Will Curved Displays Become Mainstream in Electronics? Appraisal for Aesthetic and Usability Aspects of Various Curves and Sizes

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Abstract

This study investigated the benefits of a curved display compared with a flat display, and discovered the optimal radius of curvature for large-size curved television based on the subjective judgment on aesthetics and usability. The experimental results showed that the optimal radius of curvature varies depending on the display size and it increases as the size becomes larger. The curvature with a radius equal to 2000 mm is optimal for a 55-inch television, and the curvature with a radius range between 2000 mm to 3000 mm is appropriate for 65-inch and 75-inch televisions.

Author Keywords

curved display; curved television; optimal curvature; aesthetics; usability.

1. Introduction

With increased prolonged watching of various types of visual display terminals (VDTs) such as televisions, laptops and smartphones, continuous movement of ocular muscles has been considered one of the causes of eyestrain [1]. While watching the displays, people adjust their focus constantly by moving their ocular muscle nearly continuously. In the case of large-size screen displays such as television, this issue becomes a more severe problem because there is a large difference between the distance from the viewer's eyes to the center of display and the edge of the display. A curved display was recently introduced to the market, emphasizing greater visual comfort and more immersive experience in contrast to a flat display [2]. At certain viewing positions, the curved display provides a constant viewing distance between the eyes and display as schematically illustrated in Figure 1 [3] and it delivers more focused and comfortable image to viewers [4, 5].

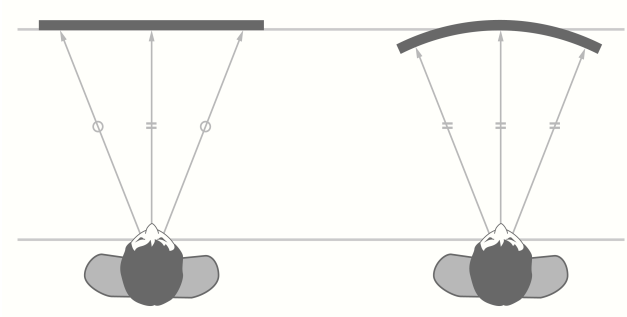

Figure 1. Viewing distance of a flat display (left) and a curved display (right)

The curvature of such television screens is fixed across the display, but few research have been made regarding the optimal radius [6]. However, the optimal radius of curvature for display might differs depending on the product types or display sizes. For example, even two curved displays have same radius of curvature, it is perceived more curved for the display with larger size whereas it looks relatively flat for the smaller size display. Moreover, the watching distance from the display can play a decisive role on optimal display curvature. Thus, this study intends to explore the optimal radius of curvature for large-size curved television screens that provides consumer satisfaction in terms of aesthetics and usability.

2. Objective

The aim of the study is to discover the optimal radius of curvature for large-size curved television based on the subjective judgment on aesthetics and usability. Besides, the benefits of a curved display compared to a flat display is examined as well as the relationship between display size and optimal radius of curvature is investigated.

3. Experiment

Stimuli: Prior to the experiment, 18 display stimuli comprised of six curvature levels at those of radii of curvature equal to 1000, 2000, 3000, 4000, 5000 mm (the smaller the radius of curvature, the more curved a display), and a flat display with three display sizes (55, 65, 75 inches of diagonal length) were created as presented in Figure 2. The aspect ratio of each display was 16:9, as it is the most common ratio for high definition televisions [7]. In addition, three content themes, including movies, sports, and lectures (see Figure 3) were used in order to eliminate the influence of content on assessment. In this way, a total of 54 (six radii of curvature by three display sizes by three themes) display stimuli were prepared. The display panels were made of 5-mm-acrylic and the theme images were printed on photo-quality paper.

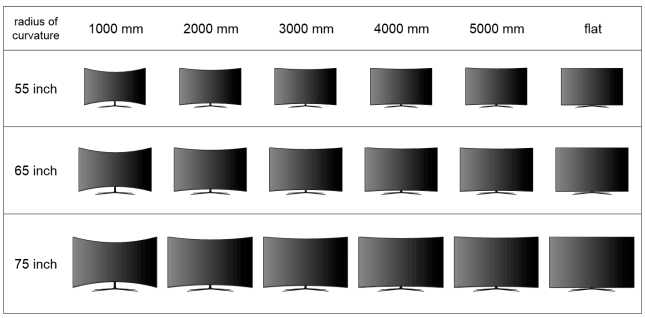

Figure 2. Eighteen display stimuli comprised of six curvature levels (radii of curvature equal to 1000, 2000, 3000, 4000, 5000 mm, and a flat display) with three display sizes (55, 65, 75 inches diagonal)

Figure 3. Three content themes for the experiment (from left to right: movies, sports, and lectures)

Experimental Setup: A total of 80 subjects composed of 40 males and 40 females took part in the experiment. The subjects ranged in age from 18 to 39 years, and the average age of them was 22.36 years with a standard deviation of 4.01 years. All subjects were paid volunteers, and each of them had normal vision or corrected to normal vision.

For the experiment, nine display stimuli were showed at the same time in a random order of display size and radius of curvature. All stimuli were shown same content theme at once to prevent the influence of displayed content on the evaluation. For example, the first nine stimuli were all sports theme, and the next displayed stimuli were movie theme. Each display stimulus was placed on the white table which was 60 cm in height to position the displays at subject's eye level, and a chair was placed 2.5 m distance from the respective display, a typical viewing distance of a television in home environment [8]. Hence total nine display stimuli and nine chairs were set in the experimental room. The experimental setup is seen in Figure 4. At the subject's seat, the measure of the correlated color temperature was 5000 K, and the illuminance was 400 lx.

Figure 4. Experimental setup: nine display stimuli in same content theme and nine chairs placed on 2.5 m distance from the respective display

Method: The experimenter explained the procedure to the subjects and offered them the opportunity to ask any questions related to the procedure before starting the experiment. The subjects were instructed to watch each of the 54 display stimuli and evaluate them in terms of aesthetics and usability since previous studies described that those of two aspects are recognized as the most important dimensions for evaluating product quality [9, 10]. The aesthetic aspect implies the beauty and formative stability of the television, and the usability aspect is related to immersive experience and visual comfort when people watch the television. For the evaluation, the subjects were provided with a 7-point Likert scale in that -3 points means very bad, whereas +3 points means very good. For example, they gave a score of three points on aesthetic aspect if they think the given display stimulus is incredibly beautiful.

The experimental process of evaluation is illustrated in Figure 5. The 54 display stimuli were presented in a random order, and each subject sits on the chair and assesses the aesthetics and usability of the display in front of them. After finishing the subjective evaluation, the subject moves to next seat and evaluate on the next display. They repeated this process nine times to complete one session, and total six sessions were carried out in the experiment. Time taken to complete the entire experiment was about an hour.

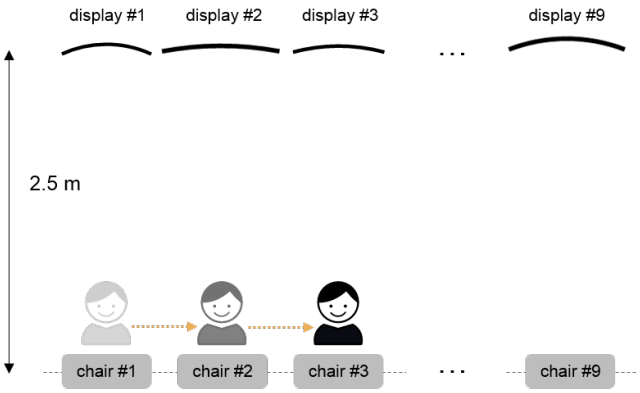

Figure 5. Experimental process of the evaluation

Results and Analysis: The evaluation score of the aesthetics and usability level for the 54 display stimuli were collected through the experiment. To analyze the effect of displayed content on the assessment results, an analysis of variance (ANOVA) was conducted using SPSS statistical analysis software (SPSS version 20.0 for Windows). The analysis yielded statistical significance at an alpha level of 0.05, and the result showed that the effect of the content theme is not statistically significant. It indicates that displayed contents do not influence on deciding the optimal radius of curvature of television. Consequently the evaluation scores of three themes on respective display were combined into a single score by calculating an average.

As a result, the curved display with a radius equal to 2000 mm got the highest score in aesthetics regardless of display sizes as shown in Table 1. In terms of the usability, the evaluation results of the curvature with a radius equal to 2000 mm and those of 3000 mm were fairly similar. In the case of 55-inch display, the display with 2000 mm radius of curvature was judged as the most comfortable and immersive for watching, whereas the curvature with a radius equal to 3000 mm received the best reviews both in 65-inch and 75-inch display by a narrow majority. That is, the subjects preferred the curvature with a range between 2000 mm to 3000 mm radius across different display sizes. Also, within the same radius of curvature, generally the larger displays, 65-inch and 75-inch, were more preferred than the 55-inch display. Presumably the subjects thought that the 55-inch display is not large enough to feel the advantage of the curved display.

Table 1. The mean scores of the evaluation on aesthetics, usability, and average and the standard deviations in parentheses. (scale: -3 to +3). The evaluation was conducted at a distance of 2.5 m from the display stimuli.

Display size	Evaluation aspect	Radius of curvature (mm)					
		1000	**2000**	**3000**	**4000**	**5000**	**flat**
55-inch	Aesthetics	-0.02 (1.76)	0.57 (1.41)	0.42 (1.37)	0.27 (1.43)	-0.09 (1.38)	-0.57 (1.37)
	Usability	-0.34 (1.79)	1.07 (1.31)	0.99 (1.40)	0.88 (1.47)	0.62 (1.48)	0.23 (1.56)
	Average	**-0.18**	**0.82**	**0.70**	**0.57**	**0.26**	**-0.17**
65-inch	Aesthetics	-0.46 (1.78)	1.13 (1.20)	1.09 (1.23)	1.12 (1.18)	0.76 (1.23)	-0.27 (1.46)
	Usability	-1.02 (1.76)	1.59 (1.15)	1.71 (1.18)	1.54 (1.23)	1.39 (1.29)	0.23 (1.59)
	Average	**-0.74**	**1.36**	**1.40**	**1.33**	**1.08**	**-0.02**
75-inch	Aesthetics	-0.85 (1.89)	1.39 (1.59)	1.20 (1.38)	1.03 (1.28)	0.59 (1.44)	-0.27 (1.65)
	Usability	-1.22 (2.00)	1.40 (1.69)	1.52 (1.54)	1.47 (1.56)	0.91 (1.60)	-0.09 (1.81)
	Average	**-1.04**	**1.40**	**1.36**	**1.25**	**0.75**	**-0.18**

Next, a two-way ANOVA was performed to analyze the effect of curvature level and display size on the average score of aesthetics and usability, since it was regarded as the overall consumer satisfaction of the curved television. The result confirmed that not only the two main effects but also the interaction effect between curvature level and display size were statistically significant at an alpha level of 0.05. However, the post-hoc test indicated that except for the 55-inch display, assessment results for the curvature with a radius equal to 2000 mm are not statistically different from those with a 3000 mm. Hence it is assumed that in the case of the 65-inch or larger displays, the visual characteristics of the display with a radius of curvature equal to 2000 mm and a 3000 mm are similar and therefore the subjects hardly recognized the difference in quality.

By taking both aesthetics and usability aspects into consideration, it was concluded that the curved display with a radius equal to 2000 mm is appropriate for a 55-inch television, and display with a radius of curvature range between 2000 mm to a 3000 mm is optimal for 65-inch and 75-inch televisions as summarized in Figure 6. Based on the results, it is plausible that the optimal radius of curvature varies according to the display size, and the curved form is more recognizable when the size gets larger.

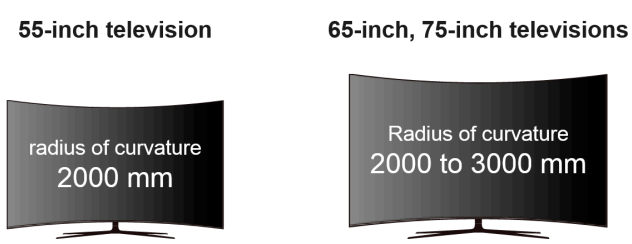

Figure 6. The optimal radius of curvature for 55-inch television (left), 65-inch and 75-inch televisions

Besides, the display with a radius of curvature equal to 1000 mm and the flat display received a poor rating both in aesthetics and usability aspects. The reason is that the curvature with a 1000 mm radius seems to be excessively curved to watch whereas the flat display failed to appeal to the subjects because they already be familiar with the shape.

4. Discussion

In this study, a survey investigated the optimal radius of curvature for the large-size curved television screens that provide consumer satisfaction in terms of aesthetics and usability.

The curvature with a radius equal to 2000 mm is optimal for a 55-inch television, and the curvature with a radius range between 2000 mm to 3000 mm is appropriate for 65-inch and 75-inch televisions. In reality, however, the curved televisions that produced on the marketplace from two major electronics companies have a radius of curvature equal to 4200 mm, and those to 4600 mm respectively [12, 13]. In other words, the optimal curvatures proposed in this study are much more concave in comparison to the curved televisions on the market. Obviously the major reason of the wide discrepancies in curvatures is technological problem, but there might be some other reasons. People already got used to flat televisions since they have been watching them for last few decades, hence some people may feel uncomfortable with the curved television which has a radius of curvature of 2000 mm because of its greater curvature. From the practical and strategic point of view, therefore, a gradual reduction in the radius of curvature of television until it reaches the optimal curvature could be a solution to approach for consumers. For example, people might feel less psychological resistance if the curvature of the 55-inch curved television in the near future set as a radius of curvature of approximately 3000 mm, and the following curved television has a curvature of 2000 mm.

Moreover, the study revealed that the optimal radius of curvature varies depending on the display sizes, as well as it increases when the display size gets larger. This result is closely paralleled with the result obtained from the authors' previous study conducting on computer monitor [11]. In that study, it was discovered that the optimal radius of curvature for 27-inch monitor display is slightly bigger than those for 23-inch display. Hence supplementary research should be carried out to examine the optimal display curvature depending on the type and size of various display devices because a curved display has become more and more widespread.

Despite of the meaningful results from the experiment, however, there are some limitations in this study. First at all, the experiment was conducted using the acrylic panel which displays a printed image, not an actual television. Therefore the display stimuli looked somewhat different from the real products. For example, there is no bezel and stand on the stimuli and the display is too thin compared to the real television, and it might be caused difficulty for the judgment of aesthetic quality of the display stimuli. Also the stimuli displayed as a printed static images, not a movie. This cannot show the major problems which are appeared on a real display such as distortion or reflection of the screen, and it might be influenced on the usability assessment. Second, the experiment was conducted in the experimental room, and it was quite different from the space that people generally watch television in reality. The evaluation in real environment helps more accurate evaluation on aesthetics of television considering the harmony with surroundings, as well as the assessment of usability might be changed depending on the viewing distance which is decided through a space size. Thus, the validation test is recommended using the actual curved televisions in real situation to confirm the superiority of the radius of curvature derived from this study.

5. Conclusion

This study investigates the benefits of a curved display compared with a flat display, and discovers the optimal radius of curvature for large-size curved televisions. For the experiment, a total of 54 display stimuli were composed considering radius of curvature, display size, and displayed content: Six curvature levels (displays with radii of curvature with 1000, 2000, 3000, 4000, 5000 mm and flat display) by three display sizes (55, 65, and 75 inches diagonal) by three content themes (movies, sports, and lectures). The subjects made subjective judgments on each display in terms of aesthetics and usability. The experimental results indicated that the curvature with a radius equal to 2000 mm is an optimal for a 55-inch television, and the curvature with a range between 2000 mm and 3000 mm radius is appropriate for both 65-inch and 75-inch televisions. Moreover, it is revealed that the optimal radius of curvature varies depending on the display size and it increases as the display size becomes larger. Empirical findings provide evidence that recent attempts in large-size curved displays deserve more attention.

6. References

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