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AicQoL2023Bangkok

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11th AMER International Conference on Quality of Life
Al Meroz Hotel, Bangkok, Thailand 28-30 Apr 2023

Effect of Contrast Polarity towards Eye Fixation Rates when Reading on Smartphone

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Abstract
This study is conducted to investigate the effect of contrast polarity towards eye fixation patterns when reading text on a smartphone in bright and dark conditions involving the effects when reading on a smartphone such as in real-life situations. The number of fixations and duration of fixation showed no statistically significant difference (p=0.160 and 0.099 respectively). However, emmetropic subjects showed a higher result in bright conditions compared to myopic subjects (p=0.046). This concludes that emmetropic eye movement efficiency seems superior, possibly due to lower spherical order aberration as pupil size decreases in bright illumination.

Keywords: Contrast Polarity; Fixation Rates; Eye Tracking; Light conditions

DOI: https://doi.org/10.21834/ebpj.v8i24.4680

1.0 Introduction

The mechanism of eye movement enables a person to conduct daily activities by gathering information from various types of environments. When performing activities, eyes move in a series of saccade and fixation (Turano et al., 2003). According to Turano et al., (2003), a saccade can be defined as a rapid eye movement which redirects the objects onto the fovea which is the greatest visual resolution, while fixation means the pause between the saccade that enables the visual system to process an image. However, other researchers also stated that there is no one simple definition for fixation as some definitions are formulated as a combination of the properties such as fixation number, fixation duration, and amount of small movements (Hessels, Niehorsters & Hooge, 2018).

The introduction of advanced eye tracking technology today has allowed easy analysis of eye movement patterns that provides better data quality and higher data validity. Besides, the widespread use of smartphones in a variety of tasks has increased awareness to study the performance of eye movement when reading using a smartphone. Nowadays, eye movement patterns when reading on a smartphone using different contrast polarity in both bright and dark illumination have been widely studied. Lin et al., (2015), relates the positive and negative contrast polarity with pupil size and glare and aberrations that affect eye movement pattern. She then proves that reading in bright illumination using positive contrast polarity caused lower fixation duration and lower fixation number as the speed of the eye movement is increasing. Some researchers also compare the findings between myope and emmetrope and found out that myope has a higher fixation number and fixation duration compared to emmetrope (Buehren, Collins & Carney, 2005). However, the

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measurement of the eye movement pattern in their studies was done using controlled viewing conditions, hence do not rule out the effects when reading on smartphone such as in real-life situations. Since the prevalence of social media usage with different contrast polarity in smartphones is increasing nowadays, this study aims to investigate the effect of different contrast polarity on Twitter towards eye movement patterns among myope and emmetrope populations, in both bright and dark illumination.

2.0 Literature Review

2.1 Eye Movement in General

The roles of eye movements are to move the gaze to the places where information is needed to perform a task. The eyes usually reached the next object first before any action starts, which indicates that eye movements are planned into the motor pattern and lead to each action. The vision and action do not occur simultaneously as concluded by Land et al., (1999) in their study which is the eyes seek the target first, before starting an action. Besides that, it was also concluded that the time relations between fixating and manipulating an action are quite tight with vision leading action by about half a second.

The oculomotor system must get the new instructions ahead of the arms and hand motor systems. During or before the end of the previous action, the central executive in the front part of the brain will supply the oculomotor system and the motor system of the arms, together with information regarding the object's identity or location, the action to be performed, and the checking action required. During the process, the eyes will first identify the object's location either by the combination of the object's memory or direct vision. The eyes will then be directed towards the object before any contact. Once the object is located, an action will be initiated.

Previous studies have shown that when a person does an activity, the eyes move in a consistent pattern of fixation and saccade (Land, 2006). Pan & Gay (2004) define fixation as a motionless gaze which lasts about 200-300 milliseconds (ms), in which visual attention is aimed at a specific area of a visual display. Meanwhile, according to Tullis & Albert et al., (2013), fixation duration is the average time for fixations. Fixation duration typically ranges from 150 to 300 msec. The greater the average fixation duration, the greater the level of engagement.

2.2 Eye Movement in Different Contrast Polarity on Visual Display Unit (VDU)

The increasing demand for electronic devices such as smartphone usage has been a worldwide phenomenon and becoming part of integral to our daily lives. In 2016, there were more than seven billion cellular subscription users worldwide. Besides, the percentage of internet users also increased globally 7-fold from 6.5% to 43% between 2000 and 2015 (Byatt, 2001). According to Survey & Survey (2018), the estimated prevalence of social networking users in Malaysia in 2018 is 24.6 million, with 97.3% of Facebook users as the highest prevalence recorded in their survey. This is followed by Instagram account (57.0%) and YouTube (48.3%), Google+ (31.3%), Twitter (23.8%) and LinkedIn (13.3%). The dark mode seems to be offering a more comfortable and flexible reading environment for readers (X. Fang et.al., 2022). Nowadays, various features in social media that use the negative contrast polarity concept were created over the positive contrast polarity concept to increase visual comfort during screen time.

Positive polarity contrast can be defined as dark letters on light background whereas negative polarity contrast is light letters on a dark background (Piepenbrock, 2013). Recent research has shown that positive polarity text is superior compared to negative polarity regardless of the ambient illumination effect (A. Buchner & Baumgartner, 2007). Piepenbrock, Mayr, & Buchner et al. (2014), stated that positive polarity advantage has been proven as the text size decreases. Several studies have shown that presenting text on a monitor in positive polarity results in better performance than presenting text in negative polarity (Wang et al. 2003, Chan and Lee 2005, X. Fang et.al, 2022). However, there are also several failures to find such a positive polarity advantage (Wang and Chen 2000, Ling and van Schaik 2002, Hall and Hanna 2004). According to a study conducted by Buchner, Mayr & Brandt et al., (2009), they found out that no positive polarity advantage was observed when the overall display luminance of positive and negative polarity displays was equivalent. Lombardo et al. (2010) also explained the influence of spherical aberrations of the eye on the visual input. This is because positive contrast polarity features a bright background and causes the pupil to constrict. In turn, the readers will experience less aberration and reduce the distortion of visual input. Conversely, negative contrast polarity will cause the pupil to dilate and produce more aberration and visual distortion when reading.

According to a study conducted by Lin et al. (2015), subjective evaluation of light aberration that caused glare discomfort was highly correlated with eye movement and pupil constriction. Higher aberration increased the speed of eye movement and larger pupil constriction. Hence, it can be stated that positive contrast polarity which causes higher aberration will cause lower fixation duration and lower fixation number as the speed of the eye movement is increasing. However, the statement met a contradiction with another research regarding eye fixation when exposed to glare and aberration. The result showed that glare reduced reading performance. This is because the more adverse the lighting condition, the slower the reading speed became. The decrease primarily happened as a result of increased fixation duration and fixation rates (S. Glimne, 2013). Besides, Miyao et al. (2003) also concluded in their study that an increase in mean fixation duration could be the result of difficulty in comprehension, difficulty in visual processing, or both.

2.3 Myopia Condition That Affects Eye Movement

The prevalence of myopia varies by country and by ethnic group, reaching as high as 70% in some Asian populations (Wong & Foster, 2000). Saw et al. (2006) conducted a study to compare the prevalence of myopia in Malaysia and Singapore and they found that the prevalence of myopia is higher in Singapore in all ethnic groups compared to Malaysia. It was predicted that the prevalence will keep increasing from year to year in both countries. The higher aberrations of myopic eyes have been extensively studied (Cheng, Bradley, Hong &Thibos, 2003). Biehren, Collins & Carney (2005), have found that myopes have greater levels of certain higher-order aberrations, particularly following the reading. According to Collins, Buehren, & Iskander et al. (2006), the effect of higher-order aberration is directly related to pupil size. In practice, this means that higher-order aberrations associated with myopia and reading will have more influence on the image quality of the myopic eyes due to increasing pupil size. Hence, theoretically, it can be stated that reading using negative contrast polarity in dark illumination will cause higher fixation duration and fixation number in the myopic population due to the aberrations and pupil dilatation experienced by myopic eyes.

3.0 Materials And Methods

3.1 Apparatus

During the experiment, a "thread" on Twitter consisting of a few paragraphs was displayed on a smartphone screen. The smartphone used was Samsung J1 2016, with a 4.5" screen and a resolution of 480x800 pixels. The brightness of the display was fixed at 50% to provide comfort for participants. Eye movement recording was accomplished by using a head-mounted infra-red Dikablis Eye Tracker (Ergoneers GmbH, Germany). It used an adequate sampling frequency (50 Hz) to detect the fixation number and fixation duration. The Dikablis consisted of a lightweight head unit and transmitter (weight: 69 g). The system was calibrated using the manufacturer's four-point procedure for each participant. The two videos recorded by the dual camera; pupil and corneal reflection of the subject and subject's field of view will then be transferred to a laptop computer and interpreted using D-Lab Software.

3.2 Subjects

The subjects were selected among UiTM Puncak Alam students from the Faculty of Health Sciences. 10 subjects, consisting of 4 emmetropic and 6 myopic students with ages between 19-25 years old were selected. Inclusion criteria consist of optimum visual acuity (VA) at a distance and near with best spectacle correction, owning a social media account on Twitter or Facebook and spending a maximum of 30 minutes per day scrolling their timeline daily. Non-myopic subjects with the spherical equivalent of −0.25 D to +0.50 D using non-cycloplegic subjective refraction, while myopic subjects are from −1.00 D to −5.50 D, astigmatism of less than 0.75 DC for both group population and anisometropia of less than 1.0D. Meanwhile, exclusion criteria include having binocular vision disorder, colour vision or contrast sensitivity problem, and ocular or systemic disease that affects colour vision or contrast sensitivity.

3.3 Procedures

Screening procedures were done to fulfil all the inclusion and exclusion criteria. Subjects that failed the screening procedures were excluded from the study. Before proceeding to the data measurement, informed consent was obtained from every participant after a verbal explanation of the procedures of the study was given. The screening procedures included case history, visual acuity, subjective refraction, phoria test, and amplitude of accommodation.

Participants wore the final prescription obtained during the subjective refraction throughout the experimental procedures. The experiment was then done binocularly with the participant's best-corrected vision. They were instructed to sit in front of a smartphone at a viewing distance of 40 cm and a nine-degree angle from the participant's eye.

Dikablis eye tracker was placed on top of the participant's head and the eye movement recording system was calibrated for the participant before the measurement procedure. During the measurement procedures, the participant was asked to read a "thread" on the Twitter application on a 10 cm x 6 cm smartphone screen. The presentation time for each measurement was 30 seconds. The target size (letter size) used was 0.3 cm x 0.3 cm subtended at 0.2 degrees.

Participants were introduced towards four different conditions during the measurement. They consist of; positive contrast in bright illumination, positive contrast in dark illumination, negative contrast in dark illumination and negative contrast in bright illumination

The four adjusted conditions were randomly selected. During bright illumination conditions, the normal reading condition was used while during dark illumination conditions, total darkness was introduced inside the room. Meanwhile, a washout period of one minute was introduced between each interval condition to relax the accommodation. Participants were instructed to look at distant objects for one minute after reading and scrolling the "thread" for 30 seconds for each condition. All of the conditions were carried out in the same experimental room to avoid variation in room illumination and room setup. Hence, the total time taken for each participant was approximately 20 minutes. The performance of fixation number and fixation duration were evaluated by the eye tracking system, which objectively executed the eye tracking data performance between the four conditions.

3.4 Statistical Analysis

Data obtained were analysed and tabulated using Statistical Package for Social Sciences (SPSS) software version 23.0. The eye movement pattern under different conditions was analysed using repeated measure ANOVA (Friedman test). Descriptive analysis was interpreted using D-Lab Software. The data used to compare the eye movement status are the fixation duration and fixation number in several different conditions. Post hoc tests (Wilcoxon signed-rank) are performed to assess the differences in the fixation duration and fixation number between myopic and non-myopic group populations.

4.0 Findings

4.1 Demographic Data
10 subjects (three males, and seven females) were involved in this study. They were in the range of ages between 19 to 25 years old. Six subjects were myope while four subjects were emmetrope.

4.2 Number of Fixation and Duration of Fixation
The graph shown in Figure 1 and Figure 2 indicates the number of fixation and duration of fixation under four different conditions:
- Condition A - Positive polarity in bright condition
- Condition B - Negative polarity in bright condition
- Condition C - Negative polarity in dark condition
- Condition D - Positive polarity in dark condition

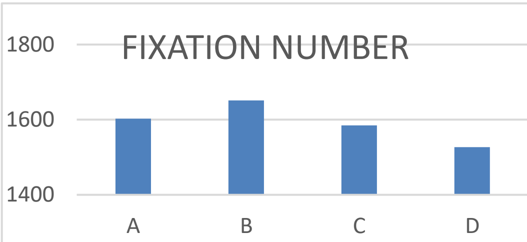

Fig. 1: Number of fixation under different conditions

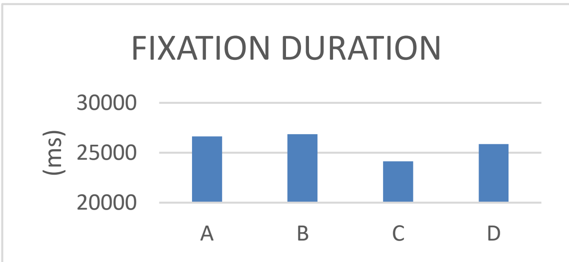

Fig. 2: Duration of fixation under different conditions

The graphs show that both the number of fixation and duration of fixation was recorded as highest in condition B. Meanwhile, the lowest record of the number of fixations fell under condition D, while the lowest record of the duration of fixation fell under condition C. In comparison between emmetrope and myope, it shows that for emmetrope, the highest number of fixation was recorded in condition A while the lowest number of fixation was in condition C. Meanwhile, for myopic subjects, the highest number of fixation fell under condition B while the lowest number of fixation was in condition C.

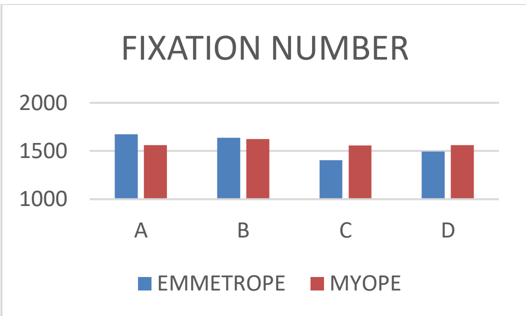

Fig. 3: Number of fixation between emmetrope and myope

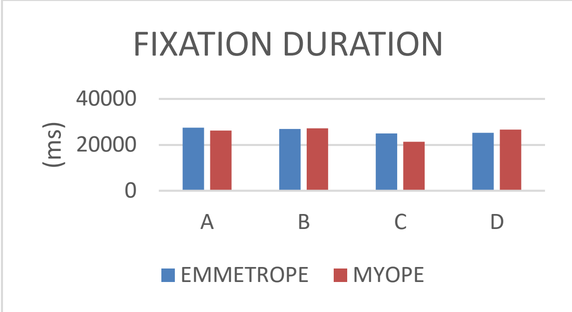

Fig. 4: Duration of fixation between emmetrope and myope

The findings were also similar to the parameter of number of fixations (refer to Fig.3 and Fig. 4). Emmetropic subjects showed the highest reading in condition A and the lowest reading in condition C. Meanwhile myopic subjects recorded the highest reading of fixation duration in condition B while the lowest reading in condition C.

Both numbers of fixation and duration of fixation showed a p-value of more than 0.05 (p=0.160 and 0.099 respectively). There were no significant differences in the number of fixations and duration of fixation under the four different conditions. The number of fixations and duration of fixation showed a significant difference between myope and emmetrope in condition A only (p=0.046). Meanwhile, the other three conditions showed no significant difference between myope and emmetrope with a p-value>0.05.

5.0 Discussion

5.1 Comparison in Bright and Dark Illumination

Our results showed no statistically significant difference in the eye movement pattern, which are the number of fixations and duration of fixation using both positive or negative contrast polarity. There was only an effect of display luminance, with better performance for the higher-luminance displays. This suggests that the positive polarity is not an advantage and is in fact due to the typically higher luminance of positive polarity displays. The readability of text presented on computer screens is better when the overall display luminance level is high, as in positive polarity displays. Display polarity per se does not affect readability. Other than that, they also concluded that the advantage of positive contrast polarity linearly increases with decreasing character size. Besides, a study conducted by (Bochud & Gerbely, 2013) also proved that when reading on electronic displays, the direction of contrast (negative/positive) has no significant influence on central eye movements involved in reading. Therefore, positive and negative contrasts can be recommended when presenting text to users on-screen, providing good readability.

In addition, our study also showed that there was also no statistically significant difference when using positive or negative contrast polarity in both bright and dark illumination. However, previous studies proved that the advantage of positive contrast polarity would be observed over negative contrast polarity, regardless of the ambient illumination (Buchner and Baumgartner, 2007; Lu and Sperling, 2012; Piepenbrock et al., 2014; Piepenbrock et al., 2013). Subsequent work has shown that this effect is likely the result of pupillary dilation caused by the difference in illumination between positive and negative polarity displays, or more precisely, the luminance of the large background areas in these conditions. As the pupil dilates over the imperfect surface of the eye, incoming light and its associated optics are distorted, thus affecting the eye movement pattern. Thus, positive polarity showed a smaller number of fixations and smaller fixation duration. The study employed dark ambient illumination (5 lux) and typical office lighting (550 lux). A wide variety of illumination used between previous research and the current research may be the factor of the opposite findings

5.2 Comparison between Emmetrope and Myope

The findings show a statistically significant difference in the number of fixation and duration of fixation between myope and emmetrope in positive contrast polarity in bright illumination. This may be explained by the higher eye movement efficiency of emmetropic due to lower spherical order aberration as pupil size decreases in bright illumination and bright contrast used, compared to the myopic population.

Meanwhile, previous studies proved that myopes have greater levels of certain higher-order aberrations, particularly following the reading. According to Collins, Buehren, & Iskander et al. (2006), the effect of higher-order aberration is directly related to pupil size. They stated a hypothesis that the higher the order aberration, the higher the changes in pupil dilatation. In practice, this means that higher-order aberrations associated with myopia and reading will have more influence on the image quality of the myopic eyes due to increasing pupil size. In return, activities such as reading in poor light conditions would be a good example of a situation where higher-order aberrations would give a significant impact on retinal image qualities. Thus, as opposed to the findings of current research, myopes will show higher fixation number and fixation duration when reading in ambient illumination using negative contrast polarity compared to emmetropes. Besides that, another study conducted by Stoimenova et al., (2007) regarding the effect of myopia on contrast threshold proved that emmetropes exhibit lower contrast thresholds for negative than for positive contrast in both photopic and mesopic conditions, the opposite pattern being exhibited by myopes. Thus, this means that emmetropes will exhibit greater reading ability with less fixation number and fixation duration in negative contrast polarity, compared to myopes in both bright and ambient illumination. From this result, it will give a sight of proper recommendations for the best screen type to be seen.

6.0 Conclusion And Recommendations

6.1 Conclusion

The result of this study showed that there was no significant difference when reading using both positive and negative contrast polarity in both bright and dark conditions. However, there was a significant difference between myopic and emmetropic subjects when reading in bright illumination using a positive polarity display. Emmetropic subjects showed a higher number of fixation and duration of fixation (p=0.046) when reading in bright illumination using a positive polarity screen display. This is due to the higher eye movement efficiency of emmetropic due to lower spherical order aberration as pupil size decreases in bright illumination and bright contrast used, compared to the myopic population.

6.2 Limitations and Recommendations

The limitation of this study is the small sample size used by the subjects, which may affect the accuracy of the findings. In future, it was recommended to have a bigger sample size to provide more reliability of the results with greater precision and a smaller margin of error.

Acknowledgement

Research reported in this publication was supported by Geran Kolaborasi Entiti Penyelidikan UiTM (KEPU), under award number 600-RMC/KEPU5/3(010/2023)

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