed every test for 10 times, but more participants with broader range of age is sought for further research, ensuring the consistency of results. Recent studies show that reading performance and pointing movements in touchscreens for elderly people achieved lower comprehension in comparison with young people [60, 61, 62]. Rather than static text, with the rise of online courses and electronic educations, a high number of videos that contain texts have been used in recent years. The text legibility, while considering font and background colors can also address with the future research [15].
Moreover, in this study the value of $\Delta R$, $\Delta G$, and $\Delta B$ are examined individually without considering the consequences that two or three of the PCD values change concurrently. Future research can address changing the value of green, red, and blue simultaneously and provide new understandings of font/background color combinations. Along with font/background color combination, other color properties such as saturation, tone, intensity, and hue may impact the recognition efficiency that providing a general framework to assess the importance of all font properties, would be beneficial.

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