Readability Performance and Subjective Appraisal of Curved Monitor

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Abstract

This study compares usability of a curved and a flat panel in aspects of readability performance and subjective judgment of preference. For the experiment, a bendable 27-inch monitor panel was facilitated that enabled users to adjust curvature manually. The experiment consisted of two parts. In first part, College students read texts and measured reading time on both curved and flat panels. In next part, students found each optimal radius of curvature on different display images. Based on the measurement, subjects read faster on curved panels. Across different images, a curved panel was consistently preferred. The study provides empirical evidence that a curved display has the potential for creating a new monitor market.

Author Keywords

Curved display; monitor; readability; optimal radius; bendable display.

1. Introduction

Since large curved displays were introduced on the market, there had been a noticeable increase in both consumers' interest and market share [1, 2]. The producers assert the excellence of the curved panels with a basis in the principle of human vision. The human vision system has been evolved to perceive three dimensional surroundings rather than a flat surface [3, 4]. The curved display is designed to enable immersive viewing experience toward viewers [5].

Along with the market interest, some recent studies have provided some empirical evidence that the curved display has positive potential to appeal consumers because it is better in usability as well as more aesthetically appealing than the flat display. As a related work, Häkkinen and his colleagues measured reading experiences on curved paper-like displays and revealed that reading text on concave surface was easier to read where the text direction was the same as the curvature direction. Also, they found that the perpendicular direction to the text is better to read [6]. Shupp and his colleagues tested the task efficiency of multiple monitor interfaces and revealed that curved displays enhanced task performance in comparison with flat interfaces [7]. Na et al. investigated the optimal curvature for both 23 and 27 inch monitors. The optimal curvature on 23 inch display was 600 mm and 700 mm, and the optimal curvature on 27 inch display was 700mm and 800mm. They revealed that the optimal curvature of monitor varies depending on display size and may increase as display becomes larger [8]. Ahn et al. compared flat displays with curved displays with respect to location of focused points, posture and satisfaction, and preferred tilt angles. They reported that curved displays were judged to be preferable to flat displays in general, but the specific reasoning was not yet clearly found [9].

In this study, we tried to contribute to finding more evidence about what advantages or disadvantages people may have when they are viewing the curved display. In particular, we focused on a monitor display because most of the related works have been concerned about either large size displays, such as televisions, or small ones, such as smartphones. We aimed to examine whether the positive effect of a curved display applies also to the case of a monitor, expecting the empirical finding may contribute to the opening of a new market opportunity.

2. Objective

We intended to examine whether people perform better when—and prefer that—the monitor panel is curved. Moreover, we attempted to find the optimal curvature across various types of content.

3. Material

Stimuli for display contents: To simulate monitor contents displayed on a 27-inch panel, six types of contents were prepared. As presented in Figure 1, they consist of (a) photography (human faces), (b) worksheet (Microsoft Excel), (c) computer graphic image (Microsoft Windows default background), (d) geometric image, (e) 3-D game scene, and (f) plain text. With regard to plain text, five variations were made, and each contained 2,500 Korean letters. The texts were presented in a san-serif typeface with 12-point size adequate for comfortable reading as recommended in a previous study [10]. The contents sheet was easily attachable or detachable by the experimenter.

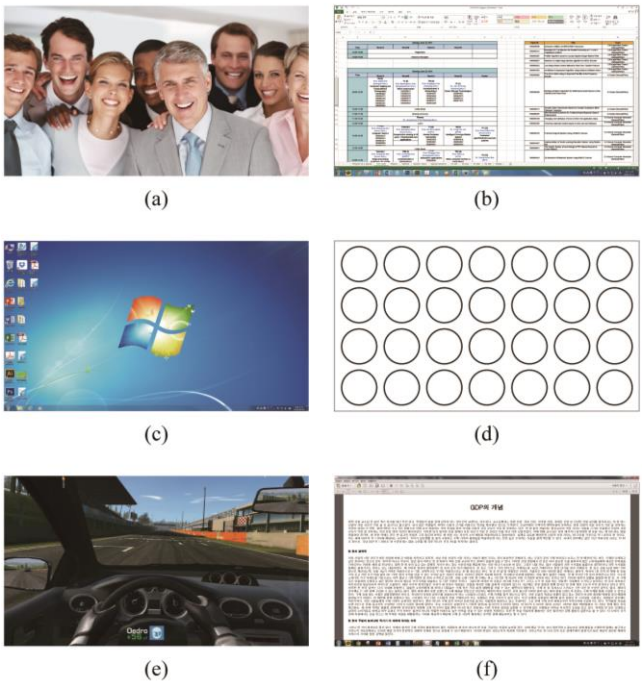

Figure 1. Six types of contents were displayed on a 27-inch monitor: (a) photography (human faces), (b) worksheet (Microsoft Excel), (c) computer graphic image (Microsoft Windows default background), (d) geometric image, (e) 3-D game scene, and (f) plain text.

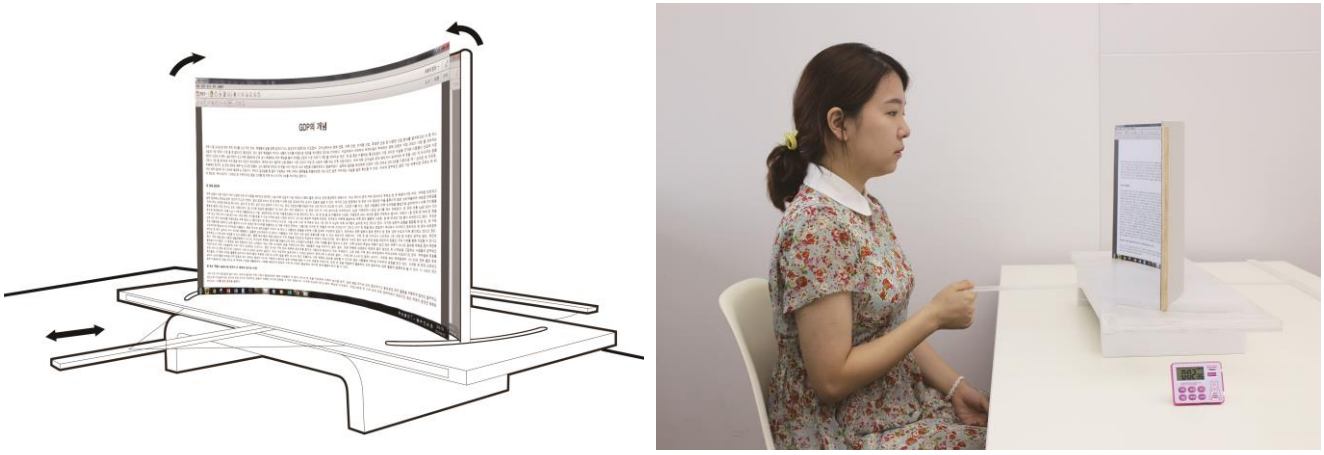

Figure 2. Illustration of bendable monitor mock-up (left), Experimental process (right).

Bendable display panel: A bendable display panel was devised that flexibly varies in curvature. As illustrated in Figure 2, the radius is easily controllable by pulling or pushing a bar handle. When it is pulled, the radius is decreased up to 200 mm. By contrast, when pushed, the radius increases. When this tension between push and pull reaches an equilibrium state, the panel becomes flat. If the bar handle is pushed farther, the panel takes on a convex shape. The radius of the convex panel reaches 1,000 mm. The size of display panel is 27 inch diagonal with a 16:9 aspect ratio [11].

4. Experiment

Participant: A total of 30 college students, 15 male and 15 female, participated in two parts of experiment. The average age of the subjects was 21.93 years with the minimum age of 19 years and maximum age of 29. The standard deviation of age was 2.91 years. All of subjects were paid volunteer.

Procedure: The subjects were seated at a 60 cm distance from the bendable display panel [12]. Before beginning the experiment, sufficient explanation of experiment procedure was provided toward subjects. Subjects were guided to practice the bendable display panel until they were fluent as well. After the practice, the experiment was progressed.

The experiment consisted of two parts. In one part, subjects were requested to read the text displayed on both flat and curved displays. An experimenter attached one of the text contents to the panel, and subjects pulled or pushed the bar handle until they found an optimal radius to read the given text contents. When an answer was found, the radius was recorded by the experimenter. For reading text on a flat panel, the experimenter made the panel flat manually. For each reading, different text contents were provided, and the variations of text contents were given to subjects in random order. The time duration was measured in seconds. Then, in the second part, subjects were asked to find an optimal radius for viewing the five types of contents (i.e. (a)~(e) in Figure 1). Likewise, in part I, subjects found the each optimal radius, and the five contents were presented in random order manually. The each radius of five contents were recorded as well.

The experiment room was lit with 6500 K, and illuminance was 600 lx. Under this illumination, the luminosity reflected from a white area in the content image was measured as 77.40 cd/m2. The time to complete the experiment was 30 minutes.

5. Results and Analysis

We screened the radius data and found that none had chosen a radius with a convex shape in any of the given tasks. Similar experiment result revealed that reading text on concave surface was easier to read than convex surface [6]. Consequently, we could consider all radius data as the radii of a concave panel. Then, based on both radius data and reading duration, we performed statistical analyses and report the results of the two parts in the following.

Readability: In part I, each subject went through two periods of text reading: one time on a flat panel and the other time on a curved panel. In order to eliminate the individual differences in reading speed, we transformed time duration into ratio data. The time duration for the flat panel was designated as 1, and the ratio of the time duration for the curved panel was computed. Based on the transformed ratio data, we found out the averaged ratio of reading text on a curved panel was 0.93 (SD = 0.15), indicating that the subjects spent less time reading 2,500 Korean letters when the text was displayed on a curved panel (see Figure 3). In order to examine the statistical difference, we performed a pairwise t-test, and it yielded a statistical significance [$t(29) = 2.46$, $p = 0.02$]. The result of experiment show that the curved display panel is shown better reading performance than a flat display panel.

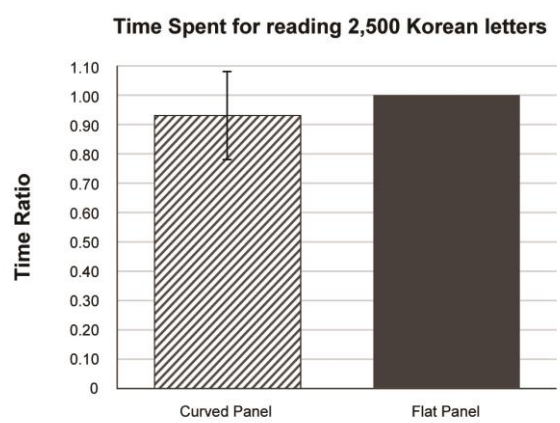

Figure 3. A comparison of ratios of time spent to read 2,500 letters on curved panel when the time spent to read 2,500 letters on flat panel was 1.00.

Preference between flat or curved panel: In order to compare the optimal mean radii depending on different types of contents, we collected the radius data from parts I ((f) in Figure 1) and II ((a)~(e) in Figure 1). These data were analyzed to examine the possibility of curved display which can appeal to the user across different content types.

Table 1. Averaged radii and standard deviation of optimal curvature in 6 types of monitor contents. (a)~(f) are from Figure 1.

Monitor Contents	Mean radii (mm)	SD (mm)
(a) Human faces	661.00	279.12
(b) Worksheet	900.00	811.66
(c) Computer graphic	827.67	394.57
(d) Geometric image	776.67	537.51
(e) 3-D game	625.67	243.82
(f) Plain text	666.67	275.22

As shown in Table 1, we observed that subjects found the largest radius for viewing a worksheet (900.00 mm) followed by computer graphic image (827.67 mm) and geometric image (776.67 mm). In order to examine whether these average radii were statistically different, we performed a repeated measure one-way ANOVA test. Despite the observation, the results revealed that the mean difference was not statistically significant [$F(5,174) = 1.62$, $p = 0.16$]. Moreover, the post-hoc test did not show any statistical significance of difference at all. This provides evidence that despite the observation, we can generally assume that the curved monitor panel can appeal to the user across different content types. On the other hand, the scores of standard deviations were noticeably large across all types of content. This implies that the curved monitor panel will be, in general, preferred, but the ideal radius will be arguable depending on the preferences of individual users.

6. Discussion

Based on the empirical study, we found that the curved panel was preferred to the flat panel, and people read text faster when the panel was curved. We examined both psychological and cognitive aspects, and the results supported the previous studies on the advantages of curved displays. This study provides empirical evidence that a curved display possesses a market potential also as a monitor panel.

Limitation: There are a few issues to be further investigated: First, standard deviations of the data were overly high in part II. It was observed that the optimal range of radius was influenced by individual variation rather than converging into a narrow range. Hence, more elaborate investigation and prediction are required for application to manufacturing optimization. On the other hand, it can be interpreted that the results imply the potential for a flexible radius display.

Secondly, this study was conducted on simulated monitor contents which were displayed on a reflected surface. Because the contents on an actual monitor emit light, it cannot be concluded that results from this study are equivalent to the result from the study carried out on actual monitor. Thus, a supplementary study should be conducted using more realistic stimuli referring to the range of optimal radii discovered from this study.

Optimal curvature for consumer adaptation: Our experiment result reached quite greater curvature comparing with the curved TVs in the market. That may be the effect of display size, which mentioned in present study done by Na. et al. They argued that depending on display size, the optimal curvature may increase as display becomes larger [8]. The 27 inch panel used in the experiment is not big comparing with TV display, thus the smaller radius of curvature, the more curved shape, may be appropriate to the monitor display.

However, in perspective of consumer adaptation, it is hard to directly apply the radius of curvature which came from the experiment. In the past, the CRT display had slight convex shape and consumer felt awkward on the change from CRT to Flat display. Thus the smaller curvature should applied preferentially into display and gradual change to our result radius of curvature is more appropriate in aspect of consumer adaptation. Furthermore, the experiment result didn't used actual display so that the lack of consideration on reflection was occurred. The reflection issue is always pops up at the display market. Our experiment used printed material, thus it is hard to expect how reflection of images at the opposite ends of the screen will be appeared at the monitor when our radius of curvature applied. Hence, the gradual application of curvature is needed as well.

Further research: The reflection might be add as considerable feature in further research as well. Whether the screen size is big or small, there still exist reflection of images at the opposite ends of the screen [13]. However, the assertions that curved display can decrease reflection are also exist. The advocates of curved display contend that the concave screen can reduce the reflections on a screen because the structure can eliminate the reflections arise from certain angles [14]. Thus the reflection should be considered in the further study and it is needed to examine that how reflection influence on the decision of optimal radius of curvature.

Further study can also extend this research by investigating the optimal curvatures in various computer relate tasks. The optimal radius of curvature were found in part I and II. However, only text reading performance was further investigated with a task flow which are similar to actual reading situation at the monitor screen. Thus, a further experiment can be performed with different tasks which are progressed at monitor screen. For example, the game context (i.e. (f) in the Figure 1) is one of the computer relate task and can be investigated. The sense of real environment is particularly effective for gamers, thus the immersion is important for game environment [15]. This characteristic is differ from reading task, so it can be examined to find more appropriate optimal radius of curvature. Likewise, various computer tasks can be examined at the further study.

7. Conclusion

Both consumers' interest and market share are increasing on curved displays. Despite the trends lead the increase of curved display market, there were few researches which investigate the usability of curved display. Thus, this study investigated the superiority of a curved display compared to a flat display in terms of readability performance and subjective judgment of preference. For an experiment, a bendable display panel of which the

curvature is easily adjustable was prepared. The experiment was composed of two parts. In part I, participants were asked to read texts on both curved and flat panels, and results indicated that a curved panel supports a better reading performance than a flat panel. Next, in part II, an optimal radius of curvature for five different types of displayed contents was explored, and the consistent tendency was observed all across the content images. Participants preferred a similar radius of curvature regardless of displayed contents. From the results of experiment, it can be said that the curved monitor is better than flat monitor in usability aspect. Although further research should be implemented to increase the validity of these experimental results, the study revealed that a curved display has the potential to open up a new monitor market.

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