Visual Search and Attention: What Eye-Tracking Reveals about Visual Performance in the Curved Display

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Abstract

The purpose of this study is to investigate the effect of the curved display on visual performance and user experience. Eye-tracking technique and self-report were adopted to assess the visual performance when watching multimedia on the curved display. For visual examination, two curvatures were chosen: flat and curved with a radius equal to 4200 mm. A series of 12 clips were presented, consisting of 2 visual tasks and 10 multimedia video clips. The result revealed an improved visual performance in the curved display, especially in terms of visual search and attention. Participants showed an active scan of visual information for a particular target among distractors and quickly responded to the visual cues. The study provides guidance for an effective visual communication through a curved display and can help manufacturers understand the strength and weakness of different display forms.

Author Keywords

Curved display; eye-tracking; visual performance; visual search; visual attention.

1. Introduction

With the development of display technology, the diversity of display forms and sizes available on the market is increasing. Recently, curved-screen TVs were introduced, marketed as providing an immersive experience and allowing a wider field of view. The main benefit for which the curved display is known is that the distance between the user and the edges of the screen is much less than the flat display, providing an increased area available in the user's peripheral vision [1, 2]. Especially when it comes to large displays, users have to utilize physical navigation (e.g., eye, head, and body movement) in order to avoid outer-edge visual distortion. In the curved display, however, the entire screen surface is expected to be equidistant from the viewer's eyes, allowing less physical navigation without any loss of detail.

There is still very little empirical comparison of user experience and visual performance between flat and curved displays. Thus, the present study aims to evaluate the effect of the curved display on visual performance and user experience. Ultimately, this study could help manufacturers understand the strengths and weaknesses of different display forms, providing guidance for an effective visual communication through a curved display.

2. Eye-Tracking Technique

Eye-tracking holds great promise as a valuable research tool for understanding how people interact with visual information [3]. The eye-tracking technique allows researchers to capture the user's eye movement patterns to compile objective behavioral data that could not be acquired via traditional observational methods [4]. Monitoring eye movements provides a wealth of detail about how users acquire and process visual information [5, 6]. Hence, eye-tracking analysis was adopted in the present study to obtain objective data for measuring visual performance when watching multimedia on a curved display.

3. Experiments

A total of 40 college students (20 males and 20 females) were recruited for the experiment. The average age of the subjects was 21.60 years old, with a standard deviation of 2.57 years. All participants had normal or corrected-normal vision. All eye-tracking data were collected using the Tobii Glasses Eye Tracker. Each subject was calibrated to the eye-tracking system, and then each was provided instructions for the experimental task.

Experimental Setup: In the experiment, only one parameter-curvature-varied. The main objective of this experiment was not to find an optimal radius of the curvature but to observe if there were any differences in eye movement patterns between flat and curved displays. Thus, two curvatures were chosen for the curvature variable: flat and curved with a radius equal to 4200 mm. The display size was 65 inches diagonally with the ratio of 16:9. Color, brightness and contrast were tuned to achieve close, albeit not perfect, matches between two screens. To reduce any possible differences in visual perception, consistent experimental conditions were used for all participants. The chairs were placed 2.0 m away from each display, depending on the participant's height and the visual angle that the camera of the Tobii Glasses Eye Tracker could capture (Figure 1). To reduce the bias in color perception inflicted by the surrounding environment, the experiment was conducted under constant illuminant (6500 K, 600 lux).

Experimental Material: Human vision can cover only a limited amount of visual information at once, around 2 degrees of visual angle [7, 8]. Therefore, when watching large displays, the eyes must constantly shift their gaze to extract meaningful information. In this experiment, participants were asked to perform two types of visual tasks: (a) search and attention. In the visual search task, they were shown a clip filled with colorful circles. Then, the participants were asked to count the number of circular figures with a specific color (e.g., red colored circles). Five different arrangements were randomly shown to the participants. This task involves an active scan of visual information for a particular target among the distractors. In the visual attention task, the participants

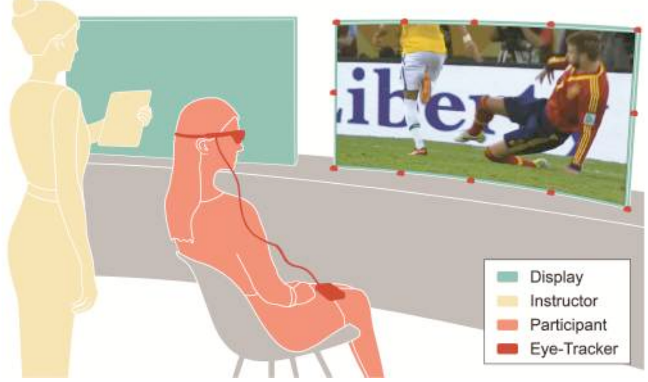

Figure 1. Experimental apparatus with multimedia video clip displayed on a curved screen

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were required to track the dots that randomly appeared on the plain screen. A total of 33 dots were randomly presented. The visual attention task demands participants to quickly react to the visual cues presented.

Besides the visual task, the participants were asked to watch a series of multimedia video clips without any specific task or instruction. All participants were presented with a series of 10 video clips, each of which was between 25 and 30 seconds long. Each video clip was viewed only once to ensure that participants were unfamiliar with the contents [9]. The video clips were chosen to embrace the dual nature of multimedia, infotainment (i.e., combined information and entertainment) [10]. Video clips varied in nature from ones that are informational (such as a news clip, an online lecture, and a commercial) to ones that are entertaining (such as a movie, a sitcom, and a sport).

For informational video clips, two types of visual presentation were chosen with the following elements: (b) fixed layout and (c) simultaneous presentation of visual objects and text captions [11, 12]. Three types of visual presentation were chosen for the entertaining video clips: (d) rapid shift in the orientation of focus, (e) scene transition producing a new orientation of focus, and (f) deep focus shot with intentionally hidden elements (e.g., the top scene of Figure 2(f): the man accidently grabs a candle instead of wine glasses; the bottom scene of Figure 2(f): the penguin defecates on the rock) [7, 8]. Two video clips were prepared for each of the five elements for the purpose of maximizing diversity. In total, a series of 12 clips was presented in the experiment: 2 visual tasks + 10 multimedia video clips.

Experimental Process: A within-subjects design was chosen, where participants viewed each clip at one of two displays, as listed in Table 1. Each participant viewed six clips at a flat display and six at a curved display depending on the experimental group (i.e., group 1 (G1) and group 2 (G2)). Forty participants were evenly spread out over two groups. Thus, for each of the 12 clips, 20 eye-movement data were recorded per each display. Moreover, in order to eliminate any sequential effect on participant evaluations, the clips were shown in the random order of clip- and display-type combinations.

Prior to being shown the stimuli, each participant was calibrated to the eye-tracking system. The subjects were asked to describe the contents of each video clip. This way, the concentration of the participants was continually focused on the experiment. After being exposed to the 12 clips, the participants were asked to evaluate two display types in terms of aesthetics, comfort, and novelty using a 7-point Likert scale ranging from -3 (very bad) to +3 (very good). The total time required to complete the experiment was approximately 20 minutes.

Table 1. Experimental group defined for the study. G1: group 1 and G2: group 2; C: Curved display and F: Flat display.

Type	Clip	G1	G2
Task	(a) Visual search task	C	F
	(a) Visual attention task	F	C
Information	(b) Fixed layout – news	C	F
	(b) Fixed layout – online lecture	F	C
	(c) Text captions – commercial	C	F
	(c) Text captions – cooking	F	C
Entertainment	(d) Shift in focus – documentary	C	F
	(d) Shift in focus – sports	F	C
	(e) Scene transition – movie	C	F
	(e) Scene transition – drama	F	C
	(f) Deep focus – sitcom	C	F
	(f) Deep focus – documentary	F	C

4. Result and Data Analysis

All eye-movement data were analyzed using Tobii Studio 3.2 software. The main measurements used in eye-tracking research are fixations, saccades, and scanpath [13]. Fixation count is the total number of fixations that a participant has on a pre-defined area of interest (AOI). A higher fixation indicates that the area is more noticeable, or more important, to the viewer than the other areas. Duration of a fixation usually acts as a measure of processing difficulty during encoding [14]. On the other hand, saccades, which are quick eye movements occurring between fixations, do not reveal anything about the salience or complexity of an object in the interface [15]. Scanpath, which describes a complete saccade-fixate-saccade sequence, indicates the participant's search strategy for a desired target, for instance, a top-down or bottom-up direction [16]. Therefore, in this study, visual performance was measured by extracting the fixation count and duration. For all segments, the initial fixation was removed from the analysis under the assumption that the initial fixations

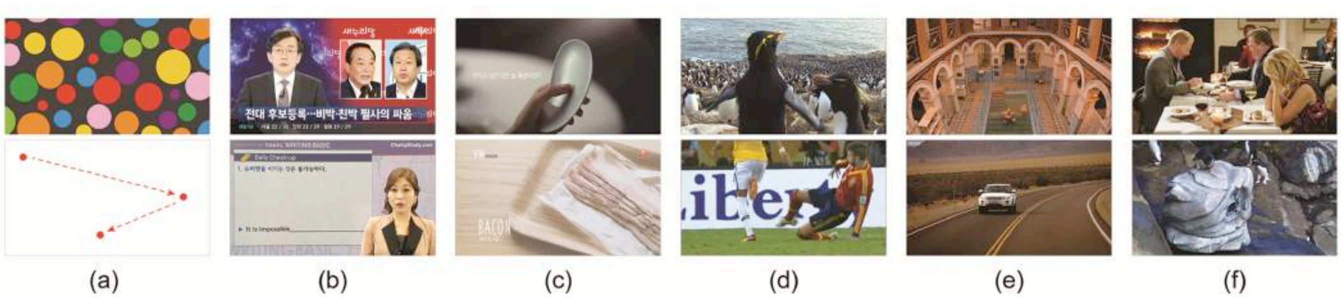
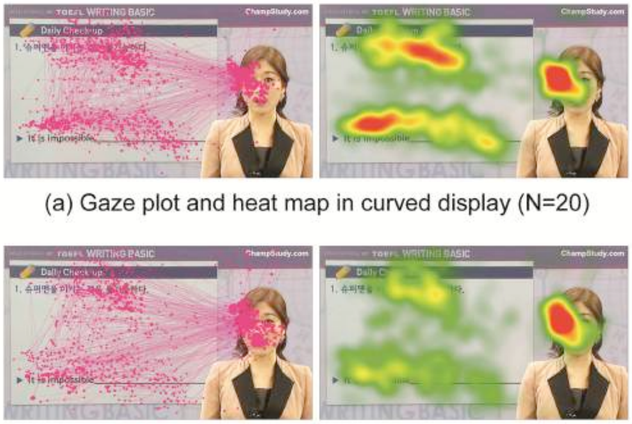


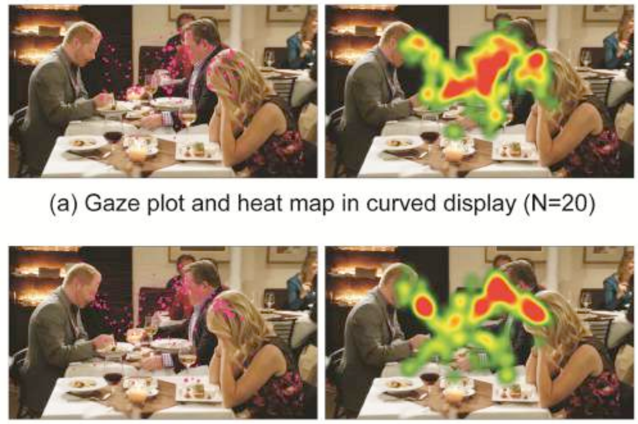
Figure 2. A total of 12 clips used in the experiment, demonstrating the diversity of the visual presentations being considered: (a) visual search and attention, (b) fixed layout, (c) text captions, (d) shift in focus, (e) scene transition, and (f) deep focus.



(a) Gaze plot and heat map in curved display (N=20)

(b) Gaze plot and heat map in flat display (N=20)

Figure 3. Gaze plot and heat map for informational video clip with fixed layout



(a) Gaze plot and heat map in curved display (N=20)

(b) Gaze plot and heat map in flat display (N=20)

Figure 4. Gaze plot and heat map for entertaining video clip with hidden elements

are generally at the center of the screen or on a random point [17].

Visual Task: In the visual search task, the average completion time (sec) was calculated for each display. The result indicated that there was no significant difference between the curved display (M = 18.18, SD = 3.30) and the flat display (M = 18.44, SD = 3.78), $t(38) = -0.22$, $p = .41$. In the visual attention task, the average reaction time (sec) for the 33 dots was calculated. The results indicate improved performance for the curved display (M = 0.19, SD = 0.10) over the flat display (M = 0.25, SD = 0.12), $t(1219) = -7.43$, $p < .05$.

Multimedia Video Clips: In the informational video clips with fixed layout, such as those covering the news and online lectures (Figure 2(b)), AOIs were defined according to the importance of information. In total, three AOIs were defined as follows: main section, anchor, and subsection. The total fixation counts were calculated for each of the three AOIs. A chi-square test of independence was performed to examine the relation between the display type and the fixation on each AOI. The relation between these variables were significant, $X^2(2) = 19.17$, $p < .05$. Participants in the flat display were less likely to pay attention to the main informational section than the participants in the curved display (Figure 3).

In the video clips with a simultaneous presentation of objects and texts, such as commercial and cooking (Figure 2(c)), the average shifting time (sec) between the visual object and text caption was calculated. The result indicated that there was no significant difference between the curved display (M = 0.93, SD = 0.66) and the flat display (M = 0.98, SD = 0.85), $t(401) = -0.75$, $p = .23$.

For entertaining clips with rapid shifts in the orientation of focus (Figure 2(d)), an average time for reorientation (sec) was calculated. As a result, there was no significant difference between the curved display (M = 0.68, SD = 0.33) and the flat display (M = 0.74, SD = 0.46), $t(55) = -0.58$, $p = .28$.

When the video clips contained scene transitions (Figure 2(e)), users had to track the main object or reorient their focus on a newly present object. Thus, an average time for reorientation (sec) was calculated. The result indicated that participants shifted their focus more rapidly in the curved display (M = 0.18, SD = 0.24) than in the flat display (M = 0.27, SD = 0.21), $t(71) = -1.69$, $p < .05$.

In the video clips with a deep focus shot (Figure 2(f)), the hidden element in each clip was defined as an independent AOI. Then, total fixation counts were extracted for the AOIs. A chi-square test of independence revealed that participants in the curved display fixated more on the hidden elements compared to the participants in the flat display, $X^2(1) = 7.72$, $p < .05$ (Figure 4).

Subjective Preferences: The results showed that the subjects preferred the curved display over the flat display across three different measurements (Figure 5). In terms of aesthetics, the curved display received a higher average score (M = 1.53, SD = 0.78) compared to the flat display (M = 0.48, SD = 0.93), $t(39) = 5.65$, $p < .05$. In the aspect of comfort, the curved display received a higher score (M = 1.03, SD = 1.10) compared to the flat display (M = 0.68, SD = 0.83), $t(39) = 2.27$, $p < .05$. Moreover, when it comes to novelty aspects, the curved display received a high score (M = 1.68, SD = 0.94), whereas the flat display received a negative average score (M = -1.65, SD = 1.14), $t(39) = 14.44$, $p < .05$.

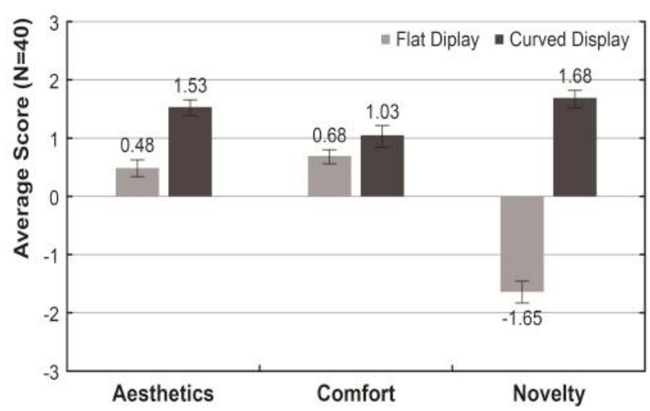


Figure 5. Result of the post-experiment questionnaire. The subjects preferred the curved display over the flat display across three different measurements.

Table 2. Summary of the experimental results (Info. stands for information; Ent. stands for entertainment).

	(a) Search	(a) Attention*	(b) Info.*	(c) Info.	(d) Ent.	(e) Ent.*	(f) Ent.*
Measurement	Mean Time	Mean Time	Fixation Count	Mean Time	Mean Time	Mean Time	Fixation Count
Significance	$p = .41$	$p < .05$	$p < .05$	$p = .23$	$p = .28$	$p < .05$	$p < .05$

5. General Discussion

The study observed an improved visual performance in the curved display compared to the flat display (Table 2). While there was no statistically significant difference between the flat and curved displays for some video clips, this is probably due to the nature of eye movement data that deal with very small differences. Moreover, only one curvature (with a radius equal to 4200 mm) was examined in this study, as it was the only one currently available in the market. In terms of visual performance, the user experience has been improved in the curved display. However, that does not necessarily mean that the higher curvature of a display, the better the user experience is. There might be a point of diminishing returns where higher curvature no longer improves user experience. As such, more in-depth studies would be worthwhile to investigate the optimal curvature of curved displays, especially in terms of visual performance and user experience.

6. Conclusion

The purpose of this research was to empirically compare the visual performance between flat and curved displays and, thereby, to help manufacturers understand the strengths and weaknesses of different display forms. The presented experiment observed an improved visual performance in the curved display, especially in terms of visual search and attention. Participants quickly refocused their attention on the visual cues presented and effectively scanned the target object among distractors. The study provides guidance for an effective visual communication through a curved display and can help manufacturers understand the strength and weakness of different display forms.

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