Are curved displays ergonomically advantageous over flat displays? Some positive results from three display curvature studies on monitors and TVs

Sungryul Park (psr926@unist.ac.kr), Jihhyeon Yi (yjh90@unist.ac.kr), Donghee Choi (choidh@unist.ac.kr), Songil Lee (songil@unist.ac.kr), Gyouhyung Kyung (ghkyung@unist.ac.kr)

Interaction and Experience Lab, UNIST, Ulsan, Korea, 44919

ABSTRACT

Background: Though curved display products such as curved monitors, TVs, and smartphones are available, it seems still inconclusive whether or not curved display is ergonomically advantageous over flat display, and if so in terms of what ergonomic aspects. To examine a visual display comprehensively, three aspects, productivity, safety, and well-being, should be considered. **Objective:** We aimed to determine whether or not display curvature is ergonomically recommendable, especially for monitors and TVs. **Methods:** Overall, we examined the effect of display curvature on visual task performance, visual fatigue, and/or watching experience by conducting three different studies. In Study 1, we examined the effect of display curvature (400R, 600R, 1200R, and flat) on visual task performance and visual fatigue. A visual search task was performed on 50" multi-monitors. In Study 2, we examined the effect of display curvature (600R, 1140R, 2000R, 4000R, and flat) on visual task performance, visual fatigue, and display satisfaction. A proofreading task was performed on 27" monitors. In Study 3, we examined the effect of display curvature (2300R, 4000R, 6000R, and flat) on presence and display satisfaction. A TV watching task was done on 55" TVs. **Results:** First, curved displays increased productivity. The mean visual search accuracy and speed were both higher at the 50" 600R and 1200R multi-monitor settings, and the mean proofreading speed was the fastest at the 27" 600R curved monitor setting. Second, curved displays increased safety. The mean visual fatigue was lower at the 50" 600R and 1200R multi-monitor settings. However, the effect of display curvature on visual fatigue was not significant in the case of the 27" monitors. Third, curved displays improved well-being. Compared to the 55" flat TV, the mean spatial presence and engagement did not significantly decrease up to a more lateral viewing position especially when the display curvature was similar to the viewing distance. The effect of display curvature on display satisfaction was, however, not significant in Studies 2 and 3. **Applications:** The findings of three studies suggest that display curvature, if its level is carefully selected, can improve monitors and TVs in terms of productivity, safety, and/or well-being.

Keywords: Curved display, visual ergonomics, visual task

1. Introduction

Since the introduction of curved display products (e.g. monitors, TVs, smartphones, and smart watches) in the market, there have been a variety of comparative studies between curved and flat displays.

Recently, it has been shown that curved displays are advantageous over flat displays in terms of visual task performance, visual fatigue, preference, and satisfaction (Czerwinski et al. 2003; Häkkinen et al. 2008). In contrast, some negative effects of display curvature

were reported in terms of legibility (Lin et al. 2009; Wang et al. 2012) and visual processing speed (Mustonen et al. 2015).

In order to evaluate new display products from the perspective of visual ergonomics (IEA 2012), three aspects of productivity, safety, and well-being should be considered. However, few studies on curved display have considered all these factors.

The purpose of the current study was to comprehensively evaluate the effects of display curvature on visual task performance, visual fatigue, and viewing experience.

2. Method

Three studies on display curvature were done. In the first study, visual task performance and visual fatigue were evaluated using a visual search task on a 50" multi-monitor. In the second study, visual task performance, visual fatigue, and satisfaction were evaluated using a proofreading task on five 27" mock-up monitors. In the third study, the viewer's presence and satisfaction associated with a TV watching task were evaluated using four 55" mock-up TVs.

2.1 Study 1

Twenty-seven students (male: 14, female: 13) participated in Study 1. Their mean (SD) age was 20.9 (1.2) yrs. Exclusion criteria were as follows: having visual acuity < 0.8 (Wu 2011), wearing a pair of glasses, being color blind based on the Ishihara test (Ishihara and Force 1943), or suffering from any ocular disease in the past six months.

The multi-monitor used in this experiment consisted of five display panels [5 display zones; LP171EE3, LG, Korea] of 244mm (width) × 382mm (height), and the overall size was 50" (1220 mm × 382 mm). The horizontal viewing distance to the central display (Z₃; Figure 1) was 500 mm.

Figure 1. Experimental setting for Study 1

A pseudo text was randomly presented on a display zone for 3 min, and a visual search task (ISO, 2008) was repeated twice on each display zone.

Two independent variables were used in Study 1. Four levels of display curvature (400R, 600R, 1200R, and flat; within-subjects) were considered. Display zones (within-subjects) had five levels – Z₁ (leftmost), Z₂, Z₃ (Center), Z₄, and Z₅ (rightmost). The order of presenting the display curvature was determined by

using a 4 × 4 Latin Square.

Five dependent variables were used in Study 1. Error rate and searching speed were used to measure the visual search task performance. To measure visual fatigue, a 100mm visual analogue scale (VAS), eye-complaint questionnaire [(ECQ; Steenstra et al. (2009)], and critical fusion frequency (CFF) were used.

2.2 Study 2

Fifty students (male: 17, female: 33) participated in Study 2. Their mean (SD) age was 22.3 (1.5) yrs. Exclusion criteria were the same as in Study 1.

The mock-up monitor used a projected image (EB-4950WU, EPSON) on a 27" polycarbonate rear screen (603mm × 346mm; Exzen, Korea; Figure 2). Image distortion on the screen was corrected using Desktop Warpalizer® (UniVisual Technologies, Sweden). The viewing distance used in Study 2 was 600 mm.

Figure 2. Experimental setting for Study 2

Each participant performed a proofreading task on a screen with a specific curvature. Korean texts from the Naver Cast (<http://navercast.naver.com/>) were used for proofreading. A reference article without grammatical errors was displayed on the left side of the screen, and an article with grammatical errors on the right side. Referring to the left article, each participant needed to

find and mark errors in the article on the right side using editing symbols.

Two independent variables were used in Study 2. Five levels of display curvature (600R, 1140R, 2000R, 4000R, and flat; between-subjects) were considered. Task durations (five levels; within-subjects) were 0, 15, 30, 45, and 60 min. Nine dependent variables were used in Study 2. Proofreading speed and accuracy, visual discomfort, subjective visual fatigue, psychophysiological visual fatigue, blink duration, blink frequency, mental workload, and display satisfaction were measured.

2.3 Study 3

Fifty-six students (male: 20, female: 36) participated in Study 3. Their mean (SD) age was 20.9 (1.5) yrs. Exclusion criteria for participation were the same as in Study 1. Each mock-up TV screen used in the experiment was made by attaching a projection film (Sunnano, Korea) on the front of a 55" (1218mm × 685mm) styrofoam panel having a specific curvature. Images were projected on the screen (Figure 3).

Figure 3. Experimental setting for Study 3

The visual stimuli used in Study 3 consisted of ten 5-min videos, which was a combination of 1-min sample from five types of video. One of ten videos was randomly used for each viewing distance × viewing location condition. Image distortions on the screen were corrected using Desktop Warpalizer™ (UniVisual Technologies, Sweden).

Three independent variables were used in Study 3. Four levels of display curvature (2300R, 4000R, 6000R, and flat;

between-subjects) were considered. Viewing distance had two levels (2.3m and 4m; within-subjects). Lateral viewing position (within-subjects) had five levels – P₁ (Center), P₂ (35cm rightward from P₁), P₃ (70cm), P₄ (105cm), and P₅ (140cm). Seven dependent variables related to watching experience were used in Study 3 – presence, visual comfort, image quality, and display satisfaction. Presence was further divided into four categories – spatial presence, engagement, ecological validity, and negative effects.

3. Results and discussion

3.1 Study 1

In the 50" multi-monitor study, curved display settings showed a better visual search task performance than the flat display setting. Compared to the flat setting, the mean error rate was 20% lower at the 1200R setting, and the mean speed was 8% faster at the 400R and 600R settings. Task performance was degraded as the display became planar, and the display zone was more lateral. The mean error rate was not significantly different across the display zones of the curved display settings, while it increased by 37% at Z₁ (leftmost) compared to Z₃ (center) of the flat display setting. The mean speed was not significantly different across the display zones in the case of the 400R and 600R settings, while it decreased by 10%–18% at Z₁ and Z₅ (the left and rightmost) compared to Z₃ in the case of the 1200R and flat settings. The mean error rate increased by 8% and the mean search speed decreased by 2% during the second session, compared to the first session.

Less visual fatigue was reported at the curved display settings than at the flat display setting. The mean perceived visual fatigue was 13% lower at the 600R setting than at the flat setting. In addition, in the case of the curved display setting, visual fatigue was similar across the display zones, while it increased up to 45% at Z₁ compared to Z₃ in the case of the flat setting.

3.2 Study 2

The effect of display curvature on proofreading speed on the 27" monitors was significant. The mean proofreading speed was 14% faster at the 600R than at the flat. The effect of task duration on proofreading speed and accuracy was

significant. During the 60-minute task, the mean proofreading speed increased by 16%, while the proofreading accuracy decreased by 22%.

The effects of display curvature on visual discomfort, visual fatigue, mental workload, and display satisfaction were not significant, while the effect of task duration was significant. During the 60-min proofreading task, the mean visual discomfort increased by 207%, the mean perceived visual fatigue increased by 166%, the mean CFF decreased by 0.6 Hz (indicating an increase in visual fatigue), and the mean mental workload increased by 153%.

3.3 Study 3

For the 55" TVs, the mean spatial presence and engagement were high when the display curvature was equal to the viewing distance, and began to decrease at a more lateral viewing position. Compared to the 4000R-4m-P₁, which provided the highest mean spatial presence, the mean spatial presence at the 2300R, 4000R, and 6000R settings at the viewing distance of 2.3m reduced by 30%–39% at P₅, but the mean spatial presence at the flat setting at the same distance began to reduce by 32%–37% at P₃. In addition, the mean spatial presence at the 4000R setting at the viewing distance of 4m reduced by 32% at P₅, while those of the 2300R and flat settings reduced by 32% (at P₄) and 31%–44% (at P₁, P₃, P₄, and P₅), respectively. Compared to the 4000R-4m-P₁, which provided the highest mean engagement, the mean engagement at the curved settings (2300R, 4000R, and 6000R) at the viewing distance of 2.3m decreased by 22%–27% at P₅, but that at the flat setting decreased by 30% at P₃–P₅. In addition, the mean engagement at the 4000R and 6000R settings at the viewing distance of 4m decreased by 29% and 24% at P₅, while those at the 2300R and flat settings decreased up to 30% at P₃–P₅. For ecological validity, negative effects, visual comfort, image quality, and display satisfaction, no effect was significant.

4. Conclusions

Three studies examined the effects of display curvature on user productivity (visual task performance), safety (visual fatigue and visual discomfort), and well-being (presence and satisfaction). The results of

these three studies can contribute to determining appropriate display curvatures for monitors or TVs.

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