Visual Psychophysics and Physiological Optics

Quantifying Sensory Eye Dominance in the Normal Visual System: A New Technique and Insights into Variation across Traditional Tests

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Purpose. Although eye dominance assessment is used to assist clinical decision-making, current understanding is limited by inconsistencies across the range of available tests. A new psychophysical test of sensory eye dominance has been developed that objectively measures the relative contribution of each eye to a fused suprathreshold binocular percept.

Methods. Six standard tests and the newly developed test were used to measure motor and sensory dominance in a group of 44 binocularly normal individuals (mean age, 29.5 ± 9.10 years). The new test required observers to perform a motion coherence task under dichoptic viewing conditions, wherein a population of moving, luminance-defined signal (coherently moving) and noise (randomly moving) dots were presented separately to each eye. The observers judged the motion direction of the signal dots. Motion coherence thresholds were measured by varying the ratio of signal-to-noise dots, in a staircase procedure.

Results. The new dichoptic motion coherence threshold test revealed a clear bimodal distribution of sensory eye dominance strength, wherein the majority of the participants (61%) showed weak dominance, but a significant minority (39%) showed strong dominance. Subsequent analysis revealed that the strong-dominance group showed greater consistency across the range of traditional eye dominance tests used.

Conclusions. This new quantitative dichoptic motion coherence threshold technique suggests that there are two separate sensory eye dominance strength distributions among observers with normal binocular vision: weak and strong eye dominance. This finding may provide a basis for clinical decision-making by indicating whether eye dominance is likely to be an important consideration in a particular patient. (*Invest Ophthalmol Vis Sci.* 2010;51:6875–6881) DOI:10.1167/iovs.10-5549

The concept of eye dominance is well entrenched in the clinical literature. It provides the foundation for a range of clinical decisions, including monovision treatment,[1–4] contact lens wear,[5] and cataract surgery.[6] Eye dominance has a long history, having first been discussed by Rosenbach[7] in 1903 and later by Walls[8] and Berner and Berner.[9] The concepts of motor and sensory dominance have been developed through these early works, with the former being determined by motor tests, such as the Hole-in-the-Card test,[8] and the latter by relative measures of visual sensitivity[9–12] or the relative ability of each eye to suppress processing of an image presented to the other eye during binocular rivalry paradigms.[13–15] At present, it is fair to say that both the importance and basis of eye dominance, be it motor or sensory, is poorly understood. What is known is that measures of motor and sensory dominance do not correlate strongly within individuals.[10,12,14,16,17] This lack of correlation is in contrast to other types of lateralized dominance, such as hand dominance,[18] and raises the question of what the relevance of eye dominance might be. Since it appears that eye dominance is not determined by a more faithful input from one eye[9,10] or more efficient cortical processing of one eye's input,[19,20] there remains the possibility that its basis lies in the nature of the interaction that occurs between the eyes when both eyes are operating together (i.e., when both eyes are contributing to a fused, stable percept) as is the case in everyday viewing. A series of recent findings[9,21–28] regarding the role of inhibitory pathways before excitatory binocular combination may hold the key to a reinterpretation of sensory eye dominance.

Traditionally, binocular interaction has been considered to be wholly excitatory[25]; however, recent studies[21–24] have highlighted interocular inhibitory signals that interact before or parallel with the standard excitatory combination of left and right eye signals. This pattern has been developed into what is now referred to as a two-stage model for the combination of left and right eye information: one stage of contrast gain control before summation that receives an inhibitory input from the contralateral eye and one stage of contrast gain control after binocular combination.[29] The balance of these inhibitory signals before binocular combination may determine which eye dominates during binocular viewing and may be the basis of sensory eye dominance. Two previous findings suggest that sensory eye dominance is associated with an inhibitory balance before binocular summation, rather than a balance between monocular excitatory signals per se. First, observers with normal binocular vision exhibit imbalances in dichoptic interac-

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tions in performing a variety of tasks,[24,26] suggesting a possible inhibitory basis for eye dominance. Second, eye dominance bears no relationship to the relative monocular contrast sensitivity, acuity, or hyperacuity of each eye,[12] suggesting that monocular excitatory signals are not solely responsible.

A psychophysical paradigm has recently been developed to investigate the nature of binocular interactions in both the normal visual system[24] and in patients with strabismic amblyopia,[29] in which quantitative, objective measurements of suppression have been made. The paradigm is based on the use of a psychophysical task that requires the separation of a *signal* population from a *noise* population. The psychophysical stimulus is presented under dichoptic conditions, wherein the signal is presented to one eye and the noise to the other. Behavioral measures of the interaction between the signal and noise are then used to investigate the way in which information is combined between the two eyes. Global motion stimuli[30] are one type of stimuli that have been used with this paradigm, as they contain both signal and noise populations and require neural processing at multiple levels within the visual system.[31] These stimuli consist of a population of noise dots that move randomly and a population of signal dots that all move in a common direction. The observer's task is to report the direction of the signal dots' motion (the coherent motion direction). The difficulty of the task is manipulated by keeping the total number of dots constant and changing the proportion of signal dots to noise dots until a motion coherence threshold is reached.[30] This threshold is expressed as the number of signal dots. With this dichoptic, global motion paradigm, the ratio of motion coherence thresholds between the right and left eyes (the number of signal dots required when signal is presented to the right eye versus the left eye) can objectively quantify the relative contribution of each eye to the fused percept. This technique therefore has a clear application to the assessment of sensory eye dominance.

To assess how dichoptic motion coherence thresholds relate to other measures of eye dominance and whether they can also provide an insight into the mechanisms underlying this phenomenon, we used seven different techniques to measure eye dominance (with two techniques repeated at near and far viewing distances to give a total of nine measurements) within a group of participants with normal binocular vision. We hypothesized that if the dichoptic motion coherence test provided an index of the relative contribution of each eye to suprathreshold binocular viewing, then it may also explain some of the variance known to be present across other tests of eye dominance.[10,12,14,16,17]

Methods

Participants

Fifty-two observers were recruited, with 44 subjects (24 women, 20 men), between the ages of 18 and 50 years (mean age, 29.5 ± 9.10) meeting the inclusion criteria. Those included had to have equal visual acuity between the eyes of at least 20/20; absence of any ocular, oculomotor, or binocular abnormalities; normal stereoacuity (≤20 seconds of arc), and a spherical equivalent (SE) refractive error between +1.00 and −3.00 D with a dioptric difference of <1 D. The mean spherical equivalent was −0.60 D for the right eye and −0.71 D for the left eye. Visual acuity was measured with a standard logMAR visual acuity chart. Correction was determined by a subjective refraction, and, if required, correction was implemented in a trial frame during testing. This study adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committees of Zhongshan Ophthalmic Center and the Hong Kong Polytechnic University. Informed consent was obtained from all participants before data collection.

Normal binocular vision and stereo acuity were assessed with the Worth 4-Dot test and the Randot stereo graded circle test (Random Dot Stereopsis Test with LEA Symbols; Vision Assessment Corporation, Elk Grove Village, IL). All assessments and subsequent tests were performed by the same practitioner (LJR) in the same test room at the Optometry Center, Zhongshan Ophthalmic Center, Sun Yat-sen University. All tests were conducted at a constant room luminance, as measured with a digital lux meter (TES Electronic Corp., Taipei, Taiwan).

Eye Dominance Assessment

Standard tests of eye dominance (three sighting tests based on motor dominance and three sensory tests, two of which were performed at both near and far viewing distances) were performed once, with the exception of the Hole-in-Card test, which was performed twice. The tests are described in the order in which the participants performed them. Each testing session took approximately 1 hour, including refraction.

The Hole-in-Card Test (The Dolman Method). The participants were instructed to keep both eyes open while holding a card with both hands and viewing a 6-m-distant target through a hole in the middle of the card.[32] They were asked to alternately close each eye to determine the dominant viewing eye. Observers were then instructed to slowly draw the card back toward their head without changing the previously aligned position. The eye that was underneath the hole in the card was considered to be the dominant eye. For all participants tested, the two repeats of the test gave consistent results.

The Point-a-Finger Test (Porta Test). The participants were instructed to extend both arms while holding a pen with both eyes open. They were then required to align the pen to a 6-m-distant object. The participants were asked to alternately close each eye and report which eye was viewing the target. The viewing eye was determined to be the dominant eye.[11,33]

The Near Point Convergence Test. The observers were asked to fixate an object moving toward the nose. The eye that diverged first to the temporal side was determined to be the nondominant eye.[16,34]

The Worth 4-Dot Test. A Worth 4-Dot Attachment (Richmond Products, Albuquerque, NM) was fitted into a Finoff transilluminator (Heine Optotechnik GmbH, KG, Herrsching, Germany), which allowed for the presentation of four circular target dots (circumference, 19 mm; 2 green, 1 white, 1 red) with equal luminance. The participants wore red/green anaglyph glasses (Bernell VTP, Mishawaka, IN) over their best refractive correction, with the red filter over the right eye and the green filter over the left eye.[16] Under moderate room illumination, the participants were instructed to fixate on Worth 4-Dot target (with the red target at the top) while it was held slightly below the participant's line of sight at near (33 cm) and far (6 m) test distances. The eye dominance test was based on the perceived color of the white dot. The participants were required to make a three-alternative, forced-choice decision as to whether the dot appeared white (no dominance), red (right eye dominant), or green (left eye dominant).

The Distance Fixation Disparity Test. The participants viewed a target through a pair of polarizing lenses.[16] The fused percept consisted of a cross with a fixation dot at the center. One vertical and one horizontal bar of the cross were presented to each eye, such that a displacement of the upper line of the cross toward the right of the fixation dot indicated right eye dominance, a displacement to the left indicated left eye dominance, and no displacement indicated no dominance. The test was conducted at near (33 cm) and far (6 m) viewing distances.

The Modified Bagolini Striated Lens Test. This test challenges binocular combination of separate striations on the Bagolini lenses by placing increasingly powerful neutral-density filters over one eye until only the striation seen by the nonfiltered eye is perceived (based on a subjective report).[35] The test is performed for each eye and the difference in the strength of neutral-density filter required to break the binocular combination is used as a measure of the strength of eye dominance and to identify which is the dominant eye. Each observer viewed a light source (30 lux/m^2) held at a 33-cm viewing distance while wearing Bagolini striated lenses under low ambient room illumination. For all recruited subjects, an X was perceived because of normal binocular fusion. Neutral-density filters (Wratten; Eastman Kodak, Rochester, NY), increasing in 0.3-log-unit increments were mounted in a bar. The filter values ranged from 0.3 (50% light transmission) to 3 (0.1% light transmission). The neutral-density filter bar was held vertically in front of one eye and moved upward to increase the strength of the filter over the eye. The participant reported the point where only one line (/ or \) was perceived instead of an X. The end point was defined as the neutral-density filter strength at which the observer reported that only one striation was visible. To ensure the accuracy of this end point, the neutral-density filter strength was increased by an additional 0.6 log unit from the end point and decreased until the observer reported that the X was visible once again. These steps were repeated until a balanced reversal was accomplished. The procedure was first performed with neutral-density filters over the dominant eye and then over the nondominant eye, as identified by the results from the hole-in-card test.

Dichoptic Motion Coherence Threshold Measurements

Apparatus. Stimuli were presented with a laptop computer (MacBook Pro; Apple Computer, Cupertino, CA; running MatLab; The MathWorks, Natick, MA, and Psychophysics Toolbox, ver. 3).[36] The stimuli were displayed with a head-mounted display (Dual Pro Z800; eMagin Corp., Hopewell Junction, NY). This model contains two OLED (organic light-emitting diode) screens, one for each eye. The screens have a high luminance, a linear luminance–response profile, and a simultaneous refresh rate of 60 Hz that avoids motion smear. The device also allows for different stimuli to be presented to each eye. To achieve this, each frame of the dichoptic stimulus was computed as a single image with a resolution of 600 × 1600 pixels. An external video board (DualHead2Go; Matrox, Dorval, QBC, Canada) was then used to split each frame between the two head-mounted display screens at a resolution of 600 × 800 pixels per screen, thus allowing for dichoptic stimulation. A photometer (TES 1330A; TES Electronic Corp.) was used to ensure equal luminance of the two screens and to perform gamma correction.

Stimuli and Task. Stimuli were random-dot kinematograms based on those used by Mansouri et al.[29] (Fig. 1). One hundred bright dots [with dot luminance modulation varied according to $[(L_{dots} - L_{background})/(L_{dots} + L_{background})]$ were displayed at 100% contrast on a mean luminance background of 35 cd/m^2. These settings allowed for highly visible dots without any smearing of the dots across the display screen. Each dot had a radius of 0.5° and moved at 6° per second. The dots had a limited lifetime whereby, on any single frame, each dot had a 5% chance of disappearing and being redrawn in a new spatial position. The dots were presented within a circular display aperture with a radius of 11.1° that was framed by a binocularly presented solid black square outline with nonius lines marked on it to aid fusion. To avoid interaction of the stimulus dots with the central dark fixation dot (radius 0.35°), the stimulus dots did not enter the central region of the display aperture (radius 2°). Dots that passed through this central region disappeared and were redrawn on the opposite side of the central area with the appropriate temporal delay to maintain a constant speed. When stimulus dots reached the edge of the display aperture, they were wrapped around. Stimuli were shown for 1 second.

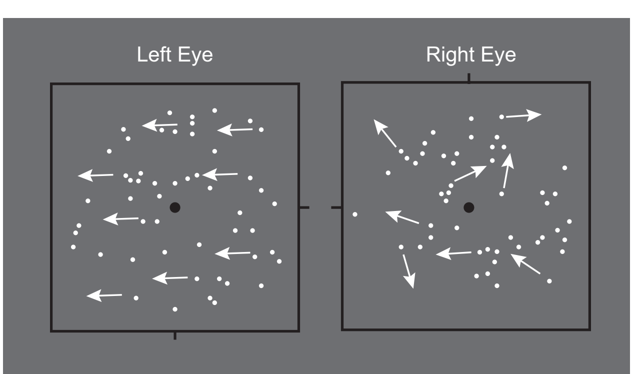

Figure 1. The stimuli used for dichoptic motion coherence threshold measurements. In this schematic representation, all the dots in the left eye are moving to the left and constitute the signal dot population. The dots in the right eye are moving in random directions and constitute the noise population. The arrows are for illustration purposes and were not presented in the actual stimulus.

In each trial, one eye was presented with a population of "signal" dots that all moved in the same direction (left or right). The other eye was presented with the noise dots that moved in random directions. The task was to indicate the motion direction of the signal dots. To measure the threshold number of signal dots required for 79% correct performance (the motion coherence threshold), the number of signal dots was varied on a trial-by-trial basis in a three-down, one-up staircase procedure with a proportional step size of 50% before the first reversal and 25% thereafter. The starting point for each staircase was 100 signal dots and 0 noise dots. When dots were removed from the signal population, they were added to the noise population and vice versa. Each staircase consisted of six reversals, and the last five reversals were averaged to estimate threshold. During each threshold measurement, two staircases were randomly interleaved. One staircase measured the motion coherence threshold when the signal dots were presented to the left eye and the other staircase measured the motion coherence threshold when signal dots were presented to the right eye. In each case, the eye that did not see the signal dots saw the noise dots. By randomly interleaving the staircases, participants could not tell which eye had seen the signal and which had seen the noise as the stimuli were fused. The interleaved staircase measurements lasted approximately 3 minutes.

Each participant was familiarized with the stimuli and task by a demonstration program in which the stimuli were presented continuously and the proportion of signal and noise dots could be controlled using the up and down arrow keys on the laptop keyboard. Once the participant was familiar with the task, motion coherence threshold measurements began. Each pair of threshold measurements began with two square stimulus frames presented separately to each eye with nonius lines next to the fixation marks. Using the arrow keys on the laptop keyboard, participants could adjust the position of the stimulus in the nondominant eye to ensure that the images in the two eyes were perfectly aligned with stable fusion. The participant then pressed a key to initiate the threshold measurements. The left and right arrow keys on the laptop keyboard were used to report the percept of leftward and rightward signal dot motion, respectively. The testing was self-paced, with each stimulus being shown 250 ms after the response to the preceding trial. To account for any short-term fluctuations (intraexamination variability), we calculated an average motion coherence perception threshold for each eye based on two repeated measures of the staircase procedure. The participants were given a 30-minute break between the two measurements, to avoid any fluctuations caused by fatigue.

Results

The ability of each test to identify a dominant eye varied. The hole-in-card, point-a-finger, near point convergence, and dichoptic motion coherence threshold tests all indicated a dominant eye in 100% of observers. The Worth 4-Dot test identified a dominant eye in 82% of observers at distance and 68% at near, whereas the distance fixation-disparity test identified a dominant eye in 75% of participants at distance and only 45% at near. Finally, the modified Bagolini striated lens test identified a dominant eye in 80% of observers.

For the motion coherence threshold test, the average threshold number of signal dots across participants was 11.5 (4.8 dots SD), which is consistent with previous reports of tests with high-contrast dots.[24] There was a bias toward right eye dominance in the motion coherence test results with 27 (61%) of 44 participants having higher motion coherence thresholds when the signal dots were presented to the left eye. This bias was not present in the results of the modified Bagolini striated lens test. Of the 35 participants in whom a dominant eye was identified by this test, 18 (51%) were right eye dominant. A comparison of the eye dominance results between the motion coherence threshold test and the modified Bagolini test in those 35 participants showed that 28 (80%) of 35 had the same eye dominance on both tests.

The phi tests was used to compare the agreement of eye dominance results across the different tests. To allow for this comparison, the results of each test were coded as 0 (left eye dominant), 1 (right eye dominant), or 0.5 (test did not detect a dominant eye). The phi coefficients and *P* values, corrected for multiple comparisons using the false-discovery rate correction[37] can be seen in Table 1. The strongest agreement was found between the modified Bagolini striated lens test and the Worth 4-Dot test at distance; however, as mentioned, neither of these tests identified a dominant eye in all observers. Of the tests that detected a dominant eye in all observers, the strongest agreement was between the hole-in-card and point-a-finger test followed by the hole-in-card and near point convergence test and the near point convergence and dichoptic motion coherence threshold test. It was notable however, that no test agreed completely with any other test reflecting the known variability in measurements across the different approaches.[10,16]

Two tests gave a quantitative measurement of the sensory eye dominance strength, the modified Bagolini striated lens test and the dichoptic motion coherence threshold test. Dominance ratios were calculated for each of these tests as follows. For the modified Bagolini striated lens test, the dominant eye was defined as the eye with the largest value and the neutral-density filter dominance ratio was calculated as [(Neutral $\text{Density}_{\text{Right Eye}}$ − Neutral $\text{Density}_{\text{Left Eye}}$)/(Neutral $\text{Density}_{\text{Right Eye}}$ + Neutral $\text{Density}_{\text{Left Eye}}$)]. For the dichoptic motion coherence threshold test, the dominant eye was defined as the eye with the lowest value, and the motion coherence dominance ratio was calculated as [(Motion Coherence $\text{Threshold}_{\text{Left Eye}}$ − Motion Coherence $\text{Threshold}_{\text{Right Eye}}$)/(Motion Coherence $\text{Threshold}_{\text{Left Eye}}$ + Motion Coherence $\text{Threshold}_{\text{Right Eye}}$)]. Therefore, for both ratios, a negative value indicated left eye dominance and a positive value indicated right eye dominance. Figure 2 shows the strong positive relationship between these two tests ($\rho = 0.8$, $P < 0.0001$). Figure 2 also shows that the disagreements in eye dominance between the two tests occurred when eye dominance was weak (the cluster of points around the 0 intercept of the two axes). It is evident that this correlation was driven by the participants who had large dominance ratios in both the dichoptic motion coherence threshold test and the Bagolini test.

Two measures were calculated to assess whether the fine-grained quantitative measure of eye dominance provided by the dichoptic motion coherence threshold test could explain the general within-participant inconsistency across the range of tests examined in this study. The first was a motion coherence threshold ratio: highest motion coherence divided by lowest motion coherence as a measure of eye dominance strength, regardless of which eye was dominant. The second was the average of eye dominance results across the other

Table 1. Agreement between Nine Different Measures of Eye Dominance in Identifying the Dominant Eye

	Hole-in-Card	Point-a-Finger	Near Point Convergence	Worth 4-Dot		Fixation Disparity		Bagolini	Motion Coherence
				Near	Far	Near	Far		
Hole-in-Card									
Point-a-Finger	0.86 (<0.001)*								
Near Point Convergence	0.57 (<0.001)*	0.52 (0.001)*							
Worth 4-Dot									
Near	0.28 (0.18)	0.33 (0.1)	0.31 (0.13)						
Far	0.39 (0.03)*	0.53 (0.002)*	0.17 (0.53)	0.4 (0.13)					
Fixation disparity									
Near	0.65 (<0.001)*	0.59 (<0.001)*	0.33 (0.09)	0.54 (0.01)*	0.53 (0.01)*				
Far	0.37 (0.05)	0.41 (0.03)*	0.21 (0.4)	0.9 (<0.001)*	0.33 (0.32)	0.32 (0.35)			
Bagolini	0.42 (0.02)*	0.44 (0.01)*	0.14 (0.65)	0.57 (0.006)*	0.92 (<0.001)*	0.64 (0.001)*	0.39 (0.16)		
Motion coherence	0.44 (0.003)*	0.38 (0.01)*	0.57 (<0.001)*	0.31 (0.13)	0.32 (0.1)	0.55 (0.001)*	0.12 (0.71)	0.29 (0.16)	

Seven tests were performed, with two repeated at the near and far viewing distances. Phi coefficients are shown for each comparison along with *P* values for each test (in parentheses).
* Significant agreement after the application of a false discovery rate (FDR) correction for multiple comparisons.

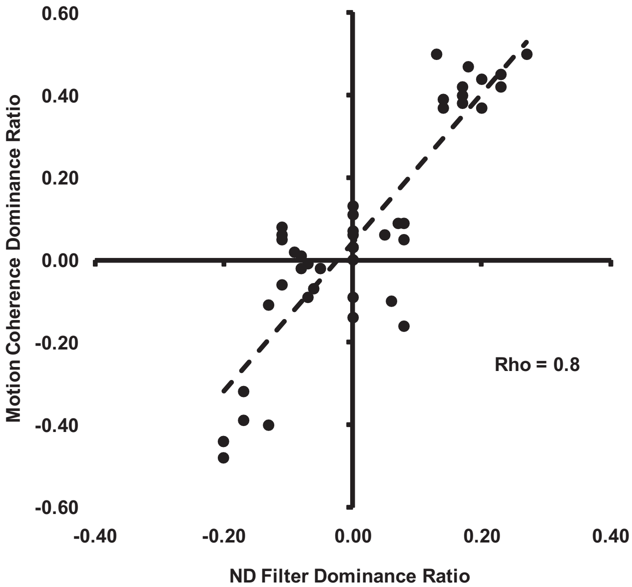

FIGURE 2. Dominance ratios measured with the dichoptic motion coherence threshold technique (ordinate) and the modified Bagolini striated lenses technique (abscissa). For both axes, a negative value indicates left eye dominance and a positive value indicates right eye dominance. The farther the value is from 0, the greater the dominance. *Dashed line*: best fit to the data.

eight eye dominance measures (the near and far test distances for the Worth 4-Dot and fixation disparity tests were considered as separate measures for this analysis), with 0 representing left eye dominance, 1 representing right eye dominance, and 0.5 showing no dominant eye. Therefore, an average of 0 (or 1) would represent complete consistency across tests, whereas a score of 0.5 would indicate highly inconsistent results. The distribution of motion coherence threshold ratios is shown in Figure 3. Two separate distributions are apparent. The first peaks just above a ratio of 1 and therefore represents weak eye dominance to which our test is highly sensitive. The second peaks at a ratio of 2.4, indicative of strong eye dominance whereby the nondominant eye needed 2.4 times as many signal dots as the dominant eye to elicit the same level of task performance. The majority (61%) of our sample had weak dominance, defined as motion coherence thresholds falling between 1 and 1.6 (i.e., threshold ratios within the first distribution). Although indicative of weak dominance, the motion coherence threshold ratios in this group were still significantly greater than 1 ($t = 7.9$, $P < 0.001$) indicating that dominance was indeed present. The remaining 39% of participants had strong dominance defined as motion coherence thresholds of over 1.8 (i.e., threshold ratios within the second distribution in Figure 3). Motion coherence threshold ratio did not correlate with the age of the participants ($\rho = 0.06$, $P = 0.7$) suggesting that any changes in monocular contrast sensitivity that may occur with age did not influence performance on this task.

A plot of motion coherence threshold ratios as a function of test consistency is shown in Figure 4. A two-step cluster analysis conducted on the *z*-score-transformed motion coherence threshold and test consistency scores identified three distinct clusters that are apparent in Figure 4. The plot shows that the participants with large motion coherence threshold ratios (i.e., strong dominance) had very high levels of consistency across the other eight eye dominance measures, whereas those with weak dominance did not.

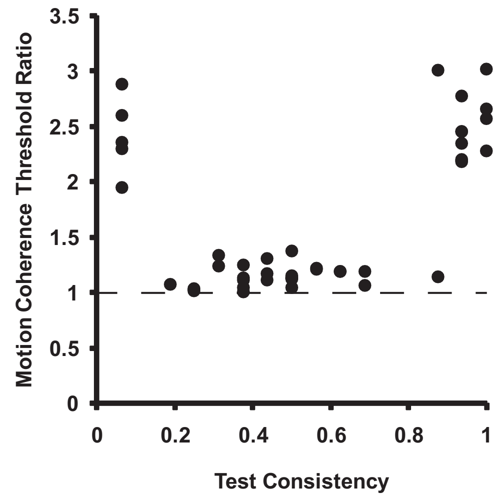

FIGURE 4. The strength of eye dominance measured as a motion coherence threshold ratio (see Fig. 3) as a function of consistency across eye dominance tests in terms of which eye was identified as dominant. A test consistency result of 0 shows complete consistency (left eye dominant), 1 shows complete consistency (right eye dominant), and 0.5 shows poor consistency. There are three clear clusters showing that weak eye dominance is associated with poor consistency and strong eye dominance is associated with strong consistency.

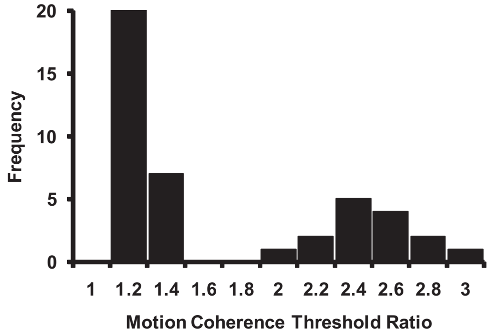

FIGURE 3. The distribution of motion coherence threshold ratios calculated as the threshold number of signal dots for the eye with the highest threshold divided by the threshold for the other eye. Therefore, this is a measure of eye dominance strength rather than a test of which eye is dominant. A ratio of 1 indicates a complete balance between the eyes; a value greater than 1 indicates progressively stronger dominance.

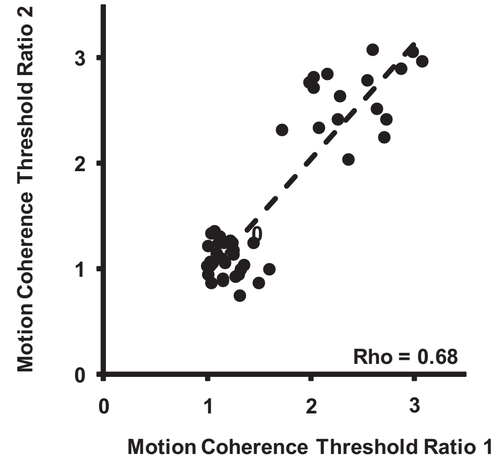

FIGURE 5. Within session test–retest reliability of the motion coherence threshold ratio measure.

The within-session test–retest reliability of the dichoptic motion coherence threshold test is shown in Figure 5. The motion coherence threshold ratio for the first staircase measurement (largest threshold/smallest threshold) is shown relative to the motion coherence threshold for second staircase measurement (the threshold for eye with largest threshold at test 1 divided by the threshold for eye with smallest threshold at test 1). There was a significant correlation between the two thresholds ($\rho = 0.68$, $P < 0.001$) and the two clusters of weak and strong eye dominance were apparent (Fig. 5).

Discussion

We have described and tested a novel, objective, dichoptic motion coherence threshold technique for measuring sensory eye dominance. The test quantifies the relative contribution of each eye to a fused, binocular percept. The novelty of this technique is that it allows for the measurement of eye dominance using highly visible, suprathreshold stimuli under conditions in which both eyes are working together. This approach differs from previous assessment techniques that either test monocular function and compare thresholds between the eyes[11,12,38] or induce a conflict between the eyes to identify which is dominant.[10,14,16,39,40] The dichoptic motion coherence test demonstrated good test–retest reliability and took little time to administer, with each interleaved staircase measurement taking 3 to 4 minutes to complete.

Within our sample of individuals with normal binocular vision, the strength of eye dominance, as measured by our test, did not have a normal distribution. Rather, the distribution revealed two separate clusters of eye dominance strength. This finding is consistent with those in previous studies demonstrating weak eye dominance in most participants but strong dominance in a small subset of participants.[12–14,16] On the basis of this clustering of high and low dominance, a comparison between our dichoptic motion coherence threshold measure and within-subject consistency across a range of other more traditional sensory and motor eye dominance tests revealed an interesting pattern. For participants in the weak eye dominance cluster, there was a great deal of inconsistency across the various tests that we measured, a finding that is in agreement with those in other reports.[12,13] However, in those with strong dominance, the range of motor and sensory eye dominance tests we used produced surprisingly consistent results. Specifically, all 17 observers who fell into the strong eye dominance category were consistent across at least seven of the eight dominance tests. Only 1 participant of the 27 in the weak-dominance cluster had this level of consistency. This result suggests that strong and consistent eye dominance exists in a significant minority of normal observers. Whether this strong dominance has a clinical significance will be a topic of future research; however, it is clear from our inclusion criteria that strong dominance does not degrade performance on clinical tests of binocular fusion functions such as stereopsis. These results may explain the inconsistency across different eye dominance tests that has been reported,[16] since most of our observers had weak dominance that presumably does not demand a consistent eye preference across multiple tests. In fact, when the participants with weak dominance on our motion coherence test were removed from the correlation analyses reported in Table 1, in which pairs of different eye dominance measures are compared, the number of significant correlations is greatly reduced (from 20 to 4). This result further demonstrates that the participants identified as having strong dominance by our test were consistent across multiple eye dominance tests, and those with weak dominance were not.

It has been shown that under certain conditions, dichoptic presentation of motion coherence stimuli can lead to binocular rivalry.[41,42] Our stimuli, however, did not induce rivalry. One explanation for this is that the brief (1-second) presentation time that we used for our measure was not long enough to induce rivalry. In addition, a pilot study in which 50 signal dots were presented to one eye and 50 noise dots were presented to the other eye demonstrated that no rivalry was experienced in response to our stimulus, even at extended viewing durations of several minutes. This discrepancy can be explained by significant differences between our stimuli and those used in these previous studies. Perhaps the most important of these differences is stimulus size. Rivalry has been shown to occur for random dot stimuli ranging in size from 0.5° to 2°.[41] An important finding was that the occurrence of rivalry decreased with increasing stimulus size, until at a stimulus size of 2° (the largest size tested), rivalry occurred only 20% of the time.[41] Our stimuli were more than five times larger than those used in these rivalry studies. It is therefore reasonable to speculate that our stimuli did not activate the rivalry mechanisms that have been reported for a subset of motion coherence stimuli. Additional evidence that our motion coherence measure of eye dominance is distinct from previous binocular rivalry based measures is the observation that our measure did not correlate with the results of the Worth 4-Dot test. This finding is relevant, as the Worth 4-Dot test requires the eyes to compete actively for perceptual dominance in a way that is analogous to binocular rivalry.

Our results fit with those of current models of binocular combination that posit inhibitory interactions between the eyes before binocular combination.[21,43,44] These interactions appear to be well balanced in most observers, as evidenced by the weak levels of dominance that we measured. However, it appears that in some individuals, these interactions are out of balance, leading to strong dominance effects. Consistent with this interpretation, large imbalances between the eyes have been reported in adult amblyopes, with the use of very similar measurement techniques.[29]

In summary, dichoptic motion coherence thresholds can be used to objectively quantify the relative contribution of each eye to a fused binocular percept. These measurements also reveal two distinct clusters of eye dominance: weak eye dominance that results in a great deal of inconsistency across a range of more traditional eye dominance tests and strong eye dominance that is robust to multiple traditional measures of dominance. Our results shed light on the general lack of agreement that has been reported among different eye dominance tests[16] and are consistent with current models of binocular combination in the normal and amblyopic visual system.[21–24,26]

From a clinical perspective, measures that provide a quantitative assessment of sensory eye dominance strength have potential applications in a range of contexts including the selection of appropriate low vision aids, cataract surgery,[6] monovision correction[1,2,16] (where one eye is focused for distance vision and the other for near) and sports vision.[38] In all these cases, it is important to determine not only the sign of dominance (i.e., which eye) but also its strength. Most methods have provided information on the former, but not the latter. The technique described herein, which is based on motion coherence threshold ratios, provides information about the strength of dominance and therefore should be of clinical value.

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