The role of sensory ocular dominance on through-focus visual performance in monovision presbyopia corrections

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Monovision presbyopia interventions exploit the binocular nature of the visual system by independently manipulating the optical properties of the two eyes. It is unclear, however, how individual variations in ocular dominance affect visual function in monovision corrections. Here, we examined the impact of sensory ocular dominance on visual performance in both traditional and modified monovision presbyopic corrections. We recently developed a binocular adaptive optics vision simulator to correct subjects' native aberrations and induce either modified monovision (1.5 D anisometropia, spherical aberration of +0.1 and −0.4 μm in distance and near eyes, respectively, over 4 mm pupils) or traditional monovision (1.5 D anisometropia). To quantify both the sign and the degree of ocular dominance, we utilized binocular rivalry to estimate stimulus contrast ratios that yield balanced dominance durations for the two eyes. Through-focus visual acuity and contrast sensitivity were measured under two conditions: (a) assigning dominant and nondominant eye to distance and near, respectively, and (b) vice versa. The results revealed that through-focus visual acuity was unaffected by ocular dominance. Contrast sensitivity, however, was significantly improved when the dominant eye coincided with superior optical quality. We hypothesize that a potential mechanism behind this observation is an interaction between ocular dominance and binocular contrast summation, and thus, assignment of the dominant eye to distance or near may be an important factor to optimize contrast threshold performance at different object distances in both modified and traditional monovision.

Introduction

As the population ages, an increasing portion is affected by presbyopia, the age-related loss of accommodation. While a wide variety of techniques are clinically available for regaining near vision by

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increasing the eye's depth of focus, true restoration of accommodation is still out of reach. However, depth of focus may be increased by reducing the pupil size with a small-aperture corneal inlay (Hickenbotham, Tiruveedhula, & Roorda, 2012; Seyeddain et al., 2010; Tomita, Kanamori, Waring, Nakamura, & Yukawa, 2013; Yilmaz et al., 2008), inducing multifocality in the wavefront aberration with bifocal contact lenses (Bradley, Rahman, Soni, & Zhang, 1993; Martin & Roorda, 2003), aspheric ablation profiles in laser refractive surgery (Alió, Chaubard, Caliz, Sala, & Patel, 2006; Epstein & Gurgos, 2009), refractive corneal inlays (Keates, Martines, Tennen, & Reich, 1995; Limnopoulou et al., 2013), or multifocal intraocular lenses (Alió, Piñero, Plaza-Puche, & Chan, 2011; Bellucci, 2005; Buckhurst et al., 2012; Kim, Zheleznyak, MacRae, Tchah, & Yoon, 2011). The combination of wavefront multifocality with pupil apodization techniques has also been found to further improve through-focus visual performance in presbyopia (Zheleznyak, Jung, & Yoon, 2014).

In recent years, an increasing number of presbyopia correction strategies have taken advantage of the binocular visual system by prescribing a unique optical correction for each eye. In traditional monovision, each eye has a clear focus at only one object distance and a relatively short depth of focus. As a result, a large difference in interocular image quality is present. Binocular visual functions that rely on the neural combination of the monocular signals include binocular summation and stereopsis. For these functions, the integrity of the monocular retinal image quality is critical for optimal performance.

When both eyes' optics are well corrected, binocular contrast sensitivity has found to be approximately 42% improved over monocular performance (Campbell & Green, 1965). This is predicted by the quadratic summation model, as proposed by Legge (1984). However, binocular summation is known to increase in the presence of binocular blur due to defocus (Plainis, Petratou, Giannakopoulou, Atchison, & Tsilimbaris, 2011) or higher order aberrations (Sabesan, Zheleznyak, & Yoon, 2012; Schwarz, Cánovas et al., 2014). Furthermore, as the image quality of the two eyes becomes less similar, binocular visual functions such as stereopsis (Halpern & Blake, 1988; Jimenez, Castro, Hita, & Anera, 2008; Lovasik & Szymkiw, 1985) and binocular summation (Jimenez, Castro, Jimenez, & Hita, 2008; Legge, 1984; Pardhan & Gilchrist, 1990) are significantly reduced. Alternatively, the approach of *modified monovision*, wherein each eye has a unique multifocal correction and anisometropia, has several benefits over traditional monovision.

Modified monovision employing wavefront aberrations has been shown to improve through-focus visual acuity and binocular contrast summation over traditional monovision (Zheleznyak, Sabesan, Oh, MacRae, & Yoon, 2013). Previous studies have also found that visual acuity (Schwarz, Manzanera, Prieto, Fernández, & Artal, 2014; Tabernero, Schwarz, Fernández, & Artal, 2011) and stereoacuity (Fernández, Schwarz, Prieto, Manzanera, & Artal, 2013) may be somewhat recovered in monovision by increasing the depth of focus of the near eye with a small-aperture corneal inlay. By minimizing the interocular difference in retinal image quality, modified monovision enables the visual system to partially recover binocular neural functions such as summation and stereopsis. However, it is important to recognize that modified monovision does not fully restore loss of binocular visual function found in traditional monovision (e.g., stereopsis and summation) due to residual differences in interocular image quality.

When patients undergo monovision, either with contact lenses or surgical procedures, the clinician assigns distance vision to the dominant eye (Evans, 2007; Johannsdottir & Stelmach, 2001). This assignment is based on the assumption that patients have a greater need for distance vision as compared to near, and that suppression is more easily achieved in the nondominant eye (Schor, Landsman, & Erickson, 1987).

However, to determine which eye is dominant, sighting tasks such as the hole-in-card test (Seijas et al., 2007) are typically used. In this test, the subject gazes at a distant target through a hand-held card with a central hole. Despite binocular viewing, by occluding one eye, the sighting dominant eye is determined as the one aligned with the target. Such tests are binary, in that their outcome is either left- or right-eye dominance and therefore overlook interpatient variability in the degree of ocular dominance. Furthermore, sighting tests are dependent upon factors such as the hand used in the test (Carey, 2001) and relative image size influenced by gaze angle (Banks, Ghose, & Hillis, 2004; Khan & Crawford, 2001). Therefore, it is not surprising that only moderate agreement has been found between different sighting dominance tests (Carey, 2001; Rice, Leske, Smestad, & Holmes, 2008; Seijas et al., 2007; Suttle et al., 2009).

Alternatively, sensory dominance tests measure imbalance in the combination of sensory inputs from the two eyes using binocular rivalry (Handa et al., 2004; Handa et al., 2006; Ooi & He, 2001) or stereo-disparity (Heinrich, Kromeier, Bach, & Kommerell, 2005; Kommerell, Schmitt, Kromeier, & Bach, 2003) to measure the degree of ocular dominance. Handa et al. (2004) have suggested a rivalry sensory dominance test to screen potential candidates for surgically implemented monovision with intraocular lenses during cataract surgery. They found that pseudophakic monovision patients with strong degrees of sensory dominance tended to be unsatisfied because of difficulty in suppressing the dominant eye. However, their results

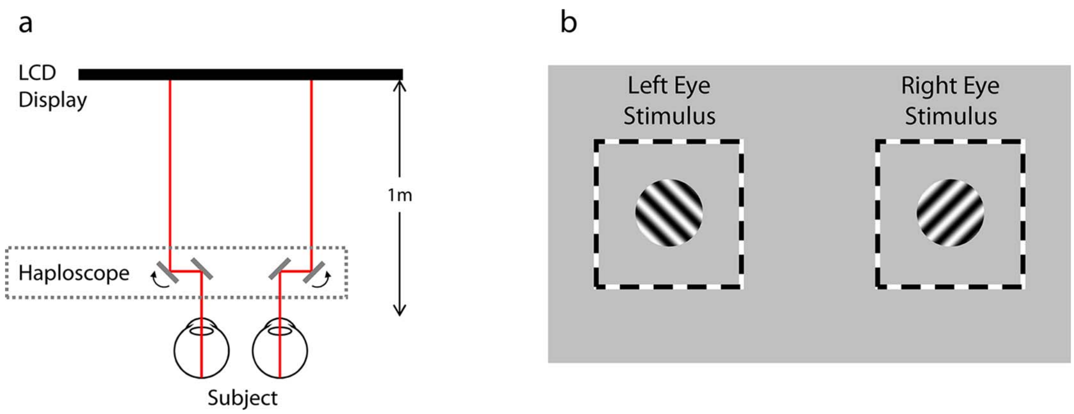

Figure 1. (a) Schematic of haploscope for measuring the degree of ocular dominance. (b) Orthogonal sinusoidal gratings at 4 cyc/deg presented to the left and right eyes.

were based on a four-question survey and did not include visual performance measurements.

The goal of this investigation was to determine the role of the degree of sensory dominance in relation to through-focus visual performance in modified and traditional monovision presbyopic corrections. The emergence of modified monovision presbyopic corrections merits a re-examination of the question of which eye should be allocated for distance and which for near vision.

To address the role of ocular dominance, subjects' degree of sensory dominance was quantified using a binocular rivalry method (Handa et al., 2006; Ooi & He, 2001). Subsequently, through-focus visual performance was measured using a binocular adaptive optics (AO) vision simulator with both modified and traditional monovision under two conditions: dominant eye assignment to distance, and nondominant eye assignment to distance.

Methods

Subjects

The University of Rochester Research Review board approved this research and informed consent was obtained from all subjects prior to participation. All procedures involving human subjects were in accordance with the tenets of the Declaration of Helsinki. Twelve subjects with normal binocular vision participated in this study (aged 29 ± 7 years). Average spherical refractive error in subjects' right and left eyes was −1.5 ± 1.9 and −1.2 ± 1.7 D, respectively. Cyclopentolate hydrochloride (1%) was used to dilate pupils and paralyze accommodation for experiments involving the binocular AO vision simulator but not for measurements of ocular dominance. Subjects were younger in age than the onset of presbyopia; however, their accommodation was fully impaired due to cycloplegia.

Quantifying the degree of ocular dominance

A binocular rivalry technique for measuring the degree of sensory ocular dominance was used. As shown in Figure 1a, subjects viewed a gamma-corrected liquid crystal display (LCD) computer monitor (VH242H; Asus, Taipei, Taiwan) through a haploscope, in which rivalrous images were shown to each eye. The LCD monitor was placed at 1-m distance from the subject and had an illuminance of 25 cd/m^2. The setup included mirrors for each eye with tip–tilt adjustability to assist in binocular fusion. Subjects wore trial frame spherical and cylindrical lenses to correct any ametropia and enable clear visibility of 20/20 Snellen letters at distance.

As shown in Figure 1b, the visual stimulus consisted of a dichoptic presentation of orthogonally oriented sinusoidal gratings (4 cyc/deg) at +45° and −45° (relative to the vertical axis). Each grating subtended 1° of visual angle to maximize the exclusive dominance of the rivalry patterns (Blake, 1989). The gratings were surrounded by a 2° × 2° dashed square on a gray background to facilitate binocular fusion.

Over a 60-s period, the time spent exclusively perceiving one grating was recorded by subjects' pressing the left or right arrow keys for the duration of clear visibility. For each 60-s period, the left eye grating contrast was 50%, whereas the right eye contrast was held fixed at a value between 10% and 95% (varied across trials). The proportion of time during each period spent viewing with the right eye as a function of right eye contrast was plotted and fitted with a sigmoid function (normal cumulative distribu-

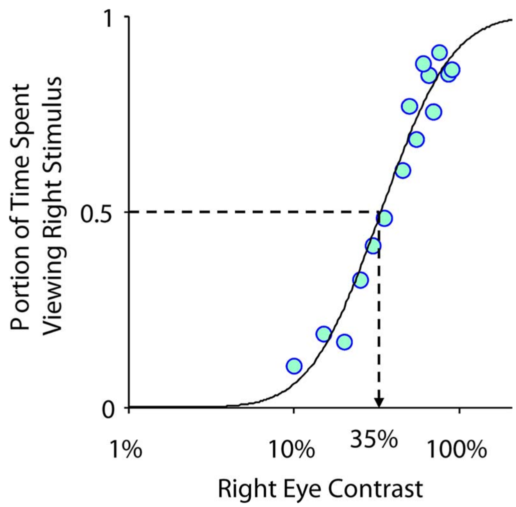

Figure 2. Portion of time spent viewing right-eye stimulus as a function of right-eye contrast for one subject. This subject had an ocular dominance value of 0.7 (35% divided by 50% contrast in right and left eyes, respectively), indicating right eye dominance.

tion). Finally, the degree of dominance was defined as the interocular contrast ratio (right-eye contrast divided by left-eye contrast) resulting in equal viewing time. An illustrative example of one subject's data is shown in Figure 2.

To estimate variability in our sensory ocular dominance measures from collected data, we drew 5,000 bootstrap samples of rivalry durations at each contrast level tested for each subject. At each contrast level, samples matched original data in number of left-eye and right-eye durations. For each simulated run of the experiment, proportion predominance for the right-eye stimulus was computed for each contrast level, and the results were fit (via maximum likelihood estimation) with a cumulative normal. The 50% point was taken as the balance contrast for that sample. Error bars pertaining to each subject's degree of sensory ocular dominance indicate the 95% confidence intervals from these 5,000 samples.

For comparison, sighting eye dominance was measured using the hole-in-card test (Seijas et al., 2007). In this test, subjects binocularly gazed through a hand-held card with a central hole (1 cm diameter). Despite binocular viewing, by occluding one eye, the sighting dominant eye is determined as the one aligned with the target.

Binocular adaptive optics vision simulator

The binocular AO vision simulator consisted of two simultaneously operating, identical monocular AO vision simulators. Similar systems have been described in detail previously (Sabesan et al., 2012; Zheleznyak et al., 2013). Each monocular AO system consisted of a custom-made Shack-Hartmann wavefront sensor to measure the eye's wavefront aberration, a large-stroke deformable mirror (DM97; ALPAO, Montbonnot, France), and Badal optometer to manipulate aberrations (i.e., aberration correction and induction), an artificial pupil and a visual stimulus for vision testing. The deformable mirror was operated in closed-loop (10 Hz) with the wavefront sensor to control subjects' aberrations in real time. The Badal optometers were used to control object distance for through-focus vision testing. Circular apertures (i.e., artificial pupils) imaged to the subjects' pupils determined the pupil size through which the subject viewed the visual stimulus during vision testing (4 mm diameter). An 840 ± 20 nm wavelength superluminescent diode served as the wavefront sensor beacon. Vision testing was performed in white light using a computer-controlled digital light processor (DLP) device. To aid in binocular fusion, artificial apertures imaged to the subjects' retina were used as peripheral fusion locks. The fusion locks subtended 2° of visual field and were centered on the visual performance stimuli (1°). During binocular vision testing, subjects reported single vision. A dental-impression bite bar mounted to translational stages was used to stabilize head movements. Cameras imaging subjects' pupils were used to maintain pupil alignment.

Optical conditions

Subjects' native lower and higher order aberrations of both eyes were fully corrected in all monovision conditions in this study using AO. Due to the eye's significant longitudinal chromatic aberration between the visible spectrum and the wavefront sensing light source (840 nm), subjects found their far point (0 D) by adjusting defocus with the Badal optometer to optimize their retinal image quality while viewing a 20/40 Snellen letter "E" through a 4 mm artificial pupil with all aberrations corrected using AO. This process was performed for each eye separately.

Both modified and traditional monovision consisted of 1.5 D of anisometropia in the near eye. However, in modified monovision, +0.1 and −0.4 μm of Zernike primary spherical aberration over 4 mm pupils was induced in the distant and near eyes, respectively, using the deformable mirror of the AO vision simulator. Alternatively, higher order aberrations were absent in the traditional monovision condition. It should be noted that in clinical practice, traditional monovision does not eliminate subjects' native higher order aberrations. However, in this study we chose to correct subjects' native higher order aberrations in order to isolate the

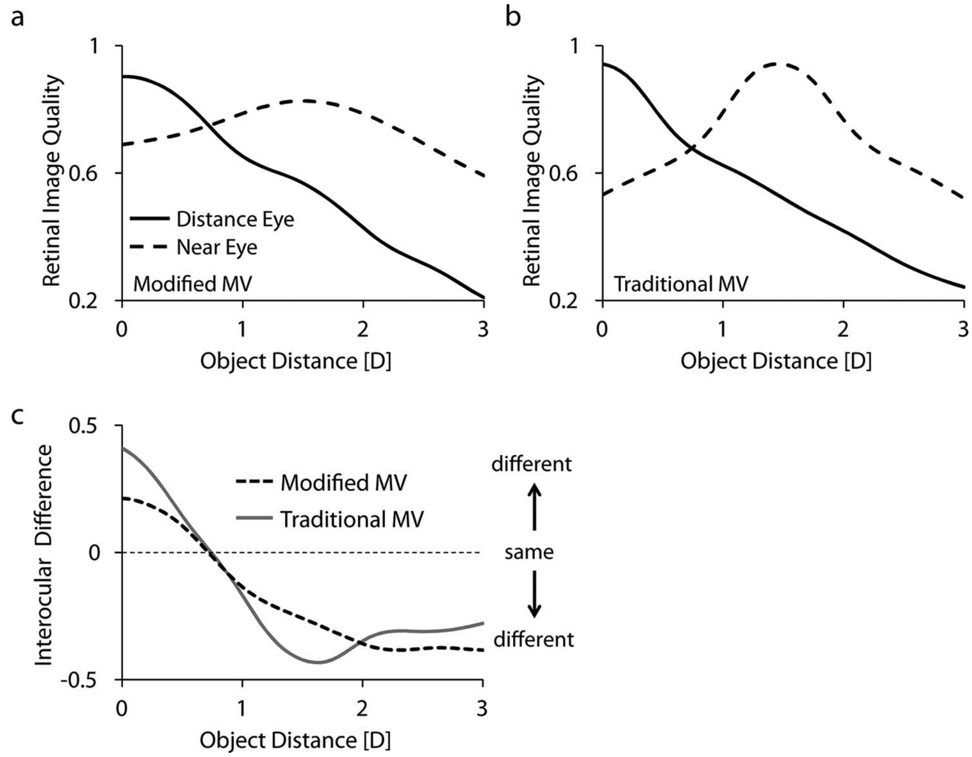

Figure 3. Through-focus monocular retinal image quality in (a) modified and (b) traditional monovision (solid and dashed black lines refer to the distance and near eyes, respectively). (c) Through-focus interocular difference in retinal image quality in modified (dotted black line) and traditional (solid gray line) monovision.

effect of spherical aberration in the modified monovision condition. Four-mm artificial pupils were used for all conditions. Theoretical monocular retinal image quality for modified and traditional monovision is shown in Figure 3a and b, respectively. Theoretical retinal image quality was computed using the image convolution metric, described in detail elsewhere (Zheleznyak et al., 2014; Zheleznyak et al., 2013). Such metrics based on image convolution have been previously shown to highly correlate with visual performance under various optical conditions (Watson & Ahumada, 2008; Young, Love, & Smithson, 2013; Zheleznyak et al., 2014; Zheleznyak et al., 2013). Through-focus interocular difference in retinal image quality (Figure 3c) was defined as the difference between the distance and near image quality at each object distance.

As stated previously, to determine the impact of ocular dominance, visual performance was measured in two circumstances by (a) assigning the dominant and nondominant eyes to distance and near, respectively, and (b) vice versa.

Through-focus visual performance testing

All visual performance measurements (visual acuity and contrast sensitivity) were performed binocularly. Visual acuity (VA) was measured over a range of target vergences (i.e., through-focus) ranging from distance (0 D) to near (positive diopters) in nine subjects. A black tumbling letter "E" on a white background was used to measure high-contrast VA with a 4-alternate forced choice method. A digital light projector (Sharp XR-10X; Sharp Corporation, Abeno-ku, Osaka, Japan), conjugate to the eye's retinal plane, was used to present the visual stimulus. The retinal illuminance was 70 cd/m^2 over a 4-mm pupil. A psychometric function based on 30 trials was obtained using the QUEST (Watson & Pelli, 1983) algorithm. VA was defined as the letter size for which 62.5% of responses were correct. Three VA measurements were averaged together for each optical condition, each based on 40 trials, and were represented in units of logMAR.

Contrast sensitivity (CS) was assessed using Gabor stimuli of 10 cyc/deg spatial frequency and a two-alternate forced choice method in three subjects. The stimuli were displayed on the digital light projector using a bit-stealing method (Tyler, Chan, Liu, McBride, & Kontsevich, 1992) implemented in MATLAB Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) to increase the bit depth from 256 (8-bit) to 1,786 (10.8-bit) gray levels. Contrast thresholds (75% correct) were obtained using the QUEST (Watson & Pelli, 1983) algorithm. Three threshold measurements

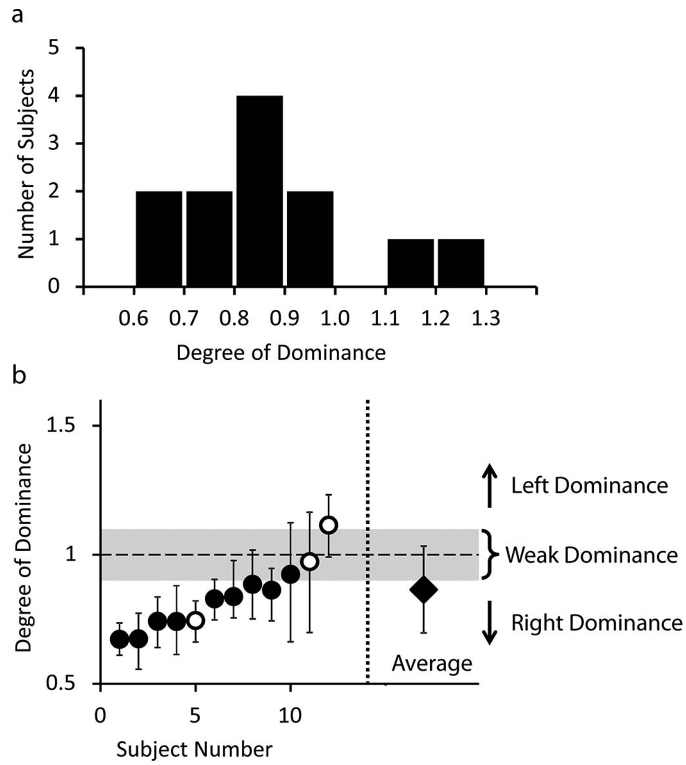

Figure 4. (a) Histogram and (b) plot of degree of sensory ocular dominance in 12 subjects. Black and white filled circles denote subjects with right and left sighting dominance, respectively. A degree of dominance value of unity indicates no dominance. Below and above unity signifies right and left eye dominance, respectively. Error bars correspond to 95% confidence intervals for each subject. The horizontal gray band of weak dominance spans ±10% around unity.

were averaged for each optical condition, each based on 40 trials.

Results

Degree of sensory ocular dominance

The degree of dominance was measured in all subjects and is shown in Figure 4. Weak ocular dominance was defined as a dominance value (RE/LE contrast ratio) within ±10% of unity (between 0.9 and 1.1) and two subjects fell into this range. The average degree of sensory dominance was biased toward right-eye dominance (0.84 ± 0.13) ranging from 0.67 to 1.11. Eleven subjects (92%) were right-eye dominant.

The sighting ocular dominance task (hole-in-card) was in agreement with the sensory dominance test in 10 (83%) subjects. The two subjects with conflicting dominance results had degrees of dominance of 0.75 and 0.97. Right- and left-eye sighting dominance is indicated in Figure 4b with black and white filled circles, respectively. The high correlation between sighting and sensory dominance tests in our study is likely not reflective of the general population and may be due to our relatively low sample size ($n = 12$). For example, Seijas et al. (2007) compared sighting and sensory dominance tasks in 51 subjects, and found correlations between tasks to vary from 27% to 58%. All subjects recruited for this study were right-hand dominant. This was unintentional and likely due to the sample size; however, it should be noted that hand and eye dominance are not necessarily correlated (Coren, 1999).

In this study, ocular dominance was quantified by only varying the contrast of the right eye, whereas the left-eye contrast remained fixed at 50%. In a subsequent control experiment, we confirmed that the choice of which eye views fixed or variable contrast did not have a significant impact on the degree of dominance.

Through-focus visual acuity

Through-focus visual acuity was measured in nine subjects with a mean degree of dominance of 0.83 ± 0.14 ranging from 0.67 to 1.11. Figure 5a and b show through-focus visual acuity in modified and traditional monovision, respectively. The binocular induction of spherical aberration in modified monovision led to an improvement in near acuity with respect to traditional monovision. In our previous study (Zheleznyak et al., 2013), spherical aberration was induced only to the nondominant eye to demonstrate the concept of modified monovision. The present study employed further optimized modified monovision by inducing a different sign and magnitude of spherical aberration to each eye. As shown in Figure 5a, visual acuity in modified monovision was slightly degraded at 0.5, 1.0, 2.5 and 3.0 D when the nondominant eye was assigned to distance; however, this difference was not statistically significant ($p > 0.05$, Student's paired t test). The average difference in visual acuity for all object distances between assigning the dominant and non-dominant eyes to distance vision in modified monovision was −0.01 ± 0.08 logMAR. In traditional monovision (Figure 5b), the average difference in visual acuity between eye assignment methods for all object distances was 0.00 ± 0.08 logMAR.

Figure 5c shows the average through-focus visual acuity difference in eye assignment methods for the individual subjects. This value was obtained by subtracting the visual acuity with the nondominant eye at distance from the dominant eye at distance paradigm at each level of defocus, and then averaging over all defocus values for each subject. The difference in visual acuity for eye assignment methods and the

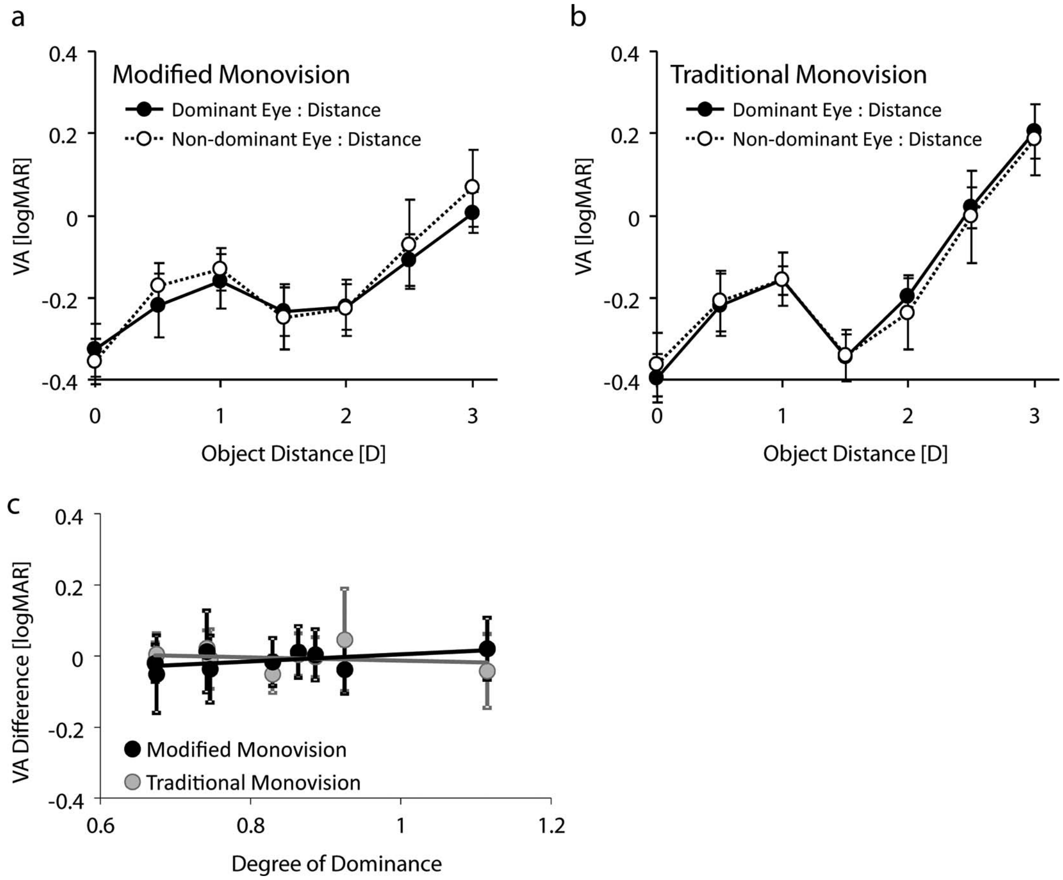

Figure 5. Average through-focus visual acuity with (a) modified and (b) traditional monovision. Black circles with solid line correspond to the dominant eye assigned to distance. White circles with dotted line correspond to the nondominant eye assigned to distance. (c) Average visual acuity difference between eye assignment paradigms in modified (black circles) and traditional (gray circles) monovision as a function of subjects' degree of dominance. Error bars indicate standard deviations.

degree of dominance for modified and traditional monovision was poorly correlated ($R^2 = 0.29$ and 0.05, respectively).

Through-focus contrast sensitivity

Figure 6 shows through-focus contrast sensitivity at 10 cyc/deg for three subjects. The subjects' degrees of dominance were 0.74, 0.86, and 0.89 (mean: 0.83 ± 0.08). The percent change in contrast sensitivity due to changing eye assignment was shown in Figure 6c, and was defined as the difference in contrast sensitivity between two eye assignment paradigms divided by the contrast sensitivity obtained with the conventional paradigm of the dominant eye at distance. A positive value indicates improvement in contrast sensitivity from assigning the dominant eye to distance, whereas a negative value indicates a reduction. Asterisks denote a statistically significant difference between eye assignment methods ($p < 0.05$, Student's t test, paired by subject). The sample size ($n = 3$) was too small to find a correlation between the percent change in contrast sensitivity and the degree of dominance.

Comparing modified to traditional monovision, the induction of −0.4 μm of primary spherical aberration to the anisometropic eye led to a significant degradation in contrast sensitivity at 1.5 D, regardless of eye assignment. Peak contrast sensitivity was found in traditional monovision at 0.0 and 1.5 D, where subjects experience monocular diffraction limited viewing.

Contrast sensitivity was significantly impacted by ocular dominance in both modified and traditional monovision. Modified monovision was significantly impacted by eye assignment at 0.0, 1.5, 2.0, and 2.5 D, whereas traditional monovision was significantly impacted only at 0.0 and 2.0 D.

As shown in Figure 6c, at 0.0 D there was a benefit in using the conventional paradigm of assigning the dominant eye to distance vision. However, this same paradigm led to a significant degradation in contrast sensitivity at intermediate and near object distances. Alternatively, assigning the nondominant eye to distance (and therefore, dominant eye to near) revealed

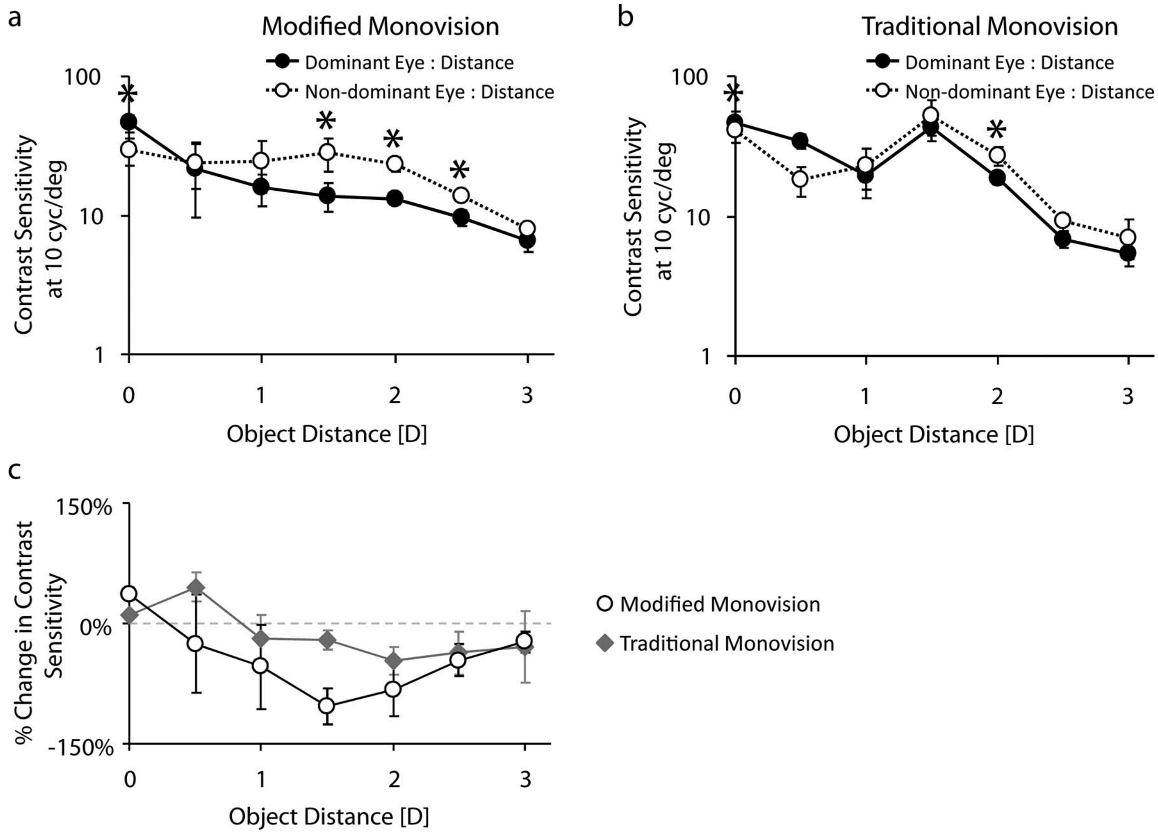

Figure 6. Average through-focus contrast sensitivity with (a) modified and (b) traditional monovision. Black circles with solid line correspond to the dominant eye assigned to distance. White circles with dotted line correspond to the nondominant eye assigned to distance. Asterisks (*) denote a statistically significant difference ($p < 0.05$, Student's paired t test). (c) Average through-focus percent change in contrast sensitivity between eye assignment paradigms in modified (black circles) and traditional (gray diamonds) monovision. Error bars indicate standard deviations.

a reduction in contrast sensitivity at 0.0 and 0.5 D, and an improvement from 1.0 to 3.0 D. Therefore, contrast sensitivity was superior at each defocus level in the case of the dominant eye coinciding with better monocular retinal image quality. This can be observed by comparing the interocular difference in image quality shown in Figure 3c with the percent change in contrast sensitivity in Figure 6c.

Discussion

This investigation applied a binocular rivalry technique to measure the degree of sensory ocular dominance. Subsequently, the impact of subjects' degree of dominance on through-focus visual performance in monovision presbyopia corrections was investigated. We found that subjects' sensory eye dominance spanned a continuum, from moderate to weak dominance. Ocular dominance had a significant impact on through-focus contrast sensitivity though not, however, on high-contrast visual acuity. This finding indicates that subjects with varying degrees of ocular dominance are capable of suppression and that high-contrast acuity is limited by the optical quality of the superior eye. Furthermore, binocular contrast sensitivity was greater when the dominant eye coincided with the eye with superior optical quality.

In the clinical convention of monovision presbyopia corrections, the dominant eye is typically assigned to distance vision (Evans, 2007; Johannsdottir & Stelmach, 2001). Consequently, distance vision is prioritized over near vision due to the facilitation of binocular suppression of the nondominant eye during distant viewing (Schor et al., 1987). However, few studies have shown this approach to be beneficial to visual performance. Handa et al. (2004) found a lower satisfaction in monovision patients with strong degrees of sensory ocular dominance; however, this was based on a subjective questionnaire. In this study, only contrast sensitivity was influenced by ocular dominance and not high contrast visual acuity, suggesting that low contrast visual tasks may be more affected by ocular dominance and ease of suppression.

We hypothesize a potential mechanism for the influence of ocular dominance on binocular contrast sensitivity may be an interaction with binocular contrast summation. As shown in Figure 6c, contrast sensitivity was impacted more by ocular dominance in modified monovision (relative to traditional monovision). Because the interocular difference in retinal image quality is smaller at distance and near in modified monovision as compared to traditional monovision (Figure 3c), we may expect enhanced binocular summation. Furthermore, we found that binocular contrast sensitivity was optimized when the dominant eye corresponded to the eye with superior retinal image quality.

We have previously shown that binocular contrast summation is greater in modified monovision as compared to traditional monovision (Zheleznyak et al., 2013) due to a larger similarity in retinal image quality (Jimenez, Castro, Jimenez et al., 2008; Jimenez, Castro, Hita et al., 2008; Pardhan & Gilchrist, 1990). This hypothesis is supported by a study from Handa, Shimizu, Mukuno, Kawamorita, and Uozato (2005), in which binocular summation was only found in subjects with relatively weak degrees of sensory ocular dominance. Furthermore, Lema and Blake (1977) suggested a shared neural mechanism mediates binocular summation and stereopsis, two binocular functions that are optimized in the absence of an interocular imbalance in retinal image quality (Halpern & Blake, 1988; Legge, 1984; Lovasik & Szymkiw, 1985; Pardhan & Gilchrist, 1990). To test this hypothesis, future work should measure both monocular and binocular contrast sensitivity in order to quantify binocular contrast summation.

Previous studies found that there are no differences in distance visual acuity when the dominant or nondominant eye was assigned to distance (Collins, Goode, & Brown, 1993; Robboy, Cox, & Erickson, 1990). Our study confirms this finding at distance, and extends this result for intermediate and near distances. Moreover, through-focus high contrast visual acuity was independent of the degree of ocular dominance. Similarly, Zheleznyak et al. (2013) previously found binocular visual acuity to be equal to monocular visual acuity over a range of object distances in modified and traditional monovision, which explains the mechanism between increasing monocular depth of focus in modified monovision (Figure 3a) and the improvement in binocular visual acuity at near object distances (Figure 5a).

A limitation of this study was that the degree of ocular dominance was only measured at a single spatial frequency (4 cyc/deg). Binocular rivalry has been shown to be insensitive to changes in spatial frequency (Blake & Fox, 1974). However, it has also been shown that ocular dominance does not affect binocular rivalry for low spatial frequencies (1 and 2 cyc/deg; Handa et al., 2005). Further investigation is needed to determine the spatial frequency dependence of ocular dominance and its relation to binocular contrast summation. For future study, it will also be important to understand the relationship between various methods of assessing the degree of sensory ocular dominance, such as those based on rivalry described herein and stereo-disparity (Heinrich et al., 2005; Kommerell, Schmitt, Kromeier, & Bach, 2003).

Conclusion

Binocular rivalry is an effective technique for quantifying subjects' degree of ocular dominance, providing a finer measure of dominance than conventional sighting tasks. In the clinical setting, quantifying the degree of dominance may be a valuable tool in screening potential candidates for surgically induced monovision presbyopia corrections. Furthermore, ocular dominance was found to have no significant impact on through-focus high contrast visual acuity in both modified and traditional monovision presbyopic corrections.

Keywords: ocular dominance, binocular vision, presbyopia, monovision, aberrations, adaptive optics

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