Quantitative evaluation of sensation of presence in viewing the "Super Hi-Vision" 4000-scanning-line wide-field video system

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Abstract

Purpose. To decide the system specifications for a future broadcasting system with a stronger sensation of presence, it is essential to understand the effect of viewing angle on this sensation. This study aims to establish a clear quantitative relation between the viewing angle of the displayed images and the viewer's sensation while watching them.

Methods. We have developed a 4000-scanning-line video system with a wide field of view. It is called Super Hi-Vision, and it enables images to be presented with enough resolution and brightness on an almost flat screen. We measured viewers' body sway while they were viewing still images presented by the system with six variations of visual angle, under the assumption that the smaller the difference between the real world and the scene presented by video systems becomes, the smaller the difference in the response of human equilibrium would be between viewing the real world and viewing the scene presented by video system. The total distance of body sway (hereafter called total body sway) was calculated as an index of the response.

Results. The total body sway shortened as the field of view increased, and the effect tended to saturate over 76.9 arcdeg.

Keywords--- **Sensation of presence, Field of view, Posture control, Equilibrium, Body sway, Super Hi-Vision, 4000-scanning-lines**

1. Introduction

Technological advances have made it possible for us to construct and test video systems that have a very wide visual field, very high resolution, and the ability to present stereoscopic images. One goal of constructing these systems has been to make viewers feel as if they are in the space displayed by the video system, i.e., to convey to viewers the sensation of presence. We (Japan Broadcasting Corporation, NHK) have been studying audio-visual systems with a wide field of view and three-dimensional audio with the goal of making one the center of a future broadcasting system. A wide field of view and three-dimensional audio tend to increase the sensation of presence, but the quantitative evaluation of the sensation has not been achieved. It is essential to establish methods that can quantitatively evaluate the sensation to design a future broadcasting system. We have developed a 4000-scanning-line video system as an experimental apparatus to evaluate the wide field effect on the sensation. It is called Super Hi-Vision, which consists of a high-resolution camera, a wide field-of-view display, a 22.2 multi channel audio system, and a disc recorder. The display system enables wide field images up to 100 arc-degrees to be presented with enough resolution and brightness on an almost flat screen.

The first prioritized method for the quantitative evaluation of the sensation would be a subjective one. However, the subjective evaluation of presence is very difficult, because it is highly subjective with significant ambiguity between viewers as to what constitutes it. Questionnaires on the sensation have been conducted [1][2][3], but their validity is not clear for our objective. An alternative psychophysical strategy without direct subjective evaluation was tried, whose index was the induced tilt angle of the subjective vertical line after 15 seconds of adaptation to slanted images [4]. The amount of induced angle saturated at more than 80~90 arcdeg. for the displayed images.

Another objective index that has been tried is the response of a subject's posture control while standing. The simple act of standing on two feet is a dynamic one maintaining equilibrium, and it has three major feedback inputs: somatosensory, vestibular, and visual. The change in only the visual input as one's eyes open and close affects the human posture control system [5][6]. Therefore, it is possible that the sensation of presence felt from presented images also affects posture control through visual input. Many studies have quantified the effect of visual input on the posture control by measuring the body sway in response to a variety of visual input stimuli [7-10]. In almost all of these studies, the magnitude of the vection, which is the sensation of self-motion induced by viewing motion images, was measured as an index of the sensation of presence, and was related to the viewing angle or a portion of the retina. Brandt et al. pointed out that peripheral vision plays an important role in vection [7]. This suggests that wide field images including the peripheral visual field affect the viewers' sensation of presence. The result of another study on the effect of reciprocating rotated stereoscopic and monoscopic images on the viewers' body sway showed that the effect saturates over 90 arcdeg. of field of view, and was more effective when the subjects viewed stereoscopic images [8]. These studies showed that the motion of picture captured by peripheral vision significantly contributed to vection. This is consistent with the characteristics of the peripheral vision, whose resolution is lower than central vision but whose sensitivity to the motion is higher than central vision [9]. The large area of peripheral vision might be responsible for the contribution.

Moreover, a comparison of central and peripheral vision areas of equal size showed that central vision played a more important role in stabilizing posture control than peripheral vision [10]. The contribution of peripheral vision to posture control can be minimized by using still images. In TV programs, motion pictures showing enough shaking to induce vection are rare. Therefore, an evaluation of presence by using only vection while viewing television is not sufficient; presence must also be evaluated using still pictures.

In this study, we used still images to investigate the relationship between viewing angle and the response of the human equilibrium system in order to eliminate the vection-like effects of motion-sensitive peripheral vision as much as possible. Our assumption to be tested was that the smaller the difference between the real world and a scene presented by a video system becomes, the smaller the difference in the responses of human equilibrium would be to viewing the real world and the presented scene. Most of the previous studies on the relationship between viewing angle and human equilibrium have projected images on the inner surface of a dome screen that could present images up to 180 arcdeg. It is useful to evaluate the relationship using a flat screen, because TVs have flat or almost flat screens. In fact, the video system we used in the experiments has 4000 scanning lines on a flat screen [11], which provides enough resolution and brightness over a 100 arcdeg. field of view. Thus, we evaluated the relationship between the viewing angles of up to 100 arcdeg. and the response of the human equilibrium system. The field of view was varied over six angles, from approximately 30 arcdeg, which corresponds to HDTV (High Definition Television), to approximately 100 arcdeg., which is the normal viewing angle of the 4000 scanning line system.

Strictly speaking, we measured the excursion of the intersection point of the action line of the vertical supportive force with the supporting surface, which is different from the projection point of the mass center of body to the surface of the force platform [12][13]. They are almost equivalent only when the subject is standing still on two legs. Therefore, we use the word "body sway" in this paper to indicate the excursion of the intersection point of the action line of the vertical supportive force with the supporting surface.

2. Methods

2.1. Viewing conditions and test images

The field of view was varied over six angles by shrinking oversampled images to sizes corresponding to the angles. Table 1 shows field of view, number of scan lines, and number of pixels in a scan line. The aspect ratio, which is the ratio of the horizontal and vertical size of the images, was the same (16:9) for all images. The smallest images (approximately 30-arcdeg. horizontal field of view) corresponded to HDTV (High-Definition Television, or Hi-Vision in Japan) and the biggest ones corresponded to the 100-arcdeg. 4000 scanning line system. The viewing

Table 1 Field of view at viewing distance of 3.15m and resolution.

Field of view (arc degree)	100	93.3	87.3	76.9	61.6	33.2
Scanning lines	4000	3555	3200	2666	2000	1000
Pixels per line	7110	6320	5688	4740	3555	1777

Figure 1. Still images

distance was 3.1 meters, at which viewers with a visual acuity of 0 in LogMAR (minimum angle of resolution) cannot resolve or perceive scan lines on the display surface. The alternative to varying the visual angle is varying the viewing distance. This was not used because viewing distance affects body sway [14]. Three landscape pictures (Figure 1) were taken on reversal film (Fujifilm Fujichrome Velvia100F ISO100) with a 4 by 5 inch still camera (Cambo wide ds) mounting a wide-field lens (Schneider Super-Anguron 5.7/47LX). The camera was set at a height of 1.5 meters with its axis horizontal. The developed films were oversampled to 14220 pel to 8000-line digital data with a drum scanner (Heidelberg DC3900) and trimmed to images with a 16:9 aspect ratio. Shrunken images (see Table 1) were made by image processing while keeping the ratios of upper and lower and left and right hemispheres identical. The shrink ratios were determined to integer to minimize the degeneration in image quality.

2.2. Apparatus

Images were presented on an approximately flat screen with sufficient resolution and peak brightness (approx. 50 cd/m^2). Table 2 shows the specifications of the video system part of Super Hi-Vision. First, the horizontal visual angle of the system was decided to be 100arcdeg. from the results of a past study that evaluated the sensation of presence by using the tilt angle of the subjective vertical line induced by slanted images [4]. Secondly, the resolution of the system was decided to be 7680pel*4096line for viewers with a visual acuity of 0 in LogMAR to be unable to resolve scan lines on the display surface at 3.1m viewing distance. However, any display or video monitor with 7680*4096-pixels had not been developed, but 1.7-inch LCoS (Liquid Crystal on Silicon) panel with 3840*2048-pixels was available. Therefore, we use two 1.7-inch LCoS panels with 3840*2048-pixels in order to obtain the resolution for green channel in the first projection unit, and one LCoS panel for red and blue channel respectively in the second projection unit [15]. Figure 2 shows the projection units. The improvement of resolution of green channel is more effective than other channels, because the contribution of green channel to brightness is larger than other channels. The relative positioning of the two panels for green must be accurately offset by 0.5 pixel [16]. The optical output of the display is approximately 5000 lumen, resulting in peak brightness on a 320-inch screen of about 50 cd/m^2 (screen gain 0.85, or about 40 cd/m^2 with a 450-inch screen whose screen gain is 1.5). Because there are two projection units for dual-G and R/B, the images from these units are not projected the same position on the screen without any correction. Therefore a convergence error correction scheme was developed to convert the red and blue images so that the convergence error on the screen is corrected.

Viewers' body sways were measured with a force platform (Nihon denki sanei 1G06). The platform had two outputs of X and Y, which corresponded to lateral and sagittal body sway respectively. When the amplitude of the platform output was 0.1 volt, the eccentricity of the body sway was 1 cm. These outputs were filtered with a pre-filter (NF Corp. Multifunction filter 3611), and then captured with a PC and an analog/digital converter (Interface CBI-3133A, 12-bit, sampling frequency: 120 Hz)

Table 2 Specifications

Pixel number	Green 7680*4096 Red and blue 3840*2048
Scanning	Progressive scan
Projector	approx. 5000 lumen
Screen size	320inch (approx. 7 m*4 m)
Screen gain	0.85

Figure 2. Dual green projection unit (lower) and red/blue projection unit (upper).

2.3. Procedure

Viewers stood for 120 seconds on the force platform with the inner sides of their feet in contact, which called the Romberg foot position. Body sway data for 120 seconds were captured, but only the 30 sec-90 sec data were processed to avoid any instability at the start of the period. The total body sway for 60 sec was calculated. The difference in total body sway subtracts the total sway for each viewing angle from the sway for 33.2 arcdeg. were evaluated.

2.4. Test subjects

Twenty healthy adults, 5 males and 15 females (age, mean 32.6 years; range, 24 to 50) who had normal posture control participated as test subjects, after having provided informed consent. Their heights ranged from 151 cm to 180 cm and had a mean of 163.2 cm. Their visual acuity ranged from 0.2 to -0.3 in LogMAR. They were instructed to view the center part of the images at the same height as their eyes while relaxing. This was to avoid the effects of eye position on body sway.

3. Results

Figure 3 shows the excursion of body sway. The x-axis is the lateral sway component, and the y-axis is the sagittal sway component. Figure 4 shows the mean difference of the 20 subjects in total body sway subtracts the total sway for each viewing angle from the sway for 33.2 arcdeg. plotted against field of view. The wider the field of view is, the shorter the total body sway becomes. A repeated-measurement ANOVA with two factors (picture and fields of view) showed that Mauchly's assumption of sphericity was assumed in the factor "picture" (p=0.708) but not in the factor "field of view" (p=0.009) or their interaction (p=0.012), and the main factor of picture (p=0.615) and their interaction (p=0.939, Greenhouse-Geisser epsilon=0.484) were not significant, but the main factor of field of view (p=0.046, Greenhouse-Geisser epsilon=0.595) was significant. This significant decrease in the total body sway with field of view suggested that viewing wide-field images stabilized human equilibrium. To test whether the stabilizing effect saturates or not with increasing field of view, Helmert contrasts within subjects were performed. The results showed a significant difference between 33.2 arcdeg. and more than 61.6 arcdeg. (p=0.014) and showed a tendency, than 76.9 arcdeg. (p=0.071). There was no difference above 76.9 arcdeg. (p=0.476, 0.705, 0.773). This suggested that the human equilibrium system stabilizes as the field of view of still images increases and that the images effect on equilibrium tends to saturate over 76.9 arcdeg. of field of view.

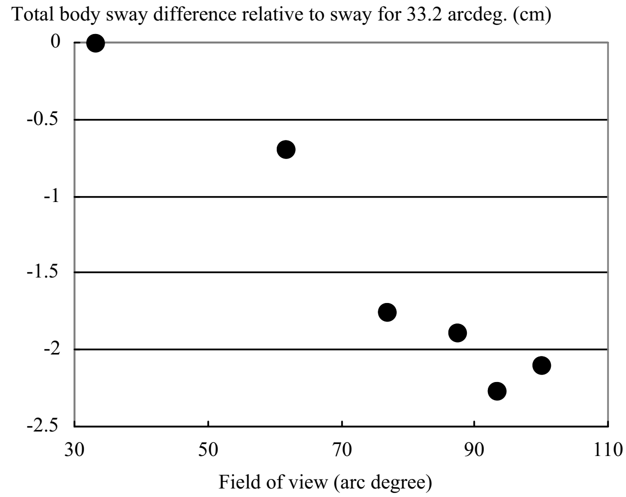

Figure 4. Mean difference in total body sway

4. Discussion

The total body sway results suggested that still-image field of views of more than 76.9 arcdeg. have little effect on human equilibrium. Hatada et al. reported that the induced tilt angle of the subjective vertical line after 15 seconds' adaptation to slanted images saturated at 80~90 arcdeg. [4]. They used two scenery images and one geometric image (grating pattern). Their results using an open landscape picture similar to our landscape pictures are consistent with our results showing that the field of view's effect on the induced tilt angle of subjective vertical line saturates over approx. 80 arcdeg. The major differences in the experimental conditions between their study and ours are screen shape (dome vs. flat), picture shape (circular vs. rectangular), evaluation index (induced tilt angle of subjective vertical line vs. total body sway), viewing distance (0.85 m vs. 3.15 m), and number of subjects (4 vs. 20). While there are some differences in the experimental conditions between the two studies, their consistency suggests that the total body sway can be an index of the

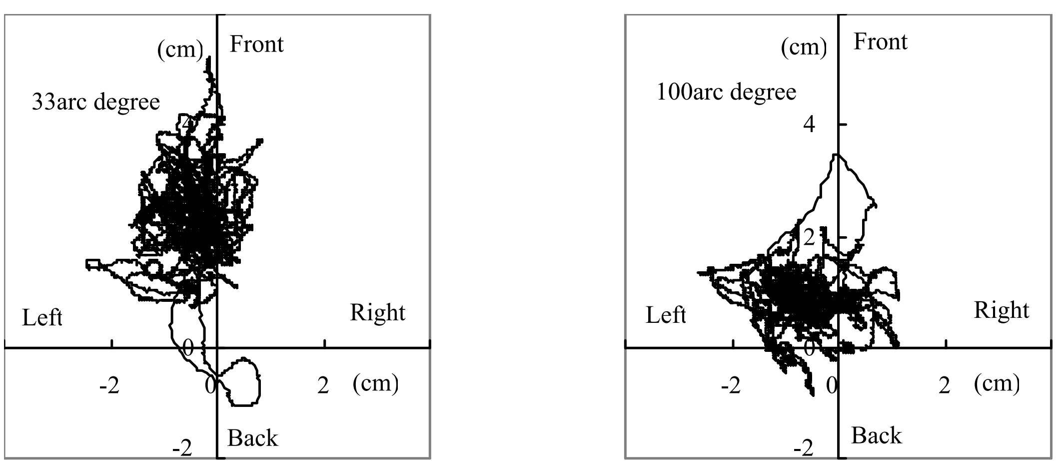

Figure 3. Excursion of body sway

sensation of presence. These results suggest that we can perceive the maximum sensation from viewing scenery images if the field of view is 80-100 arcdeg or more.

4. Conclusions

To evaluate the sensation of presence while viewing a wide-field video system, we studied the effect of viewing angle on the response of the human equilibrium system. The study was conducted using a 4000-scanning-line video system with a flat screen. The results showed that the effect saturates over 80-100 arcdeg. field of view, which is consistent with the results of a past study that evaluated the sensation by using the tilt angle of the subjective vertical line induced by slanted images, and they verify our assumption that the smaller the difference between the real world and the scene presented by video systems becomes, the smaller the difference in the response of human equilibrium system becomes. These results suggest that it is desirable for a wide-field video system to have a 80-100 arcdeg. viewing angle to convey the full sensation of presence.

Further studies on the sensation of presence in viewing motion pictures and on the assessment of the sensation using both subjective and objective indexes will be needed before we can arrive at desirable specifications for a wide-field video system.

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