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Preference survey of curvature of large-size displays

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Abstract **—** This study investigated the aesthetic judgment of large-size curved displays and found out the most preferred radius of them. For the survey, 1:1 scale curved display mock-ups were presented to subjects, and the displays were made of acrylic frame with various sizes and curvatures. The subjects were asked to assess their preference for the displays in both aesthetic appeal and visual comfort at a distance of 2.5 m. The survey results showed that the most preferred radius of curvature varies depending on the display size, and it increases as the display size becomes larger. For 55-in. displays, the most preferred radius of curvature was found as 2000 mm across the contents attached on the displays. With regard to the 65- and 75-in. displays, the subjects' preference was increased to 3000 mm that lightly varied depending on the presented contents.

Keywords *— curved display, preferred curvature, aesthetic appeal, visual comfort.*

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1 Introduction

With increase of prolonged watching visual display terminals in various types such as televisions, laptops, and smartphones, continuous movement of ocular muscles has been considered as one of the major 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-sized displays like televisions, 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 viewer's eyes to the edge of display. Curved displays were recently introduced to the market, emphasizing greater visual comfort and more immersive viewing experience in comparison with flat displays.[2,3] At certain viewing positions, curved displays provide a constant viewing distance between the eyes and display as schematically illustrated in Fig. 1, and it enables viewers to concentrate on watching and help them feel more comfortable.[4–6]

The curvature of such television screens is fixed across the display, but few research have been made regarding the preferred curvature.[7] The preferred radius of curvature for display might differ depending on display sizes, product types, or displayed contents. For example, even if two displays have the same radius of curvature, it is perceived as more curved for the larger display because the larger display would form a closed cylinder.[3] Moreover, the watching distance from the display might play a decisive role on preferred display curvature. In this regard, this study intends to discover the most preferred radius of curvature for large-size curved displays that supports consumer satisfaction in terms of aesthetic appeal and visual comfort.

2 Related works

People make a purchase decision in considering various aspects of the product such as brand, design, usability, price, or packaging,[8] and usability and aesthetic appeal are recognized as the most significant aspects for evaluating product quality.[9,10] In this study, usability corresponded to visual comfort when people watch the display, and aesthetic appeal implies the formative stability and beauty of displays. Some previous studies suggested that curved displays might be excellent in both of the two aspects.[11,12]

The superiority of curved displays over flat displays in visual comfort was discovered in some of following studies. For example, Shupp's research team presented the benefits of user performance when tiling multiple monitors as a curved shape.[3] Choi and her colleagues investigated the effect of the curved display on visual performance and user experience based on the eye-tracking technique and self-report, and they revealed an improved visual performance and preference in the curved display compared with flat display.[11] A similar experiment using eye-tracking was carried out in Radvile and Cenys's study, and they discovered that curved display supports faster and easier work.[13]

On the aspect of aesthetics, despite that no research has been conducted to evaluate aesthetics of curved display, if has been often claimed that the curved form is more beautiful than the flat form. For instance, Silvia and Barona conducted two experiments to examine the effect of angularity on preference, and the results showed that people preferred the round shapes more than the angular shapes.[14] In a study of Bar and Neta, it was examined that emotionally neutral objects with pointed features would be

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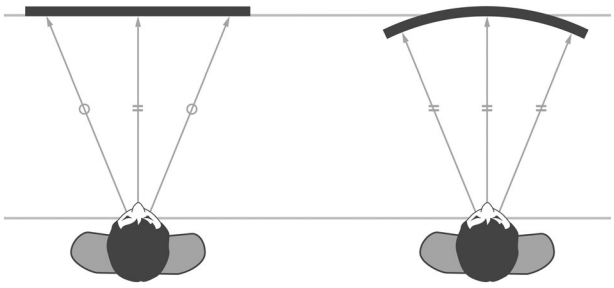

FIGURE 1 — Viewing distance of a flat display (left) and a curved display (right).

liked significantly less than corresponding objects with curved features.[15]

In the process of the evaluation, we attempted to facilitate 1:1 scale mock-ups for realistic experience. A previous study on the aesthetical judgment of product design in general emphasized the effect of product size on one's aesthetic impression.[13] Subsequently, we tried to provide the display stimuli as in their actual sizes for more accurate evaluation.

3 Objective

The aim of the study is to investigate the most preferred radius of curvature for large-size curved displays based on the subjective judgment of aesthetic appeal and visual comfort. Besides, this study intends to examine the benefits of a curved display compared with a flat display as well as the relationship between display size and preferred radius of curvature.

4 Plan for survey study

4.1 Stimuli

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

4.2 Survey setup

A total of 80 subjects composed of 40 men and 40 women took part in the survey. 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.

Nine display stimuli were showed at the same time in a random order of display size and curvature. All displays were shown the same content theme at once to prevent the influence of displayed content on the evaluation. For

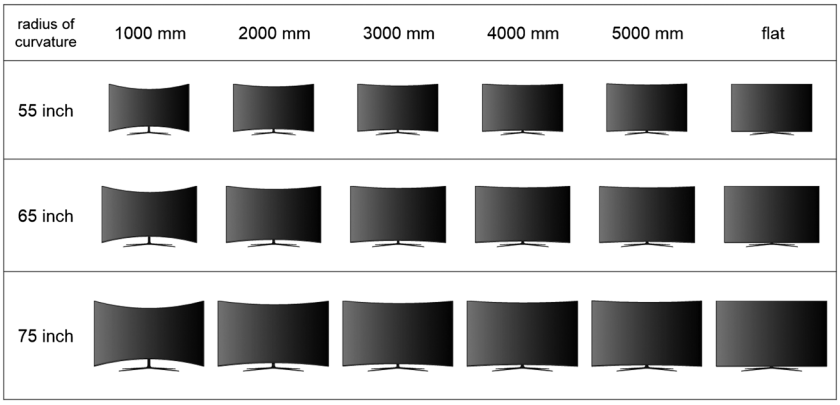

FIGURE 2 — Eighteen display stimuli composed of six curvature levels (radii of curvature equal to 1000, 2000, 3000, 4000, and 5000 mm, and a flat display) with three display sizes (55, 65, and 75 in. diagonal).

FIGURE 3 — Three content themes for the survey: (from left to right) movies, sports, and lectures.

example, the first nine displays showed a sports theme, and the next displays showed a movie theme. Each display stimulus was placed on a white table, which was 60 cm in height to position the displays at the 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 a home environment (Fig. 4).[17] Hence, a total of nine display stimuli and nine chairs were set in the room. At the subject's seat, the measure of the correlated color temperature was 5000 K, and the illuminance was 400 lx.

4.3 Procedure

The procedure was instructed to the subjects. The subjects were instructed to watch each of the 54 display stimuli and evaluate them in terms of aesthetic appeal and visual comfort. For the assessment, 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 3 points on aesthetic aspect if they think the shape of the given display stimulus is incredibly beautiful. The process of evaluation is illustrated in Fig. 5.

The 54 display stimuli were presented in a random order, and each subject sits on the chair and assesses the aesthetic appeal and visual comfort of the display in front of them. After finishing the subjective evaluation, the subject moves to the next seat and evaluates the next display based on the same criteria. They repeated this process nine times to complete a session, and a total of six sessions was carried out in the survey. Time taken to complete the entire survey was about an hour.

FIGURE 4 — Survey setup: nine displays and nine chairs placed initially on 2.5 m distance from the respective display.

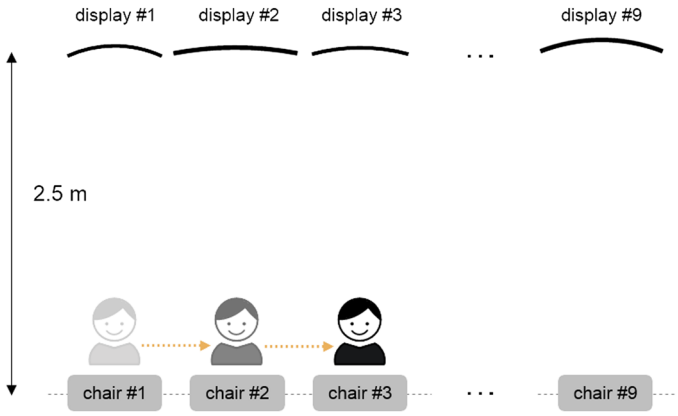

FIGURE 5 — The evaluation process.

5 Results and analysis

The evaluation score of the aesthetic appeal and visual comfort for the 54 display stimuli were collected through the survey. In order to examine the effect of displayed content themes on the assessment results, an analysis of variance 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 affect deciding the preferred radius of curvature. Consequently, the evaluation scores of three themes on respective displays were combined into a single score by calculating an average.

As a result, the curved display with a radius of curvature equal to 2000 mm obtained the highest score in aesthetic appeal regardless of display sizes as shown in Table 1. In terms of visual comfort, the evaluation results of the display with a radius of curvature equal to 2000 mm and that of 3000 mm were fairly similar. In the case of 55-in. display, the most preferred radius of curvature was found as 2000 mm, whereas the display with a radius of curvature equal to 3000 mm received the best reviews both in 65- and 75-in. display by a narrow majority. That is, the subjects preferred the radius of curvature ranged between 2000 and 3000 mm across different display sizes. Also, within the same radius of curvature, generally the larger displays, 65- and 75-in. displays, were preferred to the 55-in. display. Presumably, the subjects thought that the 55-in. display is not large enough to feel the advantage of the curved display.

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

By taking both aesthetic appeal and visual comfort into consideration, it was concluded that a radius of curvature equal to 2000 mm is appropriate for a 55-in. display, and a

TABLE 1 — The mean scores of the evaluation on aesthetics and usability, and average and the standard deviations in parentheses (scale: −3 to +3).

Display size (inch)	Evaluation aspect	Radius of curvature (mm)					
		1000	2000	3000	4000	5000	flat
55	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	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	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

The evaluation was conducted at a distance of 2.5 m from the display stimuli

radius of curvature ranged between 2000 and 3000 mm is the most preferred for 65- and 75-in. curved displays as summarized in Fig. 6. Based on the results, it is plausible that the most preferred radius of curvature varies according to the display size, and the curved form is more recognizable when the display size gets larger.

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

6 Discussion

In this study, a survey was conducted to investigate the most preferred radius of curvature for large-size curved displays that provide consumer satisfaction in terms of aesthetic appeal and visual comfort. The result indicated that a radius of curvature equal to 2000 mm is most preferred for a 55-in. display, and a radius of curvature ranged between 2000 and 3000 mm is appropriate for 65- and 75-in. displays. In the real world, however, the curved televisions that are produced on the marketplace from two major electronics companies currently have a radius of curvature equal to 4200 and 4600 mm, respectively.[18,19] In other words, the curvatures suggested in this study are much more concave in comparison with the curved displays on the market. Obviously, the main reason of the wide difference in curvatures is technological limitation, but there might be some other reasons. People already got used to flat displays because they have been watching the display for the last few decades, hence some people may feel uncomfortable with the curved display, which has a radius of curvature equal to 2000 mm because of its greater curvature. From the practical and strategic point of view, therefore, a gradual reduction in a radius of curvature could be a proper solution for consumers' adaptation on curved displays. For example, people might feel less psychological resistance if a radius of curvature of the 55-in. display in the near future is set as approximately 3000 mm, and the following display has a radius of curvature equal to 2000 mm.

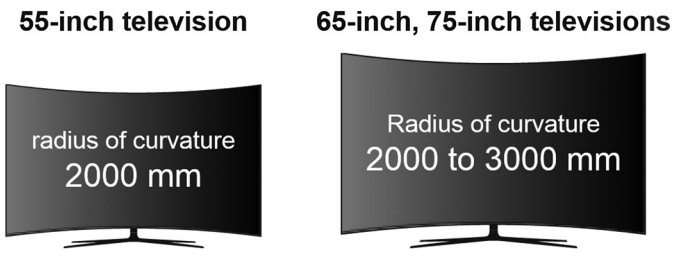

FIGURE 6 — The most preferred radius of curvature for 55- display (left), 65-, and 75-in. displays.

Furthermore, the study revealed that the most preferred radius of curvature varies depending on the display sizes, as well as it increases when the display size becomes larger. This result is closely paralleled with the result obtained from the authors' previous study conducted on computer monitor.[12] In that study, it was discovered that the preferred radius of curvature for a 27-in. monitor display is slightly bigger than those for a 23-in. display. Hence, supplementary research should be carried out to reveal the ideal display curvature depending on the display size or type because a curved display has become more and more widespread in various kinds of display devices.

Despite the meaningful results from the survey, however, there are some limitations in this study. First, the survey was carried out using acrylic panels that display a printed image, hence, the display stimuli looked somewhat different from actual display devices. For example, there is no bezel and stand on the stimuli and the display is too thin compared with the real display, and it might cause difficulty for the judgment of aesthetic quality of the display stimuli. Also, the display stimuli were shown as printed static images, not a movie. It is hard to show the major problems that appear on a real display such as visual distortion or reflection of the screen, and it might influence the assessment of visual comfort. Second, the survey was conducted in a controlled room, and it was quite different from the space wherein people generally watch displays in reality. The evaluation in real environment helps give a more accurate judgment on aesthetic appeal of display stimuli considering the harmony with surroundings and the assessment of visual comfort might be changed

depending on the viewing distance, which is decided through the space size. Thus, the validation test is recommended using the actual curved displays in real situation to confirm the superiority of the radius of curvature derived from this study.

7 Conclusion

This study investigated the benefits of a curved display compared with a flat display and discovered the most preferred radius of curvature for large-size curved displays. For the survey, a total of 54 display stimuli were composed considering display size, curvature, and displayed content: six curvature levels (displays with radii of curvatures equal to 1000, 2000, 3000, 4000, and 5000 mm and flat display) by three display sizes (55, 65, and 75 in. diagonal) by three content themes (movies, sports, and lectures). The subjects made subjective judgments on each display in terms of aesthetic appeal and visual comfort at a distance of 2.5 m. The survey results indicated that a radius of curvature equal to 2000 mm is the most preferred for a 55-in. display, and a radius of curvature ranged between 2000 mm and 3000 mm is appropriate for both 65- and 75-in. curved displays. Moreover, it is revealed that the most preferred 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.

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