Relationship between Spatial Cognition in Human Postural Control System and 3-D Visual Wide-Field Image

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ABSTRACT: **A new evaluation method of visual wide-field effects based on human postural control system is proposed. In designing a television system for future, it is very important to understand the dynamic response of human beings in order to evaluate the visual effects of displayed images quantitatively. Visual effects produced by 3-D wide-field images are studied. An observer's body sway originated from postural control is discussed using rotating 2-D and 3-D images in both directions. Comparisons between stationary and rotating images are also performed. A local peak appears in power spectra of the body sway for the rotating stimuli (3-D and 2-D). On the other hand, no distinctive component appears in the power spectra for the stationary images. By extending the visual field, the cyclic component can be recognized in the auto-correlation function of the body sway for the rotating images. These results suggest that displayed images induce the postural control. Total distance of sway path is also analyzed to evaluate the postural control. The total distance for the rotating images slowly increases in proportion to viewing angles, and is approximately saturated after 50°. Moreover, It is shown that the total distance for the rotating 3-D image is little longer than for the rotating 2-D image.**

1. INTRODUCTION

The "sensation of reality" produced by an image is regarded as an important psychological effect, caused by a fusion of observer space and displayed space, which may be produced by a visual wide-field display. "Sensation of equilibrium" or "sensation of direction" produced by a displayed image is a very important factor about the psychological effect of a moving visual scene.[1]-[4] A 3-D display produces a greater psychological effect than a 2-D display. The psychological effect can be understood as the response of the human postural control system in moving visual stimuli. In designing a television system for the future, it is very important to understand the dynamic response of human beings in order to evaluate the visual effects of displayed images quantitatively.

A flowchart of human postural control system in observation of a displayed image is illustrated in Fig. 1. The spatial coordinates, which are necessary environmental information for human postural adjustment, are reconstructed as the "spatial map in the brain"[5] based on integration of information from three sensory systems: the visual system, the vestibular system and the somatosensory system; therefore, human posture is maintained based on integrated information. These coordinates in the brain, which usually consist with the spatial coordinates of the real environment, however, may be different when induced by a displayed image. If the observer's postural control is influenced more strongly by the displayed image, the coordinates in the brain move nearer to the coordinates of the displayed space.

In experiments, the coordinates in observer's spatial map in the brain were influenced by rotation of an image, cyclically changing the direction, perceived only by the visual system. Information from the visual system conflicts with that from other sensory systems and, as a result, produces the induced body sway in the postural control. If the ratio of the spatial information from the image is greater, it induces the observer's body sway more strongly. Therefore, the degree of fusion between the observer space and the

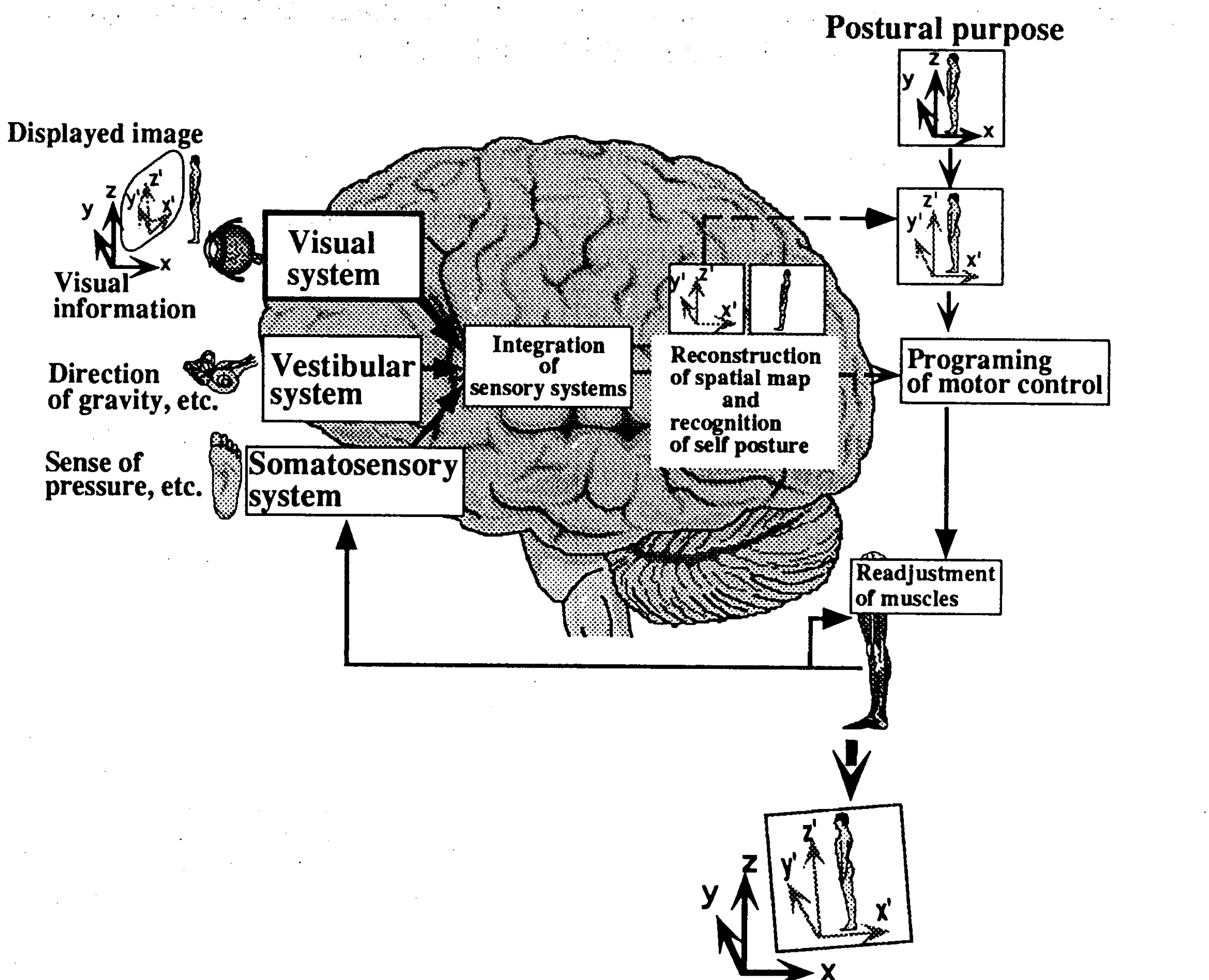


Fig. 1 Flowchart of postural control system in observation of a displayed image.

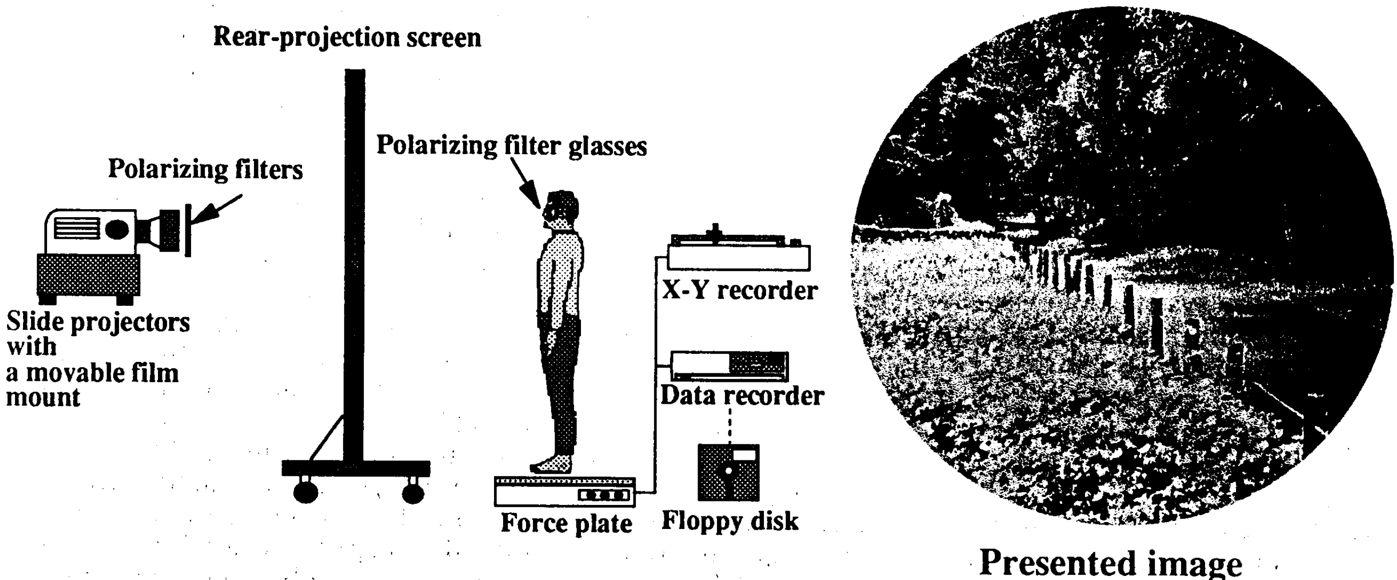


Fig. 2 Schematic diagram of the experimental apparatus.

displayed space can be quantified by measuring the observer's body sway. An observer's body sway was measured as a response to cyclically rotating visual stimuli in both directions here, where rotating 3-D and 2-D images were examined. In this paper, the experimental results are discussed for various viewing angles, comparing stationary images with rotating images.

2. EXPERIMENTS

A schematic diagram of the experimental apparatus and the presented image are shown in Fig. 2.[4] For the presentation of 3-D images, two 35 mm color slide films forming binocular stereoscopic pair were projected on a rear-projection screen through circular polarizing filters. For the presentation of 2-D images, one slide film corresponding to a left eye image was projected. To induce body sway in the subject's postural control, the images were rotated, cyclically rotating in both clockwise and counterclockwise directions about a horizontal axis. Experiments were performed at varying viewing angles.

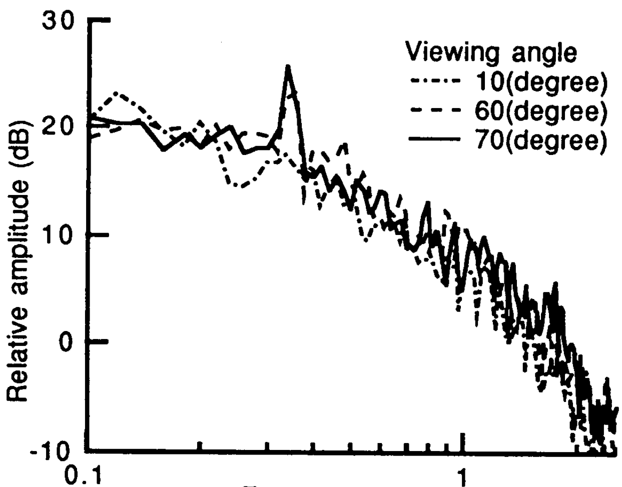
The subjects were standing upright on a force plate during observation of the images under natural viewing conditions; a position of their feet was maintained in the Romberg position (closed tiptoes), slightly unbalanced in the sagittal direction, because of positive postural control. They wore polarizing filter glasses for the 3-D images, and no glasses for the 2-D images. Displacement of the center of gravity was recorded on floppy disks by a data recorder (sampling frequency of 5 Hz, 14 bit A/D converter) and an X-Y recorder. Moreover, its displacement was normalized by the subject's height since the height of the center of gravity is approximately proportional to this.

In the experiments, presented images were rotated about the horizontal axis, cyclically changing the direction at a tilt angle of ±11.8°, reversal frequency of 0.3 Hz (constant velocity), because if frequency of the reverse was too high, the subject's postural control could not be readjusted, and it would be difficult to find the factor. Moreover, it was reported that visual information mainly influences frequency components of less than 1 Hz in the power spectrum of body sway.[6] Viewing angles were changed from 10° to 80° (absolute image sizes were varied from 18 cm to 172 cm); the observer distance was 103 cm. Experiments were done twice for each of four normal subjects for 3-D and 2-D images, both rotating and stationary.

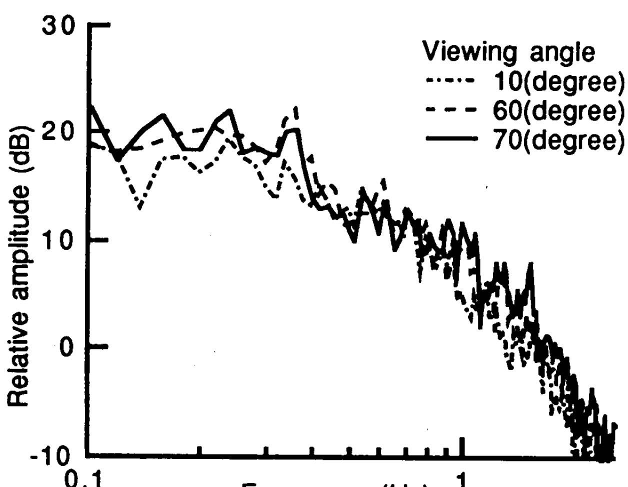
3. RESULTS

3.1. A cyclic component of body sway produced by displayed images

In this section, the frequency components of body sway obtained with rotating images are discussed,



(a) Rotating 3-D image (sagittal body sway)



(b) Rotating 2-D image (sagittal body sway)

Fig. 3 Power spectra of body sway obtained with rotating images at some viewing angles.

and it is shown by means of the power spectrum and the auto-correlation function that body sway can be induced by a displayed space.

3.1.1. Power spectra of body sway

Power spectra of body sway obtained with 3-D and 2-D rotating images at some viewing angles (10°, 60°, 70°) are shown in Fig. 3, and are the average of FFT (256 points of the body sway, Hamming window function) for the four subjects, each taken twice.

In Fig. 3 (a), a local peak appears around 0.3 Hz in the sagittal body sway power spectra (X-axis). In the frontal body sway power spectra (Y-axis), however, the particular feature dose not obviously appear for any viewing angle for the presentation of rotating images.[4] Amplitude of the components of the power spectra decreases in inverse proportion to frequency. For a rotating 2-D image, although not as distinctive as for the 3-D image, the local peak also appears in the power spectra, and the amplitude of the other components decreases in inverse proportion to frequency (Fig. 3 (b)). The local peak is sharpened in proportion to viewing angle.

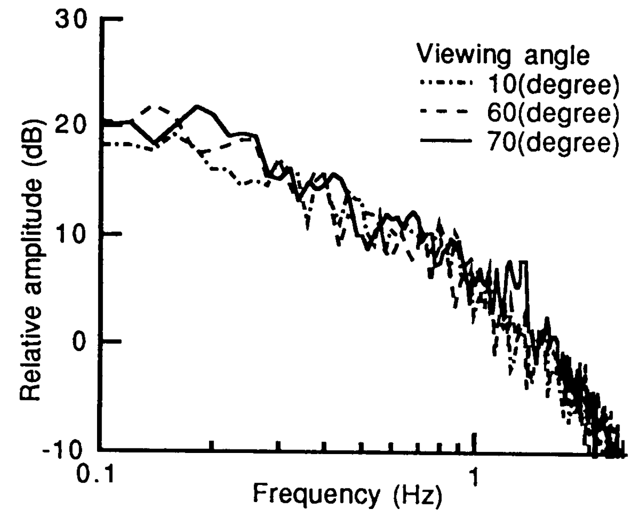
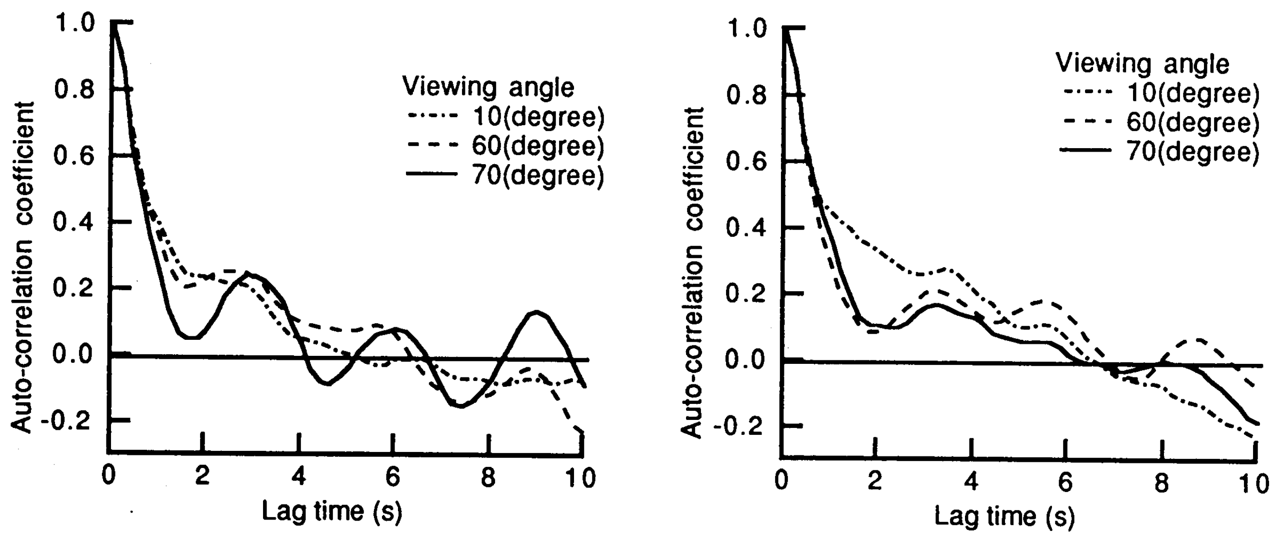


Fig. 4 Power spectra of sagittal body sway obtained with stationary 3-D images at some viewing angles.

An example of the power spectra obtained with stationary images is shown in Fig. 4. The particular feature which appears in Fig. 3 (a) and (b) dose not appear around 0.3 Hz in any power spectra of body sway in any axis, and the amplitude of frequency components in all power spectra decreases in inverse proportion to frequency.

It was already reported that a local peak in a power spectrum of body sway around 0.1~0.5 Hz was produced by "vection" (perception of self motion).[1] Therefore, the local peak in the power spectra obtained by our experiments suggests that cyclic body sway may be produced by rotating visual stimuli in both directions.



(a) Rotating 3-D image (sagittal body sway) **(b) Rotating 2-D image (sagittal body sway)**

Fig. 5 Auto-correlation functions of body sway obtained with rotating images at some viewing angles.

3.1.2. Auto-correlation functions of body sway

For rotating images, the auto-correlation function of body sway was calculated to recognize the existence of a cyclic component. The averaged auto-correlation functions obtained with the rotating 3-D and 2-D images are shown in Fig. 5. The auto-correlation functions for sagittal body sway (X-axis) have a cycle of approximate 3 second for an extension of the visual field, although it is not as distinctive with the 2-D image as with the 3-D image (Fig. 5 (a) and (b)). The auto-correlation functions for frontal body sway (Y-axis), however, do not contain any cycle for any viewing angle in the presentation of rotating images.[4]

It was also recognized that the auto-correlation functions of body sway for stationary images do not contain any cycle (see Fig. 6 for example), like those for frontal body sway (Y-axis) obtained with rotating images.

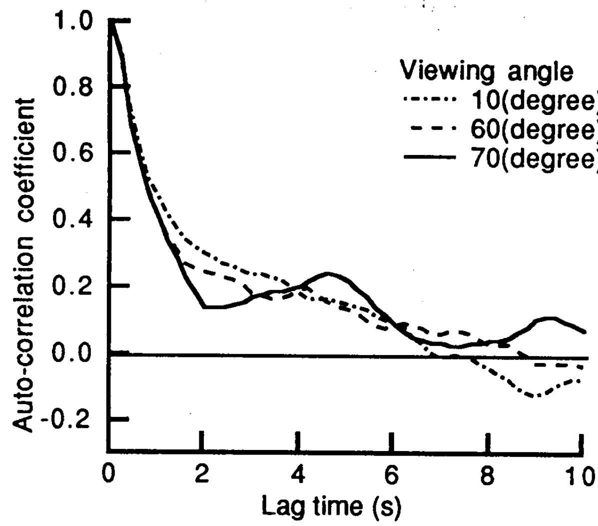


Fig. 6 Auto-correlation functions of sagittal body sway obtained with stationary 3-D images at some viewing angles.

The results suggest that the subject's body sway is influenced by rotating images; therefore, a cyclic component exists in the body sway. Moreover, they show that an obvious cyclic component exists only in sagittal body sway (X- axis) because the motion of the displayed image induces body sway in the right and left directions. Also, a rotating 3-D image influences body sway more strongly than a rotating 2-D image.

3.2. Total distance of sway path

Total distance of sway path was also calculated to evaluate postural control quantitatively. It is the summation of the distance between positions of the subject's center of gravity on the force plate, and is generally used to evaluate human equilibrium function quantitatively.

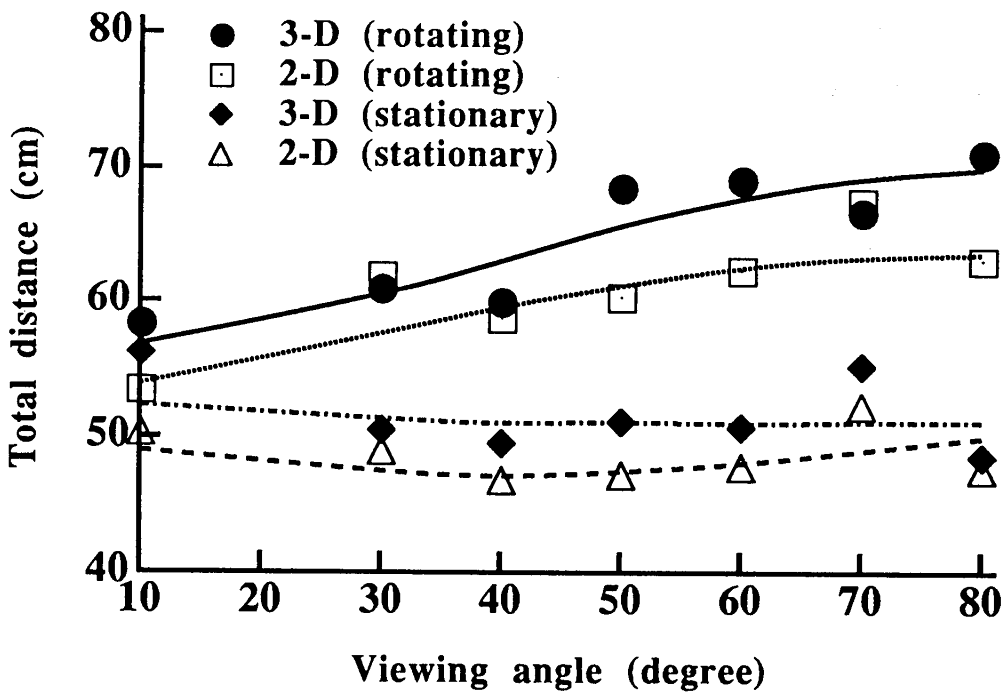


Fig. 7 Total distance of sway path for viewing angles.

The averaged total distance of sway path for viewing angles is shown in Fig. 7. The total distance for rotating images slowly increases in proportion to the viewing angle, and is approximately saturated after 50°. For stationary images, on the other hand, it remains approximately constant. It is also shown that the total distance for a rotating 3-D image around wide viewing angles is little longer than for a rotating 2-D image. However, there is little difference for stationary 3-D and 2-D images.

4. CONCLUSION

A new evaluation method of visual wide-field effects based on human postural control system is proposed. Body sway obtained with visual wide-field 2-D and 3-D images is discussed. The results are outlined in the following: (1) for the presentation of rotating images, there exists a cyclic component in the subject's sagittal body sway (X-axis); (2) for rotating images, the total distance of sway path slowly increases in proportion to the viewing angle, and is approximately saturated after 50°; (3) the total distance for a rotating 3-D image around wide viewing angles is little longer than for a rotating 2-D image.

The first result shows that human postural control may be influenced by a displayed image, because the displayed space could influence the reconstruction of the coordinates in "spatial map in the brain". The second result suggests that human postural control is influenced more strongly by a displayed image extending visual field. The third result suggests that an observer feels a greater sensation of reality for 3-D images than for 2-D images.

REFERENCES

(1) F. Lestienne, J. Soechting and A. Berthoz:"Postural Readjustments Induced by Linear Motion of Visual Scenes", Experimental Brain Research, Vol. 28, pp. 363-384 (1977).

(2) T. Brandt, J. Dichgans and E. Koenig:" Differential Effects of Central Versus Peripheral Vision on Egocentric and Exocentric Motion Perception", Experimental Brain Research, Vol. 16, pp. 476-491 (1973).

(3) T. Hatada, H. Sakata and H. Kusaka:"Psychophysical Analysis of the "Sensation of Reality" Induced by a Visual Wide-Field Display", SMPTE Journal, Vol. 89, pp. 560-569 (August 1980).

(4) T. Shimizu, S. Yano and T. Mitsuhashi:"Objective Evaluation of 3-D Wide-Field Effect by Human Postural Control Analysis", SPIE Proceedings, Vol. 1666, pp. 457-464 (February 1992).

(5) T. Kasai:"Eye-hand Coordination and Space Perception", J. IEICE, Vol. 76, No. 11, pp. 1156-1163 (November 1993); in Japanese.

(6) M. Shirato, T. Kanaya, T. Kamito and T. Unno:"Correlation between Directions of Body Sway", Equilibrium Research, Vol. 48, No. 4, pp. 318-324 (1989); in Japanese.