1040-5488/06/8308-0589/0 VOL. 83, NO. 8, PP. 589–593
OPTOMETRY AND VISION SCIENCE


ORIGINAL ARTICLE

# Effect of Aging on Stereoscopic Interocular Correlation

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## ABSTRACT

***Purpose.*** This study was designed to evaluate the minimum interocular correlation (IOC) needed by the visual system to correctly perceive a static stereoscopic stimulus as a function of normal aging. It was also our goal to evaluate the feasibility of clinical charts testing this aspect of visual perception.

***Methods.*** Stereoscopic IOC threshold was determined in 100 normal observers (average age ± standard deviation, 45.7 ± 20.4 years) drawn from a clinical population between the ages of 10 and 85. We used partially correlated red–green random dot stereograms (RDS) displaying flat, square surfaces at 360 arcsec of either crossed or uncrossed disparity.

***Results.*** Older observers needed a higher binocular correlation to perceive the stereoscopic stimuli when compared with the younger groups. There is a slight increase in the threshold value of the individuals in the 45- to 64-year-old group and a further effect on the observers over 65 years of age. Data did not reveal any effects of gender, near point phoria, or fixation disparity on IOC thresholds.

***Conclusions.*** Normal aging produces a statistically significant deficit in binocular correlation processing. This process is marginally correlated with stereo acuity measures even when stereoacuity floor effects are factored out. Although further experiments directly comparing stereoacuity and IOC are necessary and more refining is required to obtain optimum parameters, clinical stereoscopic IOC test charts appear feasible and may not assess the same processes as stereoacuity charts. (Optom Vis Sci 2006;83:589–593)

Key Words: stereoscopic vision, stereoscopic correlation, aging, binocular, stereoacuity

Stereoscopic perception occurs so effortlessly that it could seem to be a simple aspect of visual processing. In fact, it is apparent that simplicity hides a process far more complex than we could suspect. One of the most intriguing parts of this process is how image points are matched between the two eyes before disparity processing is performed. This step is often called the binocular correspondence problem and is a necessary part of stereoscopic perception.[1–3]

It was thought for a long time that a great deal of monocular processing and shape recognition was a prerequisite for the binocular matching process to occur. However, as demonstrated by Julesz' computer-generated random dot stereograms,[4] this assumption was overturned by the fact that stereopsis can emerge from the presentation of stereograms in which monocular shape recognition is very unlikely. To study the correspondence problem and the correlation threshold, the use of random dot stereograms (RDS) is of primary importance because they are the only type of stimulus that does not contain monocular clues for depth and shape.[4]

In dense (50% density) stereograms, perception of depth is possible only if the interocular correlation (IOC) is above a certain threshold. Therefore, detection of IOC is an important step in stereopsis.[5]

In general, IOC can be described as the degree to which images perceived from both eyes match one another. Interocular correlation in a RDS is the proportion of dots identically positioned at disparity "d" while the remainder is randomly positioned.[6,7] Thus, an IOC of 100% would be fully correlated, whereas a value of 0% is a purely random stereogram.

The salience of a flat plane at disparity "d" decreases as we decrease the IOC.[1,3,5,6] Most of the studies involved used computer-generated dynamic stimuli and their tasks required some training to be accurately performed. Because motion and training are now known to greatly facilitate binocular correlation detection,[1,8] their results cannot be extrapolated to a clinical evaluation using static stimuli. Thus, it is still not well established how many points need to be correctly matched to form a robust depth perception from a RDS.[2]

Some abilities decline during normal aging even in the absence of any ocular pathologies, which could be indicative of neural changes in the elderly.[9] Among these abilities, stereopsis is probably the most indicative of neural changes that can be easily tested by clinicians in office settings. Many authors have concluded that stereoacuity effectively decreases with increasing age, even in coarse stereopsis tasks.[8,10–12] They also supposed that this loss in stereopsis can be mostly accounted for by neural changes of the visual pathway, but it is still unclear which factors explain the apparent loss. However, the study performed by Haegerstrom-Portnoy and colleagues on 900 individuals concluded that most of the important decline in coarse stereopsis (performed with the Frisby test) is caused by alterations in early stages of vision processing (i.e., loss of transparency of the ocular media and retinal dysfunction).[13]

Other studies have reported the significant effect of aging on the processing of second-order stimuli. These stimuli are defined by motion, texture, or depth (including RDS) and are more complex to process than first-order stimuli, which are defined by luminance or color.[14] Studies demonstrated, some with the help of functional magnetic resonance imaging, that second-order properties involve additional brain areas and require more extensive processing for the brain to perceive the image.[15] Thus, the larger neural network required for this processing presents additional opportunities to detect the effect of aging on neural function.[16]

The present study evaluates what baseline IOC is needed by the visual system to still be able to perceive a static flat plane at a given disparity. We also investigated if aging can influence the response of normal observers on such a task. The relationship among gender, Randot stereoacuity, near point phoria, and fixation disparity with IOC has also been examined in our study.

## MATERIALS AND METHODS

### Subjects

A total of 100 subjects (mean age $\pm$ standard deviation [SD], 45.7 $\pm$ 20.4 years) was randomly chosen in an optometric clinical population. We tried to evenly distribute the observers among four age groups. Those age groups were respectively 10 to 25 (n = 21; mean age $\pm$ SD, 16.9 $\pm$ 3.9 years), 26 to 45 (n = 26; 36.5 $\pm$ 5.9 years), 46 to 65 (n = 31; 52.8 $\pm$ 4.2 years), and 66 to 85 (n = 22; 73.9 $\pm$ 6.1 years) years old.

Testing sessions were conducted immediately after a complete eye examination of the subject performed by one of the authors (SL). Informed consent was obtained from each observer after the individual or his or her parent reviewed a letter of information. Every subject had to be at least 10 years old. Visual acuity was restricted to 20/20 (6/6) or better in each eye as measured with the Snellen chart at 20 feet. Observers with any amount of refractive error were included as long as their refraction showed no more than 1.50 D of anisometropia. The required stereoacuity was 50 arcsec or better as measured with the Randot Stereogram test. Ocular motility, distance phoria, near point phoria, and fixation disparity were also carefully tested, but were not restrictive. Subjects had to be exempt of any manifest ocular or neural disease. Special care was taken with regard to the presence of media opacities and the integrity of the macula; subjects with any obvious abnormality were rejected.

### Stimuli

The test was presented as a 50% density random dot stereogram generated by the Matlab PC program and printed on white sheets using a Hewlett-Packard 1500L Laserjet color printer (Hewlett-Packard Company, Montreal, Quebec, Canada). The stereogram was composed of red, green, and black dots on a yellow background. Every dot of the stereogram was 0.355 mm wide and subtended approximately 180 arcsec at the 40-cm viewing distance.

The visual stimuli formed by the stereograms were square-shaped flat planes consisting of 40 $\times$ 40 red, green, or black dots subtending four square degrees. To perceive the stimuli, the observers needed red–green glasses as a means of separating the eyes' points of view. Outside the stereoscopic squares, the stereogram was made of randomly distributed black dots on the yellow background and was thus fully correlated (100%) at zero disparity. The disparity of each square stimulus was randomly made either crossed (in front of the chart plane) or uncrossed (behind the chart plane) and always had an absolute value of 360 arcsec (i.e., two dots of disparity).

The stereogram charts contained six rows of five stereoscopic square stimuli. A total of six charts were made: three "easy" and three "difficult." Each row of stimuli was attributed a constant correlation value. The three easy charts contained, from top row to bottom row, the correlation values of 100%, 90%, 80%, 70%, 60%, and 50%. The difficult charts presented correlation values of 60%, 40%, 30%, 25%, 20%, and 15%.

### Experimental Procedures

The testing session occurred in the room where the eye examination took place. Observers were tested in accordance with the Declaration of Helsinki for research involving human subjects. The illumination in the room was normal light condition. The subject wore his or her best correction for reading distance (40 cm) as determined by the visual examination. He or she was then asked to put the red–green filters over the prescription eyeglasses.

When ready, the observer was presented with a randomly selected easy chart at 40 cm. The subject was then asked to indicate if he or she could see the squares on the first row (100% correlation). Some observers needed a few seconds to adapt to the test, but all were able to perceive the stereoscopic squares on the first row. The subject had to mention for each square if it was perceived as being in front or behind the plane of the chart. The subject gave his or her answer verbally and did not get any feedback as to whether his or her answer was correct. To proceed to the next row, the subject had to correctly identify four out of the five stimuli. No time limit was set to perform the test and subjects were asked to take the time needed to be sure of their answers before they responded. Threshold was set as the last correlation value at which the observer could correctly perceive a minimum of four stimuli in a row of five. If the entire easy chart was correctly identified, the subject was then presented with the difficult chart and answered in the same fashion. The whole procedure was performed a second time and the average of both results was used for statistics (Fig. 1).

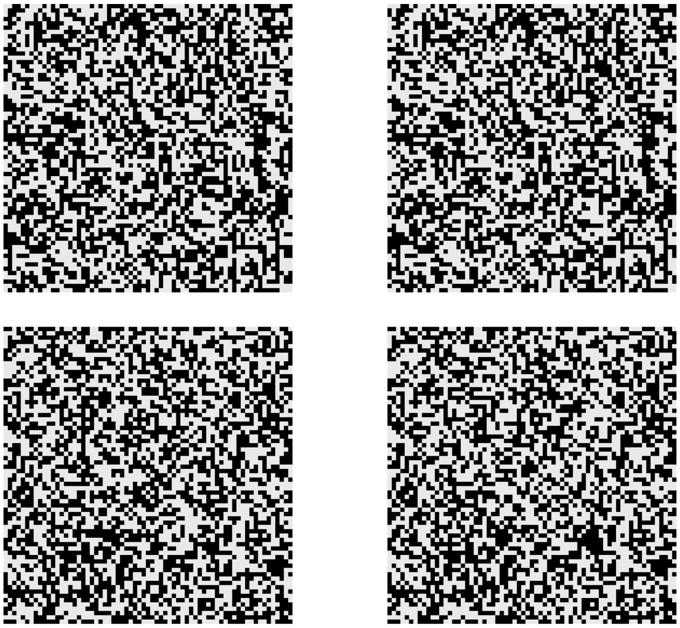

**FIGURE 1.**

Examples of stimuli used. Top images represent an interocular correlation (IOC) of 100% crossed disparity square. Bottom elements represent a 50% IOC uncrossed square (uncrossed fusers). The real charts used red–green filters to separate the input for each eye.

## RESULTS

The distribution of the binocular correlation threshold of the observers plotted as a function of age can be viewed in Figure 2. The average performance threshold in our sample is 31.72% with a standard deviation of 8.48%. We fitted our sample's data with a linear regression function and we obtained a significant positive slope (n = 100; percent/year ± standard error [SE], 0.14 ± 0.04; $t_{98} = 3.5$; $p < 0.001$). The correlation between age and stereoscopic IOC is low but significant ($r = 0.33$; $t_{98} = 3.27$; $p < 0.01$) and yields a determination factor of 11%.

When grouped into age categories, the analysis of variance (ANOVA) reveals a significant difference between groups ($F_{[3,96]} = 3.81$; $p < 0.05$). As can be seen in Table 1, individuals in the older age groups have higher thresholds than the observers in the younger age groups. Post hoc t tests with inference correction (Bonferroni) showed a significant difference between the 66- and 85-year-old groups and all the other observers ($t_{98} = 2.46$; $p < 0.01$). We also found a significant decrease in the performance of the 46- to 65-year-old group when compared with the younger groups ($t_{76} = 2.54$; $p < 0.01$).

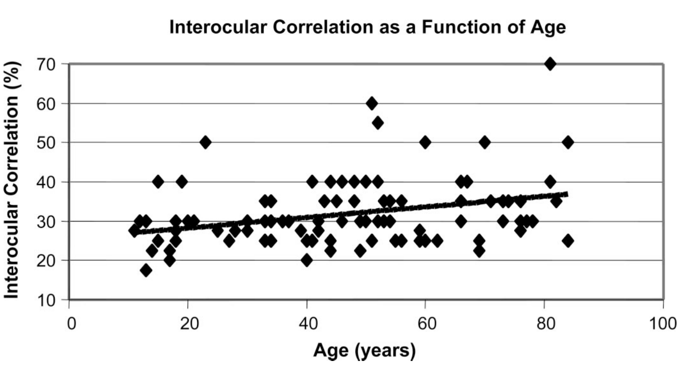


**FIGURE 2.**

The interocular correlation for the 100 subjects plotted against their age. The line represents the linear trend.

**TABLE 1.**

Interocular correlation data for the 100 subjects divided into age groups

| Age group (years) | n | Correlation (%) | Standard deviation (%) | Standard error (%) |
|---|---|---|---|---|
| 10–25 | 21 | 28.81 | 7.32 | 1.60 |
| 26–45 | 26 | 29.04 | 5.05 | 0.99 |
| 46–65 | 31 | 33.23 | 8.83 | 1.59 |
| 66–85 | 22 | 35.55 | 10.49 | 2.24 |
| Total | 100 | 31.72 | 8.48 | 0.85 |

When females (n = 64; IOC ± SD, 30.89 ± 6.75) and males (n = 36; 33.19 ± 10.85) are grouped separately, the t test shows no significant difference between groups. Also, we found no correlation between near point phorias ($r = 0.07$) or fixation disparity ($r = 0.14$) with IOC. These factors seem to have little link with the stereoscopic IOC threshold in the perception of a static stereoscopic shape for our population.

Further analysis revealed that baseline Randot stereoacuity has a low, but significant, correlation with stereoscopic IOC ($r = 0.44$; $t_{98} = 4.87$; $p < 0.001$). Thus, stereoacuity would account for 19% of the variation of stereoscopic IOC thresholds according to our data. However, our stereoacuity data are restricted by our selection criterion (50 arcsec) and the Randot's finest disparity (20 arcsec). To circumvent this problem, we have recalculated the correlation between stereoacuities and IOC thresholds on a subset of individuals. We eliminated all the subjects who reached 20 arcsec as to avoid a floor effect, leaving us with 44 subjects who never reached the limits of the Randot Stereogram test. The new correlation results are almost identical to the ones obtained when all subjects were analyzed ($r = 0.43$, $t_{42} = 3.12$; $p < 0.01$). The new calculation reveals that stereoacuity would account for 19% of the variation of stereoscopic IOC thresholds, exactly like the previously calculated value.

We plotted stereoacuity against stereoscopic IOC (Fig. 3) to illustrate the relationship between both variables. The trend of the relation between variables is represented by the line on the graph (n = 100; arcsec/percent ± SE, 0.46 ± 0.09; $t_{98} = 4.90$; $p < 0.001$).

Furthermore, the ANOVA showed that age (Fig. 4) affects fine stereoacuity ($F_{[3,96]} = 6.24$; $p < 0.01$) as measured with the Randot test. Figure 4 shows the distribution of the observers' fine stereoacuity as a function of their age. We fitted the distribution with a linear regression (solid line), and we obtained a significant positive slope similar to the one obtained with stereoscopic IOC as a function of age (n = 100; arcsec/year ± SE, 0.17 ± 0.04; $t_{98} = 4.25$; $p < 0.001$).

The weak but significant correlation between stereoscopic IOC and stereoacuity performances could be the result of aging on both processes independently. To further establish whether there were similar properties between these two variables, we elected to isolate observers that performed poorly on both tasks. The proportion of individuals in our sample with a fine stereoacuity deficit ($p < 0.05$ when compared with their age group) is approximately 26% (n =

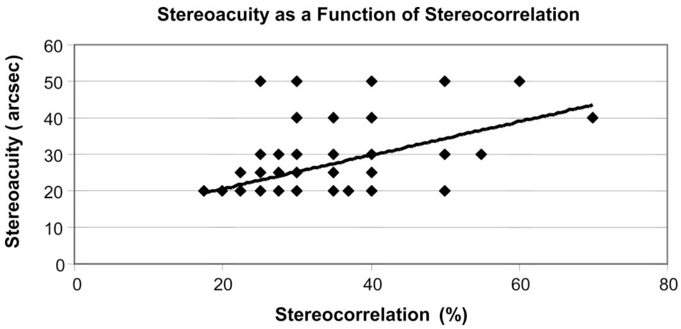


**FIGURE 3.**

The Randot stereoacuity for the 100 subjects plotted against their stereoscopic interocular correlation. The line represents the linear trend.

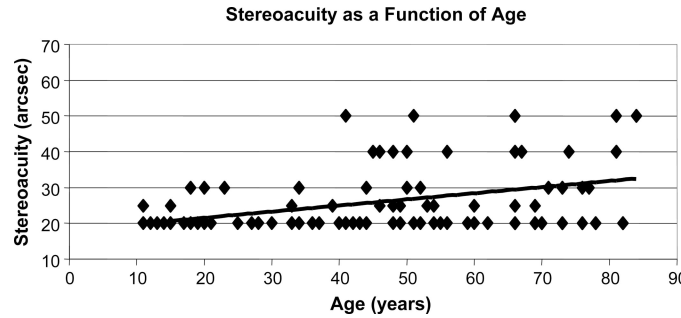


**FIGURE 4.**

The Randot stereoacuity for the 100 subjects plotted against their age. The solid line represents the linear trend.

100; 95% $IC_{\Pi} = [0.17, 0.35]$). This proportion rises to 56% (n = 23; 95% $IC_{\Pi} = [0.35, 0.77]$) when we consider only the subjects with a stereoscopic IOC deficit ($p < 0.05$ when compared with their age group).

So it can be hypothesized that aging affects both stereoacuity and IOC processing without the two necessarily involving the same neural operation, although there must be an overlap between mechanisms.

## DISCUSSION

Our findings indicate that there is a significant effect of aging on binocular correspondence processing. Older subjects required a higher level of IOC to correctly perceive a stereoscopic stimulus. Our results also indicate a small but significant correlation between fine stereoacuity performance and results to our stereoscopic IOC task. Obviously, there must be an overlap between both processes, but we cannot conclude from the present results whether the same underlying mechanisms are involved in the small age-related loss on both functions given the different scales used. However, a confidence interval subanalysis on our data hints at the notion that they should only partially overlap.

One of the studies that more closely resembles ours suggests that there would be no effect of aging on low IOC stereopsis performance. In a stereoscopic shape recognition task, Norman and colleagues found that the decline in performance was remarkably the same for both younger and older groups when they reduced the binocular correlation of their stimuli.[17] However, they used more prominent shapes for the older observers than for the younger observers. Also, their apparatus and methodology were significantly different from ours and they did not use correlation values inferior to 40%. These differences between both studies can explain the divergence between their conclusion and our results.

The true "normal population" aging effect could even be more important than shown here when we consider that our study is probably biased by our very strict selection of candidates (20/20 or 6/6). People who present with ocular problems associated with aging may also have more marked perception processing changes without the two being causally related. It could indicate a faster aging process of all aspects of the visual pathway and of the individual at a larger scale.[13] Therefore, our inclusion criterion should bias older individuals whose binocular processing is less affected by aging.

One of the factors that would be more likely to modify results to our test is the density of the elements in the stereograms we used. At least one study indicates that efficiency of binocular combination decreases as the density of elements increases in RDS. Thus, 50% RDS would be less than optimal for correlation tasks.[18] The authors of that study suggest that a density of 20% would be more favorable to the performance of the observers, at least for the detection of correlation in a dynamic stimulus. Once again, it would be interesting to observe the effect of this factor in our test apparatus and, furthermore, its effect on aged observers.

With the results of our study, we have more evidence of second-order processing age-related loss. Such results have already been found in previous work.[16] For instance, age-related effects have been found for processing symmetry,[19] second-order orientation and motion perception,[14] interattribute spatial processing,[20] and decreased capacity for processing human faces in the elderly.[21] Faubert[16] concluded that perceptual processes that solicit larger neural networks are more affected by aging because of the saturation of alternative routes required in the aging brain to process perceptual input.

The clinical use of an IOC stereopsis test chart is still unresolved but appears feasible with further optimization of the chart. Further investigation needs to be conducted to isolate abnormal conditions of the visual pathway that could induce a marked reduction of performance to our test. These conditions could include amblyopia, anisometropia, strabismus or neural diseases like Alzheimer or Parkinson disease.

## ACKNOWLEDGMENTS

*This study was supported by Canadian Institutes of Health Research Grant to JF.*

*Received August 28, 2005; accepted April 26, 2006.*

## REFERENCES

1. Muller C, Lankheet MJ, Van De Grind WA. Binocular correlation does not improve coherence detection for fronto-parallel motion. Vision Res 2004;44:1961–9.
2. Harris JM, Parker AJ. Constraints on human stereo dot matching. Vision Res 1994;34:2761–72.
3. Cormack LK, Riddle RB. Binocular correlation detection with oriented dynamic random-line stereograms. Vision Res 1996;36: 2303–10.

4. Julesz B. Foundations of Cyclopean Perception. Chicago: University of Chicago Press; 1971.
5. Gheorghiu E, Erkelens CJ. Spatial-scale interaction in human stereoscopic vision in response to sustained and transient stimuli. Vision Res 2004; 44:563–75.
6. Cormack LK, Stevenson SB, Schor CM. Interocular correlation, luminance contrast and cyclopean processing. Vision Res 1991;31: 2195–207.
7. Tyler CW. Binocular cross-correlation in time and space. Vision Res 1978;18:101–5.
8. Zaroff CM, Knutelska M, Frumkes TE. Variation in stereoacuity: normative description, fixation disparity, and the roles of aging and gender. Invest Ophthalmol Vis Sci 2003;44:891–900.
9. Spear PD. Neural bases of visual deficits during aging. Vision Res 1993;33:2589–609.
10. Wright LA, Wormald RP. Stereopsis and ageing. Eye 1992;6:473–6.
11. Brown B, Yap MK, Fan WC. Decrease in stereoacuity in the seventh decade of life. Ophthal Physiol Opt 1993;13:138–42.
12. Haegerstrom-Portnoy G, Schneck ME, Brabyn JA. Seeing into old age: vision function beyond acuity. Optom Vis Sci 1999;76:141–58.
13. Schneck ME, Haegerstrom-Portnoy G, Lott LA, Brabyn JA. Ocular contributions to age-related loss in coarse stereopsis. Optom Vis Sci 2000;77:531–6.
14. Habak C, Faubert J. Larger effect of aging on the perception of higher-order stimuli. Vision Res 2000; 40:943–50.
15. Smith AT, Greenlee MW, Singh KD, Kraemer FM, Hennig J. The processing of first- and second-order motion in human visual cortex assessed by functional magnetic resonance imaging (fMRI). J Neurosci 1998; 18:3816–30.
16. Faubert J. Visual perception and aging. Can J Exp Psychol 2002; 56:164–76.
17. Norman JF, Dawson TE, Butler AK. The effects of age upon the perception of depth and 3-D shape from differential motion and binocular disparity. Perception 2000; 29:1335–59.
18. Cormack LK, Landers DD, Ramakrishnan S. Element density and the efficiency of binocular matching. J Opt Soc Am (A) 1997;14: 723–30.
19. Herbert AM, Overbury O, Singh J, Faubert J. Aging and bilateral symmetry detection. J Gerontol (B) 2002;57:P241–5.
20. Faubert J, Bellefeuille A. Aging effects on intra- and inter-attribute spatial frequency information for luminance, color, and working memory. Vision Res 2002;42:369–78.
21. Boutet I, Faubert J. Recognition of faces and complex objects in younger and older adults. Memory Cogn 2006; 34:in press.

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