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A Research on Curved Display Comparing to Flat Display Regarding Posture, Tilt Angle, Focusing Area and Satisfaction

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Objective: This study is conducted on the differences between flat and curved displays with respect to location of focused points, posture and satisfaction as well as preferred tilt angles.

Background: In order to avoid physical and eye fatigue caused by misplayed sitting posture, many studies have asserted that the display requires appropriate location, size and tilt angle as well as curvature. However, most studies have focused on the work environment and the results are varied in the extent.

Method: Eye height data in sitting posture were collected from 30 participants. Participants selected the most comfortable viewing angle within the range from 0° to 12° while watching videos for both curved and flat display. Then, physical and eye fatigue and overall satisfaction were subjectively evaluated. Lateral diagram describing viewing display condition was set and used to develop linear models for expecting the preferred tilt angle.

Results: Due to sitting in the natural viewing posture rather than upright, the eye height is lowered to about 4.6 centimeters, on average, for both displays showing no significant differences. In contrast, preferred angles for the two displays are significantly different and this can be interpreted that curvature vary the points focused. Two linear models as functions of sitting eye height are developed to expect preferred tilt angle for each display. Based on the result of overall satisfaction evaluation, curved display is statistically better than flat display.

Conclusion: The results show that flat and curved displays are significantly different expect for the viewing posture. However, reasons for preferring curved display are not accurately factorized and the linear models are limited in the experiment condition such as size of display, distance between display and viewer and other physical environmental factors. Further studies on curved displays under more various conditions are required.

Application: This study can contribute to use of the curved display in various way.

Keywords: Curved display, Viewing angle, Display curvature, Vision, Tilt angle

1. Introduction

As technology being developed, it is possible to produce more diverse visual display terminal (VDT). Accordingly, many studies have been conducted on VDT focusing on size of screen, resolution, screen height settings or distance between eyes and

Screens (Rempel, Willms, Anshel, Jaschinski, & Sheedy, 2007; Seghers, Jochem, & Spaepen, 2003; Shin and Hegde, 2010).

In order to reduce eye fatigue, six extrinsic eye muscles control the position of each eye in general (Kroemer and Hill 1986). The muscles can be fatigued when displays for TV or computer or mobile phone screens are located inappropriately, and the head moves to locate the eye on where the fatigue can be relieved. If the user keeps inappropriate posture at this time, his/her neck may be too strained. In the office, workers do their job by operating computers. VDTs, in particular, is very important regarding its location, inclination, resolution, and many studies related have been conducted on size, resolution, relative location of user and the display, inclination, and so on. According to the result, the screens which had larger size and higher resolution bring more effective results (Shupp, Andrews et al., 2009). Also, it was found that eye fatigue tended to occur more when the display was located closer than the user prefers (Jaschinski, Heuer et al., 1998). Regarding the height of the display, the results of studies are not consistent, but they agreed to conclude that the height of displays has to be lower than user eye height to relax eye muscles and neck muscles (Grandjean, Hünting et al., 1983, Straker and Mekhora 2000, Fostervold 2003). Similar to the studies related to the height, an inclination of display which changes as a location of displays changes differs in degree between researches (Straker and Mekhora 2000). Nonetheless, those researches have been limited to the use of displays in office where the 'efficiency first' principle exists, being lacking in general use out of the office.

Looking at the flow of developments and researches of the technology for VDT, they have been focused on size, resolution or 3D visualization, but they are being extended to connectivity between devices or curvature of the screen (Han 2013). According to the report written by Han (2013), curved TV screens attracted public attention most at 2013 Consumer Electronics Show (CES), which is the biggest international exhibition for home appliance and where the most recent technologies for home appliances are unveiled. The researches related to the curved display have not been needed desperately since the product is hard to realize because of technical problems. Now the product has been released without demonstrating the superiority.

The curved displays differ from the ones with flat screen; watching the flat displays, the users perceive different viewing distances when they gaze at the center of the display and the edges of it, and this may induce ocular torsion. As illustrated in Figure 1, this difference can be reduced by watching curved display. With flat displays, the viewing distance when a user gazes at the edge of the screen is getting more differed from the distance he/she gazes at the center as the size of screen increases. This phenomenon occurs less with a large, curved screen. According to a previous study conducted on the curved screen of which curvature was formed by locating several flat displays, it was found that the display with curvature was more effective than the flat one (Shupp, Andrews et al., 2009). This result proved curved displays had the reduction effect of the difference of viewing distance, but the experiment was limited to the office. Moreover, the radius of screen was 762mm, which cannot be applied to the use of displays in general. Comparing computer displays, TV is not same in terms of size and viewing distance as well as the

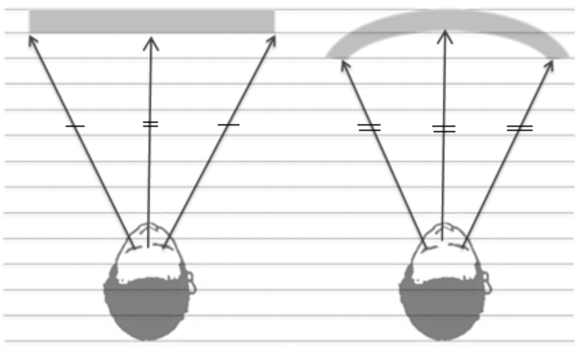


Figure 1. Difference of viewing distance between flat and curved TV

purpose; TV has larger screen and longer viewing distance than computer VDT.

Therefore, more studies need to be conducted on displays used more generally, such as TV including curved displays, in particular. As mentioned previously, the studies related to inclination of computer displays for the use in work environment have not been agreed on the results and it is hard to apply to large displays.

In this experiment, curved and flat displays which can be used as TV in households, identical in the size (55 inches), were compared in terms of changes in postures during watching TV, preferred tilt angle, gaze point and overall satisfaction and analyzed.

2. Literature Review

In order to compare two types of TV, evaluation factors were needed to be selected, so investigation into the literature related to TV and the watching behavior was done.

Watching TV, people normally concentrate their attention to faces, hands or the various movements of them (Smith 2012). The main subject should be aligned on the intersection of the vertical and horizontal lines, which divide the screen into nine equal parts for better composition, and this rule is called "Rule of Thirds" (Grill and Scanlon 1983, Krages 2005). However, it is sometimes hard to keep the subjects on the intersections when the display plays videos such as sports video because the subjects move very dynamically. In such cases, the users tend to gaze at the center of the display on average (Jin 2013).

A location of a gaze point depends on the gaze direction of which the virtual line is perpendicular to the screen surface. If a tilt angle is defined as the difference of angle between the vertical line and the display, the angle changes as the gaze point changes. In other words, there is only one angle corresponding to a particular watching posture if eyes do not look upward nor downward, so the tilted angle of display will affect the watching posture. Also, fatigue can occur during VDT use (Seghers et al., 2010), and TV is not the exception. According to the research done by Jin (2013), viewing satisfaction of TV drops as physical fatigue occurs implying watching posture is directly related to the viewing satisfaction.

Based on the contents above, the experiment was designed to compare curved and flat TV displays for the viewing satisfaction considering neck and eye fatigue, viewing posture, the main gazing point, and optimum tilt angle.

3. Method

3.1 Hypothesis

The null hypothesis and alternative hypothesis of this study was as follows.

H_0: There is no significant difference for factors related to watching TV between curved display and flat display.
H_1: There is significant difference for factors related to watching TV between curved display and flat display.

3.2 Subject

The experiment was conducted targeting 30 participants whose ages were between 20 and 50 years old (male: 24, female: 6). 'Eye height, sitting' is defined as the vertical distance from the sitting side to eye point as shown in Figure 2. In this experiment, statistics data for eye height (sitting) provided by Size Korea's human dimensions research and distribution project sponsored by

Ministry of Knowledge Economy was used. When eye height (sitting on the given couch) was defined as the vertical distance from the bottom to eye point, 451.5mm, the height of the chair, was added to eye height (sitting on the given couch) of Korean population to compare the eye height (watching) of the subjects group with ones of Korean population.

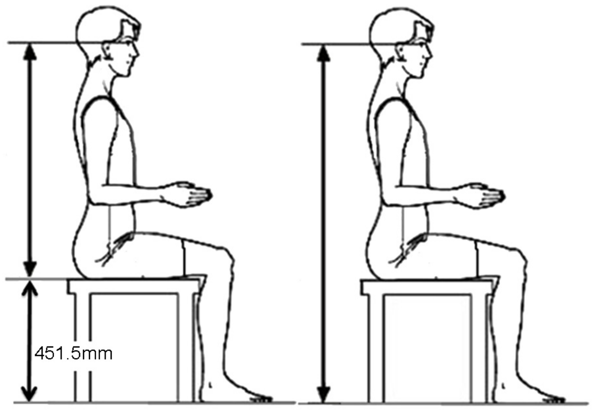


Figure 2. Description of Eye Height, sitting (left) and Eye location, sitting on the given couch (right)

3.3 Variables

Control variables were TV size, location, and distance between TV and subjects, and independent variable was type of display shape; flat and curved. Dependent variables were postures while watching TV preferred tilted angle, main gazing point, and TV viewing satisfaction. The experiment was designed to analyze the effect of type of display shape on each dependent variable.

3.4 Apparatus

A jig device which could adjust the tilted angle continuously by wireless remote control was developed for this experiment. 55 inch flat TV and curved TV whose curvature rate was 5000mm were placed on the jig device, and the preferred tilted angles were measured. The angle could be tilted from 0° to 12° and it was recorded every second and saved to text file (Figure 3).

3.5 Procedure

The experiment was conducted targeting flat and curved display. First, after subjects were seated in the 451.5mm seat height chair and the eye heights (sitting) were measured and guided to watch different videos during over 12 minutes. By a pilot study, the videos were confirmed that they have no significant difference in terms of eye's fatigue, satisfaction, immersion among themselves, so the effect of the videos could be prevented.

The distance from TV and chair was 3,400mm. A grid was marked on the other side of the wall, so the degree how much subjects moved could be calculated quantitatively. While viewing TV, subjects adjusted the tilted angle freely and found the optimal angle before the videos ended.

Also, the angle data was stored in real-time to figure out the angle adjusting pattern while the video was playing. Then the viewing satisfaction, visual and physical fatigue, and viewing immersion for the flat display TV were surveyed through questionnaires.

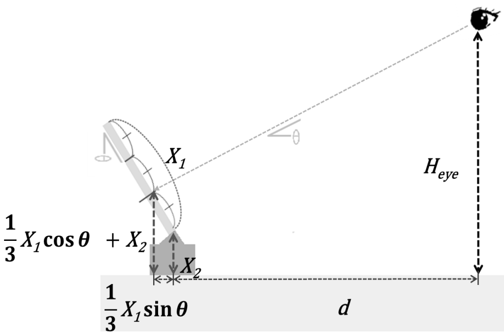
After the experiment for the flat display TV, the same experiment for the curved display TV was repeated. Also, lateral view was taken by video recording to analyze the changes and patterns for the postures during the experiment.

Figure 3. TV, angle-adjustable jig and recording system

3.6 Expecting viewing angle

The tilted angle is determined by several factors. If the gazing points are same when watching TV, the elements that change the angle is eye height (seating), TV height, TV length, and distance from TV.

In this experiment, it was assumed that the gazing point was at the lower trisecting line of the screen and the center of the screen applying golden rule. Figure 4 is the model under the assumption that the gazing point is at the lower trisecting line. In this case, the tilted angle θ could be calculated by equation (1). When the gazing point varies, it can be calculated by changing a coefficient of the TV length (X_1). When the gazing point is at the center of the screen, the coefficient of X_1 should be 1/2.



θ : tilted angle
X_1 : TV length
X_2 : TV height
H_{eye} : Eye height, sitting
d : Distance from TV

Figure 4. A diagram when focusing on the lower trisecting line

$$\tan\boldsymbol{\theta} = \left\{\frac{H_{eye}-(\frac{1}{3}X_1 cos\theta+X_2)}{\frac{1}{3}X_1 sin\theta+d}\right\} \quad (1)$$

θ : tilted angle
X_1 : TV length
X_2 : TV height
H_{eye} : Eye height, sitting
d : Distance from TV

A relationship between the eye height (sitting) and the tilted angle when the gazing point was at the lower trisecting line was derived by transforming the equation (1). The results were the same as equation (2).

$$\theta_{exp} = 0.1599\ H_{eye} - 11.37 \quad (2)$$

θ_{exp} : expected tilt angle
H_{eye}: Eye height (sitting on the couch)

Like the above, a relationship between the eye height (sitting on the couch) and the tilted angle when the gazing point was at the center of the screen was derived. The results were the same as equation (3).

$$\theta_{exp} = 0.1607\ H_{eye} - 12.85 \quad (3)$$

θ_{exp} : expected tilt angle
H_{eye}: Eye height (sitting on the couch)

These results showed that eye height (sitting on the couch) and the preferred tilted angle has perfect linear relationship regardless of the gazing point, when assuming that TV length, height of the chair, and the distance from TV are same.

4. Results

4.1 Sample representativeness test

In order to verify representability of the participant group, eye height during viewing TV (eye height, sitting on the given couch) of the participant group was compared to those for Korean population as shown in Table 1.

The Shapiro-Wilk test showed that the eye height of the participants sitting on the given couch were normally distributed (p = 0.642). However, the distribution of the eye height of Korean population had approximately 10cm greater than the one of participants. In the experiment, the males outnumber the females four to one resulting in bias effect in gender. Considering the effect, the difference became even larger. Later, it was found that the phenomenon was caused by an instrument effect, which is slumping effect of the couch.

In addition to the analysis of video images, an extra experiment was conducted for verifying degree of slumping and analyzed. The result indicated that the eye height, sitting on the couch, decreased 11cm, on average, although the values varied depending on weight and sitting hip breadth of the participants. Reflecting this, the difference of eye height, sitting on the couch, between two groups could be reduced to 0.7mm by lowering eye height 11cm and adjusting the gender ratio (4:1) as Figure 5 illustrates. That is, the result of the experiment can be applied to Korean population through verifying the representability of the participant group.

Table 1. Distribution of eye height, sitting on the given couch, Korean population (2004)

	Participant group (N=30)	Korean population (N=6005)	
Distribution	Eye height, sitting on the given couch (cm)	Eye height, sitting on the given couch (cm)	Difference (cm)
Maximum	123.0	135.8	12.8
75th Percentile	116.0	126.5	10.5
50th Percentile	114.0	123.2	9.2
25th Percentile	110.9	120.1	9.2
Minimum	103.0	101.6	-1.4

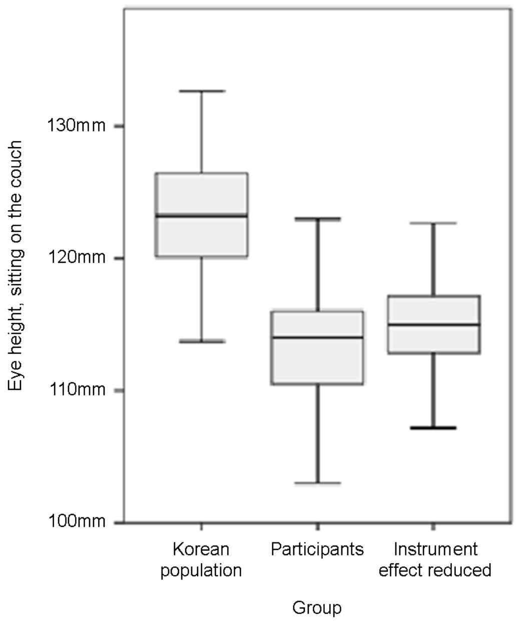


Figure 5. Box plot for eye height, sitting on the couch, of participant group and Korean population, and for the corrected value of participant group

4.2 Change in posture and eye height

Figure 6 shows a sitting posture in general (left) and the posture sitting on the couch during TV viewing (right). By analyzing changes in eye height measured before and after the experiment, it decreased 4.5cm and 4.6cm for the flat display and the curved one, respectively. This was because the posture during TV viewing differed from general sitting posture leading to the viewing distance increased by about 10cm. Also, paired sample tests were done to inquire whether the curvature affected the eye height and the result showed no significant difference (p = 0.831). Through the result, it was concluded that the effect of the flat and the curved displays were not different.

Figure 6. Posture differences

4.3 Preferred tilted angles

According to the data on the most preferred angle of TV for each participant, for both displays, the participants were commonly divided into two groups, the one preferring display not tilted and the other preferring tilted display. Regarding degrees of tilt of them, the displays showed differences; according to the results of the Shapiro-Wilk test, the tilt angles were distributed normally centered at 6~7° for the flat TV (p = 0.127), whereas the angle between 2° and 4° were selected most and the distribution was skewed to the left for the curved TV (p = 0.68) as shown in Figure 7 and Figure 8. Similarly, the average preferred angles of the flat TV was greater (5.67°) than the curved one (4.56°) According to paired comparison test, the two TVs differed in the preference of tilt angles (p = 0.021, α = 0.05).

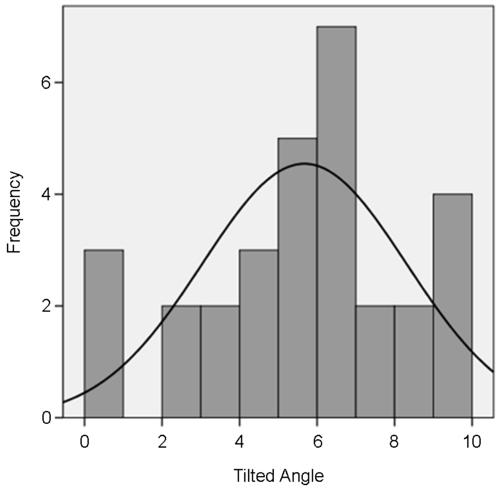


Figure 7. Frequency histogram, Flat TV

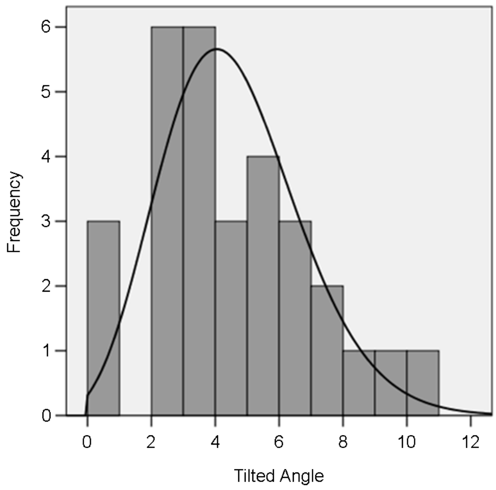


Figure 8. Frequency histogram, Curved TV

4.4 Difference in Focused points

Realistically, there is a gap between the preferred angles selected by the participants and predicted angles. To maximize accuracy of predicting preferred tilt angle, two cases were compared; one case assuming the gaze point was located at the center and another case assuming the gaze point was at the lower trisecting line. The predicted tilt angle was calculated by using equation (1), section 2.4., and the result is on Table 2. This allowed concluding that the flat display was more likely to correspond to the gaze point at the lower trisection and the curved display was likely to do to the point at the center. Table 3 represents the variables of Equation (1) and their values. During the experiment, the distance between the couch and the display is 3,400mm, but 100mm was added to it in calculating the distance between the eyes and the display (*d'*) as mentioned in section 4.2.

Table 2. Probability that the absolute value of error is less than 2° for each focus point

	Focus point	Probability that the absolute value of error is less than 2°
Flat display	Center	0.50
	Lower trisecting line	0.67
Curved display	Center	0.64
	Lower trisecting line	0.37

Table 3. Independent variable and constants used

Variable/Constants	Description
X_1: TV length	Given, 704mm
X_2: TV height	Given, 511.5mm
H_{eye}: Eye height, sitting	Independent Variable
d': Actual distance from TV	Given, 3,500mm

The accuracy increased when the angles are predicted by using Equation (2) and (3) for the flat TV and for the curved TV, respectively, since the participants gazed at the lower trisection of the former and at the center of the latter. This means the preferred tilt angle for the flat TV is greater than for the curved one, in general.

4.5 Satisfaction level

According to the survey on satisfaction measured in a 100-point scale, the curved TV satisfied the participants more than the flat TV with the average value 82.2 and 76.3, respectively. Having with standard deviation of 11.14 (flat) and 8.84 (curved), it can be inferred that the flat TV induced more variance between the individuals than the curved TV.

Also, the significant difference of satisfaction between the two displays was found by performing a paired t-test was performed (p = 0.004, α = 0.01).

5. Conclusion

In this study an experiment was conducted to compare flat display TV with curved display TV. TV viewing posture changes, preferred tilted angle, and preference for the type of display were probed.

The results tested the following hypothesis established in 3.1. Null hypothesis was accepted for the TV viewing posture, and rejected for the TV preferred tilted angle, main gazing point, satisfaction.

Paired-t test was conducted to analyze the changes in viewing postures. The results showed that there was no significant difference between two types of displays. So it was figured out that curvature of the display doesn't affect the viewing posture. In this experiment, there was no particular behavior except the change in eye height (sitting). These results might be caused by viewing time not long enough and unnatural behavior due to the video recording. This point could be the remaining challenges of this study.

For the preferred tilted angle, the results were different between curved and flat display. Mean angles of the flat and curved display were 5.67° and 4.56° respectively. Also the distribution of the preferred angle for the curved display was tended to be less than the one for the flat display. This result was consistent to the prediction of the preferred angle meaning the gaze points of each display are different; the curved display attracted gaze mostly to the middle of the screen, but the gaze point of the flat one was located at the lower 1/3 point. Gazing at the center helps to look at the entire display at a time. Applying concept of useful field of view (UFOV), the advantage of the gaze point at the center can be explained. UFOV is defined as the area that the visual information can be extracted at a brief glance without eye or head movements. Assuming the UFOV is constant, it covers more area on a display when the gaze point is at the center, comparing when it is not. Therefore, it can be interpreted that the tendency of users gazing at the center of curved display is more helpful in viewing TV as whole without moving other body parts. This may be one reason explaining higher score on the curved display.

Moreover, the preferred angle of flat display is always greater referring to Equation (2) and (3) considering reasonable eye height (< 1,850 cm), yet it is limited to the experimental conditions such as height of the couch or the distance the display. This process can be applied to other cases with different environmental conditions by modifying coefficients and constants.

This study is worth because it suggests the model that can be modified according to conditions and applied to general population. Also, the model is linear, so not many data is required to modify the model.

For future studies, slumping effect of a chair resulting in lower eye height should be considered for experimental design. Later, in addition to a three-dimensional effect, reduction in the viewing distance and newness, more concrete reasons why the curved TV satisfies users more can be inquired by future studies.

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