Article • Comparison Between the BEST Stereopsis Test and the Stereo Fly Test

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ABSTRACT

Purpose: The Bernell Evaluation of Stereopsis Test (BEST): Dinosaur Version is a new polarized-free stereopsis test designed to measure local stereopsis. This test has two distinctive features: (1) it uses lenticular technology to create color images in order to improve interest to the subjects, and (2) it is designed to overcome the shortcomings of apparent motion and monocular cues associated with other polarized stereo acuity tests. The purpose of this study is to compare the BEST with a standard polarized stereopsis test, the Stereo Fly test.

Methods: Forty-five subjects (mean age 26 +/- 3.77 years) were tested with the BEST and Stereo Fly tests following a complete binocular vision examination. The stereopsis obtained in the BEST (test 1: clip-art animals) was compared with the Stereo Fly test (Wirt circles).

Results: The results show a moderate correlation (Spearman's rho: $r=0.612$, $p<0.0001$) between the BEST (Test 1: clip-art animals) and the Stereo Fly test (Wirt circles). The stereopsis values measured by the two tests were not significantly different from each other (Wilcoxon signed rank test, $Z=-0.733$, $p=0.75$). The BEST was found to be in good agreement ($k=0.60$, 95% CI 0.28 to 0.91) with the Stereo Fly test in measuring stereopsis in adults with normal binocular vision.

Conclusion: The results demonstrate that the BEST is comparable to the Stereo Fly test in measuring stereopsis in adults with normal binocular vision. Further studies in diverse patient populations, such as young children and developmentally disabled patients, are required in order to determine the value and application of the different sections of the BEST when compared with other clinical stereopsis tests.

Keywords: BEST, lenticular stereo test, local stereopsis, stereo fly test, stereo test

Introduction

Stereopsis is the most sensitive test of sensory fusion and is used to assess the presence and level of binocular vision.[1] Stereopsis testing is an important part of a comprehensive eye examination, especially in the pediatric population. Several factors can disrupt stereopsis.[2-11] Strabismus and amblyopia, which have a higher incidence in infants and children, disrupt normal binocular vision and stereopsis. The presence of anisometropia may also impair the development of binocular vision and therefore stereopsis. Considering the sensitive period

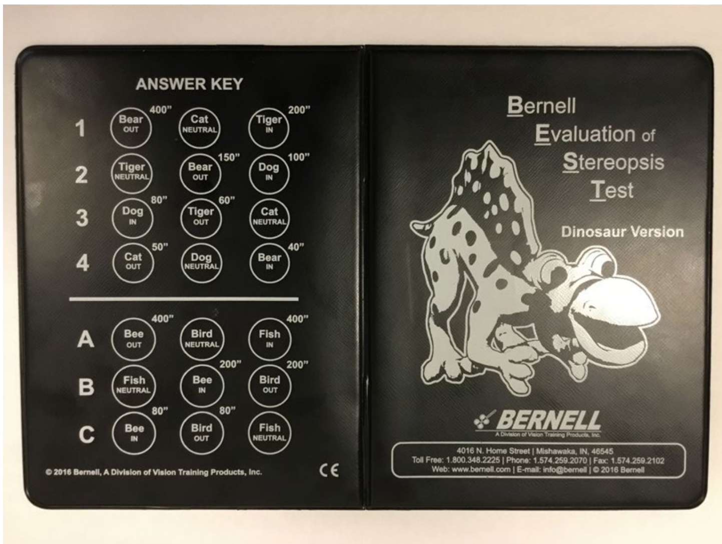

Figure 1. *BEST stereopsis test.*

Figure 2. *BEST clip-art animals. (Left side) Plate 1: Test 1. Four rows of clip-art animals (bear, cat, dog, and tiger). (Left side) Plate 1: Test 2. Three rows of clip-art animals (bee, bird, and fish). (Right side) Plate 2. Dinosaur measuring gross stereopsis.*

for the development of binocular vision,[12-18] it is imperative that these disruptive conditions are detected and treated early in order to avoid any further interruption of binocular vision development. Hence, measuring stereopsis is important in assessing the presence and level of binocular vision, as well as in documenting the changes in visual function during and after treatment of these disruptive conditions.

Several commercial clinical tests for stereopsis are available to measure local (contour) and global (random-dot) stereopsis.[19,20] These tests vary in numerous ways. The type of test targets and the validity of the tests among different age groups are considered by the test designers when designing these tests. Adults are commonly tested by identifying a stereoscopic target using a forced-choice presentation (e.g., the Titmus Wirt Circles). Tests designed for preschool and early elementary school children often require them to identify simple shapes or animals that appear in depth at various stereopsis levels.

Local stereopsis tests measure horizontal disparity processes without the need for reference or correlation to other parts of the retinal field. The presence of monocularly visible contours in a local stereo test aids the fusion mechanism by reducing the need for accurate sensory-motor control.[9,21-23] In contrast, global stereopsis test design (random-dot stereograms) removes monocular depth cues. This method may provide a different measure of higher cortical stereopsis and the presence (or absence) of bifoveal fusion[8,24,25] than local stereopsis (contour stereograms). Local stereopsis test design may allow monocular detection of overlays and/or parallax motion, which may introduce occasional false negatives in testing.[6]

The other major difference between stereo acuity test designs is whether they require the use of polarized filters in order to appreciate stereopsis. This arrangement of cross-polarization allows the patient to see only one target with each eye and then lets them cortically combine (fuse) the two images into a single target with depth. In a similar manner, the use of colored anaglyphic lenses with two differently filtered colored images, one for each eye, are also used in creating stereoscopic images. A few other tests, such as the Lang[7] and the Frisby,[1] do not require any polarized filters or anaglyphic lenses. The advantage of such tests is that they allow the testing of stereo acuity in patients with developmental disability who have difficulty tolerating spectacles.

The Stereo Fly test (Stereo Optical Co., Chicago, IL, USA) is a widely used test

Table 1. BEST Stereo Test Key, Test 1: Clip-Art Animals

Row	Animal	In/Out	Stereopsis (in arc sec)
1	Bear	Out	400
1	Tiger	In	200
2	Bear	Out	150
2	Dog	In	100
3	Dog	In	80
3	Tiger	Out	60
4	Cat	Out	50
4	Bear	In	40

measuring local stereopsis. The test is designed to be administered to adults and children using polarized glasses. The test target, administered at 40 cm, consists of a large stereo disparity housefly, three rows of five animals per row, and nine sets of targets with four circles in each (Wirt circles). The disparity range is from 3000 to 40 seconds of arc. Patients are expected to identify targets that appear to pop out from the target page. The final correctly recognized test target represents the stereopsis.

The BEST (Bernell Corp, South Bend, IN) is a new glasses-free stereopsis test designed to measure local stereopsis. The BEST booklet (Figure 1) has three test divisions on two plates (Figure 2). Plate 1, on the left side of the booklet, has two tests. Test 1 (top left) shows four rows of clip-art animals (bear, cat, dog, and tiger) that vary between 400 and 40 arc seconds, popping either in or out, designed for adults and older children. Test 2 (bottom left) comprises three rows of clip-art animals (bee, bird, and fish) that vary between 400 and 80 arc seconds for younger children. Plate 2, on the right side of the booklet, has a picture of a dinosaur that assesses gross stereopsis. The answer key is displayed at the back of the booklet, giving the stereopsis of each target. Table 1 summarizes the BEST targets and corresponding stereopsis.

The BEST uses lenticular technology[28] to create stereoscopic targets (at different levels of stereopsis) in color images. Lenticular printing creates a specially prepared image that allows different images to be seen at different angles by each eye when connected with the lenticular lens. This lenticular material is a sheet of plastic with extruded lenticulas (lenses that have to be perfectly aligned with the images underneath). This allows the presentation of a combination of two or more images, seen by each eye separately. Changing the angle of viewing causes changes of the images under the lens and gives a perception of depth. When the angle of the lens is perpendicular to the viewer, each eye will see a different image, and stereopsis awareness is possible. This is intended to improve interest and attention for the patients and negates the requirement of anaglyphic (red/green) or polarized glasses.

If the test was arranged similarly to traditional polarized tests, a monocular patient could obtain accurate results by moving the test side-to-side to see which image moved. In order to prevent such a clue, this test is designed such that one image in each row of three appears to be closer (or raised), and one appears farther (recessed). Even if the patient can tell the answer by comparing which target is different using apparent motion and monocular cues, it is highly unlikely that they can determine whether the target is raised or recessed by these cues alone.

There are a few advantages of glasses-free, lenticular-technology tests such as the BEST for the assessment of stereo acuity. First, there is the potential for easier screening of and test administration to patients with developmental disability, as well as to children who have limited attention spans or difficulty tolerating Polaroid glasses. Second, there is no need to fit and to remove other filters during the eye examination, which may save the clinician time. Third, without filters, the clinician can observe the patient's eyes more easily to monitor the monocular and binocular alignment of the eyes. Therefore, if the patient guesses correctly when apparent strabismus is observed, the clinician knows that it is a false negative. Fourth, as the only local stereopsis test with attractive colored stereoscopic pictures, it is easier to capture the interest of challenging patients and quantify the stereopsis quickly. Hence, determining how patient performance on the BEST compares to that on the commonly used Stereo Fly test will add to the clinical methods available for screening and assessment of binocular vision.

The purpose of this study is to compare the BEST clip-art animals with a standard polarized stereopsis test, the Stereo Fly Wirt circles.

Methods

Forty-eight adult subjects (mean age 26 +/- 3.77 years) were tested with the BEST and Stereo Fly tests according to the manufacturers' instructions.[29-30] The procedures used were modified from the original manufacturers' instructions as given below.

Prior to stereopsis testing, the subject's distance and near visual acuity, distance and near cover test, extraocular motility, near point of convergence, and monocular estimation method (MEM) retinoscopy were completed through the subject's habitual correction in order to determine the status of their binocular vision. Three subjects with abnormal binocular vision due to strabismus were excluded from the data analysis, bringing our sample size to 45 subjects. The MCPHS University institutional review board approved the study.

Test Procedures

Both the BEST and Stereo Fly tests were administered based on a modified protocol at 40 cm, perpendicular to the subject's face, in normal office illumination. The tests were administered with the subjects wearing their habitual correction. The order in which the subjects completed the BEST and Stereo Fly tests was randomized.

Table 2. Ranking of Stereo Acuity for Stereo Fly Wirt Circles and BEST Clip-Art Animals

Stereo Fly Wirt Circles	Stereo Fly Rank	BEST Clip-Art Animals	BEST Rank
800	1		
400	2	400	2
200	3	200	3
140	4		
100	5	100	5
80	6	80	6
60	7	60	7
50	8	50	8
40	9	40	9

Stereo Fly test

The Stereo Fly test was administered with the subject wearing polarized spectacle filters. Two sets of tests in this booklet assess local stereopsis. The first set contains a series of nine diamonds having four circles in each. These are modified Wirt circles. Only one of the four circles or rings in each diamond appears to be closer as compared with the other three. The range of stereacuity is 800 to 40 seconds of arc. The subject was asked to look at each of the four circles and choose the one that seemed to come out closer. This was continued from diamond 1 to 9 or until the subject made two successive errors. The last correctly identified circle was recorded as subject's stereopsis. The second test set contains three rows of five animal pictures, with each row ranging in stereoacuity from 400 to 100 seconds of arc. This set was not tested as part of this study.

BEST Stereo Test: Dinosaur Version

The BEST was administered to the subject at 40 cm. As our subjects were adults, only the clip-art animal portion of the BEST was administered. We modified the test administration as follows. For each row (1-4), the subjects were asked first to name or to point out the picture (animal) that stuck out and then to name or to point to the picture that was deeper. This was continued until the subject gave up trying or made two successive

Table 3. Kappa (k) Coefficient of Agreement. 'Pass' and 'Fail' cut-off based on 40 arc seconds on the BEST and the Stereo Fly Tests. The kappa (k) coefficient of agreement shows a good agreement between the BEST and the Stereo fly test (κ = 0.60, 95% CI 0.28 to 0.9).

		Pass	Fail
Stereo Fly test	Pass	35	2
	Fail	3	5
	κ = 0.60, 95% CI 0.28 to 0.91		

mistakes. The last correctly identified clip-art animal was recorded as the subject's stereopsis.

The stereopsis obtained in the BEST Test 1 was compared with the Stereo Fly Wirt circles. The stereo acuity levels were ranked in order to allow easier comparison (Table 2). Only non-strabismus patients were included in this comparison. As our study sample was an adult population, the BEST Test 2 clip-art animals designed for young children were not assessed.

Results

The results indicate a moderate[31] correlation (Spearman's rho: r=0.612, p<0.0001) between the scores for each subject on the BEST Test 1and the Stereo Fly Wirt circles. The stereopsis scores measured by the two tests were not significantly different from each other (Wilcoxon signed rank test, Z=-0.733, p=0.75). The kappa (k) coefficient of agreement (the measure of strength of agreement between tests, taking into account chance performance) was determined between the BEST and the Stereo Fly tests. In order to perform this analysis, we classified any stereoscopic threshold of 40 arc seconds as a pass and any stereoscopic threshold below 40 arc seconds as a fail (Table 3) for the two tests. This cut-off of 40 arc seconds was chosen based on the fact that (1) the majority of the normal adult population tested in the clinic has about 40 arc seconds of stereo acuity, and (2) this would act as a strict criterion for our sample. (Please note: using 60 or 80 arc seconds, a more liberal criterion, as a pass-fail cut off for our sample resulted in nearly perfect agreement.)

The BEST Test 1 was found to be in good agreement (k=0.60, 95% CI 0.28 to 0.91) with the Stereo Fly test in measuring stereopsis in adults with normal binocular vision. These results suggest that the polarized-free BEST Test 1 results were measuring a similar level of stereopsis clinically as was the polarized Stereo Fly test in our non-strabismic adult subjects.

Discussion

The results show that the BEST is in good agreement with the Stereo Fly test in measuring stereopsis in adults with normal binocular vision. The distribution of the stereopsis scores for all 45 subjects on both tests are presented in Figure 3 for comparison. A majority (39 out of 45 subjects) of the stereopsis values between the two tests were essentially identical. Six subjects had 10 arc seconds of difference between the tests. Using 40 arc seconds as the pass-fail cut-off, we found that 35 subjects passed both tests (with all 35 subjects having identical stereopsis scores), and five subjects failed both tests (with four of the five having identical stereopsis scores). Two passed the Stereo Fly test but failed the BEST. Three failed the Stereo Fly test but passed the BEST. The results also indicate a moderate correlation between the scores for each subject on the BEST Test 1 and the Stereo Fly test.

Our study demonstrates that for this sample, the new polarized-free BEST Test 1 results are comparable to the polarized Stereo Fly test. The use of the BEST in a clinical setting to measure local stereopsis may have a few advantages, such as the ability to test patients (e.g., those with developmental disability) who will not wear test glasses. The test makes it easier to observe ocular alignment during stereopsis testing. The BEST design also significantly

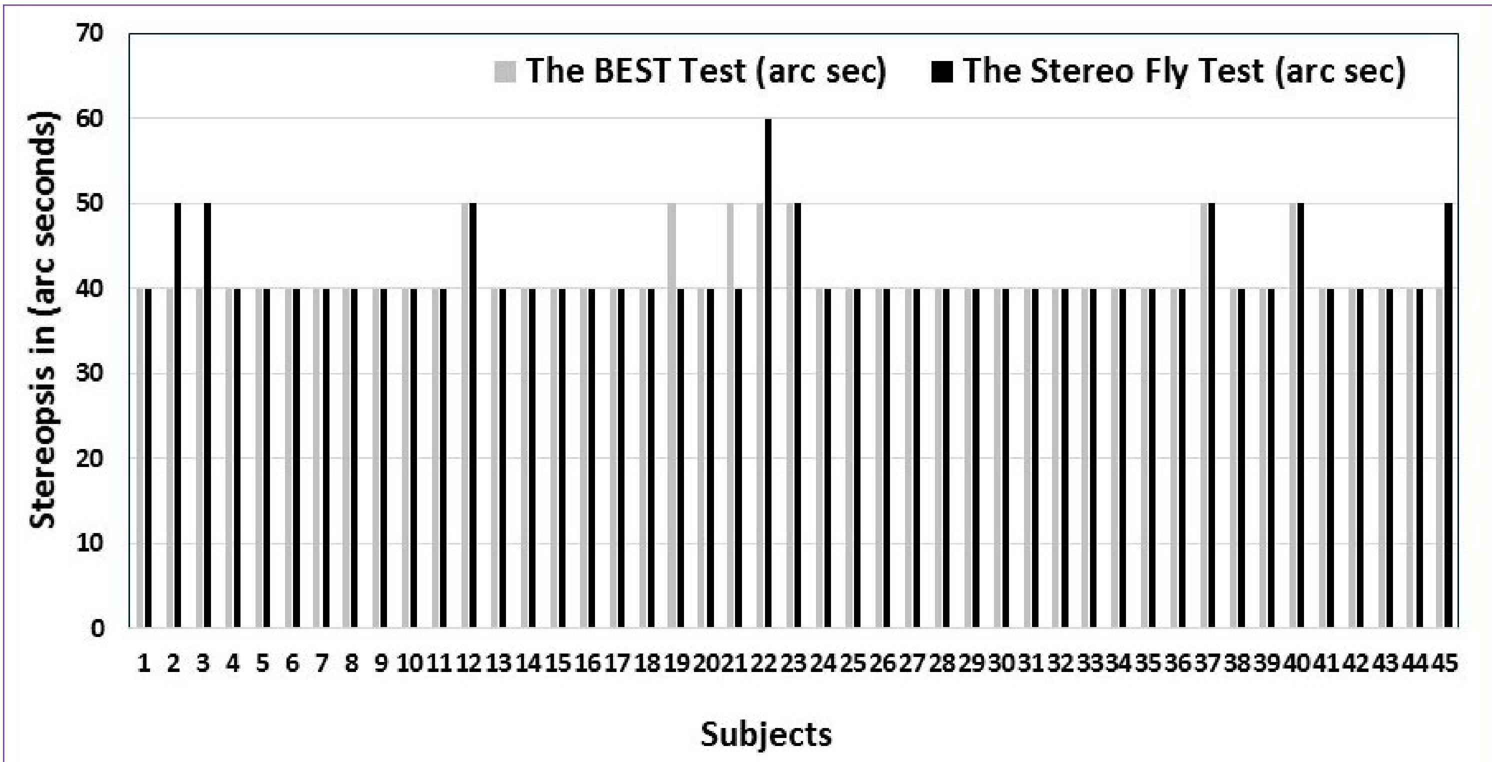

Figure 3. *Distribution of results on the Stereo Fly test and the BEST (in arc seconds) for all subjects*

reduces the effect of apparent motion. If a patient moves or tilts the test from side to side, they may potentially be able to tell which which clip-art targets are different, but not whether they appear to go above or below the page. The manufacturer also recommends masking the other test targets when using the BEST with young children in order to avoid distraction.

As the BEST manufacturers use lenticular technology, there have been challenges in designing test targets with levels of stereopsis similar to the Stereo Fly test. Hence, the BEST has fewer (eight) levels of stereopsis compared to the Stereo Fly test (nine levels). The lowest threshold on the BEST is 400 arc seconds, compared to 800 arc seconds on the Stereo Fly test. This may be an issue for certain patients, who may have stereopsis levels lower than 400 arc seconds. As low-threshold stereopsis testing is helpful in detecting binocular vision symptoms, as well as for the performance evaluation of optometric treatment, clinicians using the BEST to monitor binocularity over the treatment period, especially in amblyopia or vision therapy, need to be cautious when interpreting BEST results. In particular, when the patient's stereopsis results fall between 100 and 200 arc seconds, there is only one level (150 arc seconds) of stereopsis measurement. The nearest stereopsis level to this target on the Stereo Fly test is 140 arc seconds. Clinicians administering vision therapy and binocular vision treatment looking for marginal improvement in stereopsis should keep this in mind when using the BEST.

The other important psychophysical aspect in which the BEST differs from the Stereo Fly test procedure is the number of test targets that the subjects must compare before judging the stereopsis. For example, in the Stereo Fly test, the subjects are trying to determine the Wirt Circle that is raised among the four circles in a 4-alternative forced-choice (AFC) method for each test stimulus. In the BEST, subjects scan across the entire row of three animals to determine which one is popping out (3-AFC). Once they have determined a response, they will next have to determine which animal is receded in the same row between the remaining two choices (2-AFC).

The evidence is equivocal that having to make a choice across three or four choices makes a difference[32-34] in response. Few studies[33-35] suggest that four choices (4-AFC) tests are the most accurate with least variability. While others[36] show two (2-AFC) and three (3-AFC) choice thresholds to be on average about the same. Although the study[36] suggests that 3-AFC tests are a better option, as they are cognitively less demanding and less time consuming when testing children in clinical situations. In another study[37] involving stereo acuity testing on preschool children, the 2-AFC Stereo Smile test showed higher testability than the 4-AFC Preschool Randot test, raising the possibility that 2-AFC may have advantages in testing preschool children.

The results of these studies suggest that there are marginal tradeoffs between 3-AFC and 4-AFC testing procedure outcomes, which may apply to our comparisons between the Stereo Fly Wirt Circles (4-AFC) and the BEST Animals (3-AFC). Although our results do not indicate any major differences in responses to three- versus four-choice patterns, administration of the BEST was marginally quicker than that of the Stereo Fly based on our clinical experience. This may offer an advantage in testing patients with developmental disabilities and shorter attention spans. However, this cannot be considered as a major advantage in normal adults over the Stereo Fly test in clinical stereo acuity testing.

Based on our experience with the BEST, we have a few recommendations that may potentially improve the effectiveness of the testing method. In order to minimize the guessing of a correct answer by using apparent motion or monocular cues, one modification may include holding the test in front of the patient with the bee in row A directly in front of the patient's nose, as this appeared to minimize monocular cues and apparent motion.

The existing manufacturer's instructions for administering and scoring the different sections of the BEST are rather inconsistent and confusing compared to other widely used clinical stereopsis tests. For this reason, there are several recommendations offered.

(1) We recommend modifying the testing procedure as described in this study: i.e., asking the patient first to name or to point out the animal that appears closer (among the three animals) and then to name or to point to the picture that appears deeper (among the three animals) for each row, before proceeding to test the subsequent row. Using this modification, the stereopsis testing will be administered in a descending disparity order (in arc seconds) similar to other commonly used clinical stereopsis tests, thereby helping clinicians to grasp the administration of the test easily.
(2) For quicker administration (e.g., during screening), the clinician may ask the child only to name or to point to the picture that is deeper (among the three animals) in each row. This will test stereo acuity in the range of 200 to 40 arc seconds in Test 1 clip-art animal characters and 400 to 80 arc seconds in Test 2 clip-art animal characters for young children.

As our study measured stereopsis in adults, they were readily able to identify the animals on the BEST. However, in young children, this may or may not be the case, as some children may not be sufficiently adept at labelling and stating the correct picture name. The bird could easily be mistaken for a chicken. In order to avoid such an ambiguity, the manufacturer might consider a matching card (with large test animals) in order to familiarize the child with the target choices and to practice the correct naming response before administration of the test. If this is difficult, a set of figures might be used for the child to point (a non-verbal response) to the figure of their choice.

Conclusion

Our study demonstrated that the BEST is comparable to the Stereo Fly test in measuring stereopsis in adults with normal binocular vision. This study was conducted in an adult, non-strabismus population as an initial step in establishing the test's value for clinical stereopsis testing. Threshold stereopsis testing determined in this study may be helpful in detecting binocular vision problems and in determining the effect of treatment with lenses and/or prism. Further studies in more-diverse patient populations, such as young children or patients with developmental disability, are needed to determine the value and application of the different sections of the BEST compared to other clinical stereopsis tests.

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