Improved Stereoacuity Testing with the Judgement of Equal Distances

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Abstract

Stereoacuity tests do not usually require the judgement of equal distances. A stereoacuity test which included zero disparity and required equal distance judgements was used to investigate the effect of overall aniseikonia on depth perception thresholds and the disparity of subjective equidistance (DSE). The results of this investigation are reported. The same data were used to determine the effect that a forced choice without the judgement of equal distances would have on test results. Three different ways of responding to a forced choice were simulated by redistributing equal distance responses between left and right nearer responses. These simulations often produced apparently better stereoacuities. From this, it is concluded that equal distance judgements improve the quality of stereoacuity test results.

Résumé

Les tests d'acuité stéréoscopique n'exigent pas habituellement un jugement sur la distance qui sépare les cibles des yeux. L'auteur a utilisé un test d'acuité stéréoscopique comportant une disparité de zéro et nécessitant un jugement quant à des distances égales pour étudier les effets de l'aniséiconie globale sur les seuils de perception stéréoscopique et la disparité du jugement subjectif de l'équidistance. Les résultats de cette étude sont présentés. On a employé les mêmes données pour déterminer l'effet qu'aurait sur les résultats un choix forcé sans jugement de distance. Nous avons simulé trois façons de répondre à un choix forcé en redistribuant les réponses relatives à des cibles équidistantes entre les réponses relatives à des cibles plus rapprochées à gauche et à droite. Ces simulations ont souvent semblé produire de meilleures acuités stéréoscopiques. Nous avons donc conclu qu'un jugement quant à la distance entre les cibles et les yeux permet d'obtenir des résultats de meilleure qualité lors des tests d'acuité stéréoscopique.

This article aims to demonstrate that stereoacuity test results are enhanced by including test objects at an equal distance from the patient. The author's interest in the perception of equal distances was caught when some patients found it easier to perceive a difference in depth when the leftmost object was nearer and others when the rightmost object was nearer. Some perceived equally distant objects as left nearer and others as right nearer. Sometimes the nearer object was perceived to be farther away. These observations led to the conclusion that conventional stereoacuity test designs had overlooked an important element of depth perception. This is that small amounts of aniseikonia can make a more distant object appear to be nearer.

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In this project, the paradigm is 2 vertical rods separated laterally by a small distance. As is customary, rod separation in depth is expressed in terms of geometrical disparity.[1] There are 2 rod arrangements for each disparity, left nearer and right nearer. Before an understanding of the effect of aniseikonia was achieved, the author added together the patient's responses at a given disparity without taking into account the nearer rod. Thus, if aniseikonia caused one rod to appear to be nearer when it was not, at least half of the responses would be wrong. Stereoacuity calculated from such data could be over or underestimated. To avoid this, patient's identifications of left and right nearer disparities had to be tallied separately.

When responses to left and right nearer are tallied separately, disparities are in a sequence from greatest left nearer to greatest right nearer. Zero disparity (equidistance) has its place in the middle of this sequence. When test data are arranged in this way, there are 2 threshold disparities for stereopsis, left nearer and right nearer. These disparities are the same if there is no aniseikonia or other distortion. With aniseikonia, left and right threshold disparities will be different. The disparity perceived to be equidistant is midway between these thresholds. The term "disparity of subjective equidistance" was suggested by an anonymous referee to describe the disparity at which distances were perceived to be equal.

The disparity of subjective equidistance (DSE) is a valuable piece of information which can be extracted from test data. In a previous investigation, a group of 40 persons was tested with a procedure such that left, right and equal responses were tallied separately for each disparity.[2] Results showed a distribution of DSE from 12 arc sec left nearer to 6 arc sec right nearer. Only 10% of these subjects had a DSE of 0 arc sec. At the time, it was assumed that a non-zero DSE was due to aniseikonia but this was not proven.

In a recent investigation, an attempt was made to demonstrate a relationship between DSE and aniseikonia. To this end, aniseikonia was induced in a small number of subjects and their stereoacuity measured. Aniseikonia was produced by an afocal lens system of 2.4% magnification or by a mirror system with a variable magnification of up to 9%. The results of this investigation are reported here and are used to demonstrate the advantages to be gained by including equal distances when testing for stereoacuity.

Methods

A first surface mirror system (Fig. 1) provided known amounts of overall aniseikonia. The optical path length between the subject's right eye (R) and the rods (T) was increased by 39 mm by mirrors A to D. The path length between the left eye (L) and the rods was increased by a similar mirror arrangement (E to H) in which mirrors F and G were mounted on a slide. This slide moved at right angles to the line joining L and T as shown by the arrow. A scale and pointer attached to the slide was used to determine the path length from E to H. From this, the percent magnification of the right eye's retinal image with respect to that of the left was calculated. An increase

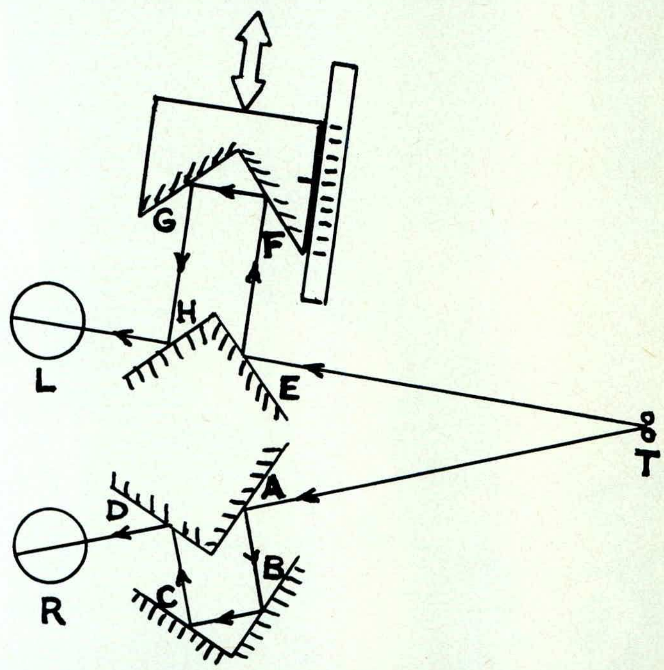

Fig. 1 Mirror arrangement for changing size of left eye's (LE) retinal image by means of a variable optical path length. First surface mirrors E and F were fixed. Mirrors F and G were moveable so as to increase or decrease the path length relative to that of the right eye. Path to right eye (RE) was by first surface mirrors A, B, C and D.

Table 1
Complete data for one subject showing number of left, right and equal responses for each disparity and for each of the 3 conditions of lens induced aniseikonia.

Magnification	**Response**	**Number of responses Disparity (arc sec)**											**SA DSE[1]**	
		left nearer						right nearer					(arc sec)	
		-24	-16	-12	-8	-4	0	4	8	12	16	24		
	left	9	9	9	9	9	9	6	3	0	0	0		
2.4% right eye	right	0	0	0	0	0	0	0	0	2	6	8	6	+10
	equal	0	0	0	0	0	0	3	6	7	3	1		
		(see note 2)						*		^	*			
	left	9	9	9	9	8	2	1	0	0	0	0		
none	right	0	0	0	0	0	0	1	5	9	9	9	8	+4
	equal	0	0	0	0	1	7	7	4	0	0	0		
						*		^		*				
	left	9	7	7	1	0	0	0	0	0	0	0		
2.4% left eye	right	0	0	0	0	4	7	9	9	9	9	9	6	-6
	equal	0	2	2	8	5	2	0	0	0	0	0		
				*		^	*							

1. SA = Stereoacuity, DSE = Disparity of Subjective Equidistance.
2. * = threshold, ^ = DSE

Table 2
Equal response data of Table 1 redistributed so as to simulate a forced choice between left or right nearer.

Magnification	Redistribution of Equal Responses	SA	DSE
		(arc sec)	
	not redistributed	6	+10
2.4% right eye	shared equally between left and right	6	+10
	all given to left	4	+16
	all given to right	6	+6
	not redistributed	8	+4
none	shared equally between left and right	6	+2
	all given to left	4	+8
	all given to right	2	-2
	not redistributed	6	-6
2.4% left eye	shared equally between left and right	4	-8
	all given to left	4	-4
	all given to right	2	-10

in path length caused a decrease in retinal image size. The size of the left eye's retinal image could be varied from 1% larger to 9% smaller than that of the right eye. The binocular field of view was restricted to 5.2 deg horizontal by 7.6 deg vertical by the dimensions of the mirrors.

An afocal lens system provided a fixed overall magnification of 2.4% by combining 3 Tillyer trial lenses each of 0.0 diopters. For each lens, surface curvatures and center thickness were measured precisely. Trigonometrical ray tracing was then used to find the magnification and dioptric power of the combination when mounted in a trial frame.

The automated stereoacuity test has already been described in detail.[3] From the subject's point of view, 2 black vertical lines (the rods) were seen through a rectangular window in the center of a screen which lay in a frontal plane. By means of one of two switches, the subject reported which line (left or right) was nearer. If they seemed equidistant, both switches were actuated. When the perception of the lines had been reported, a shutter closed the window for 2.4 sec after which another pair of lines was presented.

Disparities used for this investigation were 24, 16, 12, 8, 4 and 0 arc sec. There were two arrangements at each disparity, one with the left rod nearer and the other with the right rod nearer.

Monocular cues to depth were eliminated by masking the rod's extremities and by backlighting which showed the rods in silhouette. At the test distance of 60 cm, the rods were both 4.5 min arc wide and were always separated laterally by a gap of 17 min arc. Each test consisted of 3 randomized presentations of the 11 rod arrangements for a total of 33 responses.

Subjects (4) were all in their early twenties. Each had a stereoacuity of 8 arc sec or better. Stereoacuity was tested with the lens before the left eye, the right eye and without the lens. The lens arrangements were in a random order and each was tested 3 times. One subject was tested with mirror settings of 8, 6, 4, 3, 2, 1, 0 and -1% right image bigger than left. These were presented in a random order.

The threshold of stereopsis was defined as the least disparity beyond which less than 66% of responses were correct. This was appropriate for 3 possible responses. There were 2 thresholds, left and right nearer. The disparity mid-way between these thresholds was calculated and was taken to be the DSE. Stereoacuity was the difference between the DSE and either threshold. The DSE was assumed to lie in the subject's apparent frontoparallel plane. The angular relationship between the plane of the rods at the DSE and the frontoparallel plane was that for each 4 sec of disparity the plane of the rods was rotated by 1.77 deg.

Results

Stereoacuity results were similar for all subjects; the mean and standard deviation being 6.4 and 1.9 arc sec respectively. The change in DSE from 2.4% left image bigger to 2.4% right image bigger depended on the subject. For the 4 subjects tested, these were 4, 8, 8 and 16 arc sec respectively.

All data of the subject with the greatest change in DSE are given in Table 1. Thresholds are indicated by an asterisk (*) written under the threshold disparity. The DSE is indicated with a caret (ˆ). The change in DSE with induced aniseikonia is obvious.

An issue central to this investigation was whether or not equal distance judgements gave better data. If an equal response were not permitted, a choice would be forced between left and right nearer. To find out how such a forced choice would modify the results, data were stripped of equal distance responses by assigning them to left or right nearer responses.

This redistribution was made in 3 ways. In the first, equal responses were shared equally between left and right nearer responses. When the number of equal responses was odd, the extra one was given to the left or right response with the bigger total. In the second, all equal responses were given to left nearer. In the third, all were given to right nearer. The revised data were analysed for stereoacuity and DSE as before. As there were only 2 responses, threshold was 78% correct. These results are presented in Table 2.

The mirror system results of a different subject are presented in Fig. 2. This graph shows rod disparity versus % magnification. The upper and lower solid lines join thresholds of depth perception. DSE's are midway between thresholds and are joined by a dashed line. Because of the system's limitations, both thresholds could not be obtained beyond 4% magnification. However, the left nearer threshold was obtained with magnifications of 6 and 8%. An interesting discontinuity in the curves occurs between 2 and 3%.

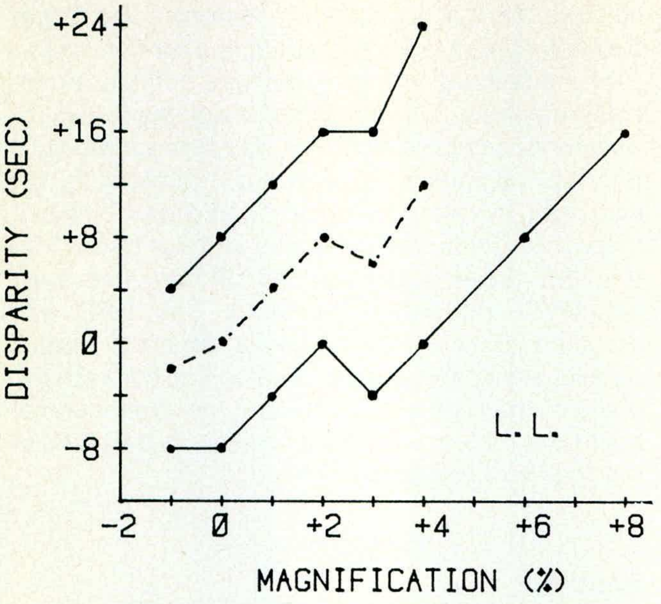

Fig. 2 Graph of disparity versus magnification found with the mirror system. Thresholds of stereopsis are continuous lines. Disparity of subjective equidistance is a broken line.

Discussion

Induced overall aniseikonia can cause a shift in DSE. This was demonstrated in each of the 4 subjects. However, the amount of this shift was found to vary from subject to subject. The least shift was 4 and the greatest 16 arc sec. This considerable difference precludes using a patient's DSE to estimate aniseikonia. Nevertheless, the amount of induced aniseikonia required to shift a patient's DSE to zero could be used to measure his or her aniseikonia.

Zero disparity is not superfluous to a test when the DSE is not zero. This can be seen in the data of Table 1. With 2.4% magnification before the right eye, zero disparity was always perceived as left nearer. With magnification before the left eye, zero disparity was identified as right nearer 7 times and as equidistant twice. In this instance, zero disparity was the right nearer threshold. If zero disparity had not been included in the test, 4 arc sec right nearer would have been taken as the threshold. This would have changed the calculated stereoacuity from 6 to 8 arc sec and the DSE from -6 to -4 arc sec.

A forced choice was not included in this investigation. However, it was simulated by distributing equal responses between left and right nearer. Stereoacuities and DSEs from the revised data are seen in Table 2. A forced choice usually resulted in an apparently better stereoacuity. In the results without induced aniseikonia, stereoacuity was 8 arc sec with equal responses included and 2 arc sec with all equal responses given to right nearer. This demonstrates that a forced choice can alter stereoacuity significantly. Therefore, a forced choice should be avoided if data quality is to be maximized.

From the author's experience, patients prefer a test with left, right and equal responses to one with a forced choice between left and right, probably because it is natural to say that distances are equal when neither rod seems nearer. A forced choice offends some patients because they object to a response which is not true to their perception.

Patients who want to improve their performance can do so by not making equal responses. This behaviour is very easy to detect by looking at the data. When only left and right responses have been made, a threshold of at least 75% correct must be used. In some instances, the absence of equal responses is due to very good stereoacuity. If the DSE lies between two disparities and the stereoacuity is 2 arc sec there may be no equal responses.

Equal distance responses are useful only if the test uses real objects. When anaglyphes (TNO) or vectographs (Randot) are used, the surface of the test plate is the reference surface against which other distances are judged. It is a common observation that patients rotate such tests about a vertical axis in order to improve performance. Even with aniseikonia, nearness judgements are unaltered because they are made with respect to the surface of the test and not the frontoparallel plane.

One might conclude that anaglyphes or vectographs are to be preferred because aniseikonia has no effect on stereoacuity measured with them. This is not true. These tests either do not include disparities of 8 arc sec or smaller or else cannot guarantee these disparities to be as marked. Howard demonstrated that good stereoacuity is of 8 arc sec or better.[4] Therefore, anaglyphes and vectographs are of limited use.

Acknowledgement

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