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BINOCULAR FACILITATION OF VEPs BY REAL STEREO-TARGET

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Abstract

The VEPs was detected with the binocular liquid crystal shutter and with the wooden block stereoptic target set up around the Vieth-Müller circle. The surface of the whole target was arranged in a checkerboard pattern with an uneven surface to produce binocular disparity. Visual stimulation was given by the binocular liquid crystal shutter which triggered an average computer to induce a steady state VEPs. The binocular excitatory effect was smallest when the distance to the target measured as long as 150 cm, while it was largest when the distance was shortened to some 45 cm. The amplitudes of the binocular VEPs grew by more than $\sqrt{4}$ times.

The stimulating area also showed a relationship to the binocular effect and it seemed to be necessary to stimulate more than 10° of uneven surface. The maximum binocular effect was also obtained when the uneven surface of the blocks had an average 4 cm depth. In patients with binocularity disturbance, the binocular excitation was limited to less than $\sqrt{2}$ times. Therefore, the VEPs excitation by real stereo viewing indicates a binocular activity of disparity sensitive neurons in the visual cortex.

INTRODUCTION

Objective determination of stereopsis was attempted by means of visual evoked potentials (VEPs) with newly developed device. In the past investigations such as Spekreijse1), Tsutsui2,3), and Perry & Childers4), the amplitude of VEPs by binocular stimulation was found to be larger than that of monocular stimulation. Most of those reports showed the ratio of binocular excitaion to be about $\sqrt{2}$ times as large as the monocular amplitude. On the other hand, Srebro5) emphasized the binocular effect increased more than two times has significance in binocular function. In my previous report6), I reported that remarkable binocular excitation was obtained by a binocular liquid crystal shutter on viewing a solid real target of great disparity such as a French-style doll. This evidence suggested that the effect might be due to the disparity sensitive neurons in the visual cortex reported by Poggio & Fischer7) and Fischer & Krüger8).

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MATERIALS AND METHODS

The apparatus comprised a solid real target, liquid crystal shutter, and an signal-averaging computer. The solid target was mainly composed of wooden blocks with 4 cm × 4 cm × 20 cm dimensions, which were arranged with an

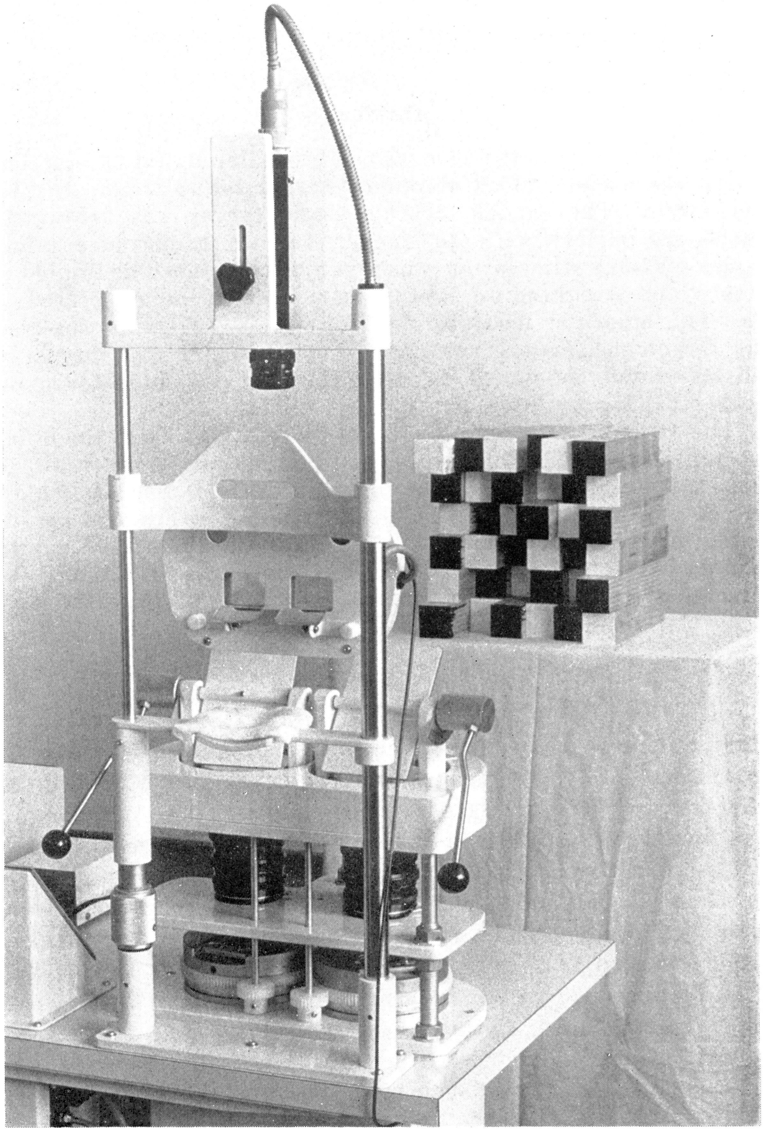

Fig. 1. Liquid crystal shutter and solid target.

irregularity sufficient to enable placement at the front or rear of the Vieth-Müller circle (Fig. 1 and Fig. 2). Six or seven layers of these blocks were stacked up. The average distance between the surface of blocks and the Vieth-Müller circle was 4.5 cm. The fusional area was determined practically, with bars set up within 15 degrees of the central fixation point of the circle. The use of peripheral areas beyond the range of 15 degrees was not practicable owing to the disappearance of physiological diplopia. The black and white surface were arranged so that their assembled surfaces might be seen as a black-and-white checkerboard pattern. The actual application of the checkerboard pattern to the surface of the target was based on the idea that this is one of the most fundamental ways for pattern stimulation of the VEPs. The luminance of whole solid target was 76 cd/m^2 under a diffuse illumination. The contrast $(\frac{Lmax-Lmix}{Lmax+Lmix})$ of black and white surface was 67% on the same plane.

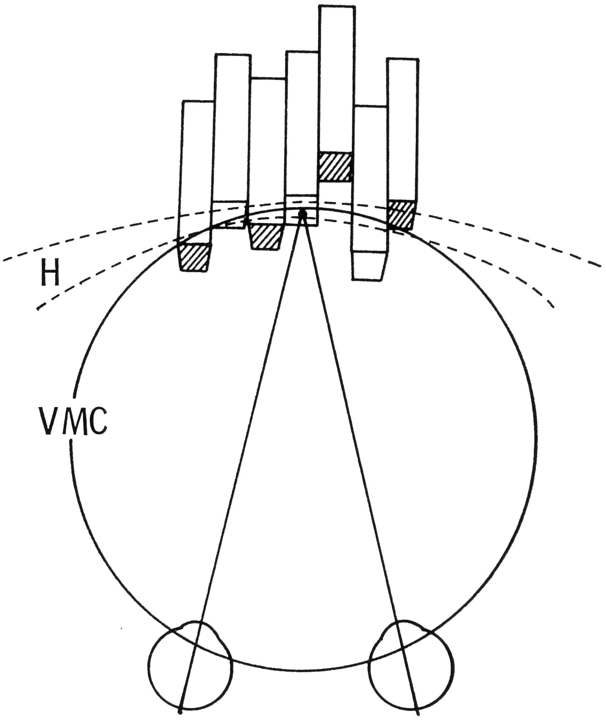

Fig. 2. Arrangement of wooden blocks and Vieth-Müller circle.

The binocular liquid crystal shutter (produced by Nihon Tenganyaku Co.) was placed in front of the eye and oscillations with a frequency of 8 to 10 Hz were used for monocular or binocular stimuli, which in turn triggered the computer by the shutter opening current. By means of these stimuli in the neighborhood of a 10 Hz frequency level, the liquid crystal shutter became transparent in 1 msec and opaque in 4 msec. The stereoptic disparity was obtained by binocular looking but little binocular disparity was felt by monocular looking.

The EEG was taken from electrodes between Oz and earlobe and computerized addition was made 50 times. The following two different methods were applied for the calculation of the binocular effect :

One was the system of dividing the binocular VEPs' amplitude by the mean value of the two monocular VEPs' amplitudes, whereas the other involved dividing the binocular amplitude by the larger of the two VEPs' amplitudes in each of the subject's eyes. In this investigation, no significant difference was found between the effects derived from the use of these two methods.

The subjects with normal binocularity were 11 cases aged from 24 to 47 (average age 30), and those with abnormal binocularity were 11 cases (5 esotropia and 6 exotropia) aged from 6 to 45 (average age 20).

RESULTS

1. Influence of the target with uneven surface on monocular viewing.

Experiments were conducted using 22 eyes of 11 subjects with normal binocularity on the effect of uneven surface on the monocular VEPs. In this experiment, the target was placed at three different distances from the subject,

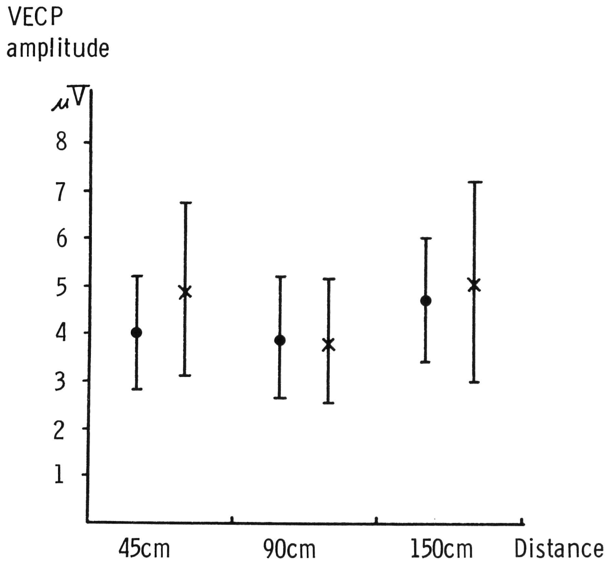

Fig. 3. Influence of uneven surface on monocular VECP (n=22, Bars represent SD). ● uneven surface × flat surface

45 cm, 90 cm and 150 cm. For the control, the surface of the wooden block was arranged in an even manner to obtain a flat surface.

No significant differences between these two arrangements were found, though the amplitude of the VEPs in the case of the even surface was sometimes rather larger than that of the VEPs measured with the uneven surface (Fig. 3). Accordingly, the excitation of the VEPs by the uneven surface was not recognized in a monocular stimulation.

2. The binocular effect on subjects with normal binocularity.

The amplitudes of steady state VEPs obtained by binocular viewing is remarkably enhanced (Fig. 4).

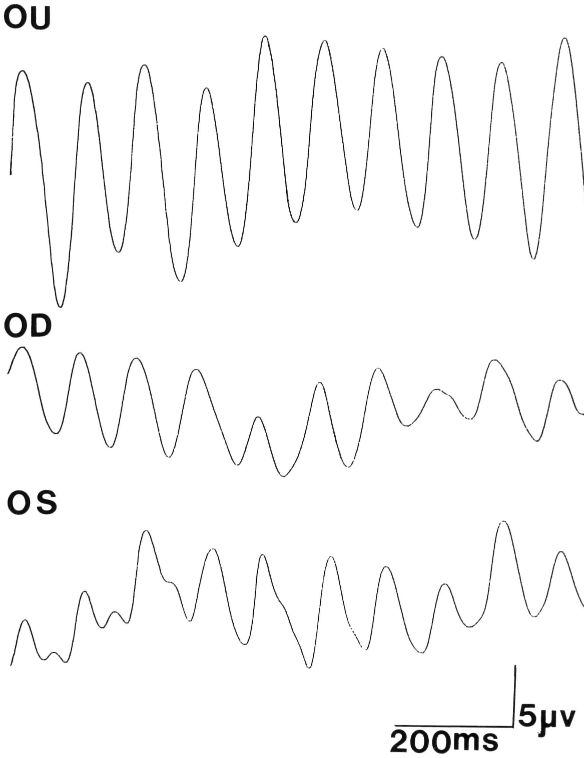

Fig. 4. Binocular enlargement of VEPs' amplitudes.
A : Subject with normal binocularity

The rate of the binocular effect obtained using targets with even surface ranged from 121% to 135%, which was somewhat lower than the $\sqrt{2}$ times (Fig. 5). In this experiment, the three different visual distances of 45 cm, 90 cm and 150 cm did not have any influence upon the above rates. Another experiment was performed using the uneven-surface target, which resulted in 230.3%,

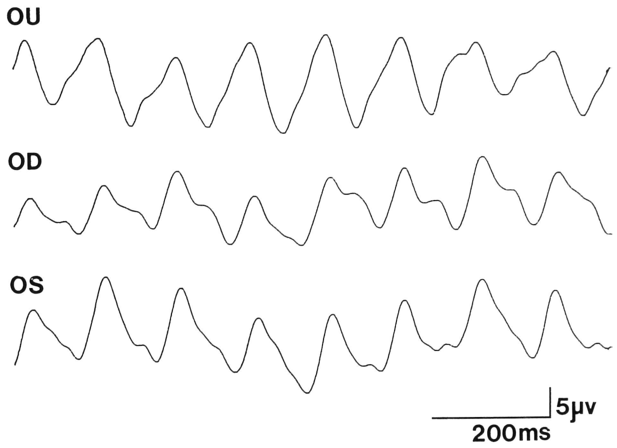

Fig. 4. B : Subject without binocularity

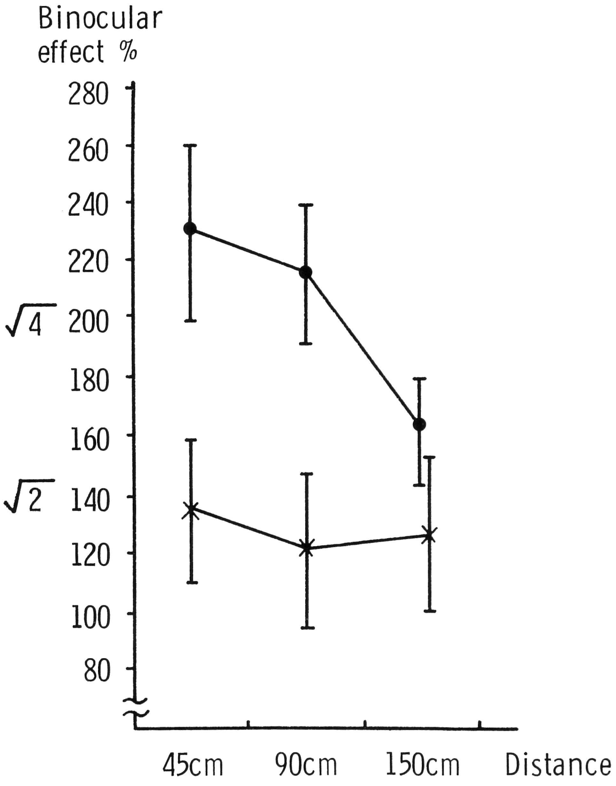

Fig. 5. The binocular effect in subjects with normal binocularity (n=11, Bars represent SD). ● uneven surface × flat surface

215.7% and 161.1% at the respective distances of 45 cm, 90 cm and 150 cm. This result conclusively showed that the shorter the visual distance, the more remarkable the effect or excitation becomes—the longer the former becomes, the less remarkable is the latter. Moreover, significant differences ($p < 0.001$) were found with the respective distances when comparing with the flat and even-surfaced target as the control.

3. The influence of size of uneven surface with constant target width.

The following experiments were performed to get an idea of the degree of the subtending angle of the uneven surface required to cause binocular excitation. In these experiments, the total angle of the wooden block building was kept fixed, while the area of the uneven surface in the central area was altered. The whole target was built up of blocks, 7 pieces vertically by 10 pieces horizontally, and also set up with a visual distance of 90 cm. The total

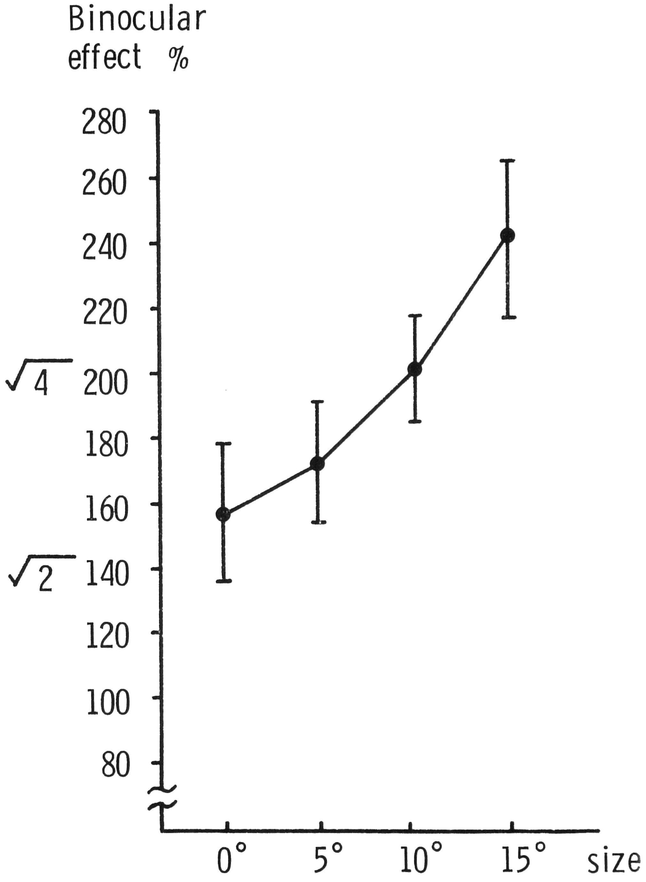

Fig. 6. The binocular effect and the size of uneven surface (n=7, Bars represent SD).

subtending angle of the whole target was 17° vertically and 24° horizontally.

Subjects were 5 cases with normal binocularity. The experiments revealed a tendency whereby the uneven surface with the widened angles of 5°, 10° and 15° caused a corresponding growth in the binocular effect (Fig. 6). No further experiment was made on the target beyond 15° because the Panum's fusional area was unmeasurable due to the decreased visual sensitivity in the peripheral area.

4. The influence of depth of uneven surface.

The grade of disparity was varied by the distance between surfaces of blocks and Vieth-Müller circle. The average distances were set 1 cm, 4 cm and 7 cm respectively, and the binocular effect was compared on 7 normal subjects. The distance from subjects to the target was 45 cm. The rate of the binocular effect obtained from 1 cm depth was 146.9% and that of from 4 cm depth was 213.6% (Fig. 7). Significant difference ($p < 0.001$) was found between these two. While the binocular effect was reduced to 154.2% in the experiment using 7 cm depth. The subjects felt a discontinuity of the surface of the target with 7 cm depth and visual attention was focused to only one block surface.

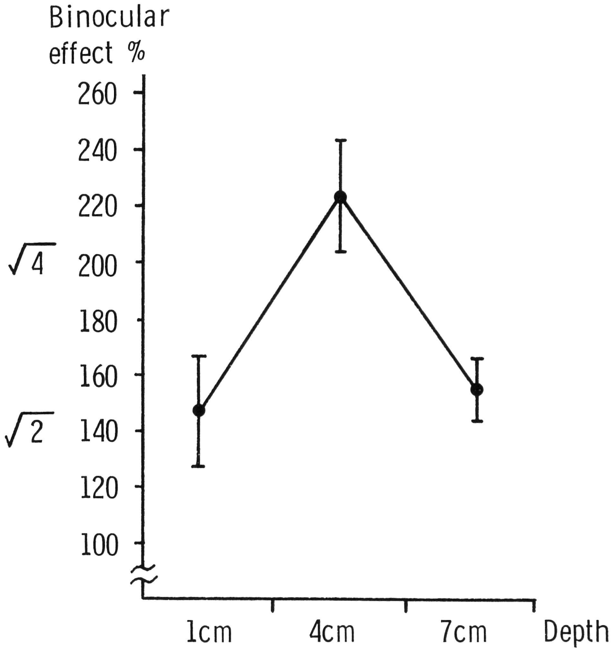

Fig. 7. The binocular effect and the depth of blocks (n =7).

5. The binocular effect on subjects with binocularity disturbances.

As an abnormal control, subjects with abnormal binocularity were examined by the same method. The subjects were 5 cases of esotropia and 6 cases of exotropia. In these cases, an absence of amblyopia was ensured in order to exclude the low VEPs caused by this condition. From the results, some strabismus cases showed binocular excitation up to a level of $\sqrt{2}$ times but there was no characteristic feature of binocular effect as seen in the normal subjects (Fig. 8). Comparing with the normal binocular effect, a significant decrease was recognized with the distances of 45 cm and 90 cm (Compare Fig. 5 with Fig. 8).

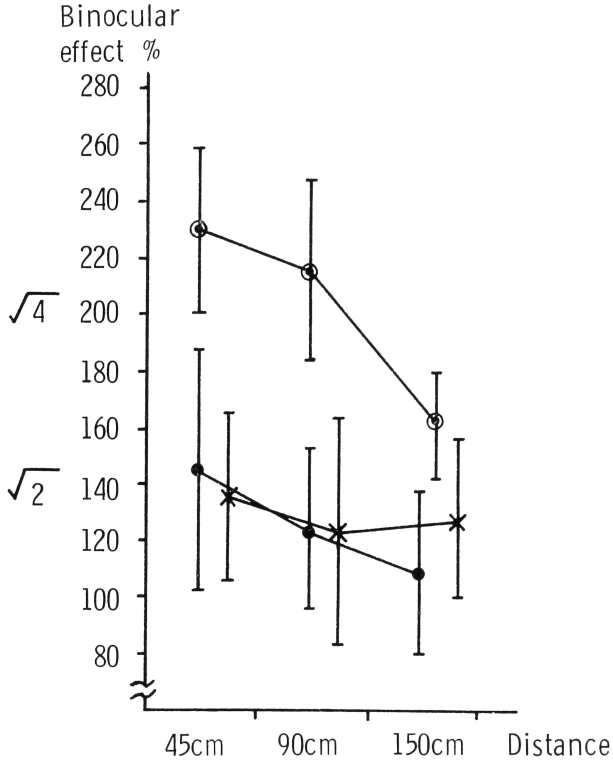

Fig. 8. The binocular effect in subjects with binocularity disturbances (n=11, Bars represent SD).
● Strabismus by uneven surface × Strabismus by flat surface
⊙ Normal by uneven surface

DISCUSSION

From the previous experiments, I observed a phenomenon that when the VEPs were evoked with the stereoptic target of uneven surface, the binocular effect greatly increases. In our previous studies[9,10], we also found that the synchronization ratio of the VEPs, which had been determined by alternate stimulations of both eyes using a liquid crystal electric shutter, has some relation to binocular function. In another of my previous paper[6], I reported a remarkable increase of the binocular effect ($\sqrt{4}$ times) obtained by using a target with rich disparity like a skirt of French-style doll. On the basis of those studies, we improved our methodology to obtain more quantitative data.

In the recent subjective examinations of stereopsis the spatial disparity in a real object, as in the Frisby test, tends to apply. It is well known that a real uneven surfaced target with binocular disparity acts as a basis for stereoptic vision. This is the reason why we arranged the checkerboard patterned wooden blocks in such a way to present high disparity of a stereoptic target at the front and rear of the Vieth-Müller circle.

Regarding the normal excitation ratio of the VEPs in binocularity, Spekreijse's report in 1966[1)] revealed that the ratio would double if the checkerboard pattern of lower contrast was applied to a visual target. However, various reports have subsequently been presented, showing the existence of differing opinions. The ratio increases by 8% to 48% (Perry & Childers)[4)] or by 40% under a bright flash, and by 100% under a dim flash (Ciganeck)[12)]. The ratio grows $\sqrt{2}$ times or so (Wanger & Nilsson)[13)], or from 1.40 times to 2.11 times (1.6±0.07) with a TV checkerboard pattern (Abe)[14)], or it attains 160% with the TV checkerboard pattern reversal (Adachi)[15)], or grows by 125% to 130% under a 1.7° flash (Campos)[16)]. Most of these ratios amout to a level of numerical values in the neighborhood of $\sqrt{2}$ times. Blake & Levinson[17)] stated that the binocular effect in the range of spatial frequency senitivity presents the $\sqrt{2}$ ratio. On the other hand, Wanger & Nilsson[13)] observed that the $\sqrt{2}=1.41$ ratio is to be fixed as a theoretical value in any binocular effect, by relating the VEPs to psychophysical phenomena. All of those experiments were performed on the basis of targets with flat surface and none mentioned the existence of any binocular disparity at the place where actual measurements were made. Srebro[5)] mentioned that the binocular VEPs becomes of value as binocularity only if it grows larger than the sum of amplitudes of both eyes, though his target was not a solid one.

In our experiment, it was found that the binocular effect extends beyond the rate of $\sqrt{4}$ times by creating disparity on the wooden blocks at the base of the Vieth-Müller circle. Moreover, the rate of binocular excitation was greater when the solid target was placed closer to the subject. In other words, human stereopsis actually functions at a distance just within a person's grasp, whereas this will change into a panoramic view when the distance is further extended to some 2 meters.

The VEPs increases further as the target's stimulating surface becomes larger in area, that is, if seen at a wider visual angle of 10° rather than 5°, or 15° rather than 10°. This illustrates the fact the retinal area required to cause stereopsis is not limited to the restricted scope of the foveal area. It can be verified that the retinal area is within its effective area if the visual angle is as high as 15°. If the angle widens beyond 15°, the Panum's fusional area is unmeasurable in an experimental sense because of the decrease in peripheral visual acuity. For this reason, the stereoptic target with a visual angle wider than 15° was not employed in this investigation.

In our preliminary study, Random dot stereogram, Frisby test, Titmus stereo test, Tiefen test, plaster figures for sketches, human figures, and stereoscopes were used as targets, but these objects showed a $\sqrt{2}$ times effect rate. Only the French-style doll showed a $\sqrt{4}$ times effect. The evidence suggested that the existence of continuous disparity around a fixation point results in a remarkable increase of the binocular effect.

Here the question is raised why a solid target abundant in disparity brings about the increase in VEPs up to $\sqrt{4}$ times level. I have considered it probable that an increase of the VEPs amplitudes could be due to accumulated discharge of disparity sensitive neurons in the visual cortex. As far as such neurons are concerned, Poggio & Fischer[7] presented their report in 1977 on different discharge situations of the depthsensitive neurons depending upon visual distances. The existence of these neurons had been detected by them in the binocular cortical cells of the monkey. Fischer & Krüger[8] detected the presence of disparity sensitive neurons in the binocular cells of the visual cortex of an unanesthetized cat and classified these neurons into three types, each displaying different reactions. These experimental procedures, however, can hardly be applied to a human being for directly detecting and verifying the presence of the disparity sensitive neurons with the use of implanted electrodes. The existence of disparity in a solid target influences the cerebral mass response as seen from scalp measurements. The evidence should be recognized as representing disparity sensitive phenomena.

The binocular excitation increasing up to the $\sqrt{2}$ times level must be called "the simple binocular effect" the first phase of the binocular visual response. This phenomena sometimes being obtainable even in strabismus patients without fusion. However, the effect beyond $\sqrt{2}$ times, especially beyond $\sqrt{4}$ times could not be obtained in the patients with defective fusion. Accordingly, the depth sensitive binocular excitation might be considered to be in the neighborhood of $\sqrt{4}$ times ratio. The significance of this study is that stereopsis of human beings has become objectively detectable by brain waves through a real, solid target based on the concept of a classic Vieth-Müller circle.

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