Balanced Eyes See Stereopsis More Quickly, but Not More Finely

Haoran Wu,1,2 Hua Bi,3 Xuhong Zhang,4 Zheyi Chen,4 Weizhong Lan,1,2 Xiaoning Li,2 Bin Zhang,3 and Zhikuan Yang1,2

1Aier School of Ophthalmology, Central South University, Changsha, China
2Aier Institute of Optometry and Vision Science, Changsha, China
3College of Optometry, Nova Southeastern University, Davie, Florida, United States
4Eye Hospital of Wenzhou Medical University, Wenzhou, China

Correspondence: Bin Zhang, Nova Southeastern University, Davie, FL 33314. USA: bz52@nova.edu.
Zhikuan Yang, Central South University, Changsha, 410015, China; 13380071988@189.cn.
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Ocular dominance refers to the tendency for a person to prefer visual input from one eye to the other.1,2 The preferred eye is defined as the dominant eye, which is used with ease or by habit to perform tasks. Traditionally, three types of ocular dominance have been reported: sighting, motor, and sensory dominance. Sighting dominance means that one eye is preferred over the other when fixating on a target.3-5 Motor dominance refers to the eye that is better at maintaining fixation at the near point of convergence.3-5 Sensory dominance refers to the eye that is better at maintaining competition for the perceptual dominance when two distinct eyes were compared, and much more difficult if a very strong signal is compared to a weak signal.6 It is also known that an unequal blur of the images in the two eyes deteriorates stereocuity more than when there are equally blurred images in the two eyes.10-15 This may be, in part, due to unequal contrast of the images in the two eyes.16-18 Unequal neural sensitivity of the two eyes could also contribute to the reduced stereocuity. Theoretically, when compared to a person with clear ocular dominance, those with two balanced eyes should be able to detect finer disparities and accomplish the task in a shorter amount of time. However, this hypothesis has not been previously tested, likely due to methodologic limitations of the traditional ocular dominance tests. In the hole-in-the-card test to test sighting dominance,20 a subject is asked to hold the cardboard with both hands and to view a target through the hole with both eyes open. Then, one of the eyes is occluded. If the target remains in view, the occluded eye is nondominant and the open one is the dominant eye.21 In the near-point-of-convergence test (NPC) to test motor dominance,22 a subject is asked to fixate on an object that is moving toward the nose. The eye that deviates first is the nondominant eye. Both of these methods are qualitative and only identify the dominant eye without determination of the extent of the dominance. Neither method directly measures the relative sensitivity of the visual part of the brain to visual signals from the two eyes.23,24

In the current study, we measured ocular sensory dominance and quantified it with the ocular dominance index for each subject, and subsequently identified the dominant eye. The aim of this study is to provide a quantitative assessment of

PURPOSE. To quantify ocular sensory dominance and investigate its relationship to stereopsis.

METHOD. A total of 69 subjects participated in the study. Ocular dominance was measured by a continuous flashing technique, with the tested eye viewing a Gabor patch increasing in contrast, and the fellow eye viewing a Mondrian noise decreasing in contrast. In each trial, the log ratio of Mondrian to Gabor’s contrasts was recorded as a subject first detected the Gabor. We collected 50 trials for each eye and an interocular difference was analyzed with a rank-sum test. The z-value was used as the ocular dominance index (ODI) to quantify the degree of ocular dominance. A subject with ODI $\geq 2$ was categorized as having a clear ocular dominance, and a subject with ODI $< 2$ was considered as having balanced eyes (unclear dominance). The stereocuity was measured with random dot patterns with durations varying from 50 to 1000 ms. The best achievable stereocuity ($D_{\text{min}}$) and the integration time needed to acquire that ($T_{\text{min}}$) were calculated.

RESULTS. A total of 30 subjects had balanced eyes and 39 had clear ocular dominance. $T_{\text{min}}$ was significantly longer in subjects with clear ocular dominance than in subjects with balanced eyes (180.18 vs. 121.17 ms, $P < 0.01$). $T_{\text{min}}$ was positively correlated with ODI ($P < 0.01$). However, $D_{\text{min}}$ in subjects with clear dominance was not different from that in subjects with balanced eyes (40.60 vs. 35.73 arcsec, $P = 0.18$).

CONCLUSIONS. Ocular dominance is not associated with how fine the stereocuity is, but rather how quickly the best stereocuity is acquired.

Keywords: ocular sensory dominance, stereopsis, integration time
the relationship between ocular sensory dominance and stereopsis and overcome limitations of previous studies.

MATERIALS AND METHODS

Subjects

A total of 69 subjects were recruited from the NOVA Southeastern University campus, and they completed the testing. The subjects were aged between 20 to 40 years with a mean age of 28.1 ± 4.9 years. There were 31 males and 38 females. To be included in the study, the subjects were required to have a best corrected visual acuity (BCVA) of 20/20 or better at distance for each eye. Subjects were excluded from the study if they had a prior history of any of the following ocular diseases: strabismus or ptosis, any ocular surgery, amblyopia, keratoconus, glaucoma, retinal diseases, optic disc abnormalities, phoria greater than 6 prism diopters at near, optic neuropathy, or other diseases that might affect BCVA. Written informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. The protocol for the study was approved by the Institutional Review Board (IRB) of Nova Southeastern University and followed the tenets of the Declaration of Helsinki.

Ocular Dominance Measurement

Ocular dominance was determined with the continuous flashing technique. The visual stimuli were presented in the center of a cathode ray tube (CRT) screen (1024 × 768 resolution; 100 Hz; Gamma corrected for linearity; Richardson Electronics, LaFox, IL, USA) against a uniform background (mean luminance 50 cd/m²) and viewed at a distance of 60 cm with a chin rest. One eye viewed the dynamic Mondrian patterns, which subtended 4.3° × 4.3° with individual elements extending to 0.15°. The other eye viewed the testing target, which was a Gabor patch tilted 45° toward either the right or the left (SF = 1 c/d, spatial extension 1.9°). The black and white strokes that framed the Mondrian and Gabor were 0.33° in width and were used to help achieve binocular fusion. Mirrors were used to present the Mondrian and target stimuli dichoptically. The subjects were instructed to exclusively view one of the two stimuli during a given trial. The eyes’ view of the dynamic Mondrian and target stimuli was counterbalanced and randomized across trials. The experiment was programmed in commercial software using a computational environment (MATLAB, version 2012Rb; MathWorks, Natick, MA, USA).

At the beginning of a trial, one eye viewed a Mondrian pattern with 100% contrast and the other eye viewed the target Gabor patch at 0% contrast. During the trial, the contrast of the Gabor patch linearly increased by 1% every 100 ms, and the contrast of Mondrian patterns linearly decreased at the same rate. At high contrast, the subject perceived the Mondrian pattern only. When the contrast of the Mondrian was reduced and the contrast of the Gabor was increased, the subject was able to see the Gabor patch. Subjects were instructed to respond immediately once they detected the tilting direction of the Gabor patch (left versus right) by pressing one of two response keys (Fig. 1A). After each trial, the ocular strength value was calculated as the log ratio of Mondrian to Gabor’s contrasts (MGR) at that moment. The higher the ratio, the greater the quantitative measure of the sensory dominance for that eye.

Subjects performed 10 practice trials for orientation and training, prior to starting 50 experimental trials. The trials in which a subject did not respond when the stimulus presentation duration expired were excluded from the analysis. To accommodate the potential distortion to the distribution and different numbers of samples in the two eyes, Wilcoxon rank-sum test was used to compare the MGRs collected from each eye. The approximated z-value, which was the interocular difference in mean values normalized by the standard deviations of values from both eyes, was used as the ocular dominance index (ODI) to quantify a subject’s overall degree of ocular dominance. A positive value of ODI indicated the right eye was stronger and a negative value of ODI...
components. Afterward, each half-image was reconstructed pixel by pixel, was introduced between the corresponding Fourier transformation into a set of sinusoidal spatial frequency components.

The method's validity was not tested directly given it is in the public domain.

**Data Analyses and Statistics**

Statistical analyses were performed with the R programming package (version 3.3.1). Mean, median, and standard deviation were used for descriptive comparison of each subject's ODI value, T\text{min} and D\text{min}, which all followed normal distribution. A t test was used for comparison of D\text{min} and T\text{min} between subjects with balanced eyes and subjects with unbalanced eyes. Linear regression was performed to assess the relationship between T\text{min} and D\text{min} versus the absolute value of ODI. A P value less than 0.05 was considered statistically significant.

**RESULTS**

We first calculated the distribution of ODI in all subjects tested; 43.48% of the subjects (n = 50) had clear ocular dominance. The median value of ODI was 1.38 (Fig. 3). For stereopsis, we calculated the distribution of D\text{min} in all subjects tested (Fig. 4A). The median value of D\text{min} was 39.41 arcsec (mean ± SD: 55.01 ± 45.00 arcsec). For T\text{min} in all subjects tested (Fig. 4B), the median value was 150.32 ms (mean ± SD: 177.71 ± 105.72 ms).

To see whether stereopsis measurements, T\text{min} and D\text{min}, were different between the subjects with balanced eyes and those with unbalanced eyes, we calculated the statistics on population data. Subjects with clear ocular dominance had significantly higher T\text{min} values (median = 180.18 ms, mean ± SD: 215.63 ± 118.37 ms) than the subjects with balanced eyes (median = 121.17 ms, mean ± SD: 128.45 ± 58.30 ms, t = -3.70, df = 67, P < 0.01). However, subjects with clear ocular dominance (median = 40.60 arcsec, mean ± SD: 61.55 ± 52.24 arcsec) had similar D\text{min} values to those with balanced eyes.
It is also worth noticing that Tmin was not correlated with the absolute values of ODI, which represents the difference of ocular strength between the two eyes (Fig. 5C, bottom panel, *P* = 0.11). However, Tmin was moderately correlated with each eye ocular strength value, indicated by the MGR (median $R = 0.20$, $t = 1.75$, $P = 0.09$). It should be noticed that Tmin was only correlated to the absolute values of ODI, which represents the difference of ocular strength between the two eyes. Tmin was not correlated with each eye ocular strength value, indicated by the MGR ($R = 0.49$, $t = 4.61$, $P < 0.01$). It is also worth noticing that Tmin was not correlated with $D_{min}$ ($R = 0.20$, $t = 1.63$, $P = 0.11$).

**DISCUSSION**

This study shows that subjects with two balanced eyes can achieve best stereoscopic vision in a shorter period of time, and those subjects with unbalanced eyes need a longer interval to do so. However, the best stereoscopic vision, once achieved, is not different between the two groups.

**On Comparison With Previous Studies**

In previous studies, the hole-in-card method or near-point-of-convergence was often used to determine the eye dominance. However, to investigate the relationship between ocular dominance and stereopsis, neither method appears appropriate. The hole-in-card method measures sighting dominance, but according to some studies, may play a role in the judgment of visual direction. The near-point-of-convergence method measures the relative strength in keeping fixation on the target approaching close to the observer. Stereopsis is directly related to how the visual cortex processes the interocular image disparity. Therefore, it is more relevant to study ocular sensory dominance. The other advantage of sensory dominance over sighting and motor dominance is its capability to quantify the degree of ocular dominance. By calculating the ODI, it is possible to explore the quantitative relationship between stereopsis and ocular dominance. This quantification of dominance was not possible with sighting or motor dominance tests.

**Dynamic Process of Stereopsis**

Instead of settling on a selected stimulus presentation duration and measuring the stereoacuity, a series of stimulus presentation durations was applied to explore the dynamic process of stereoscopic vision. Previous studies have often overlooked the dynamic process. Our data confirmed earlier study’s finding that stereoacuity improves with stimulus presentation duration, up to a certain point. Tmin represents the turning point when best achievable stereoscopic vision ($D_{min}$) no longer depends on stimulus presentation time. Our results showed that Tmin is significantly linearly related to ODI and $D_{min}$ is not. The results of this study show that despite the slow stereo vision integration those with clear dominance, their stereo vision integration is relatively slow, once integration is completed, they can achieve excellent stereoacuity. In this way, this study describes the two different aspects of stereoscopic vision.

**Speculation on the Relationship Between $D_{min}$ and Tmin**

Our results revealed that the integration rate of stereopsis is directly related to the relative strength difference between the eyes. It might take less time for the signal to arrive at the visual cortex from the dominant eye than signals from the nondominant eye. When the stimulus presentation duration is short, given the different arrival timing of the signal, the effective time for signal integration is very limited. Therefore, performance in stereoacuity deteriorates. With the longer presentation duration, there is more time for signals from both eyes to arrive, and for the visual cortex to integrate the signal. We speculate that there is a threshold for disparity information to be fully extracted. Once the stimulus presentation time is longer than the threshold value, the best stereoacuity could be achieved ($D_{min}$) and is not dependent on the degree of ocular dominance. Even a person with very unbalanced eyes can achieve an excellent level of stereoacuity. How fast one can do this might depend on the speed of binocular signal combination and integration, and how finely one sees stereoacuity might be determined by the efficiency of the cortical neurons to extract the relative disparity from the integrated signals. Ocular dominance mainly affects the first mechanism, and has little to do with the latter one. Since extraction of relative...
interocular disparity happens in visual cortical area 2 (V2) and beyond,\textsuperscript{31,32} it seems that ocular dominance may possibly work in V1, where binocular signals converge and integrate.\textsuperscript{33–35} One study has reported that the signal conduction speed is relatively faster in the dominant eye.\textsuperscript{36} Whether that is the case in sensory dominant eyes remains a case to be explored.

Clinical Implications

Accurate determination of ocular dominance is useful in clinical decision-making, as it relates to monovision management of presbyopia\textsuperscript{37–39} with intraocular lens implant in cataract surgery,\textsuperscript{40,41} contact lenses,\textsuperscript{39,42} or LASIK.\textsuperscript{43,44} The determination of ocular dominance has mainly been based on sighting dominance, which takes little time to perform. The key assumption in monovision is that the blur is suppressed more easily in the nondominant eye.\textsuperscript{39} Whether that is the case in sensory dominant eyes remains a case to be explored.

CONCLUSIONS

This study shows ocular sensory dominance is moderately correlated with integration time for stereopsis processing. Persons with unbalanced eyes need more time to achieve best stereocuity than those with balanced eyes. However, the best stereocuity achieved is not related to ocular sensory dominance. With balanced eyes or not, persons can achieve a similar best stereocuity.

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References