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**GLARE ASSESSMENT FOR LOW-REFLECTION DISPLAY  
DEVICES**

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## GLARE ASSESSMENT FOR LOW-REFLECTION DISPLAY DEVICES

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### Abstract

In the previous work published in CIE x045:2018, authors reported the applicability of current glare metrics for predicting glare on electronic displays in indoor environments and the metric of ASSIST discomfort glare were superior to other metrics. This paper presents a serial of perceptual experiments for discomfort glare, fatigue and clinical optometric assessments and reports selected findings from those experimental results comparing with the predictions by the discomfort glare metric. This paper suggests ways to better display devices design in indoor scenario applications.

*Keywords:* glare assessment; display; glare metric

### 1 Introduction

The world of electronic displays has moved on a lot in last few years. There are new technologies and certifications, all aimed at approaching display technology take the next leap forward. People typically watch displays under ambient lightings, even strong direct sunlight, that causes extremely intense perception by reflected light from the display surface. Extremely reflected glare on displays might affect visual performance, fatigue and headache, but there are rare reports to address the applicability of current glare metrics for reflected glare on displays, especially in low glare level.

More people are experiencing ocular symptoms as a result of using computers or mobile devices. Rosenfield (2011) reviewed that these symptoms include eye irritation, blurred vision, eye strain, double imaging and headache, and are now known collectively as 'computer vision syndrome', that impacts on the ability to comfortably perform the visual tasks. Mutti and Zadnik (1996) reported that about 75 percent of individuals who work for six to nine hours each day in front of a computer monitor have visual complaints. These visual symptoms can be classified as external or internal. The external component includes the symptoms of blurring irritation, dryness, and tearing associated with dry eye and ocular surface disease, and attributable to persistently open eyelids, glare, and small fonts. The internal component includes symptoms of strain, headache, diplopia and blur vision, that are associated with close viewing distance and accommodative stress (Sheedy et. al 2003).

Environmental factors of background illumination, light source, light compensation, position of the display, contrast and glare are also associated with computer vision syndrome (Blehm et. al. 2005). This paper aims to investigate a serial of perceptual experiments for discomfort glare, fatigue and clinical optometric assessments and reports selected findings from those experimental results comparing with the predictions by the discomfort glare metric. Then the paper suggests ways to better display devices design in indoor scenario applications.

### 2 Methods

Sixty-two participants aged 20-35 years with normal or corrected colour vision joined in the experiments. 30 participants for normal ambient environment and the rest of participants for environment with a glare source. The experiment was conducted in a windowless laboratory. Subjects sat in a chair and the distance from the chair to the display was 75 cm. The subject's eyes' position were located at the horizontal angle to the centre of the display. Each subject was tested individually and was allowed to hold a tablet showing the discomfort glare or

fatigue rating scale to use as an input device. The pretest-posttest was design to compare the effects on fatigue, all subjects were asked to perform a set of vision tests.

## 2.1 Apparatus

This work investigates three kinds of glossy, matte and glare-free displays with 2 polarity contents under 2 ambient lighting conditions. The resolution of three 21.5" colour displays is same as 3840×2160 pixels. One condition is the normal office with indirectly lighting on the target display and the other condition is the reflected glare condition that a set of LED flat panel lamp with luminance 20,000 cd/m<sup>2</sup> is setup behind observers. At the normal ambient condition, we measure the horizontal illuminance on the table is around  $550 \pm 50$  lx and the vertical illuminance on the wall behind the display is about  $350 \pm 30$  lx. At the reflected glare condition, the horizontal illuminance on the table is around  $550 \pm 50$  lx and the vertical illuminance on the wall behind the display is around  $650 \pm 100$  lx.

This paper measures the specular reflectance of the display that can be obtained by the luminance of specular reflection divides the luminance of glare light source. The specular reflectance is around 4%, 1% and 0.03% for glossy (HC), matte (MP) and glare-free (PL) display respectively. Two testing contents include white background with black texts (positive polarity) and black background with white texts (negative polarity). For all treatments of the experiment, the objective discomfort glare values of three displays are measured as same as the previous study performed (Hung et al. 2018).

## 2.2 Visual Function Evaluation

All study participants underwent an evaluation of visual function before and after performing each visual task. The evaluation included critical fusion frequency (CFF), refractive error, visual acuity, distance heterophoria, near heterophoria, the accommodative convergence/accommodation (AC/A) ratio, amplitude of accommodation, and accommodative facility. CFF was tested using a Handy Flicker device (Handy Flicker HF-II). Ascending and descending thresholds were recorded and averaged to calculate the pre- and post-task critical fusion frequency for each participant. Measurements of critical fusion frequency were repeated three times and the averaged values were calculated. Heterophoria was tested using a phoropter (Topcon VT-10) with the von Graefe technique. Near heterophoria was tested at a distance of 40 cm. The AC/A ratio was calculated using the heterophoria method. The amplitude of accommodation was measured monocularly by the minus lens technique. Accommodative facility was measured binocularly using  $\pm 2.00$  D lens flippers. Above methods were adopted as same as Lin's research work (2019).

## 2.3 Visual Tasks

Two group participants were required to perform the assigned visual tasks lasting two hours. The visual tasks included interactive games, watching videos, Chinese words typing, reading comprehension tests and graph interpretation exercises. A vision test was performed before and after these tasks. The participants completed the discomfort glare and visual fatigue questionnaires before performing the tasks and filled the visual fatigue questionnaires after finished each assigned visual task.

## 2.4 Questionnaires and Experimental Design

There were 6 sessions in total including 2 illumination conditions and 3 displays. Participants were requested to read articles on screen and answer about questionnaires using a 7 category-point scale (0: none, 2: a little, 4: moderate, 6: extreme). In term of subjective discomfort glare assessment, participants were asked to 8 questions as listed in Table 1 and the study was based on a randomized factorial design with repeat measures on two factors that included illumination conditions and display type. In term of fatigue assessment, participants were asked to 20 questions as listed in Table 2. The study was based on a randomized factorial design with repeat measures on three factors that included illumination conditions and timing and display types. In term of clinical optometric assessment, participants took the set of vision tests in total 14 metrics to compare with the results of the subjective fatigue assessment.

**Table 1 – Questionnaires of discomfort glare assessment**

1. Does the screen let you feel dazzling? (positive polarity)	5. Does the screen let you feel dazzling? (negative polarity)
2. Do you feel dizzy looking at the screen? (positive polarity)	6. Do you feel dizzy looking at the screen? (negative polarity)
3. Do you find the reflected-light at the screen? (positive polarity)	7. Do you find the reflected-light at the screen? (negative polarity)
4. Do you aware the reflected image of your face at the screen? (positive polarity)	8. Do you aware the reflected image of your face at the screen? (negative polarity)

Ranking scale (0: none, 2: a little, 4: moderate, 6: extreme)

**Table 2 – Questionnaires of visual fatigue assessment**

1. Aching eyes	11. Difficulty in focusing on distant objects
2. Eyes feel pressure	12. Difficulty in focusing on close objects
3. Bleary eyes	13. Difficulty in recognizing objects quickly
4. Eyes feel irritated	14. Difficulty in visually tracking moving objects
5. Eyes feel burning	15. Difficulty in gazing at objects
6. Tearing	16. Eyes are sensitive to light
7. Eyes feel dry	17. Difficulty keeping eyes open
8. Eyes are bloodshot	18. Colours of walls or other objects seem different
9. Twitching eyelid	19. Eyes are tired
10. Frequent blinking	20. Headache, head feels heavy

Ranking scale (0: none, 2: a little, 4: moderate, 6: extreme)

### 3 Results

#### 3.1 Glare Metric Calculation

The measurement and calculation results of disability glare model (DGM), Threshold Increment (TI), deBoer Discomfort Glare Rating (DGR), ASSIST Discomfort Glare (DG), ASSIST deBoer Rating Scale Value (DB) and CIE Unified Glare Rating (UGR) of 3 displays are listed in Table 3. The calculations of positive polarity revealed stronger glare values, but the results of DGR and UGR did not show the difference under the conditions of HC display and PL display.

**Table 3 – Results of glare metric calculation**

Condition	Display	Glare Metric (negative polarity)					Glare Metric (positive polarity)				
		DGM	TI	DGR	DG	UGR	DGM	TI	DGR	DG	UGR
Normal	HC	0.6	0.2	8.1	-1.8	-21.1	17.7	7.8	5.3	-0.8	-10.8
	MP	0.9	0.4	7.7	-1.7	-19.8	23.7	10.4	5.0	-0.7	-9.8
	PL	0.6	0.3	8.0	-1.7	-21.0	10.5	4.6	5.7	-1.0	-12.7
Glare	HC	2496.8	725.6	1.2	0.6	6.7	4442.8	1358.3	0.8	0.7	8.0
	MP	457.7	192.4	2.7	0.1	-1.0	9644.3	3823.6	0.1	0.9	9.3
	PL	606.1	246.2	2.4	0.2	0.0	847.7	352.6	2.2	0.3	0.4

#### 3.2 Bivariate Correlation

This work adopted the bivariate correlation to analyse the relationships among all measures included 6 vision test metrics, 8 questionnaires for glare assessment, 4 questions for fatigue assessment, 7 visual performance and 10 calculated glare indices for both positive and negative polarity. Results revealed that there were significant correlation between glare assessment questionnaire and the calculated glare indices, special in the case of positive polarity contents as illustrated in Table 4. And there were significant correlation between



discomfort glare (DG) calculated value for the negative polarity and positive polarity respectively. The DG calculated values of negative polarity content are smaller than the positive polarity content, but the means of glare score for both polarity contents are similar to each other, score difference is less than 0.5, as shown in Figure 2. In addition, results also revealed same phenomena that the mean of glare score is function of ASSIST deBoer index for the negative polarity and positive polarity respectively. In the paper, we suggest the polarity effects may be needed to take consideration in to the glare prediction models.

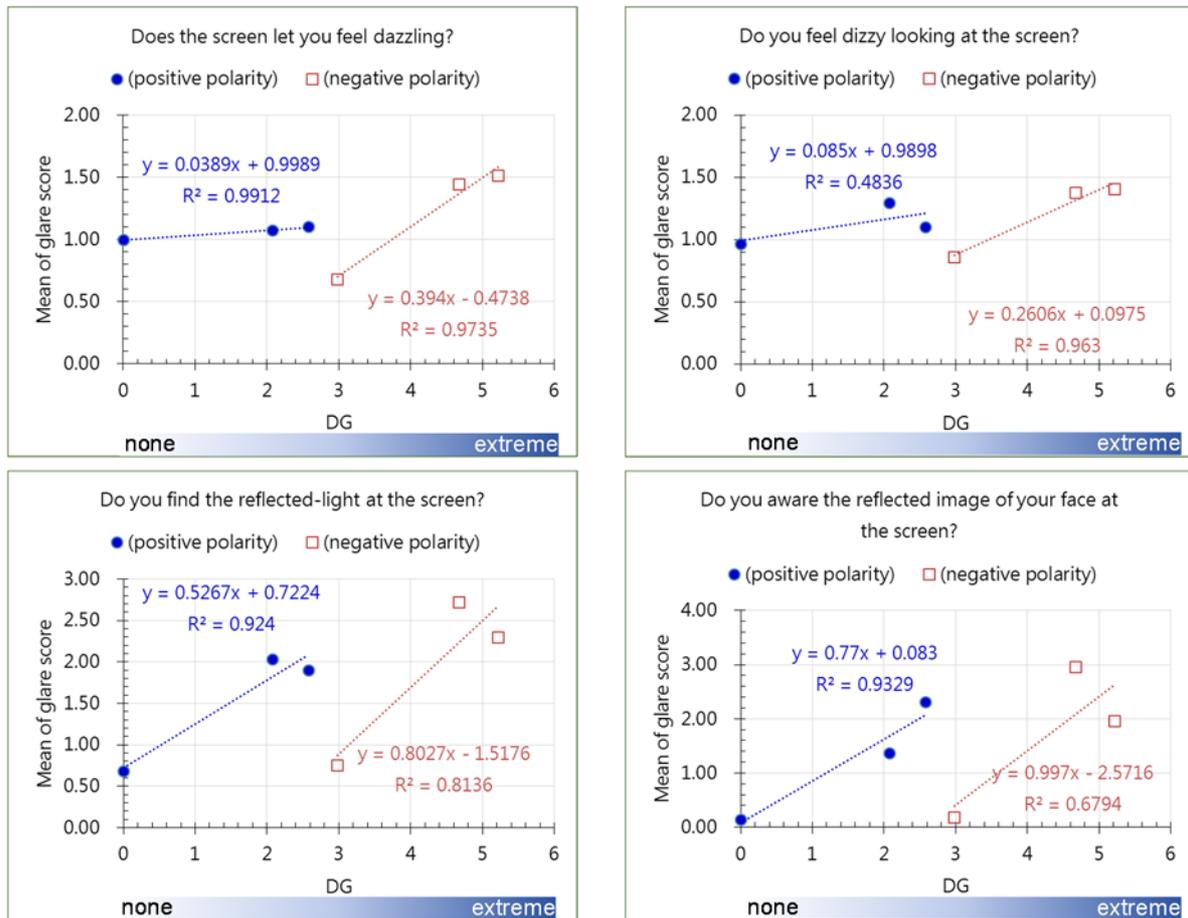
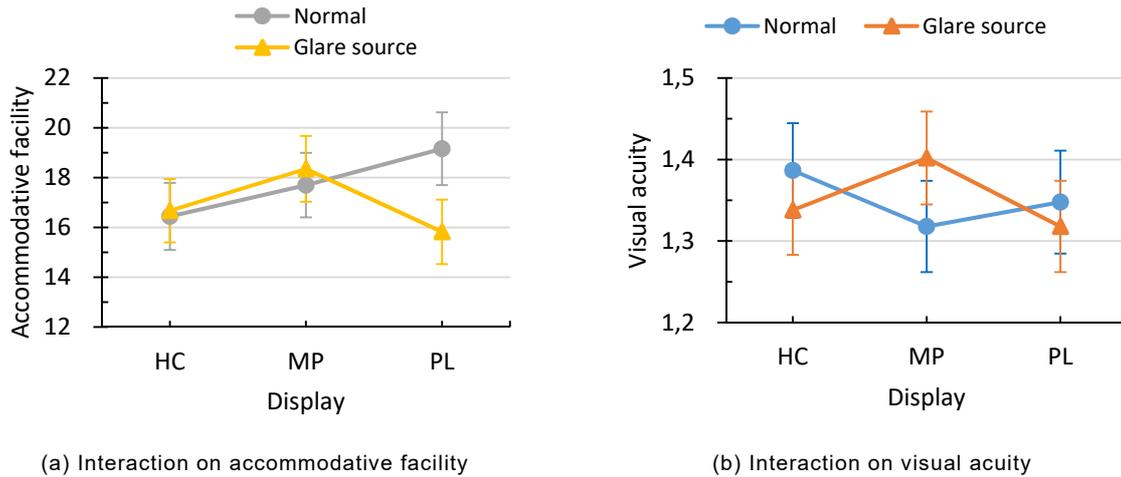


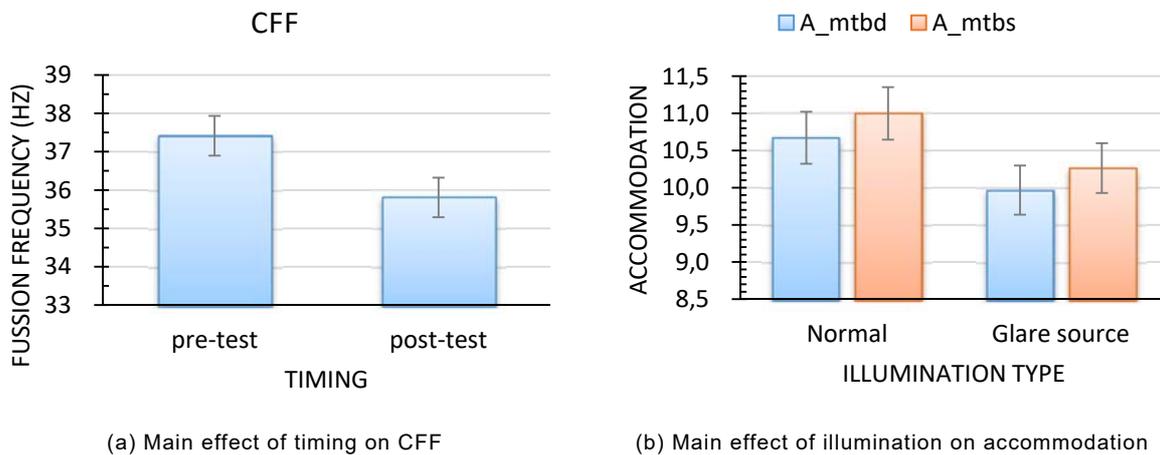
Figure 2 – Mean of glare score is function of the DG calculated value for the negative polarity and positive polarity respectively

### 3.5 Clinical Optometric Assessments

There was a significant interaction effect of Illumination and display on accommodative facility (cycle per minute) at 5 percent level  $F_{2,308}=5.06$  and the interaction also significantly effects on visual acuity  $F_{2,308}=3.095$  as shown in Figure 3(a) and Figure 3(b). Results revealed that the main effect of pre-and-post (timing) was strongly significant on CFF  $F_{0.05,1,308}=18.72$ , indicating the frequency decreased after the visual tasks. There was a significant main effect of illumination condition on both distance accommodation and short accommodation as shown in Figure 4.



**Figure 3 – Interaction of illumination and display on visual function tests**



**Figure 4 – Main effect of timing and illumination on visual function tests**

### 3.6 Fatigue Assessment

A multivariate analysis of variables (MANOVA) was conducted the test all three surface-treatment displays at 2 illumination conditions for 20 questionnaires about visual fatigue. Results revealed that there were significant main effects of illumination condition and timing on all 20 questionnaires as shown in Figure 5 and Figure 6 respectively. Although the factor of display type is not significant that is indicating the surface treatments of display type is minor factor on visual fatigue as shown in Figure 7, the overall average of fatigue rating scale for PL display in lower than others. In this study, three display are ultra-high resolution with high contrast ratio, it may be difficult to let participants feel fatigue. And the duration of total visual task around 2 hours in this experiment, it maybe not long enough.

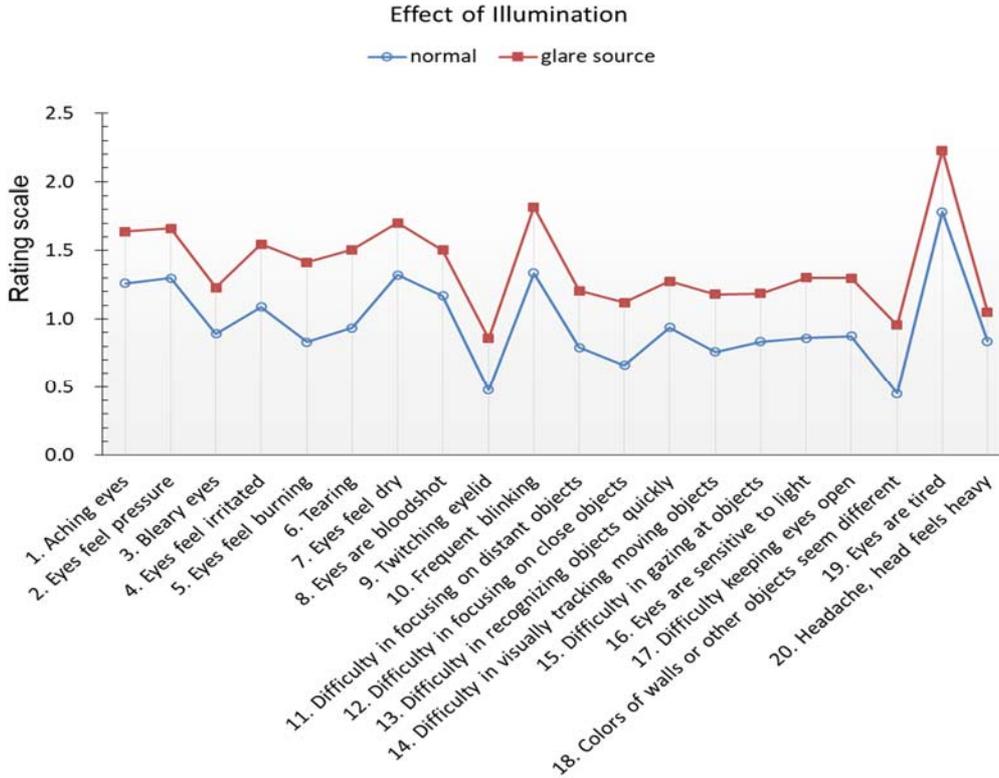


Figure 5 – Main effect of illumination on visual fatigue

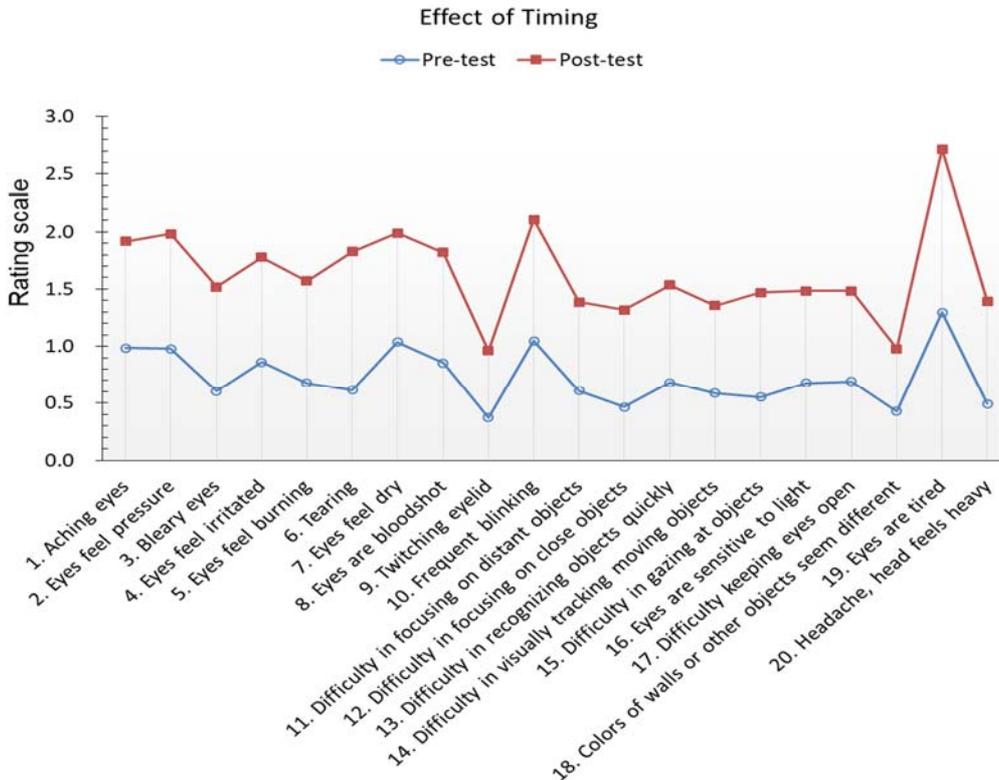


Figure 6 – Main effect of timing on visual fatigue

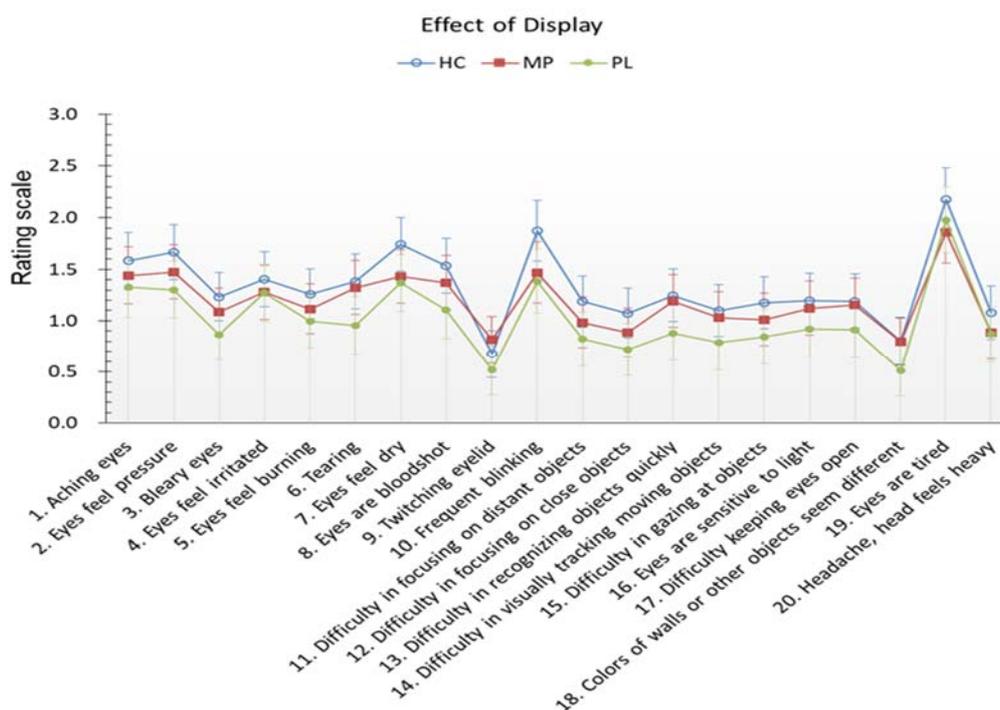


Figure 7 – Main effect of display on visual fatigue

## 4 Conclusions

Most of glare metrics are well known to quantify the discomfort glare of light sources. There is rare work to investigate the annoying or neglectable reflected glare from electronic display devices. This paper conducts experiments to test the surface-treatment displays at different polarity contents under two illumination conditions. The results showed the most correlations of vision tests and subjective evaluation are not significant. Critical fusion frequency is an effective indicator of computer vision syndrome. Furthermore, the interaction effects of display types and illuminations are significant for glare assessment, and the mean of glare score is function of the discomfort glare calculated value. The results conclude the content polarity effects should be take consideration into the glare prediction models in the future.

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