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Abstract. To better understand how the eye's optics affects stereopsis, we measured stereoacuity before and after higher-order aberration (HOA) correction with a binocular adaptive optics visual simulator. The HOAs were corrected either binocularly or monocularly in the better eye (the eye with better contrast sensitivity). A two-line stereo pattern served as the visual stimulus. Stereo thresholds at different viewing durations were obtained with the psychophysical method of constant stimuli. Binocular HOA correction led to significant improvement in stereoacuity. However, better eye HOA correction could bring either a bad degradation or a slight improvement in stereoacuity. As viewing duration increased, the stereo benefit approached the level of 1.0 for both binocular and better eye correction, suggesting that long viewing durations might weaken the effects of the eye's optical quality on stereopsis. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.JBO.20.7.075005](https://doi.org/10.1117/1.JBO.20.7.075005)]

Keywords: adaptive optics; stereopsis; higher-order aberrations; optical correction; viewing duration.

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1 Introduction

The imperfections of the eye's optics, which are generally referred to as ocular aberrations, set a limit on our vision. The existence of these ocular aberrations compromises the image quality on the retina and, in turn, affects our visual experience. Adaptive optics (AO) specializes in sensing and manipulating optical aberrations. It was first demonstrated for human eyes by Liang et al.¹ With the introduction of AO into vision research, we were then well-equipped to explore vision beyond traditional domains. Experimental studies were extensively carried out to investigate the impact of higher-order aberration (HOA) correction on major visual performances such as visual acuity, contrast sensitivity, and accommodation. Several comprehensive and informative reviews on AO for visual function research have been made so far.²⁻⁴

In fact, most of previous studies focused on monocular vision research.⁵⁻⁹ However, normal vision of human eye is binocular, and it is questionable whether these results obtained under monocular vision can be similarly transferred to the binocular case. Moreover, some visual functions, such as binocular summation and stereopsis, are unique to binocular vision. The effects of HOA correction on them remain unaddressed. In this context, Fernández et al.¹⁰ made a step forward by presenting a binocular adaptive optics visual simulator (BAOVS) for binocular vision research in 2009. Ever since, growing research interest has been drawn to investigate the binocular aspects of human vision.¹¹⁻¹³

Stereopsis is the ability to perceive depth by comparing retinal images between the two eyes. Specifically, there are two

different processes of stereopsis, i.e., local versus global stereopsis, distinguished by whether depth perception is associated with single and isolated features (typically line stimuli) or complex scenes where the correspondence problem could occur (typically random-dot stereograms). Evidence of optical effects on stereopsis was found in clinical practice that maximum disparity, one of the metrics of stereopsis together with stereoacuity, was significantly correlated to interocular differences in HOAs for both emmetropes¹⁴ and patients after LASIK.¹⁵ Efforts were also made to investigate the role of aberrations on stereoacuity. Employing their binocular system, Fernández et al.¹¹ studied the effect of aberration superimposition on stereoacuity for random-dot stereograms. They discovered that stereoacuity was degraded with extra defocus or trefoil superimposed either in both eyes or in the right eye only. However, the effect of aberration correction on stereopsis was not studied. In a later study, Vlaskamp et al.¹⁶ investigated whether HOA correction influences stereo performances for both line stimuli and random-dot stereograms. They performed binocular HOA correction with phase plates and found no effect of such correction on stereopsis. Considering the limitation that static correction could not fully compensate for dynamic ocular aberrations, the issue has not been sufficiently investigated. It is worthwhile to further research whether binocular real-time HOA correction would have a significant influence on stereopsis.

An interesting phenomenon was observed when stereoacuity was tested with interocular difference in contrast.¹⁷⁻¹⁹ That is, stereoacuity was degraded when the contrast was unequal in the two eyes. For clinical applications where interocular differences could appear, this phenomenon is of relevance. In this study, we attempt to confirm on this "contrast paradox." As we know, HOA correction basically leads to contrast improvement.⁵⁻⁷ Consequently, monocular HOA correction is performed to

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generate interocular difference in contrast and stereo performances under this condition are measured.

The effects of HOA correction on stereopsis might be dependent on other parameters affecting stereopsis. Particularly, viewing duration is an important factor in stereopsis. Although Uttal et al.²⁰ reported that stereoscopic perception could occur in random-dot tests for stimulus durations as brief as 1 ms, this was limited to stereograms with large disparities. For small disparities, the stereo performance was not as reliable. These results suggested that viewing duration might be a limiting factor for fine stereopsis. Several studies have investigated the relationship of stereoacuity and viewing duration.^{21–25} Improvement in stereoacuity was generally observed while viewing duration increased up to a critical duration, beyond which there was little change. However, to the best of our knowledge, it is rarely covered in the existing literature whether the effects of HOA correction on stereopsis vary with viewing duration. A research in this direction is valuable from a scientific point of view.

In this paper, a BAOVS based on deformable mirrors and Hartmann–Shack wavefront sensors is established to investigate the effects of HOA correction on stereopsis at different viewing durations. Monocular contrast sensitivity function is first measured for vertical sinusoidal gratings, both before and after HOA correction. Stereoacuity is tested with two-line stereograms for different optical conditions and different viewing durations. The psychophysical method of constant stimuli is used to obtain stereo thresholds. In Sec. 2, the experiment methods are introduced, including subjects, apparatus (BAOVS), and procedures. The results for contrast sensitivity function and stereoacuity measurements are given in Sec. 3. Finally, we finish the paper with discussion and conclusion in Sec. 4.

2 Methods

2.1 Subjects

Three normal subjects—1, 2, and 3 (two males and one female)—participated in this study. All subjects had no previous history of ocular surgery or trauma and had normal vision or corrected vision. Clinical refraction for each subject was implemented for correction of their low-order aberrations. Table 1 lists parts of information of all subjects. During the experiment, paralysis of accommodation and dilation of pupil were achieved through administering 1% cyclopentolate. Informed consent was obtained from all subjects and the experiment procedures conformed to the tenets of the Declaration of Helsinki. Subject 1 and Subject 3 were unaware of the intention of this study, while Subject 2 was one of the authors.

Table 1 Basic information of the three subjects.

		Refraction					
		OD			OS		
Subject	Age	S (D)	C (D)	A (deg)	S (D)	C (D)	A (deg)
Subject 1	26	-1.25	-0.50	175	-1.25	-0.25	166
Subject 2	38	-0.75	-0.75	84	-0.75	-0.25	99
Subject 3	37	-0.50	-0.25	97	-0.75	-0.25	127

2.2 Binocular Adaptive Optics Visual Simulator

A BAOVS was established as the experiment platform. The schematic view of our BAOVS is shown in Fig. 1. The BAOVS incorporated two identical optical channels consisting of the respective AO subsystem and visual stimulus display subsystem. The optical paths concerning AO and stimulus display are denoted by red lines and green lines, respectively; those concerning both are denoted by blue lines.

The two identical optical channels had symmetrical optical layouts. Here, the left optical channel is taken as an example for introduction. It comprised a 37-element piezo deformable mirror made by our laboratory with a stroke of $\pm 2 \mu\text{m}$, a Hartmann–Shack wavefront sensor with 97 lenslets, a control system, and a visual stimulus display. A semiconductor laser diode (LD) ($\lambda = 905 \text{ nm}$, $\Delta\lambda = 2 \text{ nm}$) was used to generate a near-infrared beacon for wavefront sensing. The use of near-infrared light provided more comfortable viewing conditions and higher retinal reflectance. After collimated by lens L1, the beacon light passed through a beam splitter BS1, and was directed into the eye by a reflecting prism P1. The reflected light from the eye fundus conveyed the aberrometric information. It traveled by BS1, a beam expanding lens group LG1 and a mirror M1 before reaching a deformable mirror (DM). Then the preaberrated light from DM was relayed to a Hartmann–Shack wavefront sensor HS, over a sequence of optics including a mirror M2, a beam constricting lens group LG2, a beam splitter BS2, and another mirror M4. DM and HS were placed in conjugate planes with the eye pupil. LG1 and LG2 were configured to match the beacon light with the deformable mirror and the wavefront sensor in size, respectively. The control system was a computer shared by both optical channels. It was responsible for processing wavefront slope data and sending driving signals to the deformable mirrors, using a direct-slope control

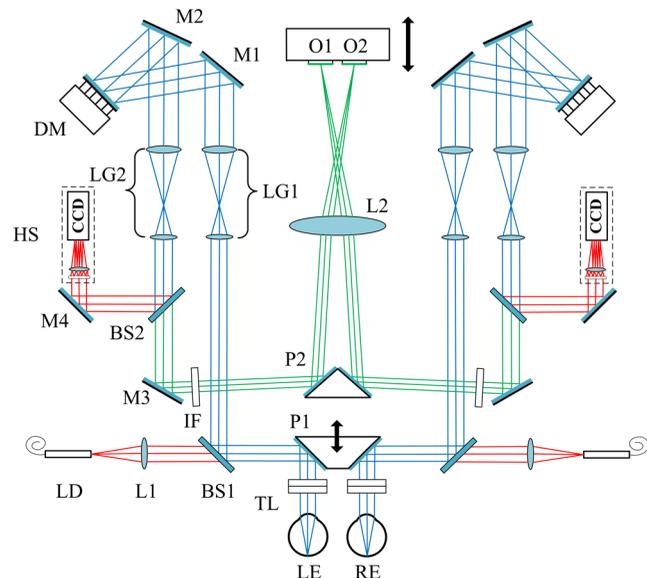


Fig. 1 Schematic view of the binocular adaptive optics visual simulator with two identical optical channels. The optical paths concerning adaptive optics (AO) and stimulus display are denoted by red lines and green lines, respectively; those concerning both are denoted by blue lines. LD, laser diode; BS, beam splitter; HS, Hartmann–Shack wavefront sensor; DM, deformable mirror; LG, lens group; TL, trial lens; IF, interference filter; L, lens; M, mirror; P, prism; O, OLED; LE, left eye; and RE, right eye.

algorithm. The control system operated at 25 Hz with a closed-loop bandwidth of about 1 Hz. Initial tilts were left uncorrected to avoid variations in the relative location of the retinal images. Correction was suspended when the subapertures of the wavefront sensor were not fully filled with light (such as eye blinks). The control system would keep resending driving signals of the last frame to the deformable mirrors. The AO system had been demonstrated elsewhere in previous studies.^{26,27}

The visual stimuli for binocular visual testing were generated by MATLAB 6.5 (Mathworks, Natick, Massachusetts) and Psychtoolbox extensions^{28,29} on another computer, and projected by two OLED displays D1, D2 (EMA-100110, eMagin Corporation). Each OLED display emitted at 540 nm (green light) with a bandwidth of 70 nm, and had a retinal subtense for 2.37×1.78 deg. The resolution was 800×600 pixels and the refresh rate was 60 Hz. A special circuit that combined two 8-bit output channels of the graphics card was used to produce gray levels of 14 bits.²⁶ The objective lens L2, reflecting prism P2, and mirror M3, associated with the aforementioned optics, were used to form images of the stimuli on the retina. Note that D1 was delivered to the right eye and D2 to the left eye. An interference filter interference filter (550 ± 5 nm) was placed between P2 and M3 to filter the stimulus light into quasi-monochromatic light.

P1 was capable of translational motion for interpupillary distance adjustment between 55 and 70 mm. A chin and forehead rest were used to preclude head movements. The trial lens for compensating defocus and astigmatism was placed at TL1. The chromatic focus shift between the near-infrared beacon and the green stimulus was compensated for by axially moving the OLED displays until best focus of the subject. The OLED displays were mounted on a stepping motor for best focus adjustment.

2.3 Experiment Procedures

Monocular contrast sensitivity function was measured before and after HOA correction (low-order aberrations were always corrected) for both eyes in the three subjects. The untested eye was occluded during testing. The stimuli were vertical sinusoidal gratings with a retinal luminance of 8 cd/m^2 . Five spatial frequencies were tested ranging from 2 to 24 cycles per degree (cpd). A two-alternative forced choice procedure was adopted in which only one of two consecutive presentations of a trial

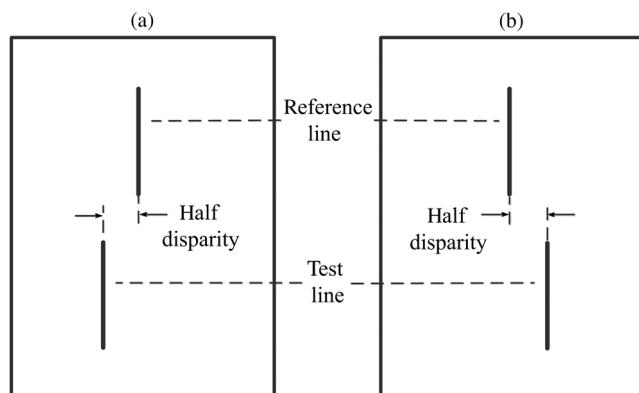


Fig. 2 The two-line stereograms used in this study. To generate disparity, the test line was horizontally shifted from the reference line in opposite directions by half the disparity. The stimuli were black lines on a bright background: (a) display for LE and (b) display for RE.

contained the gratings (the other was a blank scene with background luminance). Each presentation lasted for 100 ms. The contrast of the stimuli was controlled through an adaptive staircase procedure. Three successive correct responses led to a contrast decrease by 10% of the previous value; one incorrect response brought a 10% increase.³⁰ The psychometric data were obtained from eight staircases of 80 trials each. The contrast threshold for each spatial frequency was calculated as the average of the last five turnarounds, and its reciprocal was contrast sensitivity.

The visual stimuli for testing stereopsis in this study were two-line stereograms specifying horizontal disparity, as shown in Fig. 2. The stimuli were black lines on a bright background and the retinal luminance was 8 cd/m^2 for both eyes. There were two thin vertical lines exhibited in the display for each eye. The upper reference line stood in the middle in both displays and would fuse as a line within the fixation plane. The lower pair of lines, called the test line, was horizontally shifted from the reference line in opposite directions by half the disparity. Consequently, the test line would appear to the observer to be closer or further relative to the reference line, according to the sign of the disparity that was induced. Both the reference line and the test line were 25 arc min long, and they were 4 arc min apart vertically.

The stereoacuity was obtained in the three subjects using the psychophysical method of constant stimuli. The disparities tested were 20, 80, 140, and 200 arc sec of both crossed and uncrossed disparities. The psychometric data were acquired in five sessions. Each session consisted of 80 trials presenting the eight disparities equally in random order. The time sequence of a typical trial is illustrated in Fig. 3. A trial was started with the presentation of binocular fusion stimuli. The binocular fusion stimuli were central crosses with small solid squares placed

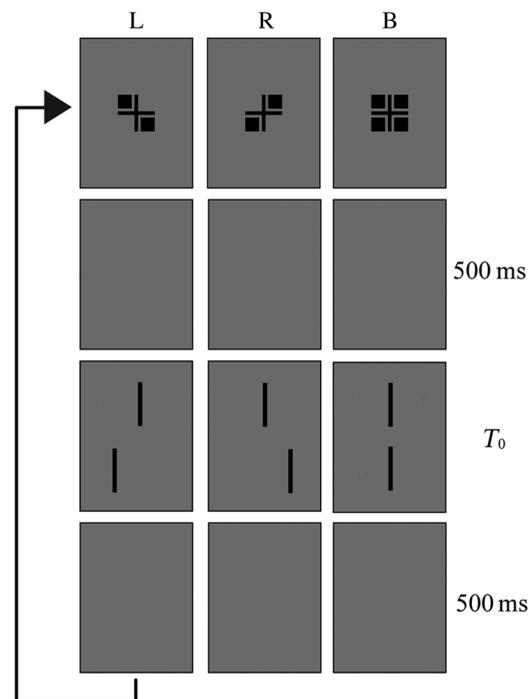


Fig. 3 The time sequence of a typical trial in stereoacuity tests. The columns "L" and "R" are visual displays for the left eye and the right eye, respectively. With accurate binocular fusion, the subject would perceive just as "B" shows.

diagonally. With accurate binocular fusion, the subject would see four squares placed regularly in the four quadrants of the cross. After the subject initiated the test with a keypress, the binocular fusion stimuli disappeared and a 500 ms blank scene of the background luminance followed. Meanwhile, there was a brief “beep” sound indicating the subsequent stereograms. The stereograms were presented for the intended duration (T_0). Subsequent to that was another 500 ms presentation of blank scene. Then the binocular fusion stimuli recurred and the system waited for response from the subject as to whether the test line was closer or farther than the reference line. There was no audio feedback on the correctness of the response. During the test, the subject was told to focus on the presentation and try to blink between trials, which was not difficult because a trial generally lasted no longer than 2 s.

The percentage of “far” responses was computed for each disparity and the data were fit to a logistic function.³¹ Stereoacuity threshold was calculated as the semi-interquartile range of the logistic function.^{11,24} Thus, a threshold was actually on the basis of 400 presentations. The same tasks were repeated for three stimulus durations (100, 300, and 500 ms) and three optical conditions of the eyes, as follows: (1) baseline correction of defocus and astigmatism for both eyes; (2) better eye AO correction of HOAs beyond the baseline correction; and (3) binocular AO correction of HOAs beyond the baseline correction. Here, the better eye is the eye with better contrast sensitivity measured with the aforementioned procedures. Afterward, in this paper, the three optical conditions are referred to as baseline correction, better eye correction, and binocular correction, respectively.

3 Results

3.1 Binocular Real-Time Aberration Measurement and Correction

Table 2 shows the root-mean square (RMS) of HOAs over a 6 mm pupil for both eyes of the three subjects. Each data were averaged from eight measurements. Figure 4 shows the representative time course of total RMS aberration for both eyes over a 6 mm pupil (measured in subject Subject 2). The black and red lines represent RMS aberration for the right eye and the left eye, respectively. Data during eye blinks have already been removed. The native total RMS aberration was 0.48 and 0.45 μm in the right eye and the left eye, respectively. After AO correction was initiated ($T = 10$ s), the residual RMS aberration of both eyes converged rapidly to a small value of about 0.1 μm and leveled off, demonstrating a good performance of the AO system.

Table 2 Root mean square (RMS) of higher-order aberrations (HOAs) over a 6 mm pupil in the three subjects for both eyes.

Subject	RMS HOAs (μm)	
	OD	OS
Subject 1	0.33	0.24
Subject 2	0.25	0.23
Subject 3	0.28	0.30

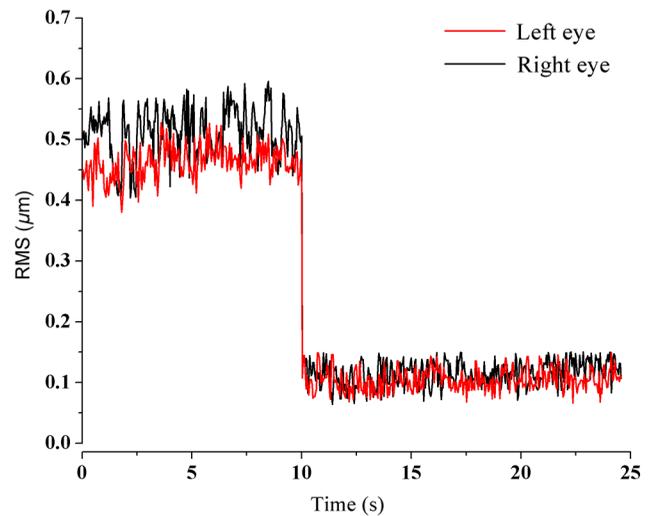


Fig. 4 The representative time course of total root mean square (RMS) aberration for both eyes. The black and red lines represent RMS aberration for the right eye and the left eye, respectively. AO is initiated at $T = 10$ s.

3.2 Monocular Contrast Sensitivity Before and After HOA Correction

Figure 5 shows monocular contrast sensitivity function for both eyes in the three subjects, on a log-log scale. According to the results, the better eye was the left eye for Subject 1 and the right eye for Subject 2 and Subject 3. It is evident that AO correction of HOAs improved contrast sensitivity for all spatial frequencies in all eyes. The average improvement across different eyes was by a factor of 1.34, 1.50, 1.99, 1.74, and 1.65 at 2, 4, 8, 16, and 24 cpd, respectively. The right eye of Subject 1, which had the largest amount of HOAs, also demonstrated the largest improvement of 3.57, at the middle spatial frequency of 8 cpd. The average improvements across different spatial frequencies for the left and right eyes were 1.75 and 1.86, 1.50 and 1.62, and 1.57 and 1.55 for Subject 1, Subject 2, and Subject 3, respectively. Associated with the results in Table 2, it seemed that a greater amount of HOAs brought larger improvement in contrast sensitivity for comparison between eyes of the same subject. However, it did not always follow for interindividual comparison, possibly due to the neural insensitivity or adaptation.^{32,33} The data were referred to a paired t test for statistical analysis. Results showed that the improvement in contrast sensitivity was significant for all spatial frequencies ($p < 0.05$), indicating the validity of our optical correction.

3.3 Stereoacuity Versus Viewing Duration under Different Optical Conditions

The stereoacuity is plotted as a function of viewing duration for the three subjects in Fig. 6. Binocular correction improved stereoacuity remarkably, by an average magnitude of 24.9, 5.7, and 3.8 arc sec at 100, 300, and 500 ms in the three subjects, respectively. This improvement was proven statistically significant for all viewing durations in a paired t test ($p < 0.05$). Better eye correction led to distinct results among the subjects. For Subject 1, better eye correction brought a severe degradation of stereoacuity from 102, 78, and 70 arc sec to 183, 120, and 105 arc sec at 100, 300, and 500 ms, respectively. Whereas for Subject 2 and Subject 3, better eye correction generally improved stereoacuity to a

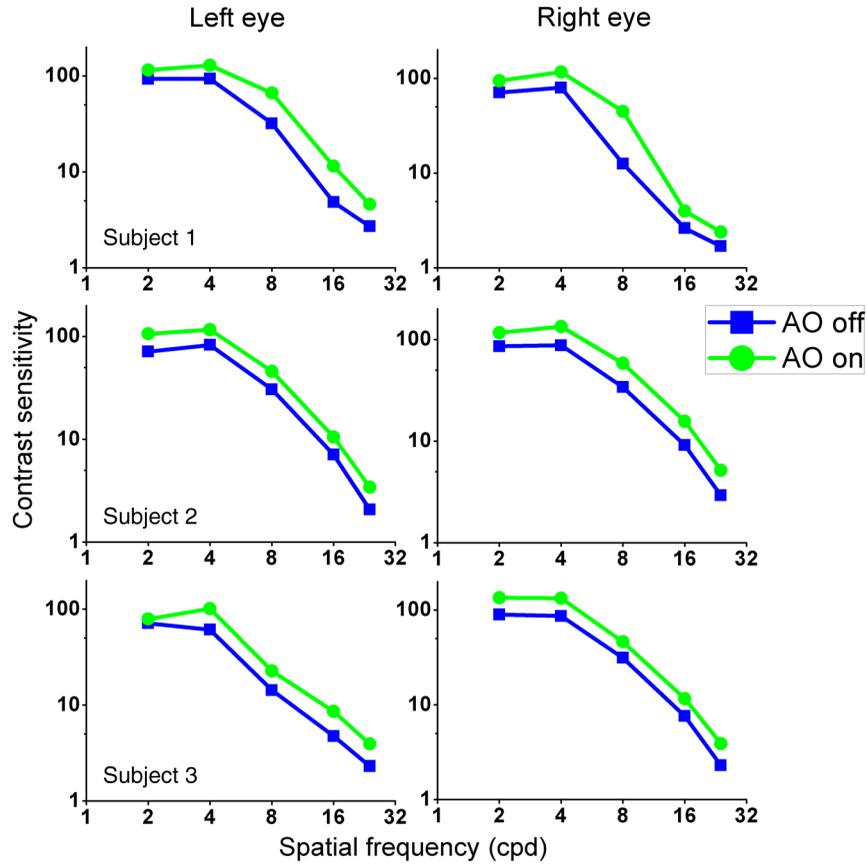


Fig. 5 Monocular contrast sensitivity function measured with and without higher-order aberration (HOA) correction. Different rows and columns display data for different subjects and different eyes, respectively. Blue squares stand for results obtained without HOA correction (defocus and astigmatism are corrected) and green circles stand for results obtained with HOA correction.

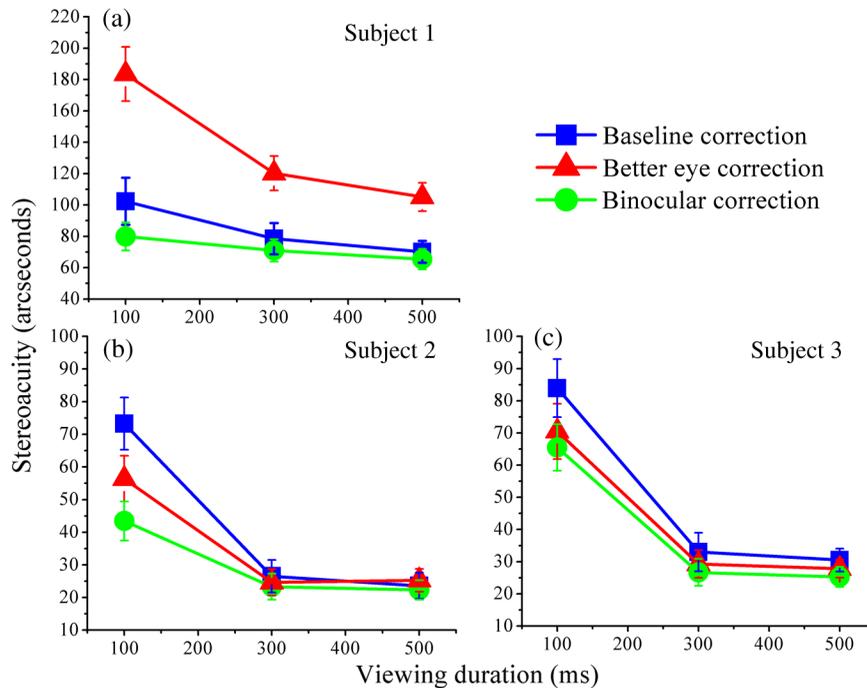


Fig. 6 (a)–(c) Stereoacuity versus viewing duration under different optical conditions for the three subjects. Blue squares represent stereoacuity with baseline correction. Green circles and red triangles represent stereoacuity with binocular and better eye correction, respectively. Note that the y-axis labels are not consistent for the three subjects. Low thresholds suggest good stereoacuity. Error bars are standard deviations.

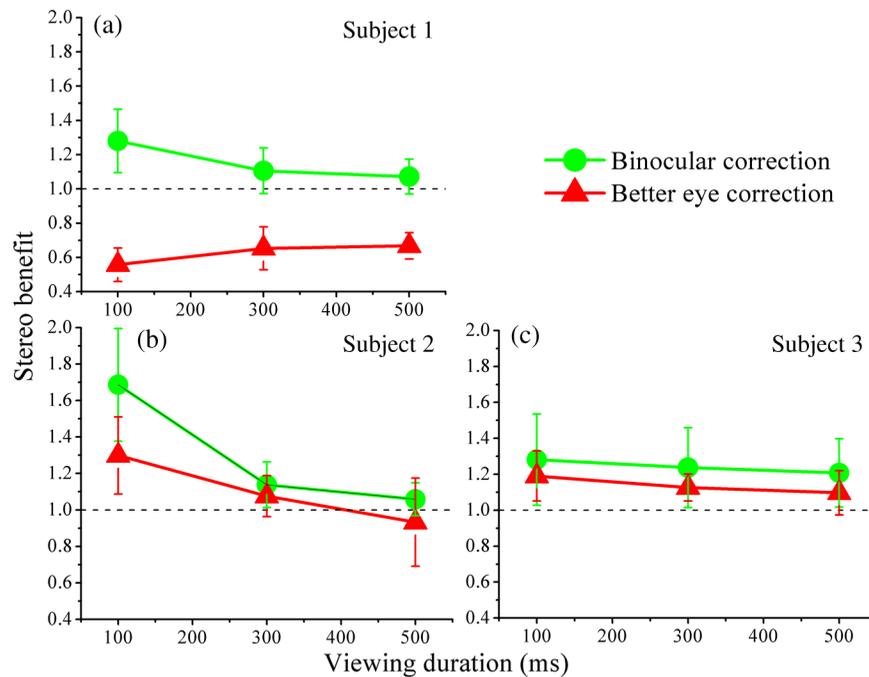


Fig. 7 (a)–(c) Stereo benefit upon binocular and better eye HOA correction at different viewing durations. Binocular and better eye correction benefits are marked by green circles and red triangles, respectively. Error bars are standard deviations. The dashed lines denote the benefit level of 1.0.

smaller extent than binocular correction did. One exception was the 500 ms case for Subject 2, in which the stereoacuity was slightly degraded by about 2 arc sec. It can be easily seen that, in all cases, stereo thresholds were always lower at longer viewing durations, suggesting a persistent effect of viewing duration on stereoacuity even when the HOAs were corrected.

3.4 Stereo Benefit upon Binocular and Better Eye HOA Correction

Figure 7 plots the stereo benefit upon binocular correction and better eye correction at different viewing durations. The benefit here corresponds to the ratio of stereoacuity with baseline correction to binocular or better eye correction. In most cases, HOA correction brought improvement in stereoacuity so that the benefit was larger than 1. In some cases for which better eye correction brought negative effects, the benefit was less than 1. As the viewing duration increased, binocular correction benefit exhibited a clear downward trend in all subjects. These benefits were commonly in the range of 1.1 to 1.3, except for the maximum benefit of 1.68 demonstrated in Subject 2 at 100 ms. As for better eye correction, the situation was also split into two parts. For Subject 2 and Subject 3, better eye correction benefit decreased slightly to above 1.0 with increasing viewing duration, just as the binocular case. However, for Subject 1, this relationship was exactly the opposite, with the benefit elevated from 0.56 at 100 to 0.67 at 500 ms. It seemed that the benefit upon HOA correction, no matter binocular or better eye, approached the level of 1.0 with increasing viewing duration. Further statistical analysis indicated that binocular correction benefit was significantly greater than 1.0 at 100 and 300 ms ($p = 0.044$, 0.028 , and 0.071 for 100, 300, and 500 ms, respectively). Better eye correction benefit, however, was not significantly different from 1.0 at any viewing duration ($p = 0.952$, 0.788 , and 0.505 for 100, 300, and 500 ms, respectively). Moreover, no

significant difference was observed between any two durations for both binocular correction benefit ($p = 0.231$, 0.209 , and 0.097) and better eye correction benefit ($p = 0.559$, 0.487 , and 0.379).

4 Discussion and Conclusion

In the current work, random-dot stereogram tests were difficult to implement due to the small field of view limited by the isoplanatic range of the AO system. Consequently, we tested only local stereopsis with two-line stereograms. The subjects were well-instructed and trained before the experiments to ensure that they made judgments based on depth perception rather than monocular cues. According to our results, significant improvement in stereoacuity was observed upon binocular real-time closed-loop HOA correction. In the work of Vlaskamp et al.,¹⁶ they performed static aberration correction with phase plates and discovered no effects of such correction on stereo performance. The disparate conclusions came mainly from the difference in correction mode. Compared with static correction, AO correction is more powerful and reliable in providing better-than-normal optics of the eye. Thus, BAOVS will play an important role in our exploration of the relationship between binocular vision and ocular aberrations in the future. Additionally, Lee et al.²⁵ measured stereoacuity as a function of viewing duration for different contrasts (0.05 and 1) and spatial frequencies. At the same spatial frequency, stereo thresholds were commonly lower for the high contrast than those for the low contrast. In our study, HOA correction could lead to contrast improvement. In effect, the HOA correction was equivalent to an improvement of the stimulus contrast. Consequently, our results agreed qualitatively with the results of Lee et al.

On the other hand, better eye correction, which induced interocular difference in contrast, unexpectedly led to mixed reactions among the subjects. Stereoacuity was somewhat improved in Subject 2 and Subject 3, and badly degraded in

Subject 1. These results were not fully in accordance with the “contrast paradox.” The improved stereoacuity with interocular differences in aberrations was also inconsistent with results obtained for other binocular functions.^{14,15,34} Halpern and Blake¹⁷ reported a similar phenomenon when they investigated the effect of interocular difference in contrast on stereoacuity. In one of their experiments, one eye of the observers always viewed a fixed low contrast while the other eye saw stimuli of different higher contrasts. They found out that stereoacuity was improved when the contrast difference was moderate. However, if the contrast difference exceeded a certain range (9 dB at 1.2 cpd and 12 dB at 2.4 cpd), stereoacuity was decreased. The situation for better eye correction in our study was similar in effect. The better eye viewed higher contrast after HOA correction, while the other eye viewed the same contrast as with baseline correction. Assuming that the neural contrast sensitivity remained constant after HOA correction, the improvement in overall contrast sensitivity was brought merely by the improvement of the eye’s optical quality. After HOA correction, the same stimulus contrast actually led to better retinal contrast. The contrast sensitivity benefit was also an indicator of contrast improvement. The contrast sensitivity benefit in the better eye of the three subjects was 1.75, 1.62, and 1.55 for Subject 1, Subject 2, and Subject 3, respectively. This corresponded to a contrast improvement (also interocular contrast difference) of about 5 dB for Subject 1 and 4 dB for Subject 2 and Subject 3. The larger contrast difference for Subject 1 might be beyond tolerance of the mechanism underlying stereopsis and thus led to a degradation of stereo performance, just as the “contrast paradox.” For Subject 2 and Subject 3, the contrast difference was within the tolerance range and stereoacuity was slightly improved. Our results were roughly in accordance with the results of Halpern and Blake, despite that the range of tolerance for interocular contrast difference seemed smaller in our case. This might be due to differences in stimuli features and experiment conditions. According to Halpern and Blake, their results could be qualitatively interpreted by a model of cooperative stereo network by Wilson.³⁵ Therefore, the present results could be seen as new psychophysical evidence to Wilson’s model.

Figure 7 exhibits a clear trend that as viewing duration increased, the stereo benefit was approaching the level of 1.0 for both binocular and better eye correction. Such a trend indicated that the effects of the eye’s optical quality on stereopsis weakened as viewing duration increased. One possible explanation is that stereopsis shares the property of temporal integration as described by Bloch’s law.^{21,36} Specifically, Bloch’s law predicts the reciprocity of stimulus intensity and viewing duration to achieve a constant threshold for viewing durations shorter than a critical duration. It can be inferred that the visual system might need to accumulate a critical amount of stimulus energy to reach a constant and high-level performance. More stimulus energy makes no difference due to neural saturation. For stereopsis, disparity estimation is fundamental. The eye’s optical quality affects the resolution and contrast of the retinal images and presumably the rate at which disparity energy accumulates. At brief viewing durations for which neural saturation of disparity energy has not been reached, a faster accumulation rate leads to better stereoacuity. Once neural saturation occurs at longer viewing durations, the difference in accumulation rate is negligible. Therefore, the effects of the eye’s optical quality on stereopsis become less significant as the viewing duration increases.

One implication of these findings is for customized vision correction in refractive surgery. The dependence of HOA correction benefit on viewing duration may provide important guidance for visual improvement in professions that require fast and accurate estimates of relative depth. In addition, the disparity changes rapidly and the exposure duration of stereopsis is short in many scenes where correction of HOAs could be more useful. Binocular HOA correction is reliable to obtain better stereoacuity at short viewing durations, while monocular correction might lead to unexpected results. For refractive surgery aimed to improve monocular visual performance, its impact on stereopsis should also be allowed to avoid possible adverse effects. In this aspect, the disparate results obtained with better eye correction may be important in studies of visual outcomes of clinical applications where interocular difference in optical quality appear routinely. A good example is the clinical correction of presbyopia with monovision and/or small aperture inlay. The effects of these two approaches performed either separately or combined were evaluated on stereoacuity.¹³ The results suggested that combining monovision and small aperture inlay can maintain stereoacuity at the level of normal binocular vision. These results, together with the results of the current work, support the idea that the perceptual mechanisms for stereopsis tolerate interocular differences to some extent. In this sense, clinical modification of monocular vision while minimizing its influence on stereopsis is possible.

It should be indicated that the results of this study could not reach general conclusions due to the limited number of observers. Extensive investigations in the future are needed for further verification of these results.

In conclusion, by establishing a BAOVS based on deformable mirrors and Hartmann–Shack wavefront sensors, we investigated the effects of HOA correction on stereopsis at different viewing durations. Binocular real-time HOA correction led to significant improvement in stereoacuity for all subjects. Better eye HOA correction led to a severe degradation of stereoacuity for one subject. For the other two subjects, it slightly improved stereoacuity. As viewing duration increased, the stereo benefit was approaching the level of 1.0 for both binocular and better eye correction. This suggested that long viewing durations might weaken the effects of the eye’s optical quality on stereopsis.

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