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Do we really need binocular single vision?

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Abstract

Aim: **To investigate whether or not we need binocular single vision (BSV) for successful depth perception.**
Methods: **A mixed-measures design was used to compare monocular subjects and binocular subjects in their ability to judge depth. Experimental stimuli were images resembling large drawing pins that were displayed on a computer screen. Subjects had to adjust the spike of the drawing pin, by means of a keypad, until it appeared to be at an angle of 90° to the head of the pin. The head of the drawing pin was at a slant of 30° from the frontal plane, around either the horizontal or vertical axis. The computer recorded the number of degrees away from the 90° position that the spike was set, the time taken and the standard deviation of the settings. A three-factor mixed measures ANOVA was used to analyse the results.**
Results: **Overall, binocular subjects were more accurate than monocular subjects ($F = 13.894$, $df = 1, 14$, $p < 0.01$) in judging when the spike was set at an angle of 90° to the head of the pin. There was no significant difference between the horizontal or vertical orientations of stimuli in terms of accuracy ($F = 1.250$, n.s.), or between the two groups in the time it took them to complete the task.**
Conclusion: **BSV is advantageous and the time and resources spent on restoring and maintaining BSV are worthwhile.**

Key words: Binocular, Binocular single vision, Depth perception, Monocular, Stereopsis

Introduction

Binocular single vision (BSV) is an area that has been studied by mankind throughout the ages. In 150 BC, Ptolemy carried out experiments in which he presented differing images to either eye. He discovered that what the viewer perceived was in fact a mixture of the two images. This was evidence that both eyes contribute to form a single image.[1] By having two eyes and this arrangement of overlapping visual fields, we have the ability to fuse the two images and perform stereoscopic depth perception.[2] The question that arises from this is whether we really need BSV or whether we can manage adequately without it. Fielder and Moseley[2] reviewed work carried out within this field. They found that much of the evidence is somewhat conflicting.

Joy *et al.*[3] asked subjects to carry out two tasks in order to assess whether stereopsis is linked to hand–eye coordination. In the first task a wire loop had to be threaded around a wire course and in the second task pegs had to be placed into holes in a plastic board. It was found that long-term monocular subjects took significantly longer to complete the two tasks than binocular subjects, suggesting that BSV and stereopsis are advantageous.

Sheedy *et al.*[4] investigated the functional advantages of binocularity. The majority of tasks carried out showed that there are significant advantages to binocular performance over monocular performance. Kousoulides,[5] on the other hand, studied two groups of children in their ability to carry out tasks such as manipulating pegs and beads and drawing pictures. No significant difference in ability was found between the group of children with BSV and the group of children with infantile esotropia, suggesting that we can function well without BSV.

Whilst stereopsis is a uniquely binocular phenomenon, there are many monocular cues that can provide information on depth. If the development of BSV is arrested, for example by strabismus, we come to rely on these monocular cues. Marotta *et al.*[6] suggest that people rendered monocular adapt to coping with one eye. Godber[7] reported on his own experience of having one eye enucleated at a young age. Although he had adapted to some extent over time, he was still functionally inconvenienced by the loss of binocularity.

Perception of slants and angles

It has been quite well documented that, when viewed binocularly, surfaces rotated around the vertical axis and those rotated around the horizontal axis differ in terms of how well an observer can perceive the rotation. When viewing a surface, each eye has a slightly different view of it and this may be a cue for detecting surface slant. This phenomenon is greater for surfaces rotated around the vertical axis than for those rotated around the horizontal axis,[8] as can be seen in Fig. 1. It has been reported that latencies for the perception of slant around the vertical axis are typically longer than those for stimuli rotated around the horizontal axis.[9]

Previous literature focusing upon the need for BSV is relatively sparse and provides conflicting evidence.

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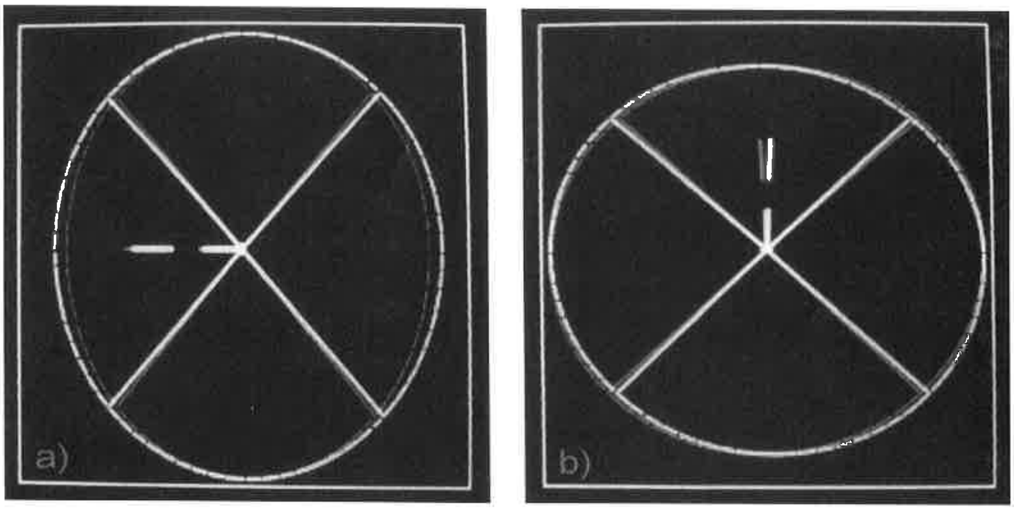

Fig. 1. The experimental stimuli resembling drawing pins. Each eye has a slightly different view of the stimuli, with one eye seeing the green outline (depicted by the pale grey) and the other eye seeing the red outline (depicted by the darker grey). This difference in the view to each eye is greater for stimuli rotated around the vertical axis (*a*) than for stimuli rotated around the horizontal axis (*b*).

Much of the treatment carried out in orthoptics aims to restore or maintain BSV where possible, but is the time and money spent on doing this necessary? The aim of the present study was to answer this question by comparing depth perception in subjects with and without BSV.

Methods

Seventeen subjects were recruited to take part in the experiment and were divided into two groups. The monocular group consisted of 7 subjects with no demonstrable BSV and the binocular group consisted of 10 subjects with BSV including stereopsis. The subjects in the monocular group all had a manifest strabismus, except one who had unilateral macular damage due to trauma.* All but one of the subjects were volunteers from the Orthoptic and Psychology departments of the University of Sheffield; the other was a family friend. Subject age ranged from 18 to 46 years, the mean being 22.00 years. There were 13 women and 4 men. The inclusion criteria for the two groups were as follows:

Monocular subjects: visual acuity of 6/6 or better in the fixing eye (with optical correction if necessary) and no demonstrable stereopsis. Subjects in this group were recruited by department-wide advertisement and prior knowledge of participants' binocular status.

Binocular subjects: visual acuity of 6/6 or better in both eyes (with optical correction if necessary) and stereopsis at a level of 60 seconds of arc or better. Subjects in this group were recruited by department-wide advertisement.

Some preliminary testing was carried out to ensure the subjects fulfilled the inclusion criteria and were allocated to the correct groups. Visual acuity was measured using a logMAR chart at the test distance of 4 m and a reduced Snellen chart at 33 cm. The presence or absence of binocular function for near fixation was determined by use of the cover test, Worth's lights macular sleeve and TNO stereotest. In addition to these tests a modified version of the 'pointing test' as used by Harvey *et al.*[10] was used to determine the dominant eye in binocular subjects.

Depth perception was investigated using a mixed-measures design, i.e. all the subjects did the task (repeated measures) but there were two groups (independent measures). It was counterbalanced for order effects, i.e. within each of the two groups half the participants did the task first with both eyes open and then with the non-dominant eye occluded. The other half of each group did the task in the reverse order. Allocation of the order in which the tasks were to be performed was based upon the order in which participants presented: subjects 1, 3, 5 etc., in each group did the task with both eyes open first and subjects 2, 4, 6, etc., in each group did the task with the non-dominant eye occluded first. The stimuli were presented to each subject in a different random order generated on the computer.

The experimental stimuli used were images resembling large drawing pins and were based upon stimuli previously used by Koenderink *et al.*[11] to study surface perception in pictures (Fig. 1). These were generated in MATLAB using the psychophysics Toolbox extensions.[12] Each stimulus contained consistent monocular and binocular cues. Subjects viewed the stimuli on a 33 cm × 25 cm Mitsubishi Diamond Plus 72 monitor, through red/green goggles at a distance of 57 cm. Each image subtended 6° of visual angle. A chin-rest was used to maintain the test distance of 57 cm, to ensure all participants had their eyes level with the centre of the stimuli and to prevent head movement.

A pilot study was performed which indicated that the procedure was satisfactory to run on other participants. Each subject was tested individually. After the preliminary tests had been done and the consent form had been signed, the subjects were given written instructions that explained the nature of the task. The room was then darkened in preparation for commencing the task.

Stimuli were presented on a computer screen. The aim

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*The visual acuity of this subject was −0.100 logMAR (6/5 Snellen equivalent) in the right eye and perception of light in the left eye.

of the task was for the subject to make adjustments to the angle of the spike of the drawing pin in 1° steps. Adjustments were made via a keypad. The task was completed when the subject perceived the spike to be at an angle of 90° to the head of the pin. The head of the drawing pin was at a slant of 30° from the frontal plane, around either the horizontal or vertical axis. The spike of the pin started off at a different random angle on each presentation; half the number of trials began with the spike at an angle greater than 90° and half began with the spike at an angle less than 90°. There were four practice trials followed by 24 further presentations of the stimuli, in which the pin was rotated around the horizontal axis in 12 and rotated around the vertical axis in the other 12 (see Fig. 1). The computer measured and recorded the number of degrees away from the 90° position that the spike was set on each presentation. When the spike was set at an angle of 90° to the head of the pin a value of zero was recorded. If it was set to one side of this position the appropriate positive value was recorded, and if it was set to the other side the appropriate negative value was recorded. As well as the angle, the computer also recorded the time taken to adjust each stimulus and the standard deviation of the settings. When the subject was happy that he or she had set the spike appropriately, they pressed a button on the keypad twice in order to move on to the next stimulus. No feedback was given between each presentation of the stimuli.

Results

The accuracy of a subject setting a stimulus is defined by the angle in degrees the spike is set away from the 90° position. Therefore a value for a setting that is closer to zero, whether it be positive or negative, is more accurate than a value further away from zero. The standard deviation calculated for a subject is a measure of how reliable his or her settings were. A more reliable subject is one whose settings have a smaller standard deviation, as this indicates that on each presentation of the stimuli the angle they perceived as being 90° was approximately the same. A larger standard deviation indicates that the subject was less sure about the angle they perceived as being 90°. The mean time is defined as the time from presentation of a stimulus to when the button on the keypad was pressed to move on to the next stimulus, averaged across each particular stimulus.

Although 17 subjects participated in the study, 1 monocular subject was excluded from the data analysis. She reported difficulty in understanding the task and the large negative numbers recorded for the mean settings were very different from the results of the other subjects within that group. The tables, graphs and statistics therefore apply to the remaining 16 subjects. Before tabulating the data, the raw data were checked for any very short times recorded for each presentation of the stimuli, indicative of the subject accidentally pressing the button on the keypad and prematurely moving on to the next stimulus. These data were excluded.

Table 1 shows the settings data. These data are shown graphically in Fig. 2. It can be seen that binocular subjects were more accurate than monocular subjects and that viewing with both eyes open was more accurate than viewing with just the dominant eye, irrespective of the type of subject. Table 1 also demonstrates that

Table 1. The mean settings (degrees) for each observer. The mean, standard deviation and standard error of each group are also shown, for the two orientations of stimuli both separately and combined

	Subject no.	Initial viewing	Viewing with one eye		Viewing with both eyes	
			Horizontal	Vertical	Horizontal	Vertical
Monocular subjects	1	Both eyes	12.92	12.33	17.67	12.08
	2	One eye	13.00	22.75	14.17	14.67
	3	Both eyes	10.50	18.92	4.83	18.17
	4	One eye	16.25	24.33	7.08	25.18
	5	Both eyes	16.42	21.67	16.83	24.83
	6	One eye	13.75	7.42	10.25	−4.33
		Mean	**13.81**	**17.90**	**11.81**	**15.10**
		SD	**2.24**	**6.65**	**5.27**	**10.89**
		SE	**0.92**	**2.71**	**2.15**	**4.44**
		Grand mean	**15.86**		**13.45**	
		Grand SD	**5.19**		**8.33**	
		Grand SE	**2.12**		**3.40**	
Binocular subjects	7	Both eyes	5.25	0.83	−8.83	−7.36
	8	One eye	−4.25	0.17	0.33	−1.50
	9	Both eyes	−2.33	2.25	−8.08	−9.75
	10	One eye	11.08	5.92	3.08	2.00
	11	Both eyes	9.64	11.58	0.75	−4.83
	12	One eye	−1.83	4.42	3.67	−7.17
	13	Both eyes	−5.67	−1.75	−10.58	−10.08
	14	One eye	14.75	20.17	13.67	7.58
	15	Both eyes	−0.25	4.92	0.83	4.08
	16	One eye	30.08	26.25	1.25	−3.00
		Mean	**5.65**	**7.48**	**−0.39**	**−3.00**
		SD	**11.08**	**9.18**	**7.20**	**6.01**
		SE	**3.51**	**2.90**	**2.28**	**1.90**
		Grand mean	**6.56**		**−1.70**	
		Grand SD	**9.95**		**6.59**	
		Grand SE	**3.15**		**2.08**	

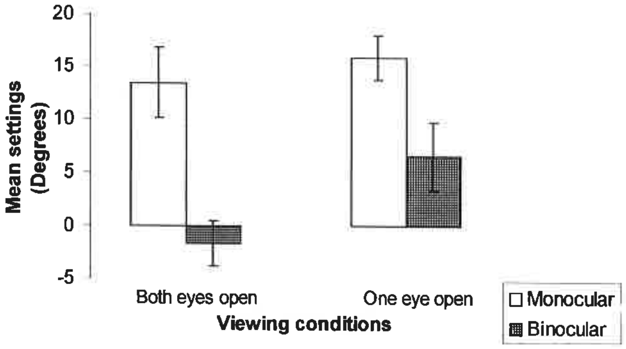

Fig. 2. Taking all stimuli into account, the mean settings for the two groups under different viewing conditions are shown. The error bars show ±1 standard error of the mean of each group, giving an indication of the variation within each of the two groups.

stimuli rotated around the horizontal axis were set more accurately than those rotated around the vertical axis. A three-factor mixed-measures ANOVA was carried out on the data. This indicated that binocular subjects were significantly more accurate than monocular subjects ($F = 13.894$, $df = 1, 14$, $p < 0.01$) and that viewing with both eyes was significantly more accurate than viewing with just the dominant eye ($F = 8.142$, $df = 1, 14$, $p < 0.05$). The difference in accuracy between the two orientations of stimuli was not significant ($F = 1.250$, n.s.). None of the interactions were significant (largest $F = 2.457$, n.s.).

Table 2 shows the time data and Table 3 shows the standard deviation data. From Table 2 it can be seen that the monocular and binocular subjects were similar in the time it took them to set the stimuli; the stimuli were set more quickly when viewing with just the dominant eye than when both eyes were open and the stimuli rotated around the vertical axis were set more quickly than those rotated around the horizontal axis. From Table 3 it can be seen that the monocular subjects had slightly smaller standard deviations than the binocular subjects, indicating that monocular subjects were slightly more consistent. Viewing with both eyes open produced smaller standard deviations than viewing with just the dominant eye. There was very little difference in the standard deviations for the two orientations of stimuli. Using ANOVA, none of the factors or interactions in relation to time (largest $F = 2.900$, n.s.) or standard deviation (largest $F = 2.769$, n.s.) was significant.

Further statistical analysis showed that order of viewing was not a significant factor (largest $F = 2.596$, n.s.). There was no significant correlation between time and setting (largest $r = 0.356$, n.s.) or between time and standard deviation (largest $r = 0.303$, n.s.) for either group of subjects.

Discussion

The results of the study indicate that BSV is advantageous when carrying out depth perception tasks. Even though Table 3 shows there to be a trend for monocular subjects to give slightly more reliable results, Table 1 and Fig. 2 show that the subjects with BSV were significantly more accurate than the monocular subjects ($F = 13.894$, $df = 1, 14$, $p < 0.01$).

The general conclusion that BSV is useful is in line with the results of Sheedy *et al.*[4] but contrary to the

Table 2. The mean times (seconds) taken to complete the task for each observer. The mean, standard deviation and standard error of each group are also shown, for the two orientations of stimuli both separately and combined

			Viewing with one eye		Viewing with both eyes	
	Subject no.	Initial viewing	Horizontal	Vertical	Horizontal	Vertical
Monocular subjects	1	Both eyes	18.72	14.30	27.04	25.66
	2	One eye	17.24	17.26	9.80	8.63
	3	Both eyes	15.32	11.41	13.80	13.58
	4	One eye	13.89	11.84	17.40	12.03
	5	Both eyes	9.72	9.69	13.19	15.41
	6	One eye	10.04	10.45	7.27	5.58
		Mean	**14.16**	**12.49**	**14.75**	**13.48**
		SD	**3.70**	**2.81**	**6.95**	**6.93**
		SE	**1.51**	**1.15**	**2.84**	**2.83**
		Grand mean	**13.32**		**14.12**	
		Grand SD	**3.25**		**6.65**	
		Grand SE	**1.33**		**2.72**	
Binocular subjects	7	Both eyes	15.89	10.83	15.16	15.67
	8	One eye	20.51	15.62	21.84	9.93
	9	Both eyes	9.08	10.53	23.27	13.95
	10	One eye	22.62	16.38	14.87	13.13
	11	Both eyes	10.88	7.60	9.39	7.27
	12	One eye	16.32	12.01	10.58	12.30
	13	Both eyes	5.84	8.98	10.99	15.82
	14	One eye	10.47	12.40	15.57	9.07
	15	Both eyes	11.35	12.27	20.26	33.14
	16	One eye	12.99	8.99	4.99	3.70
		Mean	**13.60**	**11.56**	**14.69**	**13.40**
		SD	**5.22**	**2.82**	**5.86**	**7.92**
		SE	**1.97**	**1.07**	**2.22**	**2.99**
		Grand mean	**12.58**		**14.05**	
		Grand SD	**4.21**		**6.82**	
		Grand SE	**1.33**		**2.16**	

results of Kousoulides.[5] In the study by Kousoulides[5] performance on some of the tasks was measured by the time taken until completion, but other tasks were judged subjectively.

Marotta *et al.*[6] suggested that long-term monocular subjects adapt to coping with one eye, so that they make use of monocular cues to a greater extent than people with BSV who are rendered monocular by occluding one eye. The results of the present study contradict these findings. Not only was there no significant difference between the two groups of subjects when viewing with one eye, Table 1 and Fig. 2 also show that there was a trend for binocular subjects with one eye occluded to be more accurate than monocular subjects under the same viewing conditions. In the present study the ages at which subjects became monocular were not recorded. Subject number 1 is of particular interest here. On cover test no manifest deviation was found, and on questioning it was discovered that macular damage had been sustained through trauma. If the history of trauma was recent, this subject may not yet have made any adaptations to aid depth perception. Further information regarding the age and mode of onset would have ideally been recorded for each monocular subject.

There was no significant interaction between the type of person and the viewing conditions. Consideration of Table 1 and Fig. 2 shows there was a trend for subjects with BSV to carry out the task more accurately when viewing with both eyes than one eye. Nevertheless, within the group of binocular subjects there were some who actually performed more accurately when one eye was occluded. It is possible that this was due to a learning effect based on something other than stereopsis, as these subjects had performed the task binocularly and then monocularly. However, in the data analysis the order of viewing was not a significant factor (largest $F = 2.596$, n.s.). An alternative possibility is that these subjects were more accurate monocularly because they spent more time over the task when viewing monocularly. As there was no correlation between time and setting (largest $r = 0.356$, n.s.), this seems unlikely.

It was anticipated that viewing conditions would make no difference to the accuracy of depth perception by the monocular subjects and this was confirmed in the statistical analysis. However, within the group of monocular subjects some did better with both eyes open. It is possible that these subjects had peripheral fusion which they made use of when viewing with both eyes open. Haase and Lung[13] reported that in strabismus, retinal correspondence in the area of the fovea could differ from that in the periphery of the retina. They found a tendency for harmonious abnormal retinal correspondence at the periphery of the visual field. This can give rise to peripheral fusion. In the present study, the presence of peripheral fusion in the monocular subjects could have been determined by assessing their response on the Polaroid 4-dot test. This test checks for fusion/suppression of a larger area of the retina than the Worth's lights macular sleeve.

There was no significant difference between the two groups of subjects in the time it took them to complete the task. This is in contrast with the findings of Joy *et al.*,[3] who found that long-term monocular subjects took significantly longer to complete the tasks than binocular subjects. The pegboard and wire loop used in their study are tangible objects, so when a subject has placed a peg

Table 3. The standard deviation (degrees) for each observer. The mean, standard deviation and standard error of each group are also shown, for the two orientations of stimuli both separately and combined

			Viewing with one eye		Viewing with both eyes	
	Subject no.	Initial viewing	Horizontal	Vertical	Horizontal	Vertical
Monocular subjects	1	Both eyes	3.92	4.74	2.50	3.78
	2	One eye	7.91	9.10	7.35	4.46
	3	Both eyes	4.48	3.45	4.97	6.15
	4	One eye	8.04	0.78	2.87	0.75
	5	Both eyes	1.38	2.81	2.37	4.02
	6	One eye	15.62	13.21	10.70	12.62
		Mean	**6.89**	**5.68**	**5.13**	**5.30**
		SD	**4.97**	**4.62**	**3.34**	**3.99**
		SE	**2.03**	**1.88**	**1.36**	**1.63**
		Grand mean	**6.29**		**5.21**	
		Grand SD	**4.62**		**3.51**	
		Grand SE	**1.88**		**1.43**	
Binocular subjects	7	Both eyes	5.85	3.33	5.04	5.39
	8	One eye	7.29	12.37	8.80	6.79
	9	Both eyes	7.77	9.71	6.26	6.69
	10	One eye	7.37	8.20	4.60	3.02
	11	Both eyes	6.90	7.19	6.52	7.30
	12	One eye	12.43	7.56	4.89	7.48
	13	Both eyes	5.48	6.98	3.06	7.59
	14	One eye	12.03	15.96	14.14	6.96
	15	Both eyes	11.39	7.74	4.45	7.25
	16	One eye	0.79	1.29	3.02	6.38
		Mean	**7.73**	**8.03**	**6.08**	**6.49**
		SD	**3.52**	**4.14**	**3.31**	**1.38**
		SE	**1.11**	**1.31**	**1.05**	**0.44**
		Grand mean	**7.88**		**6.28**	
		Grand SD	**3.74**		**2.47**	
		Grand SE	**1.18**		**0.78**	

in a hole or has managed to get the wire loop to the end of the course, they know that is the end of the task. The virtual stimuli used in the present study rely on the subject deciding when he or she perceives the task as being completed, rather than a definite end-point to the task. For example, a subject may have quickly set the angle they perceive as being 90°, but then deliberated over whether or not this was correct before moving on to the next stimulus. A more accurate representation of the time taken may therefore have been to record the time taken from the first to last adjustment of the stimulus, rather than from presentation of the stimulus to when the button on the keypad was pressed to move on to the next stimulus.

Stimuli rotated around the vertical axis were not significantly different from those rotated around the horizontal axis, in either the accuracy or time taken to adjust them. However, there was a trend for stimuli rotated around the horizontal axis to be set more accurately and stimuli rotated around the vertical axis to be set more quickly. This is contrary to the reports by Buckley[8] and Gillam *et al.*[9] Perhaps, the relatively small numbers of subjects limit the findings of these studies.

Conclusion

The results support the notion that BSV is useful in carrying out depth perception tasks (at least for the task described here), and that the time and resources spent on restoring and maintaining BSV are important. This study looked at the differences in depth perception between monocular subjects and subjects with normal BSV. Further study involving not only a greater number of subjects but also a wider range of people is indicated.

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