USAARL Report No. 95-21

Two Eyes Are Better Than One: Binocular Enhancement in the Contrast Domain

(Reprint)

By

Jeff Rabin

Aircrew Health and Performance Division

April 1995

United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 70-25 on Use of Volunteers in Research.

Reviewed:

RICHARD R. LEVINE
LTC, MS
Director, Aircrew Health and Performance Division

ROGER W. WILEY, O.D., Ph.D.
Chairman, Scientific
Review Committee

Released for publication:

DENNIS F. SHANAHAN
Colonel, MC, SFS
Commanding

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 95-21	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) MCMR-UAS-VS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-0577	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
0602787A	3M162787A879	PE	164

11. TITLE (Include Security Classification)
(U) Two eyes are better than one: binocular enhancement in the contrast domain

12. PERSONAL AUTHOR(S)
Jeff Rabin

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1995 April	4

16. SUPPLEMENTARY NOTATION
Printed in Ophthal. Physiol. Opt., April 1995, pages 45-48

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
06	04	
14	04	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
visual acuity, contrast sensitivity, binocular enhancement, binocular summation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The purpose of this study was to compare the improvement in visual acuity (VA) with the improvement in contrast sensitivity (CS) with two eyes as compared with one. Computer generated letter charts were used to measure VA and small letter CS (20/25 Snellen equivalent) in 13 emmetropic subjects. Letter size (for VA) and contrast (for CS) were varied in equal log steps making the task comparable for the two types of measurement. VA improved by an average of 10% (2-3 letters), while CS improved by an average of 40% (1½ lines) when tested with two eyes as compared with one. Greater sensitivity in the contrast domain prevailed even when expressed relative to variability. Using this approach, binocular enhancement was identified in 8/13 subjects with CS, but in only 4/13 subjects with VA. Binocular enhancement of letter recognition occurs in both size and contrast domains. However, the effect is 4x greater when small letters are varied in contrast rather than size. Potential applications are considered.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE (Include Area Code) (334) 255-6907 22c. OFFICE SYMBOL MCMR-UAX_SS

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

BUTTERWORTH HEINEMANN

Ophthal. Physiol. Opt. Vol. 15, No. 1, pp. 45–48, 1995
Elsevier Science Ltd for British College of Optometrists
Printed in Great Britain

RESEARCH NOTE

Two eyes are better than one: binocular enhancement in the contrast domain

Jeff Rabin

Aircrew Health and Performance Division, US Army Aeromedical Research Laboratory, Fort Rucker, AL 36362, USA

Summary

The purpose of this study was to compare the improvement in visual acuity (VA) with the improvement in contrast sensitivity (CS) with two eyes as compared with one. Computer generated letter charts were used to measure VA and small letter CS (20/25 Snellen equivalent) in 13 emmetropic subjects. Letter size (for VA) and contrast (for CS) were varied in equal log steps making the task comparable for the two types of measurement. VA improved by an average of 10% (2–3 letters), while CS improved by an average of 40% (1 ½ lines) when tested with two eyes as compared with one. Greater sensitivity in the contrast domain prevailed even when expressed relative to variability. Using this approach, binocular enhancement was identified in 8/13 subjects with CS, but in only 4/13 subjects with VA. Binocular enhancement of letter recognition occurs in both size and contrast domains. However, the effect is 4 × greater when small letters are varied in contrast rather than size. Potential applications are considered.

Ophthal. Physiol. Opt. 1995, **15**, 45–48

Most visual capabilities, including detection, discrimination, and recognition, are enhanced with two eyes as compared with one[1–15]. This improvement with binocular viewing has been attributed to the statistical advantage of having two independent sources of input rather than one which increases the probability of veridical perception[1]. Binocular enhancement also has been explained as a process of neural summation wherein information from each eye is combined at a higher stage. The information includes spurious components uncorrelated with the signal (noise) which decreases with sample size making the signal more salient with two eyes compared with one[2]. In addition to probability and neural summation, other theories of binocular enhancement have been advanced (for review)[3,8], and it is likely that the specific mechanism in play depends on the nature of the task[13]. Regardless of the mechanism, binocular enhancement is a pervasive phenomenon evident in many tasks, and important in everyday life.

While binocular enhancement has been investigated in patients with disturbances of binocular vision[5,8,9,12,14], it is not commonly used in clinical environments to quantify the degree of binocular integration. Clinical assessment of visual acuity (VA) often is performed under both monocular and binocular viewing conditions, and most clinicians will agree that, in patients with normal vision in each eye, VA is better with two eyes as compared with one. However, the improvement is slight (7–11%), typically in terms of letters rather than lines on a VA chart[2,13–15]. Hence, the value of this measurement is contingent on precise measurement of the acuity threshold.

In contrast to the small enhancement of VA, numerous studies have demonstrated larger increases in contrast sensitivity (CS) with binocular viewing, typically 40–50% higher than monocular values[2–4,8,10,13,14]. While this suggests that measurement in the contrast domain would provide a more sensitive clinical index of binocular enhancement, a larger degree of enhancement does not ensure greater sensitivity if measurement variability also is greater. To determine the relative efficacy of measuring in contrast and acuity domains, values should be expressed relative to variability.

The purpose of this study was to compare binocular enhancement in acuity and contrast domains. Letter charts, modulated in equal steps of size and contrast, were used to make the task comparable for VA and CS measurement.

Received: 21 April 1994
Revised form: 4 July 1994

Small letters were used in each test making it likely that similar spatial frequency channels were assessed. To facilitate direct comparison across acuity and contrast domains, binocular enhancement was expressed relative to the variability of the measurement.

Method

VA and CS were measured with letter charts displayed on a video monitor[16]. The monitor luminance and contrast of individual letters were under software control, and verified repeatedly by photometric measurement across the display. VA and CS charts were patterned after the work of Bailey and Lovie[17] and Pelli *et al.*[18]. The acuity charts were comprised of high contrast (93%) black letters on a white background ($116 cd m^{-2}$). Each row consisted of five letters, and, from top to bottom, decreased in size by a constant factor (0.1 log unit per row). There were seven rows total with acuity ranging from 20/50 to 20/12 (0.4 to −0.2 logMAR). The same design principles were used for the letter contrast charts, but letter size was held constant (20/25 letters), while contrast decreased, by row, in 0.1 log steps (from 93% to 5%). There were 14 rows total with 7 rows displayed at any one time, as for VA measures. The same letters were used on both charts (5 × 4 non-serifed letters about equal in legibility[17,19]) with vertical and horizontal letter spacing proportional to letter height and width, as specified by Bailey and Lovie[17]. Letter sequence was varied from trial to trial to discourage learning effects. Testing was conducted in an otherwise dark room at a distance of 4.8 m. Each subject was instructed to start from the top of each chart and read down as far as possible, and was encouraged to guess when unsure. Monocular thresholds (right and left eyes) were obtained first followed by binocular measurement. Scoring was conducted by letter with a precision of 0.02 log units (0.1 log units per five letter row). VA was scored as the log of the minimum angle of resolution (logMAR)[17], while CS was scored as the log of the inverse contrast threshold (logCS)[18]. Thirteen emmetropic subjects (ages 21–26 years) with uncorrected VA of at least 20/20 in each eye were tested. All subjects had satisfied stringent vision standards for pilot training including assessment of ocular motility, 'phoria and stereopsis. Informed consent was obtained after protocol approval by our institutional review committee.

Results

Figure 1 shows binocular enhancement of VA and small letter CS for 13 subjects. For each subject, binocular enhancement was determined by taking the difference between the binocular and monocular scores, with the monocular score representing the mean of the right and left eyes. Since all scores are expressed in log units, the difference between binocular and monocular scores is analogous to the binocular/monocular ratio (antilog of difference = ratio). As indicated in *Figure 1*, mean binocular enhancement was about 10% for VA (0.045 logMAR), and 40% for CS (0.141 logCS). The 10% improvement in VA is comparable to values reported in previous studies using gratings[2] and letter stimuli[13,15], but represents an increase of only 2–3 letters on the acuity chart. The 40% enhancement of CS also is consistent with previous studies[2,14], and represents a much larger improvement of 1½ lines on the contrast chart.

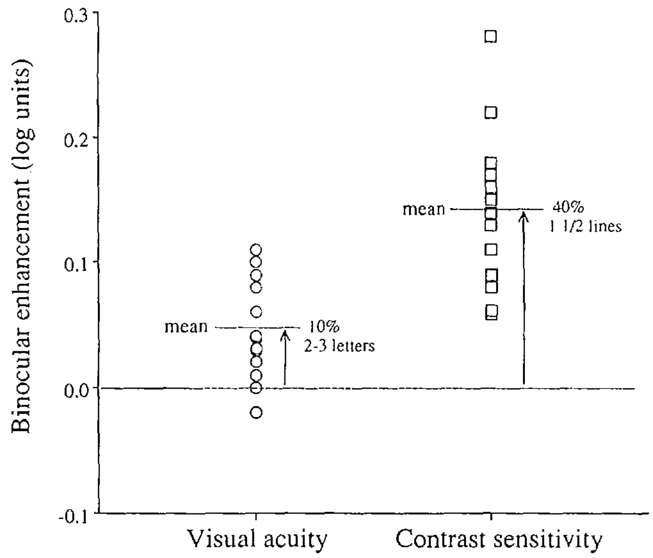

Figure 1. Binocular enhancement (difference between binocular and mean monocular log score) is plotted for 13 subjects for visual acuity and small-letter contrast sensitivity. Expressed in percentage, mean enhancement was 10% for visual acuity (2–3 letters), and 40% for contrast sensitivity (1½ lines).

Despite greater binocular enhancement in the contrast domain, a larger effect does not ensure greater test sensitivity if variability also is greater, as was the case for CS. To standardize binocular enhancement relative to variability, the enhancement for each subject (binocular − monocular score) was divided by the standard deviation (SD) of enhancement across all subjects. This expresses the improvement with two eyes as SDs from monocular performance, and allows for a more direct comparison of VA and CS. *Figure 2* shows binocular enhancement as SDs from the monocular score. Using a significance criterion of two SDs, 8/13 subjects show binocular enhancement with CS, while only 4/13 show enhancement with VA. This result demonstrates that letters modulated in contrast rather than size provide a more sensitive index of binocular enhancement.

Discussion

This study confirms that both VA and CS are better with two eyes as compared with one. The 10% improvement in VA is consistent with values reported in previous studies

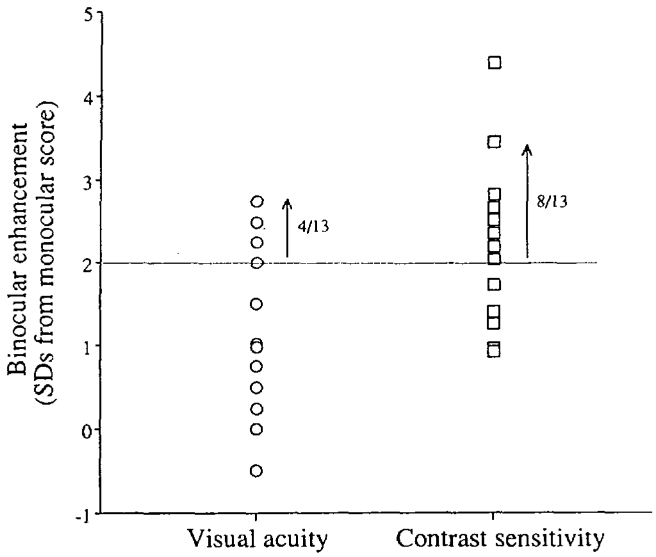

Figure 2. Binocular enhancement, expressed as the number of standard deviations (SD) from the monocular score, is plotted for 13 subjects for visual acuity and small-letter contrast sensitivity. Using a criterion of two SD, 8/13 subjects showed enhancement with contrast sensitivity, but only 4/13 with visual acuity.

using gratings and letter stimuli[1,13,15]. However, this represents only a small improvement (2–3 letters) on standard clinical tests of VA, and could be overlooked without precise measurement. The larger enhancement in CS (40%) also is consistent with previous studies of binocular enhancement. Most notable is the study of Campbell and Green[2] who reported an improvement of about 40% across a range of spatial frequencies. This enhancement was attributed to a summation process in which information from each eye is combined at a higher stage. The information includes variability uncorrelated with the signal in each eye. The standard error of the summation decreases with the square of the number of samples making the signal from two eyes more detectable by a factor of $\sqrt{2}$, or 41%. Campbell and Green[2] and Cagenello and coworkers[15] noted that an enhancement of approximately 40% along the contrast dimension entails a much smaller improvement in the spatial frequency domain (7–11%). This can be attributed to the steep descending slope of the contrast sensitivity function (CSF) for which small changes in spatial frequency are associated with larger changes in contrast sensitivity. Shifting the CSF upward by 40% along the CS dimension results in a smaller shift rightward along the spatial frequency (VA) axis. Thus, binocular enhancement of small letter CS is expected to be larger than VA, as reported in the present study.

While the enhancement of binocular CS is much greater than that of VA, the significance of this difference is complicated by several factors. First, the two tests address different aspects of visual function, one measuring a size and the other a contrast threshold. Second, the two measures often are made with different techniques having different degrees of precision making direct comparison difficult. Finally, the significance of binocular enhancement depends on the variability of measurements. A larger effect does not ensure greater sensitivity if measurement variability also is greater. The methodology used in the present study mitigates against these factors. A letter recognition task, using the same letters, step size, and scoring procedure, was used for VA and CS such that the letter recognition task was comparable for the two types of measurement. Small letters were used to measure both VA and CS thresholds making it likely that comparable, high spatial frequency channels were assessed in each measurement. By standardizing scores relative to variability, it was possible to make a more direct comparison of the degree of binocular enhancement in contrast and acuity domains. This approach suggests measurement in the CS domain is at least 2× more sensitive than VA for identifying improvement with two eyes compared with one.

There are several potential applications to the present results. Clinical assessment of the response to amblyopia therapy may be enhanced by measuring small letter CS under monocular and binocular conditions. Monocular assessment would complement monocular measures of VA, and the degree of enhancement under binocular conditions may serve as an additional index of binocular integration. In patients optically corrected for anisometropia, the degree of binocular enhancement of CS may indicate the efficacy of the refractive correction. Enhancement in the contrast domain also could be used as an adjunctive index of binocularity in monocular aphakes, pseudophakes, or in other types of refractive surgery. The degree of binocularity achieved with advanced avionics and night vision displays may be better assessed by measuring binocular enhancement in the contrast domain. Further testing will be needed to determine whether binocular enhancement of small letter CS complements more definitive tests of binocular vision such as clinical assessment of stereopsis.

References

1 Pirenne, M. H. Binocular and uniocular thresholds in vision. *Nature* **152,** 698–699 (1943)
2 Campbell, F. W. and Green, D. G. Monocular versus binocular visual acuity. *Nature* **208,** 191–192 (1965)
3 Blake, R. and Fox, R. The psychophysical inquiry into binocular summation. *Percept. Psychophys.* **14,** 161–185 (1981)
4 Blake, R. and Levinson, E. Spatial properties of binocular neurons in the human visual system. *Exp. Brain Res.* **27,** 221–232 (1977)
5 Lema, S. A. and Blake, R. Binocular summation in normal and stereoblind humans. *Vision Res.* **17,** 691–695 (1977)
6 Legge, G. E. Spatial frequency masking in human vision: binocular interactions. *J. Opt. Soc. Am.* **69,** 838–847 (1979)

7 Legge, G. E. and Rubin, G. S. Binocular interaction in suprathreshold contrast interactions. *Percept. Psychophys.* **30**, 49–61 (1981)

8 Blake, R., Sloane, M. and Fox, R. Further developments in binocular summation. *Percept. Psychophys.* **30**, 266–276 (1981)

9 Harwerth, R. and Levi, D. Psychophysical studies of binocular processes of amblyopes. *Am. J. Optom. Physiol. Opt.* **60**, 454–463 (1983)

10 Legge, G. E. Binocular contrast summation: I. Detection and discrimination. *Vision Res.* **24**, 373–384 (1984)

11 Home, R. Binocular summation: a study of contrast sensitivity, visual acuity, and recognition. *Vision Res.* **18**, 579–585 (1984)

12 Sireteanu, R. Binocular luminance summation in humans with defective binocular vision. *Invest. Ophthal. Visual Sci.* **28**, 349–355 (1987)

13 Frisen, L. and Lindblom, B. Binocular summation in humans: evidence for a hierarchic model. *J. Physiol.* **402**, 773–782 (1988)

14 Pardham, S. and Elliot, D. B. Clinical measurements of binocular summation and inhibition in patients with cataract. *Clin. Vision Sci.* **6**, 355–359 (1991)

15 Cagenello, R., Arditti, A. and Halpern, D. L. Binocular enhancement of visual acuity. *J. Opt. Soc. Am.* **10**, 1841–1848 (1993)

16 Rabin, J. Optical defocus: differential effects on size and contrast letter recognition thresholds. *Invest. Ophthal. Visual Sci.* **35**, 646–648 (1994)

17 Bailey, I. L. and Lovie, J. E. New design principles for visual acuity letter charts. *Am. J. Opt. Physiol. Opt.* **53**, 740–745 (1976)

18 Pelli, D. G., Robson, J. G. and Wilkins, A. J. The design of a new letter chart for measuring contrast sensitivity. *Clin. Vision Sci.* **2**, 187–199 (1988)

19 British Standard, Test charts for determining distance visual acuity. S 4274. London, British Standards Institution (1968)