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Viewers' optimization of preferred viewing distance by spatial resolution of TV display ☆

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ABSTRACT

We have shown in a previous paper that preferred viewing distance (PVD)—a viewer's favored distance from which to watch TV in the home viewing environment—is shorter when watching a high spatial resolution 4k TV than on a high-definition TV (HDTV). PVD depends on (1) the spatial resolution of the viewer's object of interest in the relevant scene, (2) whether viewers have sufficient time to optimize their PVD, as with still images, and (3) whether they are appropriately encouraged to pay attention to the object at hand on the screen, by, for example, narrative instructions. In this paper, we demonstrate that an analogous result is obtained in a comparison between high spatial resolution 8k TV and HDTV: The PVD of viewers for 8k TV is shorter than that for HDTV. This result suggests new possibilities for high spatial resolution TV, such as novel applications and TV programs that are especially developed for 8k TV systems.

1. Introduction

The ultra-high-definition television (UHDTV) system [1,2] is designed to have a spatial resolution of 4320 scan lines × 7680 horizontal pixels, and is often referred to as an "8k system" owing to its number of horizontal pixels. Such high spatial resolution is required so that viewers do not experience image degradation or image blurring when watching an 8k UHDTV with a horizontal field-of-view (FOV) as wide as 100 deg. Viewers thus feel as though they are in the displayed space [3,4]. This sensation – often referred to as a sense of presence or "being there" – can be experienced by viewers watching TV images of sufficiently high quality.

When producing TV programs appropriate for an 8k UHDTV with high spatial resolution, camera techniques may change accordingly from traditional zoom-ins that show viewers details of an object of interest. In addition, camera orientations that retain the object within the camera frame may decrease. This decrease in camera motion may contribute to avoiding visually induced motion sickness in viewers [5]. Avoiding excessive camera movement or changes in camera orientation (i.e., panning and tilting) is desirable for reducing the risk of motion sickness. Fewer zoom-ins may also change viewer behavior, including viewers' preferred viewing distance.

In designing a TV broadcasting system, two TV viewing distances should be considered: the design viewing distance (DVD), and the preferred viewing distance (PVD).

The DVD is important for TV broadcasting system assessment, such as the subjective evaluation of image quality and the performance evaluation of audio-visual equipment used in the broadcasting studio. Therefore, it is included among the standard viewing conditions recommended by the International Telecommunication Union Radiocommunication Sector (ITU-R) [6]. In HDTV assessment, the standard DVD is three times the image height (3 H). Although the DVD for UHDTV systems has not yet been standardized, it can be defined as the distance from which viewers with a visual acuity (VA) of 1.0 cannot resolve or perceive scan lines or pixel structure on the display surface. The DVD for UHDTV is 0.75 times the image height (0.75 H). Studies on UHDTV systems based on this DVD have been conducted to determine the sense of presence [4] and visually induced motion sickness [5].

On the other hand, the PVD, which is defined as the favored viewing distance in the home viewing environment [7–9], depends on the screen size or image height. The ratio of the PVD to the image height, which is often referred to as the relative viewing distance, decreases as the image height increases. The PVD also differs between still and moving images. The above results were obtained and recommended for standard definition TV (SDTV) and HDTV [8]. However, the PVD for UHDTV has not yet been researched because such systems and their audio-visual equipment are still being developed.

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Literature in this area suggests that image size and resolution have little effect on the PVD [9,10]. However, this appears to be inconsistent with ITU-R BT.1127 [11], which defines TV image quality as a function of the relative viewing distance and suggests that image resolution affects image quality and viewing distance. Furthermore, only a single PVD was determined in the studies cited above [9,10] because viewers in the relevant experiments moved to a preferred viewing position. If viewers are allowed to move freely to their preferred viewing position for each scene and object viewed (e.g., by standing), the resulting PVDs might differ from that cited in the literature. This is especially true of moving images or rapid changes of scene, which discourage viewers from changing their PVD because they do not have sufficient time to move to a preferred viewing position.

In our previous study [12], we hypothesized that viewers might adjust their PVD when watching a TV with a wide FOV and high spatial resolution, despite the inconvenience of decreasing or increasing viewing distances to see the details or gain an overview of the images, respectively. This hypothesis assumes that the behavior of a TV viewer is analogous to that of a viewer in an art museum because both may desire to view an entire image and its details simultaneously. In a previous study, we successfully verified our hypothesis by showing that the PVD decreases, when a viewer is watching a TV at a wide FOV and high spatial resolution, in a comparison between 4k and HDTV spatial resolutions [12]. We have also shown that viewers can actively adjust and optimize their PVD when sufficiently motivated (i.e., by being directed by a narration, as in this paper) and presented with still images for an adequate length of time. In our previous study, we had no choice but to compare the PVDs for a 4k system and HDTV, instead of comparing those for 8k and HDTV, because the apparatus was limited as we had no 8k display available. Because we now have an 8k display available and, generally speaking, the extrapolation of the previous 4k result to 8k spatial resolution is invalid, we conduct an experiment in this paper that is similar to that of our previous study but at extended spatial resolution, to verify our hypothesis for a comparison between the PVDs for an 8k system and HDTV and to verify the scientific reproducibility.

We conduct an experiment to compare viewer behavior, including viewing distances on an HDTV and an 8k system when watching the same TV program. We are primarily interested in the difference in PVD for these two spatial resolutions because a TV with a higher spatial resolution might enable viewers to watch from a closer distance than with a lower spatial resolution. To verify the difference in PVD, we measure its dynamic changes by giving viewers sufficient time to move to their preferred viewing position while watching lasting still images, along with a narrative that prompts them to attend to certain parts of those images. We are also interested in differences in the subjective evaluations of image quality, the degree of image detail, the degree of participants' interest in the program, as well as participant behavior. The subjective evaluations are conducted mainly to investigate the relationship between the viewing distance, the resolution, subjective image quality, and subjective image detail. Furthermore, the degree of participants' interest in the program is measured to test the effects of image resolution on viewer interest.

2. Methods

Our experiment was conducted according to the following procedure, which is almost identical to the experimental procedure used for our previous study [12]. We sought to measure the binocular visual acuity (VA) of participants after securing their informed consent. Participants were first shown an introduction to a TV program by using an HDTV liquid crystal display (LCD).

Following this, an 8k LCD was used to present a main TV program with two spatial resolutions. The program runs for approximately 420 s and consists of a series of still images (13 still images) accompanied by narration to investigate the effects of high spatial resolution. The program, called "Miracle Spaulding Collection," showed "Ukiyo-e" (color prints of everyday life in the Edo period in Japan) on an 8k LCD with an 85-in. long diagonal. The program consisted of still images without zoom-ins. The narrator prompted the participants to attend to a number of features of the images. For example, the narrator encouraged viewers to pay attention to a part of an Ukiyo-e title written in Japanese characters edged with Peruvian blue at ~80 s time points. At other time points, other topics that attracted viewers' attention and were related to displaying Ukiyo-e were offered. We down-sampled the 8k images into HDTV images using wavelet transformation [13].

Our experiment was based on a randomized, double-blind matched pairs design. Eighteen pairs of participants were matched in terms of sex, age within two years of each other, and binocular VA. A spatial resolution was assigned at random to every participant, each of whom was unaware that two spatial resolutions were used in the experiment. The experimenter was also unaware of the spatial resolution assignment, which was undertaken by a third party. Each participant watched the program once and adjusted his/her viewing distance freely. The viewing positions were recorded as a function of time. We define the viewing distance as the length of a straight line from the viewer to the display surface.

2.1. Participants

Fifty-nine healthy adults were enrolled in our experiment, 36 of whom were grouped into 18 pairs, each matched according to sex, age (within two years of each other), and binocular VA (2 male and 16 female pairs; mean age, 30.1 years for the HDTV group, and 29.9 years for the 8k group; range, 22–34; mean VA, 1.46). The participants were instructed to watch TV while standing and to freely select their viewing position by moving. The participants wore headgear with an upward-facing LED that was filmed by an overhead ceiling camera with a fish-eye lens in order to record the participants' movement. When the program started, each participant's viewing distance was 80 cm, which is 0.75 times the display height (0.75 H) and corresponds to the DVD. This short initial viewing distance was chosen based on the result of a preliminary experiment, which showed that an ordinary initial viewing distance, such as 3 H, tends to prevent participants from approaching the display and noticing the high spatial resolution that would enable them to watch the TV at a shorter distance. After starting at an initial viewing distance of 0.75 H, most participants freely selected their viewing distance.

2.2. Subjective evaluation

Subjective evaluations of image quality, image detail, and participants' interest were conducted after the participants had watched the program. The participants recorded their ratings on three 10-cm visual analogue scales (VAS) [14,15] for perceived image quality, the degree of image detail, and the degree to which the program aroused their interest. The entire subjective assessment was conducted in conformity with the recommendations of the ITU-R [6,8], with the exception of our assessment of viewing distance. Accordingly, the screen illumination was approximately 30 lx with a D65 background. The distance from the floor to the center of the LCD monitor was 135 cm. The participants were all non-experts.