Contrast effect in evaluating the sense of presence for wide displays

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Abstract — To evaluate the relationship between visual angle and the sense of presence for wide displays, two experiments were conducted in which the visual angle (ranging from 30 to 100°) was manipulated as a between- and within-subjects factor, respectively. Two-hundred subjects participated in both experiments. In the within-subjects evaluation, presence scores increased as the visual angle widened, while those in the between-subjects evaluation did not increase significantly for a wide visual angle. It can be concluded that "contrast effect," *i.e.,* a bias caused by comparing different visual angles, greatly affects the ratings of sense of presence.

Keywords — *Presence, contrast effect, ultra-high definition, visual angle, camera field of view.*

1 Introduction

Large, high-definition displays are becoming the preferred viewing media in video. It is generally believed that a wider visual angle increases the sense of presence for the viewer. Prothero *et al.*[1] conducted an experiment comparing two viewing conditions with horizontal visual angles of 60 and 105° and found a significantly higher presence effect for an angle of 105°. Emoto *et al.*[2] manipulated horizontal visual angles ranging from 30 to 100° and found that presence increased as the horizontal visual angle widened. However, these experiments were conducted using within-subjects designs, so a "contrast effect" caused by comparing different visual angles might have affected the ratings of presence. (Note: the term "contrast effect" means any bias caused by comparing the levels of a within-subjects factor, this is not "display contrast.") Furthermore, there is very little research that takes into account the effect of the camera field of view (hereafter called camera FOV). When the camera FOV of a displayed image matches the visual angle, viewers could feel "as if they were there," perceiving the same perspective as in the real world. To evaluate these effects, two experiments were conducted, one using between-subjects design and the other using within-subjects design for visual angle.

2 Methods

2.1 Subjects

The same 200 adults (98 female, 102 male) participated in two experiments: Experiment 1 used a between-subjects design and Experiment 2 used a within-subjects design. In Experiment 1, the subjects were divided into five groups of 40 subjects for each visual angle to make the ratio of men and women in each group as close to equal as possible. The average age of the participants was 26.3 years (standard deviation = 6.97 years; range 17–45 years). We required all screened participants to have a visual acuity of 0.14 logMAR or higher without glasses.

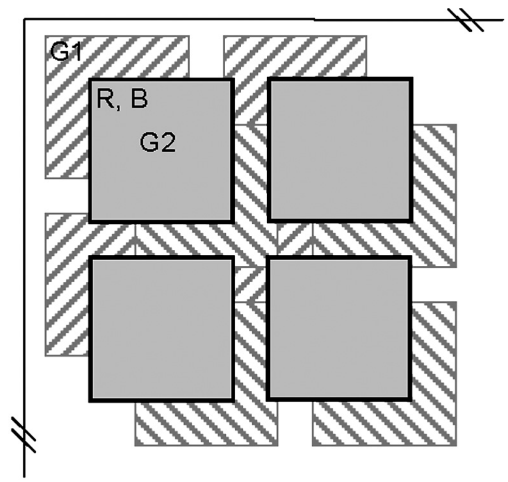

FIGURE 1 — Pixel structure of ultra-high-definition system.

2.2 Apparatus

In both experiments, an ultrahigh-definition display system (NHK, Japan)[3] was used to present images for evaluation. The system achieves high resolution using the pixel offset method, in which two 2160 × 4320-resolution LCoS (liquid-crystal–on–silicon) panels (G1 and G2) are offset diagonally by one-half pixel for the green channel, quadrupling the horizontal and vertical resolution of HDTV (1080 *p*). For each red and blue channel (labeled R and B), one 2160 × 4320 panel is used. Each panel has internal 12-bit gamma tables to reproduce the input 8-bit signals accurately. The refresh (frame) rate is 120 fps progressive.

Figure 1 shows the pixel structure of the system, and Fig. 2 shows the reproducible spatial frequency characteristics based on the pixel structure. The spatial frequency characteristic for G1 and G2 is diamond shaped, extending the Nyquist frequency to 4320 TV lines horizontally and vertically, while those for R and B are square-shaped, limited to within 2160 TV lines.

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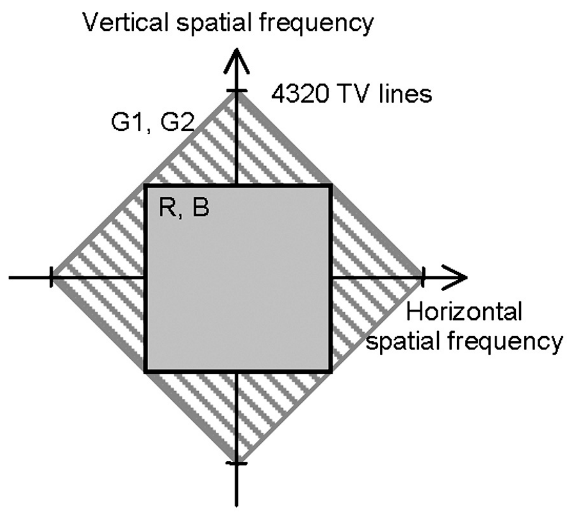


FIGURE 2 — Spatial-frequency characteristics of ultra-high-definition system.

The gamma of the projector was set to 2.2 with a black level of 16 and knee point of 235 in order to obtain the average luminance in conformity with ITU-R BT.709.[4] Figure 3 shows measured and simulated input-output characteristics of the display system. The peak white-level luminance was 60 cd/m^2 and the black-level luminance was 0.05 cd/m^2 at a quarter of the screen height; the screen luminance fluctuated from 58% to 109% of that level.

The color space of the display system entirely covered the sRGB,[5] which was based on ITU-R BT.709[4] and is close to the AdobeRGB.[6] Figure 4 shows the color space of the ultra-high-definition display system.

2.3 Materials

Eight evaluation images were used (4 scenes × 2 camera FOVs) in both experiments. Figure 5 shows the evaluation images used in both experiments. The luminance distribution of each image is also shown next to the image. The abscissa axis represents a luminance scale in cd/m^2. The images were still scenery pictures that were photographed with a 4 × 5-in. large-format camera and then digitized using a drum scanner. Each scene was shot twice at the same location, with a camera FOV of 60° (Schneider Super-Angulon AN 6.8/90 mm with a center filter designed to compensate for the fall-off of illumination for this lens) and 100° (Schneider Super-Angulon XL 5.6/47 mm with a center filter for this lens). These lenses have small distortion values of less than ±0.5%. The images were digitized at 2× oversampling with a drum scanner to have an aspect ratio of 9:16, placing the height of the optical axis at a quarter of the picture height, as shown in Fig. 6. Each image was scaled down to five different sizes (1080, 2160, 2880, 3456, and 4320 TV lines). Black pixels were padded around the images to make them have 4320 TV lines, keeping the axis of lens at a quarter of the screen height (see sample images in Table 1).

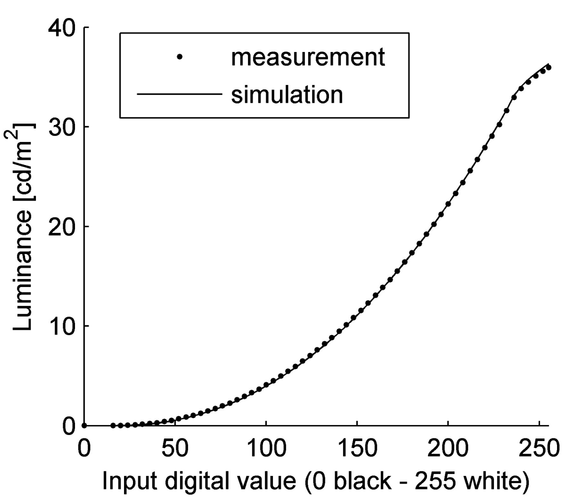


FIGURE 3 — Input–output characteristics of ultra-high-definition display system.

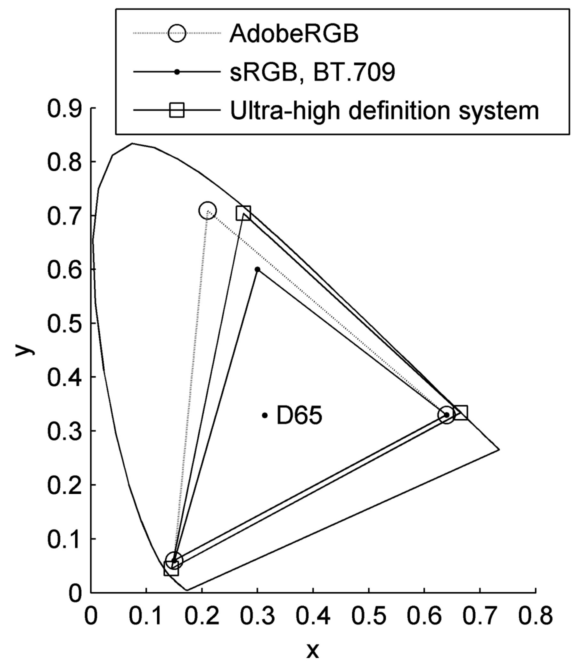


FIGURE 4 — Color space of ultra-high-definition display system.

2.4 Procedure

As is recommended for image-quality evaluation, we set the viewing distance in our experiments at 4.2 m, the point at which the structure of scanning lines is just discernable for those with 20/20 vision, known as the viewing distance for subjective assessment of image quality.[7,8] Figure 7 shows a schematic depiction of the viewing condition in the two experiments, and Table 1 shows the viewing conditions of each image size. Under these viewing conditions, the visual angles for the five image sizes ranged from 33.2 to 100°. These experiments were conducted in a completely dark TV studio surrounded with black curtains.

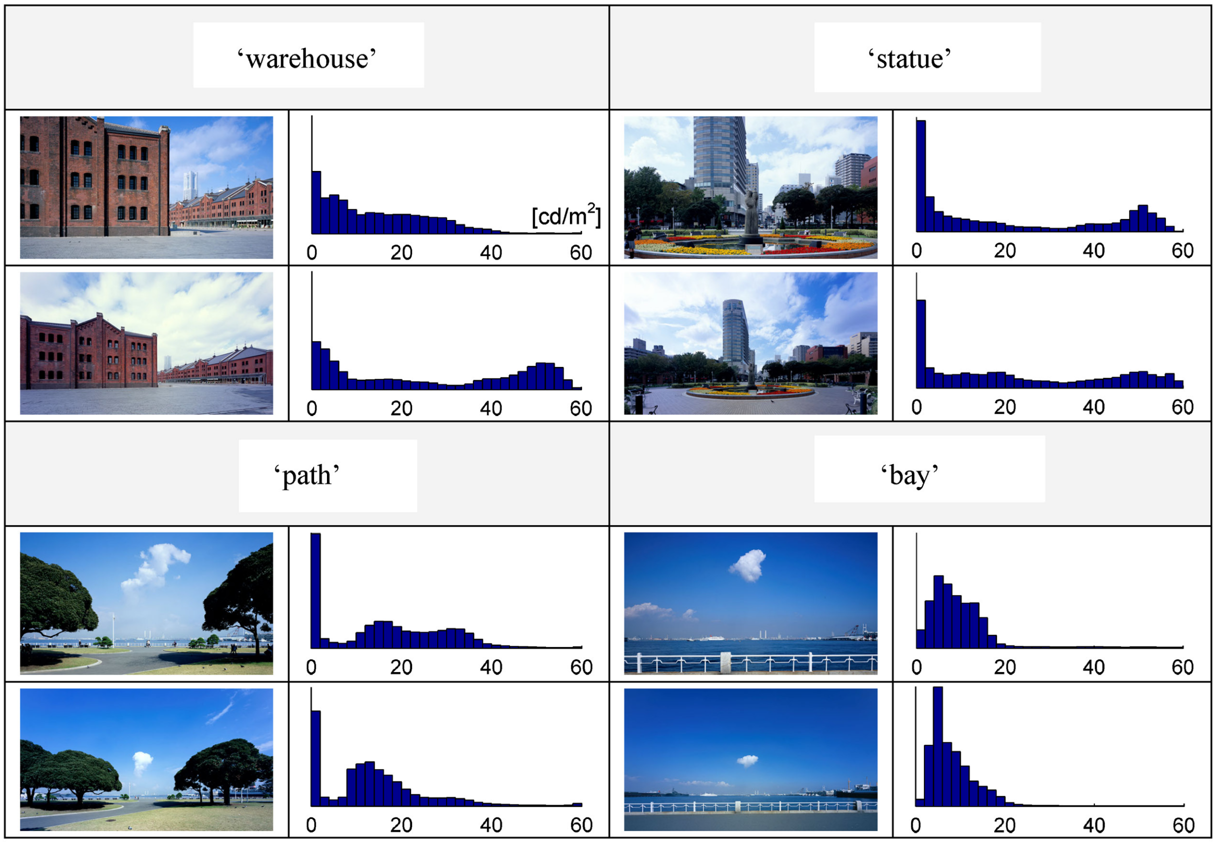
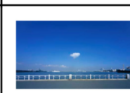


FIGURE 5 — Images used for evaluation and their luminance distributions. Upper images: Camera field of view of 60°. Lower images: Camera field of view of 100°.

Presence was defined for the subjects as "a sense of being there" in a displayed scene or environment.[9] The subjects were then instructed to evaluate the degree of "perceptual illusion of non-mediation" after they viewed each image.[10] Each subject rated the presence of the images while standing at the indicated viewing distance without a fixed gazing point. Each evaluation image was presented with a quarter of the picture height being at the subject's eye level, under which the horizon was reproduced at the subject's eye level.

All study participants completed Experiment 1, followed by Experiment 2. Before these experiments, each subject was trained to get acquainted with the scoring scale by rating the presence of some images of the same visual

TABLE 1 — Viewing conditions.

Horizontal viewing angle (°)	33.2	61.6	76.9	87.3	100
Relative viewing distance (× image height)	3.0	1.5	1.125	0.9375	0.75
Image size* (in.)	112.5	225	300	360	450
Number of scanning lines* (TV lines)	1080	2160	2880	3456	4320
Sample images					

* Image size and number of scanning lines indicate those of images without a black border.

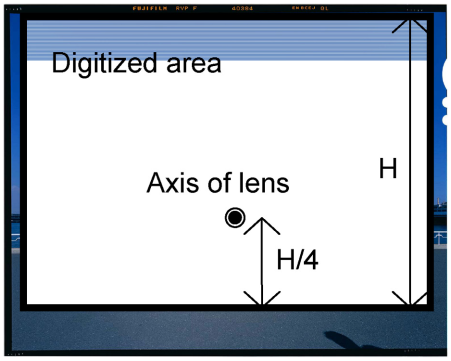


FIGURE 6 — Digitized area from 4 × 5-in. large-format film.

angle as used in Experiment 1. In Experiment 1, the five horizontal visual angles were manipulated as between-subjects factors; each group of 40 subjects evaluated each visual angle. The presentation order of the eight pictures was identical for all subjects to avoid any different order effect of the pictures across subject groups. The order was set to avoid consecutive viewing of the same scene and camera FOV, as warehouse (60°), path (100°), bay (60°), statue (100°), path (60°), warehouse (100°), statue (60°), and bay (100°). In Experiment 2, all subjects evaluated every visual angle. All of the eight pictures were consecutively presented at each visual angle with the same presentation order used in Experiment 1. The order of visual angles was randomized. Each subject viewed the evaluation image for 10 sec, followed by a 10-sec gray screen image. The subjects evaluated presence using 10-cm visual analog scales (graduated in centimeters), as shown in Fig. 8. The scales ranged from a low extreme of "I didn't feel presence at all" to a high of "I felt presence extremely."

3 Results

The effects of visual angle, picture image, and camera FOV on presence were examined using multivariate analysis of variance (MANOVA) and Pillai's trace statistics. Non-pooled separate error terms were used for simple effect tests.

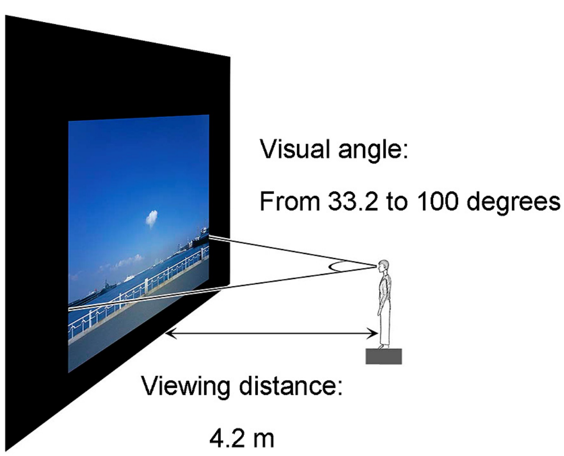


FIGURE 7 — Schematic depiction of the viewing conditions.

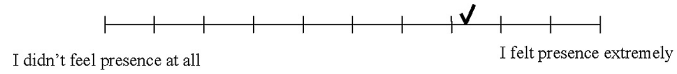


FIGURE 8 — Evaluation scale.

Figure 9 shows the mean scores of presence for each picture used in Experiment 1. The Shapiro-Wilk normality test showed that the distribution of scores for each picture does not differ significantly from a normal distribution, except for the warehouse (60°), statue (60°), and bay (100°) pictures. Levene's test for equality of variances showed no significant difference in the score variances for the eight pictures. A 5 × 4 × 2-mixed MANOVA was conducted with visual angle as the between-subjects factor and picture and camera FOV as within-subjects factors. The mixed MANOVA found significant interactions between camera FOV and picture [$F(3,193) = 26.417$, $p < .001$]; sub-effect tests were then conducted for each picture. The main effects of camera FOV were significant for warehouse ($F(195,1) = 34.521$, $p < 0.001$), for statue [$F(195,1) = 29.076$, $p < .001$], for path [$F(195,1) = 18.207$, $p < 0.001$], and for bay [$F(195,1) = 7.227$, $p < 0.01$]. The interactions between camera FOV and visual angle were not statistically significant for warehouse [$F(195,4) = 1.650$], for statue [$F(195,4) = 0.084$], for path [$F(195,4) = 0.443$], or for bay [$F(195,4) = 0.669$]. The main effects of the between-subjects factor (visual angle) were significant for warehouse [$F(195,4) = 9.978$, $p < 0.001$], for statue [$F(195,4) = 9.889$, $p < 0.001$], for path [$F(195,4) = 8.374$, $p < 0.001$], and for bay [$F(195,4) = 16.364$, $p < 0.001$]. Tukey's HSD (honestly significant difference) multiple comparison test showed significant differences of presence between the visual angle of 32.2° and the other angles. For the bay picture, presence at the visual angle of 76.9° was significantly higher than the other angles ($p < .001$ for 33.2°, $p < 0.01$ for 61.6°, $p = 0.043$ for 76.9°, $p = 0.055$ for 100°). For the other pictures, there were no significant differences between the visual angles from 61.6 to 100°.

Figure 10 shows the mean scores of presence for each picture in Experiment 2. The small confidence intervals are due to using as many as 200 participants for each visual angle. Therefore, the statistical significances of these small effects are much less important in comparison with those of Experiment 1.

4 Discussion

In our study, we examined the relationship between presence and visual angle. In a between-subjects analysis of visual angle factor, presence was significantly higher at the visual angle of 76.9° than the other angles for the bay picture, and there was no significant difference between visual angles from 61.6 to 100° for the other pictures. In a within-subjects analysis of visual angle, on the other hand, presence was evaluated to be higher as the visual angle increased. According to the subjects' reports, presence was felt to be enhanced when viewing large visual-angle images after small visual-angle images. This means that "contrast effect,"

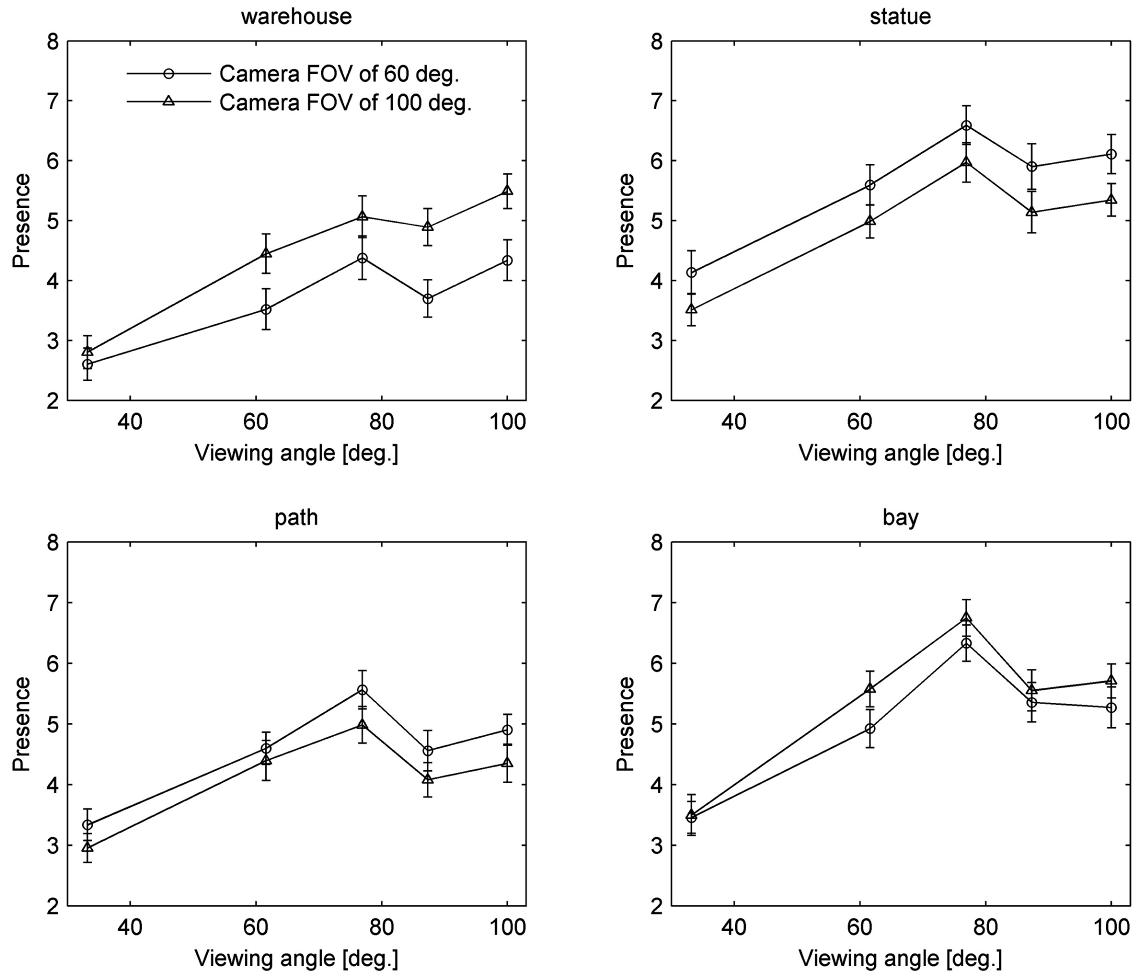


FIGURE 9 — Mean scores (and standard errors of the mean) of presence – Experiment 1.

which is any bias caused by comparing different levels in within-subjects design, affected the results especially for wide visual-angle images, consistent with the report by Freeman *et al.*[11]: "direct subject assessment of presence in naïve observers is potentially unstable and subject to prior experience and task expectations." In Experiment 2, the ratings for wide-visual-angle images might have been enhanced because the subjects perceived relatively more details of the objects in the image that had been magnified with higher resolution (*i.e.*, using more pixels).

One question is the decrease of presence at the visual angles of 76.9 and 100°. As mentioned in the Results section, the distribution of the scores for each of these visual angles does not differ significantly from a normal distribution and no significant difference in variances was found between the five visual angles. Therefore, it is assumed that these groups of subjects were homogeneous in evaluating presence and it is unlikely that the decrease of presence was directly related to a different use of the scoring scale by different groups of subjects. According to the subject reports for the wide visual angles in Experiment 1, they felt tightness or oppressiveness in the displayed large images. The feeling might be caused by peripheral image objects being distorted by the large viewing angle: this distortion appears "just on the screen surface" to the subjects. This negative effect could have degraded presence, especially for the bay picture, most of whose objects were located farther than the viewing distance in the image. However, further study is needed to confirm the relationship between negative effects and presence.

Matching camera FOV with visual angle does not seem to enhance the sense of presence, contrary to our expectation. In Experiment 1, the main effects of camera FOV were significant, while the interactions between camera FOV and visual angle were not statistically significant. This indicates that presence ratings might have been influenced by the picture composition rather than by matching the visual angle and camera FOV. Moreover, the presence of statue and bay pictures for a 60° camera FOV was constantly higher than seen with the 100° camera FOV, as opposed to the other pictures, and these are the first four pictures in the picture presentation order used in Experiment 1. Therefore, picture presentation order might have highly affected the evaluation.

In Experiment 2, the differences of scores between two camera FOVs were smaller than those in Experiment 1, and scores for the 60° camera FOV were slightly higher than those of the 100° camera FOV. This might be related to the

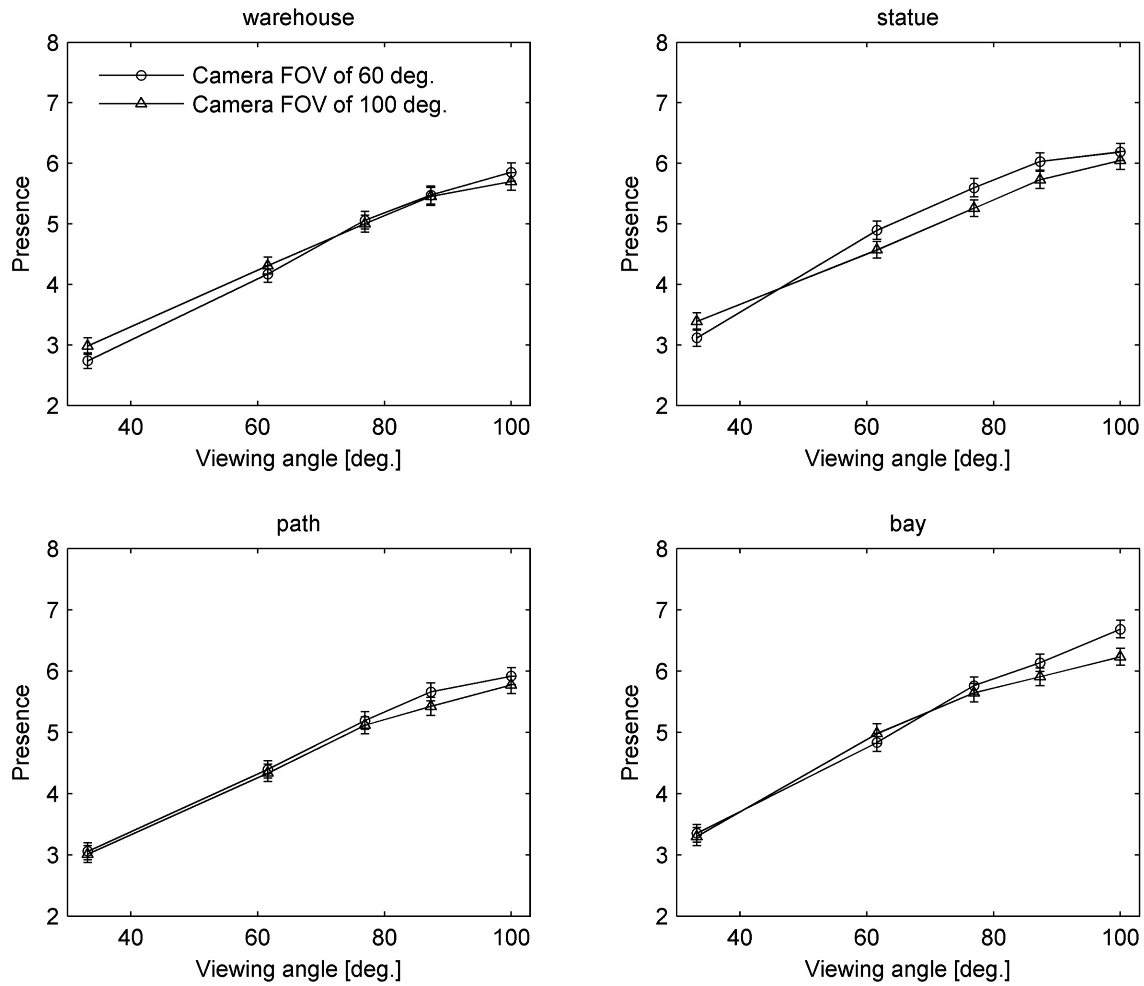


FIGURE 10 — Mean scores (and standard errors of the mean) of presence – Experiment 2.

magnification changes mentioned above, because every object in the 60° camera FOV appears bigger with higher resolution than did those in 100° camera FOV.

5 Conclusions

We evaluated the relationship between visual angle and the sense of presence for wide displays. In the within-subjects evaluation, presence scores increased as the visual angle widened, while those in the between-subjects evaluation did not increase significantly for the visual angle above about 80°. We conclude that contrast effect highly affects the rating of presence; therefore, visual angle should be carefully manipulated to evaluate presence for large displays.

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