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A Study on the Clinical Usefullness of Digitalized Random-dot Stereoacuity Test

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Existing methods of stereoacuity testing need specific glasses or optical device for use. We have designed a new stereoacuity test for the digitalized, random-dot stereogram and researched its clinical usefulness. A digitalized, random-dot, stereoacuity test card was created with a computer program that used a preferred symbol and the designed system was tested along with the Randot preschool stereoacuity, Titmus-fly and Lang tests to compare their sensitivity and specificity. The mean success rate of the digitalized, random-dot test was 98.2%, while the rates of the Randot preschool stereoacuity, Titmus-fly and Lang tests were 89.3%, 74.2% and 86.1%, respectively. Sensitivity and specificity of the new test were 100% and 95.3%, respectively, which were not that different from those of the Randot preschool stereoacuity, Titmus-fly and Lang tests. We found that the digitalized, random-dot, stereoacuity test has a high success rate and can be appropriately used in medical examinations and follow-up tests for strabismus patients.

Key words: clinical usefulness, digitalized random-dot stereoacuity test, sensitivity, specificity, strabismus

INTRODUCTION

Stereoacuity is defined as a correlative order of depth of the object in three dimensional space, with a high degree ability to perceive the depth by using the monocular vision of both eyes.[1-5] Generally, the stereoptic function is decreased when there is strabismus, suppression and amblyopia. The stereoacuity test has been regarded as important because it can confirm the absence of strabismus, suppression and amblyopia, except for intermittent exotropia and anisometropic amblyopia, if the stereoptic function is normal. The stereoacuity test is an important test which is used as an indicator to decide on the operation time and postoperative evaluation.

Stereoacuity tests include the Randot test, Titmus-fly, TNO and other related tests. We can test the stereoacuity after separating the binocular vision by using polarized or red-green glasses. However, in an actual clinic it is difficult for a clinical doctor to perform an accurate test in the case of children who hate to wear glasses and have precognition of the test itself.[6-9] A good stereoacuity test should be easy, simple and accurate without rejection. Nevertheless, most of the stereoacuity tests are

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expensive and use figures or objects which are not familiar to Korean children because they are made in foreign countries.[10]

In this study, we designed a new, stereoacuity, digitalized, random-dot stereogram which can be made without special glasses or implements and used with objects and figures. We then researched its clinical usefulness.

The purpose of the stereoacuity test is the early detection of ocular diseases such as strabismus, anisometropia or amblyopia by using the Randot, Titmus-fly and TNO tests. However, the success rate with children is decreased due to some limitations.[6-17] There are many difficulties in its clinical usage because most of the test implements are composed of animals, figures and objects which Korean children have difficulty in identifying with. To overcome these weak points, we designed a digitalized, random-dot stereogram.

The author has designed a digitalized, random-dot stereogram in such a way that it allows for different pictures such as animals figures and objects to be inserted into the test by means of a graphic program (Adobe Photoshop® ver 5.0), without the need for specialized tools and programs. Furthermore, the system can also be made available on the internet and used to test groups or for follow-up strabismus tests.

In this study, we researched the success rates and usefulness of the digitalized, random-dot stereogram by applying the test to children.

MATERIALS AND METHODS

We examined 100 normal children, without ocular or general disease, consisting of 57 males and 43 females, with a mean age of 3.9 years ranging from 2 to 5 years (Table 1). We excluded patients with strabismus or severe clinical heterophoria found in Hirschberg or alternative cover tests, corrected vision below 0.6, a difference in refraction between the two eyes of over 2 diopters, amblyopia and obvious ametropia, because their result could be affected.

We made 3 test sheets of the digitalized, random-dot stereogram with different numbers, animals, figures and objects classified by 40, 120, 200 and 400 arc seconds. We conducted combination studies

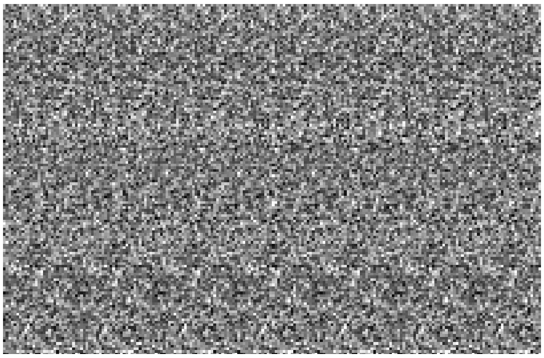

Fig. 1. Example of digitalized, random-dot stereogram (Fish, 400 seconds of arc at 40 cm).

with conventional tests, such as Randot preschool stereoacuity (Stereoptical Company, Chicago, U.S.A), Titmus-fly (Stereo Optic Co., Inc., IL, USA) and Lang (Western ophthalmic Co. U.S.A) tests, simultaneously and then comparatively studied and analyzed the results randomly.

We printed the test sheet of the digitalized, random-dot stereogram through the Random-dot production program after inserting animals, figures and objects by using the Adobe Photoshop® ver. 5.0 (Fig. 1). Because the Random-dot program produces parallax in pixel units, the printed Randot stereo parallax was defined as follows: the Θ value was set as 0.012 and approximately calculated as 43 seconds.[18] For example, when printing at 300 DPI (Dot Per Inch), the parallax of a pixel is $\tan\Theta = (25.4 \div 400) \div 300 = 0.0002117$ if it is tested from a 40cm distance, so one parallax pixel is about 40 seconds, which can be controlled by multiple intervals of 40 seconds through programming.

All tests were conducted thrice from a 40cm distance, under a 200 Lux illumination by the same tester, with the best of the three being chosen. Normal standards of stereopsis were defined as being under 200 sec. in the Randot preschool stereoacuity test, under 400 sec. in the Titmus-fly test, under 550 sec. in Lang test and under 200 sec. in the designed, digitalized, random-dot test.

The success of the test included the cases where the patients understood and cooperatively responded, even though they could not correctly answer. If they did not understand or cooperatively respond by indication, and looked at the test board, we regarded

Table 1. Patient data

Age (Years)	Male (NO.)	Female (NO.)	*No.
2.0 - 2.9	11	8	
3.0 - 3.9	20	14	34
4.0 - 4.9	14	11	25
5.0 - 5.9	12	10	22
Total	57	43	100

**No.: Number of patients*

it as a test failure.

To evaluate the efficiency of the test, we assessed the sensitivity and specificity of each stereoacuity test. The sensitivity is the ratio of children with abnormal stereopsis to those with abnormal binocular vision, while the specificity is the ratio of children with normal stereopsis to those with normal binocular vision.

In the test recognition for figure or symbol in each stereoacuity test, the decision of recognition was made when children could recognize the picture or could recognize the picture when given its name. In all children, a recognition rate of between 70% and 80% was considered to be the average and under 70% to be below average.[19]

RESULTS

The total success rates in the 100 normal children were 90%, 83%, 71% and 80% in the random-dot, Randot preschool stereoacuity, Titmus and Lang tests, respectively.

The success rates are presented in table 2. In the study of the designed, digitalized, random-dot stereogram, the success rate in the 2-year age group was higher than that studied by Lee and Bae,[19] who found a success rates of below 50%. However, the low success rate in this group was probably due to attention deficit and the lack of language compensation.

The averages of stereoacuity in the designed, digitalized, random-dot stereogram, Randot preschool stereoacuity, Titmus-fly and Lang tests according to age are presented in Table 3.

The orders of the picture recognition rates that

Table 2. Success rates of stereoacuity tests according to age group

Age(years)	No.	Success Rate (%)			
		Digital random-dot	Preschool*	Titmus	Lang
2.0 - 2.9	19	12(63.1)	9(47.3)	8(42.1)	9(47.3)
3.0 - 3.9	34	32(94.1)	29(85.2)	24(70.5)	29(85.2)
4.0 - 4.9	25	24(96.0)	24(96.0)	19(76.0)	21(84.0)
5.0 - 5.9	22	22(100)	21(95.4)	20(90.9)	21(95.4)
Total	100	90(90)	83(83)	71(71)	80(80)

*No.: Number of patient, (%): Percentage of patients who were successful in stereotest, *Preschool: Randot preschool stereoacuity*

Table 3. Mean stereoacuity in each age group

Age(years)	No.	Stereoacuity (seconds of arc)			
		Digital random-dot	Preschool*	Titmus	Lang
2.0 - 2.9	19	302	332	410	573
3.0 - 3.9	34	100	135	217	325
4.0 - 4.9	25	62	71	197	280
5.0 - 5.9	22	48	51	190	250
Mean		128	147	242	344

*No.: Number of patient, *Preschool: Randot preschool stereoacuity*

Table 4. Percentage of children who identified shapes and symbols correctly in stereotests

Shape and symbol	2.0 to 2.9 year	3.0 to 3.9 year	4.0 to 4.9 year	5.0 to 5.9 year
Lang stereotest				
star	97.2	98.3	100	100
cat	95.5	97.6	96	98.5
car	82.5	85.4	88	90.1
Titmus test				
fly	60.5	55.8	60	42.6
rabbit	94.3	96.7	100	100
squirrel	87.6	60.4	52	87.6
monkey	60.8	47.6	36	30.5
chicken	59.4	54.7	60	48.6
Preschool*				
hand	80.6	90.5	92	100
heart	30.6	22.4	48	64.5
truck	86.4	87.6	88	90.5
duck	22.4	40.6	36	55.4
house	90.2	85.6	88	84.6
tree	91.6	87.2	80	70.6
circle	85.4	91.3	84	87.6
square	34.6	64.7	42	39.4
Digital random-dot				
ㄱ	92.6	92.4	94.1	97.8
나	83.3	87.5	88.4	92.7
스	87.6	85.4	81.8	95.5
1	90.5	90.6	95.1	94.7
2	86.3	85.7	80.4	87.1
3	57.5	60.4	80.4	81.7
4	72.8	78.3	82.6	87.3
6	52.8	59.1	76.3	80.4
7	83.2	80.6	88.1	92.2
rabbit	87.3	93.5	96	100
dog	79.6	82.6	92	94.6
circle	81.4	82.6	89.5	100
triangle	80.7	91.7	92	88.4
square	55.4	62.4	66	62.2

*Percentage: Number of children who identified shape correctly/Number of children who were successful in stereotest, Same shapes and symbols of each stereoacuity tests were excluded. *Preschool: Randot preschool stereoacuity*

were used in each test were star-cat -car in the Lang test, rabbit the top in the Titmus animal test, and hand-house-tree-truck-circle in the Randot preschool stereoacuity test. The orders in the digitalized, random-dot, stereoacuity test were "ㄱ"-"나"-"스" (Korean letters), 1-7-2-4-3-6 (numbers), and rabbit-dog-circle-triangle-square (animal/shapes) (Table 4).

In sensitivity, the Lang and Randot preschool stereoacuity tests had the highest (100%) of the conventional tests, and the sensitivity of the digitalized, random-dot stereogram was also 100% (Table 5).

Specificity was high (over 90%) in the digitalized, random-dot, stereoacuity, Titmus-fly and Lang tests. The digitalized, random-dot, stereoacuity test had the highest specificity (Table 6).

Table 5. Percentage of sensitivity of stereoacuity test according to age group

Age(years)	Digital random-dot	Preschool*	Titmus	Lang
2.0 - 2.9	100(19/19)	100(19/19)	52.0(10/19)	100(19/19)
3.0 - 3.9	100(34/34)	94.0(32/34)	97.0(33/34)	100(34/34)
4.0 - 4.9	100(25/25)	100(25/25)	88.0(22/25)	100(25/25)
5.0 - 5.9	100(22/22)	95.0(21/22)	100(22/22)	100(22/22)
Total	100(100/100)	78.0(78/100)	87.0(87/100)	100(100/100)

*(/): Number of children who identified abnormal of absent stereopsis / number of children who were successful in stereotest and having poor binocular status. *Preschool: Randot preschool stereoacuity.*

Table 6. Percentage of specificity of stereoacuity tests according to age group

Age(years)	Digital random-dot	Preschool*	Titmus	Lang
2.0 to 2.9	100(19/19)	84.2(16/19)	73.62(14/19)	89.4(17/19)
3.0 to 3.9	100(34/34)	97.0(33/34)	97.0(33/34)	100(34/34)
4.0 to 4.9	100(25/25)	100(25/25)	88.0(22/25)	100(25/25)
5.0 to 5.9	100(22/22)	100(22/22)	95.0(21/22)	100(22/22)
Total	100(100/100)	96.0(96/100)	90.0(90/100)	98.0(98/100)

*(/): Number of children who identified normal stereopsis. / Number of children who were successful in stereotest and having excellent binocular status. *Preschool: Randot preschool stereoacuity.*

DISCUSSION

Stereopsis is a high degree binocular vision in both eyes, and its ability to perceive depths by using both eyes.[1-5] In 1838, Wheatstone,[20] who invented the stereoscope, for the first time discovered that stereopsis originated from the simultaneous stimulation of different horizontal retinal elements. It is due to the physiologic base of perception in binocular vision that such fusion of individually different images is recognized by depth, and fusion images are made in the Panum's area. Vertically different images do not lead to stereopsis.

Normal stereopsis uses the fovea of both eyes and partial stereopsis uses the fovea of one eye and the macula of the other. In the Titmus-fly stereopsis test, Parks considered that the former revealed a high level of stereopsis (from 14 to 40 seconds) and the latter were measured from 60 to 3000 seconds.[5,21] Ing[22] reported that partial stereopsis can not be below 67 seconds. Considering these results, early detection and treatment of abnormalities in binocular visual acuity or abnormalities of binocular ortho position are vital, especially in the age group between 2 and 5 years. Due to attention deficit and undeveloped visual / mental perception in children, these tests can not be adequately performed in most cases. In strabismus patients, the recovery of binocular vision is one of the most important treatment goals and so it is very important to test the binocular vision correctly.

There are two types of basic stereopsis test. One is to use 3-dimensional objects with real depth, and the other is to show a haploscopic device, which is divided into 2-dimensional objects in front of each eye. The former is not being used clinically, and the latter is classified accordingly to the various methods that divide both eyes or the characteristics of the figures used.[23] Clinically, stereopsis is measured by various stereopsis tests and preoperative or postoperative stereopsis tests are very helpful in deciding on the appropriate therapeutic plans. The Lang test is advantageous because of its random-dot stereogram and diffraction grid, and can be easily used in children who don't like to wear glasses. However, it has disadvantages in that the patients obtain monocular clues by moving their heads, and it is also difficult to quantitatively measure the stereopsis. In Lee and Kim's[15] studies, this test was applied to a 25-month-old child. The Titmus-fly stereopsis test is the most commonly used method, but we can obtain monocular clues due to the ring arrangement system, and may be unable to test children who are scared by the Titmus fly test. In addition, a polariscope should used in the test. However, with the Randot stereotest, even though it is a screening test, it has a random-dot stereogram and three paralyzedly arranged rings that reduce monocular clues. It is a more useful test because the highest level of stereopsis is 20 seconds, but it is hard for older children to understand because a blank should be chosen from the 4 blanks on the screening test board.

Julesz[24] made the random-dot stereogram, which one eye perceives as a disorderly dot. However, the depth of the figure or object sharpens when both eyes converge or fuse with the visual prism perception.

The author applied this random-dot stereogram in his clinic and designed the digitalized, random-dot stereogram which does not require glasses and simple features that are recognizable animals, numbers and Korean letters. This induced more interest from the children and thereby made them more cooperative in the tests. There are no monocular clues in the digitalized, random-dot stereogram used in this study. However, in the 2 to 3 year age group, stereopsis can not be induced due to a lack of the children's power of perception. In the 4 to 5 year age group, we applied the test thrice in consideration of the possibility of overlapping of the two figures. Combining these errors, the resultant sensitivity (100%) and specificity (over 90%) in this study can be underestimated.

Therefore the author is of the opinion that although the digitalized, random-dot stereogram would be a better better choice for children, the Lang test remains the best choice for the rapid screening of binocular functions, and the Randot preschool stereoacuity test is the best choice for measuring quantitative stereopsis.

Because fusion is needed in the digitalized, random-dot stereogram for confusion this can be adapted to the treatment of intermittent exotropia. It can be also used on the internet because glasses or specialized instruments are not needed in this test. Therefore, it can be used for follow-up on patients with strabismus or as one of the examinations.

In perception tests, the rate in which animals were recognized in the random-dot, stereoacuity test was higher than "dog" or "rabbit" in the Titmus-fly test. Actually, "flower", which was drawn as a tulip in the imported stereogram, was frequently recognized as "boat" by Korean children. The order of the rate of recognition in this test was ㄱ, 나, 스 (in letters) and 1, 7, 2, 4, 3, 6 (in numbers).

Bennett[25] reported that perception rates can be altered by the font used and that the degree of its difficulty differs in each case. In this aspect, the author agrees that the perception rate created by Adobe Photoshop can not be applied to all conditions. Because the same objects or animals could be expressed in a different manner due to cultural differences, the author used easily perceivable pictures and Korean letters for Korean children in the digitalized, random-dot stereogram. Therefore the author suggests that the higher success rates in most age groups in this test, in comparison with the other tests, are because of the above reasons. Investigation into children's favorite objects will be helpful in solving the problems experienced in the differences in individual preferences.

In the future, the commercialization of the digitalized, random-dot stereogram will occur with increasing demand for studies with highly perceptive objects, figures, animals and change of perception rate according to letter styles.

Many stereoacuity tests are conducted with special glasses and tools. Korean children are not familiar with these tests, so there are many limitations in their use at local clinics. The digitalized, random-dot stereogram designed by the author and using Photoshop® ver 5.0 can not only be used by inserting various animals, figures and objects, but also requires no special tools. Furthermore, its effectiveness will be increased according to the method in which clinics adapt it. It can be used effectively for preschool children because it is easy to understand and does not scare them.

Specialized tools are not needed and it can be used on the internet and as a follow-up method. Especially in intermittent exophoria, it can be of help in improving the fusion of the conversion exercise with the appropriate Randot. It is therefore viable both financially and as a follow-up procedure.

In the future, we can use the digitalized, random-dot, stereogram test designed in this study over a wider range, and the group study results of this test will be more accurate if studies are conducted into favorite Korean numbers, letters and objects.

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