Binocular Vision in Older People with Adventitious Visual Impairment: Sometimes One Eye is Better than Two

Jocelyn Faubert, Ph.D.[1] and Olga Overbury, Ph.D.[†]*

PURPOSE: To determine the effect of adventitious visual impairment (low vision) on monocular and binocular spatial contrast sensitivity of the elderly.
DESIGN: Between-within repeated measures design.
PARTICIPANTS: Fifty-nine older adults between the ages of 50 and 96. 49 of the observers had age-related macular degeneration (AMD).
MEASURES: Visual acuity screening and spatial contrast sensitivity.
RESULTS: In almost half of the population with AMD, the sensitivity to spatial information, as measured by spatial contrast sensitivity, is worse when both eyes are used than when the stimuli are viewed only with one eye. This "binocular inhibition" is not related to the contrast sensitivity of the better eye or to acuities. Furthermore, this inhibition process is reflected primarily in images with medium to low spatial frequency components (medium to large size bars).
CONCLUSIONS: These results have important implications for understanding the functional impact of low vision in older people. They suggest that almost one-half of older people with AMD view the world best using only one of their eyes, whereas for the other half, there is an advantage to using binocular vision for certain visual tasks. **J Am Geriatr Soc 48:375-380, 2000.**
Key words: age-related macular degeneration; contrast sensitivity function; binocular inhibition; low vision; aging

One of the more dramatic demographic changes in recent years has been the increase in the mean age of the population, and this will continue to rise dramatically in the next decades[1]. A direct consequence of this demographic change is the augmentation of age-related visual impairments leading to legal blindness as defined by an acuity in the better eye with best correction equal to or less than 20/200 and/or a visual field of 20 degrees or less in the better eye. Although these observers are said to be legaly blind, this is quite different from being totally blind. Low vision observers often read with the help of visual aids and participate in many activities that necessitate visual information, albeit with increased difficulty[2]. A recent study on the relationship between visual impairment and mobility and physical function concluded that severe visual impairment (acuity worse than 20/200) generated a 3-fold higher odds of related incedent mobility in activities of daily living than did acuity of 20/40 or better[3]. It is, therefore, important to understand the impact of visual impairment on visual function. Another consequence of adventitious visual impairment is that there is often a substantial difference between the two eyes, with one typically less sensitive to visual information than the other. How the individual monocular inputs are combined to produce binocular vision in adventitious visual impairment remains unknown.

Normal observers demonstrate binocular summation[4]. That is, binocular sensitivity at threshold is usually better than the sensitivity of either monocular function for spatial detection. It has been argued that probability summation alone cannot account for the amount of improvement in sensitivity for binocular viewing relative to monocular viewing, and, therefore, there must be some neural interaction or summation at the cortical level[5]. A recent study of the effect of normal aging on binocular contrast sensitivity has demonstrated that the normal aging process reduces the amount of binocular summation[6]. Research with amblyopic vision generally demonstrates that, with asymmetrical visual input, some form of suppression occurs, that is, the visual input of the worse eye is ignored and the binocular vision performance is equal to the monocular performance of the better eye[7]. Taking these two models together, it makes intuitive sense that low vision observers should demonstrate binocular performance that is better than or equal to the best monocular function. It should be better when the individual monocular inputs are similar (summation), and it should be equal to the better monocular function when there is a large discrepancy between the monocular sensitivities (suppression). However, an alternative approach is that some form of inhibition occurs, where unequal visual input from the two eyes results in binocular vision that is worse than the monocular input of the better eye.

Substantial evidence for this kind of inhibition process at suprathreshold levels is exemplified by an effect known as Fechner's paradox[8]. In this case, when a bright square is viewed with one eye and a dimmer square is viewed with the other eye, the binocular image appears dimmer than for the

From the *École d'optométrie, Université de Montréal, Montréal, Canada, and the †Department of Ophthalmology, Jewish General Hospital, McGill University, Montréal, Canada.
This research is supported by MRC Grant MT-14777 to JF.
This research was presented, in part, at the Annual American Academy of Optometry conference, Decernber 1991, Anaheim, California.
Address correspondence to Jocelyn Faubert, PhD, École d'optométrie, Université de Montréal, C.P. 6128, succursale Centre-Ville, Montréal, Québec, Canada H3C 3J7.

JAGS 48:37S-380, 2000

0002-8614/00/$3.50

brighter luminance condition. This is true even if both eyes together receive more energy than only the one eye with the brighter target.

Evidence for some type of an inhibition process has been demonstrated by Pardhan and Gilchrist in cases of amblyopia and unilateral cataracts[9,10]. They report that in some cases of amblyopia and unilateral cataracts, the binocular contrast sensitivity function (CSF) can be worse than that of the better monocular sensitivity function. The common link between the two disorders in the capacity to demonstrate the inhibition process seems to be the magnitude of the difference in sensitivity between the two eyes where, the greater the difference, the more likely some form of inhibition process will occur.

The present study addresses the issue of whether visual performance at threshold abides by the suppression or the inhibition hypotheses mentioned above in older patients with AMD.

METHODS

Subjects

All low vision participants were recruited at the McGill Low Vision Center, and the normal observers were recruited from the general clinic, both of which are located in the Department of Ophthalmology of the Jewish General Hospital. The low vision subjects were asked if they wanted to participate in the study when they came for a regular follow-up at the low vision center, and the normal subjects were people who came for a regular checkup at the ophthalmology clinic.

Procedure

Spatial sine wave gratings were generated with a Nicolet Optronics 2000 contrast sensitivity measurement system. A method of increasing contrasts with five replications was used to establish thresholds. Before each block of trials of a given spatial frequency, the stimulus was previewed at maximum contrast for 10 seconds. Viewing distance was 1 meter, and the sequence of testing for eye (left, right, or binocular) and spatial frequency condition was randomly selected. All observers wore their distance correction with an additional +1.00 diopter lens to correct for the viewing distance and to assure a proper focus. A practice session took place on two spatial frequencies (0.17 and 2.01 cpd) for each eye condition before testing. The mean luminance was 100 cd/m^2 ,and the testing monitor was the only light source in the room. Six spatial frequencies were tested; 0.17, 0.33, 1.0, 2.01, 3.81, 7.63 cycles per degree of visual angle (cpd). Contrast thresholds were calculated using Michelson contrast (Lmax-Lmin/Lmax+Lmin), where Lmax and Lmin corresponded to the maximum and minimum luminances in the image, respectively. Sensitivity was calculated as the inverse of the contrast thresholds and was converted to log units. The data analysis used in this study consisted of a repeated measures ANOVA, where the between variables consisted of the group category (see below) and the within variables consisted of the spatial frequencies tested.

RESULTS

A total of 59 observers were tested. The control group consisted of 10 normal observers with an age range of 50 to 82 years, a mean age of 65.9 years, and a standard deviation of 10.3 years. The low vision group consisted of 49 observers with age-related macular degeneration (AMD) aged between 60 to 96 years, a mean age of 79.2 years, and a standard deviation of 9.2 years. Table 1 lists the demographic information of the observers in both the normal and low vision groups. The binocular acuities were equivalent to the best monocular acuity so the values are not listed in the table. The subjects were categorized into two groups, based on their spatial CSFs. Their data demonstrated a pattern corresponding to either a summation/suppression (SS) or a binocular inhibition (BI) function. These patterns were established by calculating the log area under the CSF (area under the curve or AUC)(see Figure 1) for each testing condition (left, right, or binocular). If the binocular area score was higher or equal to the best monocular area score, then the subject fell into the SS category. If, on the other hand, the binocular area score was worse than the best monocular area score, the subject was placed in the BI category.

Using this categorization procedure, 27 observers (55%) demonstrated a SS behavior, whereas 22 observers (45%) showed BI characteristics. That is, 45% of the AMD patients had a binocular spatial CSF that was worse when both eyes were used than when only the better eye was used! Only one of the 10 observers from the normal group showed a BI pattern, and his CSF functions for the binocular and better eye conditions were almost identical.

A 2 x 3 x 6 between-within analysis of variance (ANOVA) was performed on the CSFs obtained from the low vision observers. The between condition corresponded to the categories (SS vs. BI), and the within conditions consisted of the eye conditions related to performance as measured by contrast sensitivity (binocular, better eye, and worse eye) and the six spatial frequencies tested. The analysis showed that there was no significant main effect of group, nor were there significant interactions for the spatial frequency by category, or spatial frequency by category by eye conditions. Not surprisingly, there were significant main effects of eye ($F(2,94) = 48.64$; $P < 0.001$) and spatial frequency conditions ($F(5,235) = 163.7$; $P < 0.001$). Interestingly, the results did show significant eye by category ($F(2,94) = 4.68$; $P = 0.012$) and eye by spatial frequency ($F(10,470) = 2.89$; $P = 0.002$) interactions.

To illustrate these results in graphical form, we have plotted the mean CSFs for the normal, the SS, and the BI groups in Figures 2a, 2b, and 2c, respectively. The y-axis represents the log contrast sensitivity and the x-axis the different spatial frequencies tested. The three separate curves in each figure represent the contrast sensitivity functions of the better eye and the worse eye, as determined by the area calculation mentioned above, and the binocular sensitivity.

Figure 2a demonstrates the binocular contrast sensitivity advantage obtained when viewing an image with both eyes compared with a single eye for normal observers. The CSF show that there was no difference between the better and worse eyes in contrast sensitivities at the higher and lower spatial frequencies, whereas there was some difference in sensitivity at the middle spatial frequencies. We calculated the binocular summation ratios (binocular sensitivity / best monocular sensitivity) and found that they were 1.15, 1.08, 1.02, 1.04, 1.04, 1.05 for the lowest to the highest spatial frequencies, respectively.

Note that the y-axis used for the normal subjects in

Table 1. List of Age, Diagnosis, Activities in Minute of Arc, Area Under the CSF. and Categoryv of Each Suject

AGE	DIAGNOSIS	MOA(OS)	MOA(OD)	AREA(OS)	AREA(OD)	AREA(OU)	CATEGORY
62	AMD	100	20	2.686	2.575	2.584	BI
82	AMD	20	15	1.445	1.683	1.573	BI
88	AMD	10	2.5	2.106	1.757	2.281	SS
84	AMD	10	66.7	2.025	1.345	1.923	BI
80	AMD	12	12	0.504	0.522	0.359	BI
89	AMD	15	20	1.206	1.642	1.496	BI
63	AMD	10	20	1.368	1.844	1.662	BI
63	AMD	15	20	2.253	2.363	2.487	SS
63	AMD	15	20	2.384	2.079	2.520	SS
80	AMD	3	120	1.850	2.399	2.377	BI
83	AMD	10	66.7	1.449	1.062	1.404	BI
76	AMD	4	300	1.127	1.217	1.375	SS
81	AMD	10	233.3	1.067	1.376	1.593	SS
76	AMD	4	2.5	2.142	1.371	1.985	BI
96	AMD	35	40	1.590	1.084	1.728	SS
74	AMD	10	66.7	1.860	1.922	2.021	SS
83	AMD	3	20	1.392	1.924	1.883	BI
70	AMD	80	40	1.314	0.998	1.487	SS
60	AMD	2	3	2.700	2.723	2.942	SS
73	AMD	10	50	0.201	1.810	1.544	BI
62	AMD	100	30	2.059	1.688	1.901	BI
72	AMD	30	80	1.974	2.288	2.207	BI
81	AMD	10	20	1.639	2.033	1.461	BI
75	AMD	2	2	2.197	2.265	2.365	SS
71	AMD	70	12.5	2.058	1.148	1.869	BI
94	AMD	4	8	1.726	1.963	2.081	SS
78	AMD	20	15	1.517	0.445	1.527	SS
71	AMD	10	5	2.103	2.115	2.311	SS
84	AMD	33.3	5	1.427	1.283	1.545	SS
79	AMD	10	2.5	2.299	2.294	2.471	SS
78	AMD	10	100	0.173	0.635	0.936	SS
89	AMD	5	10	1.605	1.550	1.899	SS
82	AMD	15	4	1.550	1.630	1.891	SS
82	AMD	5	10	1.058	2.122	1.875	BI
85	AMD	116.7	233.3	0.102	1.968	2.047	SS
85	AMD	13.3	116.7	1.784	1.592	1.851	SS
90	AMD	20	22.2	0.891	1.195	1.120	BI
90	AMD	40	5	1.743	0	1.570	BI
81	AMD	175	100	0.932	1.064	1.055	BI
76	AMD	70	80	2.231	2.126	2.306	SS
90	AMD	20	200	0.710	1.268	1.387	SS
79	AMD	3	2.5	2.332	2.310	2.453	SS
90	AMD	50	10	0.442	0	0.816	SS
74	AMD	20	10	1.919	1.574	1.999	SS
93	AMD	2.5	10	1.993	1.766	1.892	BI
88	AMD	2.5	100	1.229	1.687	1.818	SS
72	AMD	15	100	2.372	2.100	2.490	SS
90	AMD	20	3.5	1.849	0.223	1.712	BI
74	AMD	5	66.7	1.199	1.263	1.075	BI
62	NORMAL	1.5	1.5	3.644	3.481	3.644	SS
68	NORMAL	1	1	3.443	3.155	3.806	SS
57	NORMAL	1	1	3.335	3.482	3.847	SS
82	NORMAL	1.5	1.5	3.431	3.542	3.724	SS
68	NORMAL	1.5	1.5	3.809	3.751	3.903	SS
78	NORMAL	1.5	1.5	3.046	3.024	3.216	SS
50	NORMAL	1	1.5	3.214	3.133	3.025	BI
68	NORMAL	1.25	1.5	3.487	3.140	3.900	SS
72	NORMAL	1.25	1.5	3.711	3.755	3.923	SS
54	NORMAL	1.25	1	3.738	3.717	3.949	SS

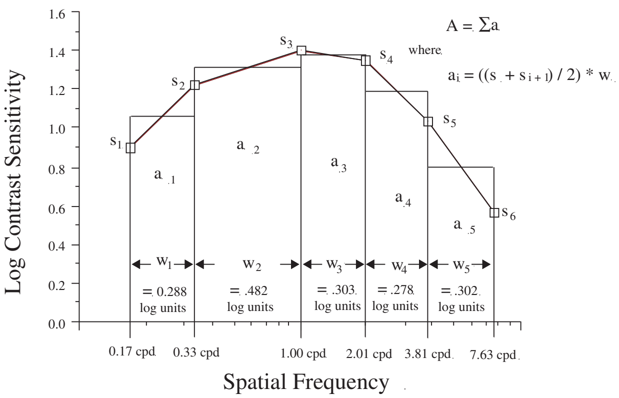

Figure 1. Illustration of a spatial CSF where log CSF on the y-axis is plotted as a function of spatial frequency content of the stimulus. Formula used to calculate the «area under the curve" scores is presented in the upper right portion of the figure.

Figure 2a is different from that used for the low vision subjects in Figures 2b and 2c. This is because low vision severely depresses the CSF, i.e., the sensitivity of low vision observers was approximately 10 times lower than that for the normal observers (1 log unit) for the best viewing performance. However, the range used on the ordinate is the same for the three graphs (1.6 log units) for comparative purposes.

Figure 2b demonstrates that, for the SS group, there was a difference between the better and worse eye sensitivities at all spatial frequencies. Furthermore, the binocular summation ratios were 1.04, 1.09, 1.04, 1.10, 1.13, and 1.31 for the lowest to the highest spatial frequencies, respectively.

Figure 2c demonstrates that there was also a difference between the contrast sensitivities of the better and worse eyes at all spatial frequencies for the BI group. However, unlike the SS group, there was a disadvantage to viewing the images binocularly, but only for the medium to lower spatial frequencies. The two highest spatial frequency conditions did not seem to produce a binocular viewing disadvantage for the BI group. To determine whether this binocular inhibition was statistically significant, we tested pairwise contrasts of the means for the binocular and best eye conditions using paired t tests with a statistical criterion of 0.008 alpha value (Bonferoni correction). We used such an alpha criterion because we made six pairwise comparisons that would give us an acceptable alpha value of 0.048 to avoid alpha slippage. The six t values obtained for the lowest to the highest spatial frequencies were, respectively: t = -1.807, p = 0.085; t = -3.889, p = 0.001; t = -3.067, p = 0.006; t = -3.45, p = 0.002; t = -0.212, p = 0.834; and t = -1.748, p = 0.095. Notice that only the 2^{nd}, 3^{rd}, and 4^{th} spatial frequencies met the statistical criterion. We must conclude, therefore, that binocular inhibition was evident for these three spatial frequencies only.

Figure 2d compares the CSFs for the SS and BI groups directly and demonstrates with overlapping functions that there were no differences between the sensitivity functions of the better eyes of the two groups. However, there was a large absolute CSF difference between the worse eye performance of the two groups, with the BI group having the poorest sensitivity. To test whether this difference between the worse eye of the two groups was statistically significant, we calculated pairwise independent t tests between the worse eye of the BI and SS groups. These values presented for low to high spatial frequencies, are, respectively: t = -1.156, p = 0.253; t = -1.4559, p = 0.152; t = -0.774, p = 0.443; t = -0.998, p = 0.324; t = -1.318, p = 0.194; and t = -1.678, p = 0.1.

Comparing the ages of the BI and SS groups demonstrates that the differences between these groups are not the result of age. The mean age for the BI group was 79.1 years of age with a SD of 9.2 years, and the mean age for the SS group was 79.4 years of age with a SD of 9.4 years. Age also showed no correlation with group categorization (Spearman RHO, r = -0.015).

A 2x2 between (group) within (better eye vs. worse eye) ANOVA on the visual acuities associated with these categories showed that there was no main effect of group (F<1), nor was there a significant group by eye acuity interaction (F<1). As expected, there was a significant effect of acuity between the better and worse eye conditions (F(1,47)= 6.9; p= 0.012).

DISCUSSION

The results of the present study demonstrate that although we normally observe some form of facilitation for contrast sensitivity at threshold in normal vision, this is not the case for patients with AMD. The data showed that 22 of 49 AMD subjects (45%) demonstrated worse binocular spatial contrast sensitivity than their best monocular sensitivity; they demonstrated some form of binocular inhibition. It was also shown that the CSFs for the BI group and the SS group did not differ at all in terms of the better eye CSF. There was a relatively large absolute difference between the worse eye CSFs of each group, but because of a large variability, this difference did not meet statistical significance. A relationship between the difference in CSFs between the eyes, where the larger the difference, the more likely binocular inhibition would occur, was previously established by Pardhan and colleagues[9, 10]. Although our data tend to show the same relationship, we cannot claim that this is the case because of the lack of statistical significance between the worse eye CSFs of the SS and BI groups. This variability is expected in low vision because there is a large variability among the disease stages of AMD patients, probably reflected most in the worse eye sensitivity. It was also demonstrated that the binocular inhibition occurs mainly at the medium and lower spatial frequencies (except for the lowest spatial frequency tested). Analysis of the age factor demonstrated that the differences between the SS and BI groups are not at all attributable to age.

The binocular summation data for both the normal and the SS groups showed positive but weak binocular summation ratios. When comparing these values with the study on aging and binocular summation by Pardhan[6], we find that our data show lower binocular summation ratios. One possible explanation for this difference is that the mean ages of our groups are older than for her group. The mean age for her older group was 58.4 years, whereas in our groups, the mean age was 65.9 and 79.4 years for the normals and the SS groups, respectively. Because we know that binocular sumation ratios decrease with age, it is not surprising that our groups show lower binocular summation ratios than her group, which had a lower mean age.

The results of the present study raise a number of issues

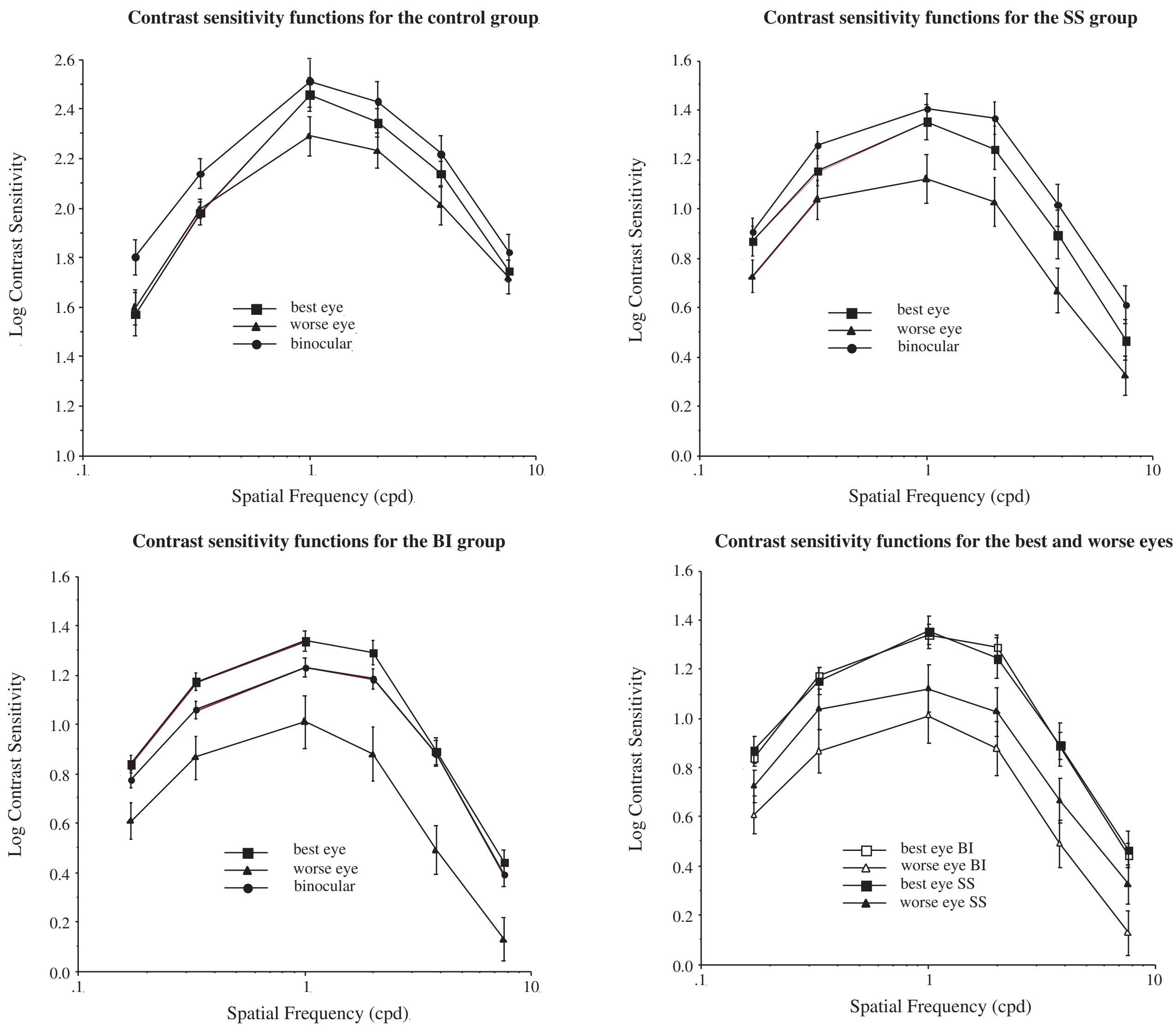

Figure 2. Mean spatial contrast sensitivity functions (CSFs) of the better eye, the worsc eye, and binocular viewing conditions for (a) the normal observers; (b) the summation/suppression (SS) group; (c) the binocular inhibition (Bl) group. Figure 2d compares the spatial CSFs of the SS and BI groups directly.

regarding binocular function in the AMD population. For one, our data imply that a low-vision observation, under certain circumstances, may be impaired by viewing with the two eyes. Our results show that almost half of the low-vision population may be better off seeing through one eye than using the two eyes. The question is: under what circumstances will the observers be served best by one rather than two eyes? Clearly, standard acuity measures are no help in determining this. The CSFs shown in Figure 2c show that the binocular inhibition effect occurs mainly at the medium and lower spatial frequencies. Standard acuities are a measure of the higher spatial frequencies perceived at maximum contrast. Contrast sensitivity to medium and lower spatial frequencies is generally related to tasks such as orientation and mobility that require this type of information. On the other hand, orientation and mobility also require a larger field of view, and this may be why both eyes are still functional for detection of contrast even if there is a detrimental effect from binocular inhibition. In essence, therefore, it is clear that all AMD patients will not perform the same way when one eye or both eyes are used. For some (the SS group), there will be no difference when viewing images with both eyes open or when the better monocular eye is used, and for others (the BI group) one eye may be better than two for certain visual tasks.

Given the above results, what would be the best way to evaluate this difference in performance between the two groups? Clearly, acuity measures alone are inadequate for assessing low vision. A more complete way would be to perform a CSF, as we have done in the present study, and to represent the overall CSF performance using the AUC value, as we have done presently, generating a single value CSF performance. Figure 3 demonstrates the average AUC values for the three conditions. It is clear that this value alone is enough to distinguish the groups. In fact, these results echo the CSF data and show clear differences between the binocular performance of the two groups. This difference is highly significant, as evidenced by a group by AUC interaction ($F(2,94) = 5.13$, $p = 0.008$) when calculating a 2x3 between-within ANOVA on AUC values.

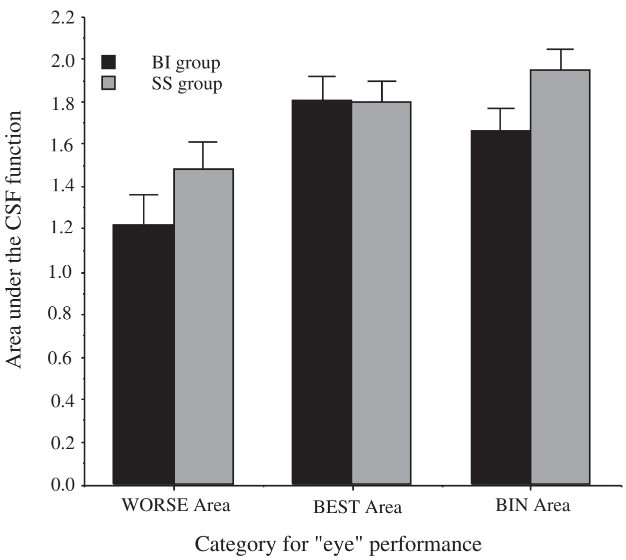

Figure 3. Mean area under the spatial contrast sensitivity curve, as calculated from the formula in Figure 1, as a function of viewing condition and subject category.

In conclusion, we have found that in the case of AMD patients, one eye is sometimes better than two. This is particularly true for visual performance when images have low and medium spatial frequency components (large and medium size objects). We have also determined that the measurement of the AUC value can be useful to establish a single value of CSFs. Our results may lead to a better understanding of the functional impact of AMD, which is the leading cause for low vision and legal blindness in the older population.

REFERENCES

1. Aging America: Trends and Projections. U.S. Senate Special Commitee on Aging, the American Association of Retired Persons, the Federal Council on Aging and the U.S. Administration on Aging. 1991.
2. Faye E. Clinical Low Vision. Boston: Little, Brown and Co. 1976.
3. Salive ME, Guralnik J, Glynn RJ et al. Association of visual impairment with mobility and physical function. J Am Geriatr Soc 1994; 42:287-292.
4. Arditi A. Binocular vision. Sensory processes and perception. In: Boff KR, Kaufman, L, Thomas, JP (eds.) Handbook of perception and human performance, Vol.1. New York. John Wiley & Sons, 1986.
5. Blake R, Fox R. The psychophysical inquiry into binocular summation. Percept Psychophys 1973; 14:161-185.
6. Pardhan S. A comparison of binocular summation in young and older patients. Curr Eye Res 1996; 15:315-319.
7. Perry NW, Childers DG. Monocular contribution to binocular vision in normals and amblyopes. In: Arden GB, ed. The visual system: Neurology, Biophysics, and Their Clinical Application. New York: Plenum Press, 1972.
8. Levelt WJM. On Binocular Rivalry. The Hague: Mouton, 1968.
9. Pardhan, S, Gilchrist, J. The importance of measuring binocular contrast sensitivity in unilateral cataract. Eye 1991; 5:31-35.
10. Pardhan S, Gilchrist J. Binocular contrast summation and inhibition in amblyopia. The influence of the interocular difference on binocular contrast sensitivity. Doc Ophthalmol 1992; 82:239-248.