A Study on Depth Perception in Reversed Vision (V): An Experiment on Binocular Stereopsis with an Inverting Stereoscope.

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Abstract :

The purpose of this experiment was to prove the hypothesis that when both eyes are turned 180 degrees at the center of the distance between them, the visual fields of both eyes would be turned over, but normal stereoscopic vision of the reversed image would be obtained by binocular parallax, while maintaining binocular convergence. It was thought that if this was proved, the fundamental supposition that both eyes are rotated entailing optic chiasma, so the retinal images turned over by each lens are reversed, and then an upright retinal image with normal stereoscopic vision can be obtained, would be supported functionally.

The inverting stereoscope was designed to make reversed figures by the rotation of two video cameras and to reflect the figure on each of two liquid crystal screens. The hypothesis was proved from the result of this experiment on the depth perception of stereograms and real materials, and so the supposition was supported.

key words: inverting stereoscope, binocular stereopsis, optic chiasma, binocular parallax, binocular convergence

Introduction

It became clear in the 17th century that vision was achieved when a visual object projected an image onto the retina, and that this image was reversed. At that time, various discoveries about the structure and the function of eyes were made, and many theories about distance perception were proposed (Torii, 1986). The astronomer Kepler discovered that objects were formed as up-down and left-right reversed images on the retina. But he did not concern himself deeply with the problem of why vision does not become reversed despite the fact that the image reflected to the retina is reversed. He limited his research to within the field that could be examined by optics, and did not extend his study to the field of physiology (Tanaka, 1989).

Physiological observations on eyes and theories concerning stereoscopic vision were made by numerous investigators beginning with Descartes after the discovery of Kepler. Stratton (1896,

1897) tried to answer the question as a psychological issue of why vision does not become reversed even though the image reflected onto the retina is reversed.

He conducted experiments focusing on this problem for the first time and tried to demonstrate whether inversion of the retinal image was necessary for the perception of things as upright. That is, he tried to answer the question of "Is the inverted image a necessary condition of our seeing things in an upright position?" (Stratton, 1896, p.611). His method of approaching the problem was to substitute an upright retinal image for the normal inverted one and he watched the result of the experiment. He conducted these experiments wearing an instrument which had a built-in lens in the right eye for periods of 3 and 8 days.

His experimental results showed that adaptation occurred against the reverse of the retinal image by the lens and that upright vision was possible. And he thought that inversion of the retinal image was not necessary for the perception of things as upright. To the question posed by Stratton, the consensus became that space perception was learned, so the direction of the retinal image was not indispensable for our perception of a thing as upright, and today the question as it was is no longer considered to be much of a issue.

Studies of the adaptation process to cope with reversed visual field have been repeated after experiments on the wearing of lenses conducted by Stratton. Research on the wearing of reverse glasses for prolonged periods was undertaken by Makino (1963) after which many such experiments were conducted in Japan.

Many variables affect experiments on the adaptation process (Dolezal, 1982). Above all a variety of methods for visual transformation, which are especially important variables, have been devised. And many optical devices have been prepared.

By using lens, mirror and prism, the top and bottom, or the right and left of the view of eye has been replaced, or reversed in the axial symmetry. In the other case, the view has been reversed in the point symmetry, that is, the top and bottom and the right and left of the view have been replaced at the same time. Furthermore, in one case, the visual fields of both eyes have been turned over separately, while in the other the visual fields of both eyes have been turned over in concert. These methods of visual transformation influence whether vision becomes inverted or replaced and also whether stereoscopic vision becomes normal or not.

The upright image can be obtained due to the left-right reversal vision, but it is well known that depth perception turns over, and the stereoscopic vision becomes reversed due to clues such as parallax (Shimojo & Nakajima, 1981). It was reported that as a result of experiments on the wearing of reverse glasses, subjects could get reversed vision, but was associated with a very pronounced feeling of incongruity or nausea owing to the reversed stereoscopic vision (Yoshimura & Ohkura, 1983 ;Yoshimura, 1989).

The purpose of this experiment was to test the validity of the following hypothesis, " when both eyes are turned 180 degrees at the center of the distance between both eyes, the visual fields of both eyes would be turned over, but the normal stereoscopic vision[1] of a reversed image would be obtained by the binocular parallax, while maintaining binocular convergence".

Due to the turning-over of the visual fields of both eyes, the visual fields of the right and left eyes become exchanged, and each visual field becomes left-right reversed and also top-bottom reversed. On this occasion, the convergence is not changed, with the inverse retinal image with stereoscopic vision obtained by parallax and normal depth perception maintained.

Furthermore, it is thought that, if this hypothesis is proved, the fundamental supposition is supported. That is, " both eyes are rotated entailing the optic chiasma, so retinal images which have been turned over by each lens are reversed, and then an upright retinal image with normal stereoscopic vision can be obtained. But without rotation entailing the optic chiasma, the retinal image would be turned over as it is and will not be upright".

Of course, verification by nerve physiology is also necessary to support this fundamental supposition. But it was judged that proof of the hypothesis should become a conclusive evidence in the functional side of the optic chiasma.

To prove the hypothesis, the inverting stereoscope was used as the method to reverse the vision of both eyes. This stereoscope was designed to make reversed figures by the 180 degrees-rotation of two video cameras and to reflect the figure on each of two liquid crystal screens, entailing an intersection in wiring.

Method

Stereograms and real materials were used as experimental stimuli.

The stereograms were simple line drawings, such as "two parallel lines"(Shimojyo, 1995), "convex / concave truncated quadrangular pyramid", "concave circular truncated cone", a Japanese letter and a picture.

At the "two parallel lines", a black circle had been placed under the lines originally as an index of the fusion of the figures. The black circle was used as the index of the reversal of the visual field in this experiment.

The "concave circular truncated cone" (No. 7), letter (No. 8) and picture (No. 13) were those of stereograms for stereoscope published by Handaya store. But small objects in the picture (No. 13)

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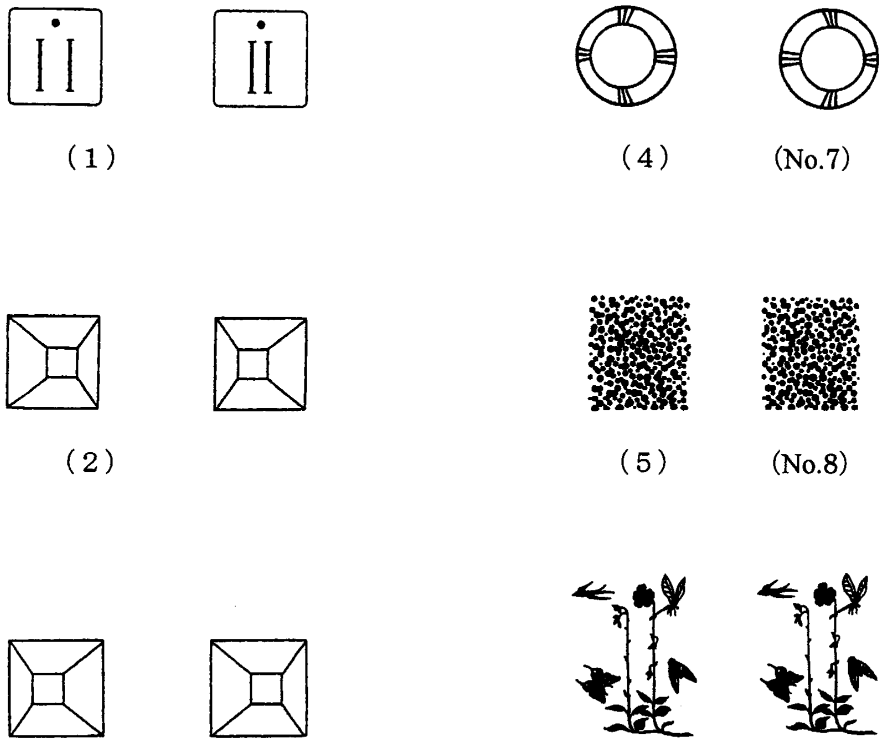
[1] Normal stereoscopic vision means here stereoscopic vision which can be experienced in daily life and does not lead to disagreement toward tactual perceptions and behaviors. Reversed stereoscopic vision means the opposite of this term.

were removed and limited to five. Two of the objects which seemed to be the most distant ones were seen to be placed at an equal distance with the stereoscope.

The Japanese letter (No. 8) ‘と’ was turned over in advance in the experiment, because otherwise the subjects had difficult in identifying it.



(1) (4) (No.7)

(2) (5) (No.8)

(3) (6) (No.13)

Fig.1 the stereograms

There were six real materials consisting of two pillars, a circular truncated cone, quadrangular pyramid, truncated quadrangular pyramid, Mach book[2] and semi-sphere (cup).

The two pillars were silver-plated iron pipes, each with a diameter of 2. 4 cm, and length of 12cm. Red or white plastic tape was wound around the bottom of each pipe. The circular truncated cone was made of cardboard, and the circular diameter of the upper surface (small circle) measured about 3cm, the circular diameter of the bottom (large circle) 10cm, and the length of the side line 12 cm. The quadrangular pyramid was made of four triangle boards of the cardboard, and the length of the base was 10cm and the height 7cm. The truncated quadrangular pyramid was made of the same quadrangular pyramid as mentioned above. The four triangles on the side of this quadrangular pyramid

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[2] This is a visual illusion that is used as a reversible perspective. The real material was called “Mach book” here which is made of thick paper to examine the Mach visual illusion.

were cut at 2cm from the top end to make the truncated quadrangular pyramid.

The Mach book was made of a square of cardboard the length of each side of which was 10 cm, and the square of cardboard was folded down in half. The angle on both sides was about 50 degrees. Each side and bent side of the real materials made of cardboard except for the Mach book were bordered with an about 1.5mm wide black line.

The semi-sphere was a cup composed of translucent plastic, and black lines were drawn on the surface from the center in a radiating pattern so as to divide the surface into 8 equal parts.

Experimental device Two video cameras (7cm. apart) were used for the inverting stereoscope. The color video camera (CCD-MC100, SONY) has a zoom lens with 410,000 pixels, making close-up photography possible with three-fold zoom expansion up to a distance of 10cm.

As for the liquid crystal screen, the indicator part of the liquid crystal color television manufactured by SEIKO (LVD232) was used. The screen size was 2.6 type (52.6mm×39.4mm) and the number of the pixels was 71,760 (vertical side 230 dot×width 312 dot).

Fig. 2 shows the inverting stereoscope and Fig. 3 the outline of the structure.

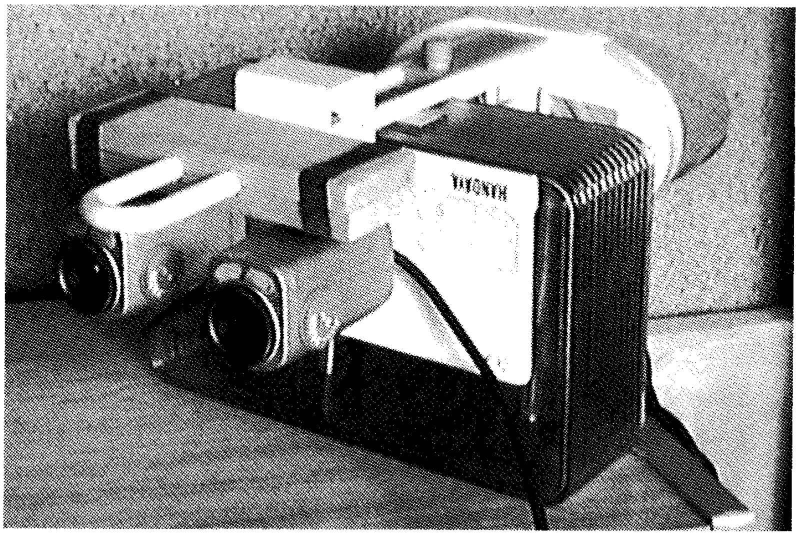

Fig.2 The inverting stereoscope

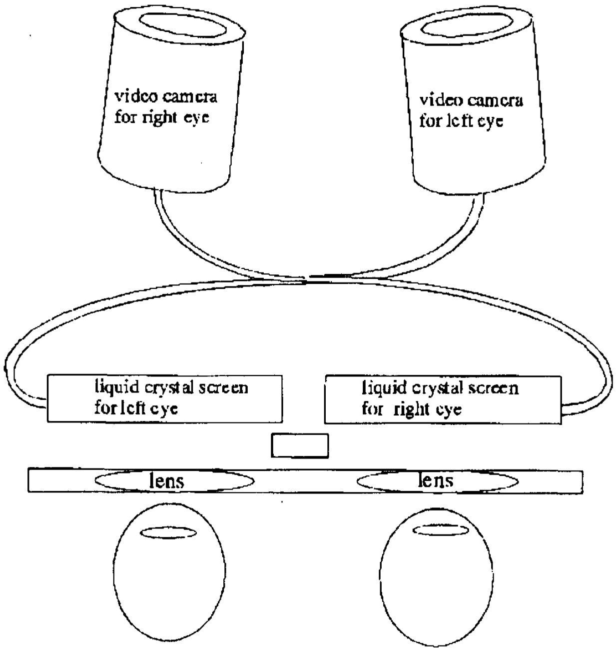

Fig.3 The figure of the structure (outline) of the inverting stereoscope

The real materials and a screen were placed in a box.

Two pillars were stood 5㎝ above the base and were moved back and forth. The height above the surface of the base was adjusted so that the surface would not be seen through the camera so as not to provide a clue to the depth perception of the pillars.

The real materials other than the two pillars were hung with a fishing line in front of a white screen. A weight was lowered with the fishing line at the bottom part of the materials, to fix them in a stationary state and prevent vibration.

The real materials corresponding to the stereograms were set in order to obtain images similar to the stereograms.

Subjects The subjects were university students aged 18 to 20 years. (18 years old: 5 persons; 19 years old: 14 persons; 20 years old: 5 persons). Their unadjusted or adjusted vision was close to normal, but some subjects showed some slight difference in right/left eyesight.

Dates of experiment The experiments were conducted on September 27 , October 2 and 4, 2001.

Results

The experimental results are stated below in the order of the stereograms and real materials because the experiments using stereograms for the experimental stimulus and using real materials were conducted in this order.

(1) The results of experiments in which stereograms were used

The results of the experiments in which stereograms were used as stimuli are shown in Table 1 and Table 2. The correct answer rate of five sheets of stereograms is shown in Table 1.

Although the correct answer rate of the letter stereogram (NO. 8) was somewhat low, the correct answer rates of the other stereograms were very high, showing that 70–80% of the subjects experienced binocular stereopsis of the reversed vision. A few persons gave wrong answers or had no confidence in their replies.

It is natural that the correct answer rate of the letter stereogram (NO. 8) is low in reversed vision because the rate is low in the vision with a usual (not reversed) stereoscope.

Table1 The correct answer rate of stereograms

the figure supposed to be seen	n	correct answer rate	Z	p
(1) two parallel lines	17	.71	1.73	.042 *
(2) convex truncated quadrangular pyramid	17	.76	2.14	.016 *
(3) concave truncated quadrangular pyramid	8	.75	1.41	.079
(4) concave circular truncated cone (No. 7)	17	.82	2.64	.004 **
(5) a letter (No. 8)	17	.40	–	–

. Note: These z-scores were calculated supposing that the expected ratio would be 0.5, if the convex or concave (distance or near) image was chosen by a subject purely at random.

Table 2 shows the results of the picture stereogram (No. 13). In the picture, flowers, a cicada, a dragonfly, a swallow and a butterfly are drawn. The subjects were asked to judge the far/near order in which these items appeared, and rank correlation coefficients were calculated between the correct order and the order stated by each subject.

Those correlation coefficients are here divided into grades, with the table showing the number of subjects in each grade. Most persons gave replies in the range of 0.70 to 0.99, indicating that many subjects were able to discern very close to the correct order.

Table2 The number of subjects in the grades of the rank correlation coefficients of far and near perception of the objects in the picture stereogram(6) (No. 13)

Rk	n
.99〜.90	6
.79〜.70	3
.49〜.40	1
.39〜.30	2

Note: Rk indicates Kendall's rank correlation coefficient

(2) The results of experiments in which real materials were used

Table 3 shows the correct answer rate of real materials. Many of the rates become 1.00 as for the results of experiments for which real materials were used, but there were a considerable number of subjects who had difficulty deciding whether the truncated quadrangular pyramid was convex or concave. So many subjects gave wrong answers to the problem. The reason why the correct answer rate was lower in the case of the real material is not obvious.

Table3 The correct answer rate of real materials

	n	correct answer rate	Z	p
(1) two pillars	7	1.00	2.65	.004 **
(2) circular truncated cone	7	1.00	2.65	.004 **
(3) quadrangular pyramid	7	1.00	2.65	.004 **
(4) truncated quadrangular pyramid	7	.57	.37	.456
(5) Mach book	7	1.00	2.65	.004 **
(6) semi-sphere (cup)	7	.86	1.90	.029 *

Discussion

In the present study, the hypothesis "when both eyes are turned 180 degrees at the center of the distance between both eyes, the visual fields of both eyes would be turned over, but normal stereoscopic vision of a reversed image would be obtained by the binocular parallax, with keeping the binocular convergence, " could be largely proved.

This showed that if both eyes were rotated by a manipulation equivalent to the optic chiasma then retinal images were reversed, and a reverse retinal image with stereoscopic vision could be obtained. So it was thought that the fundamental supposition, that is, "both eyes are rotated entailing the optic chiasma, so retinal images which have been turned over by lens are reversed and then an upright retinal image with normal stereoscopic vision can be obtained" was supported functionally.

Concerning the method of this experiment, binocular fusion became possible by adjusting convergence of the left-right camera and binocular stereopsis could be done at once, by means of the inverting stereoscope used for this experiment.

Little difficulty was experienced by the subjects for binocular fusion, even though they on the occasion of making stereopsis, misjudged or hesitated sometimes in judging whether the stimulus was convex or concave and so on.

However, because the number of the pixels of the camera and the liquid crystal screen are not adequate, some improvements were felt to be needed for the stereogram of minute design.

Improvements in the weight of the apparatus and the clarity of liquid crystal screens are necessary for these next approaches, and will have to be addressed in future investigations.

As for the experiment in which stereograms were used as the stimuli, the results of the experiment on stereograms reversed in advance 180 degrees without the inverting stereoscope might become equal to the results of the present experiment. But when real things were used as the stimuli, the use of the inverting stereoscope was indispensable. For the experiment on the coordinated behavior with depth perception (Ohta, 2003a) and for the experiment on daily life experiences wearing a stereoscope for a certain period (Ohta, 2003b), the use of the inverting stereoscope was also indispensable.

To verify the supposition about the optic chiasma proposed here, it is necessary to identify the various responses which correspond to the change in the image from reversed to upright when a reversed retinal image is transferred to the visual area of the cerebrum. And it is also necessary to elucidate many neuro-physiological aspects such as the function of disparity-selective binocular neurons in the visual area which detects the parallax from the images of both eyes.

Although the following has already been clarified, optic nerve cross fibers (decussation of optic nerve fibers) occupy 100% in birds such as the pigeon and owl, in contrast to 90% in the rat. In man 55% are cross fibers with the remaining fibers uncrossed. (Fukuda, 1986)

As for the proportion occupied by cross fibers, it is 100% in birds having eyes at the side of the head, with the proportion of non-cross fibers increasing the more the eyeballs face the front and with increasing size of the common part of both visual fields.

Also, the retinal image of the object in the outside visual fields of both left-right eyes (the image by the ganglion cell on the nasal side of the retina) is crossed and projected to the visual area on the contralateral cerebral hemisphere. But as for the retinal image of the object in the inside visual fields (the image by the ganglion cell on the head side of the retina) is projected to the visual area at the ipsilateral cerebral hemisphere.

The information of the visual area of each of the bilateral hemispheres is transferred to the other by the corpus callosum, integrated and recognized as a whole. It has been clarified from studies on split-brain patients that when the corpus callosum is cut and the object is shown briefly, the images of the left and right visual fields are not integrated, and thus are recognized as separate images.

And when crossed nerve fibers of a cat are cut at the crossing, discrimination learning can be performed with non-crossed nerve fibers from one of the eyes and the transfer to the learning by the opposite eye is possible. But when cross nerve fibers and the corpus callosum are cut, discrimination learning can be performed with non-crossed nerve fibers from one of the eyes but the transfer to the learning by the opposite eye is impossible.

These studies have made clear the kind of relation that the information of the image projected by the crossed nerve fibers has with the information of the image projected by the non-crossed nerve fibers. But it is expected that the upright stereoscopic vision will be made clear in such studies.

Taking these facts into consideration, it is thought that there is no hindrance in transfer and in making use of the information of the upright image after the visual field has been reversed due to the optic chiasma, for many stimuli to which depth perception is unnecessary.

It is considered that the image of the figure drawn on the plane probably does not bring about any disparity, and two-dimensional stimuli such as a figure, character and sign do not induce any difference. So, it is supposed that in man, the transfer of such information is made between the two hemispheres and non-crossed information is used for the recognition and learning of a figure, a character, a sign and so on.

We have to wait for verification of these problems about upright stereoscopic vision as related to the results of neuro-physiological studies.

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