Available online at www.sciencedirect.com
SCIENCE DIRECT®

Vision Research 45 (2005) 1321–1328

Vision Research

www.elsevier.com/locate/visres

Vernier acuity for stereodisparate objects and ocular prevalence

Sven P. Heinrich, Miriam Kromeier, Michael Bach, Guntram Kommerell *

Universitäts-Augenklinik, Killianstr. 5, 79106 Freiburg, Germany

Received 17 November 2003; received in revised form 17 September 2004

Abstract

Question. How precisely can objects, located in different depth planes, be aligned to the same visual direction? *Methods*. Twenty normal observers were presented with vertical Vernier lines at various stereodisparities. They had to judge whether the lower, anterior line was located on the right- or left-hand side of the upper, posterior line. *Results*. Over a stereodisparity range from zero to 62″, the threshold for detecting a lateral offset between the Vernier lines remained at the "hyperacuity" level of about 7″. With larger stereodisparities, the threshold increased about fourfold, probably due to a mutual, partial suppression of the position signals from the right and left eyes. The reference point from which the observers judged the relative visual directions between stereodisparate objects was not located midway between the eyes; rather, it was often decentred towards the right or the left eye, meaning that the observers had an "ocular prevalence". Their ocular prevalence was, however, not strong enough to have an effect on the Vernier acuity for stereodisparate objects. (Under pathological conditions like strabismic amblyopia, one should expect a 100% prevalence of the good eye, implying that the Vernier acuity reaches the monocular level, irrespective of any depth difference between objects.) *Conclusion*. Vernier acuity decreases with increasing stereodisparity. Ocular prevalence, occurring frequently among persons with normal eyes, has no effect on Vernier acuity for stereodisparate objects. For a typical everyday viewing condition, the reduced Vernier acuity beyond a stereodisparity of 62″ means that, from a viewing distance of 40 cm, precision mechanics have to guide their instrument as close as 0.4 mm to a workpiece, until they can utilise their best position acuity.

Keywords: Vernier acuity; Position acuity; Stereopsis; Ocular prevalence; Fixation disparity; Stereo vision

1. Introduction

Objects presented in the plane of fixation can be aligned with great precision. For example, the threshold for perceiving an offset between vertical Vernier [1] lines lies in the order of 5″ (Westheimer & McKee, 1977). This high precision qualifies Vernier acuity as a variant of hyperacuity (Westheimer & McKee, 1977). At high contrast, binocular judgements are about as precise as monocular judgements (Frisén & Lindblom, 1988); at low contrast, binocular judgements are slightly superior (Banton & Levi, 1991).

Whereas Vernier acuity with objects presented in one depth plane has been widely studied, both under monocular and binocular viewing conditions, information on binocular Vernier acuity with objects presented at different depth planes is lacking. This is surprising since the ability to align stereodisparate objects plays a considerable role in everyday goal-directed actions. For example, directing a ballpoint pen to the appropriate box on a form requires alignment of stereodisparate objects. While the tip of the pen approaches the box, the stereodisparity between the two objects gradually diminishes. Only when the ballpoint has reached the form is aiming reduced to a two-dimensional coordination task.

---

* Corresponding author.
E-mail address: kommerell@aug.ukl.uni-freiburg.de (G. Kommerell).

[1] Pierre Vernier, 1584–1638, military engineer in Franche-Comté.

0042-6989/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2004.09.045

The purpose of the present investigation is to determine the precision with which stereodisparate objects can be aligned to the same visual direction. Such an alignment requires computation between different inputs from the two eyes. Therefore we anticipated that the precision with which stereodisparate objects can be aligned would be less than that for objects viewed without stereodisparity.

Where is the reference point from which binocular observers judge whether an anterior object is located on the right- or left-hand side of a posterior object? Is the reference point midway between the eyes? This would only be the case if both eyes contributed equally to the visual directions. Several studies suggest, however, that an equal contribution of both eyes is rather the exception than the rule. Most people attribute a higher weight to the input from one eye than to the input from the other eye when they have to align stereodisparate objects to the same visual direction (Erkelens, Muijs, & van Ee, 1996; Haase, 1995; Kommerell, Schmitt, Kromeier, & Bach, 2003; Sachsenweger, 1958): using a term introduced by Sachsenweger (1958), most people have an "ocular prevalence". We considered that prevalence of one eye might increase the precision with which stereodisparate objects can be aligned. A marked prevalence might even allow a precision similar to that reached with one eye alone. To test this hypothesis, we examined the correlation between the threshold for perceiving an offset between stereodisparate Vernier lines and the ocular prevalence in 20 healthy observers.

To prevent any misunderstanding, we would like to point out that ocular prevalence is different from ocular dominance (Kommerell et al., 2003). Ocular dominance, as defined by sighting tests, is determined by subjective alignment of two objects presented at a stereodisparity far beyond Panum's area. A typical task is the alignment of a small hole in a hand-held card with a distant target. Such tests reveal the habit or ease of using one eye for monocular tasks (Mapp, Ono, & Barbeito, 2003). In contrast, ocular prevalence is determined by the alignment of two objects presented at a stereodisparity inside or just at the border of Panum's area.

2. Methods

2.1. Observers

Twenty observers (members of our department or students of medicine, aged between 20 and 55 years, median 25 years) were selected according to the following three criteria: (1) visual acuity for numerical optotypes (with spherical and cylindrical spectacle correction, if required) at least 1.0 (=20/20) in each eye, (2) difference between visual acuity of both eyes not more than a factor of 1.26 (approximately the 10th root of 10), and (3) absence of strabismus, ascertained with the unilateral cover-test.

We explained to the observers that the study was designed to measure the contribution of each eye to their binocular vision. Otherwise, the observers were naive as to the purpose of the study. Each observer provided informed written consent to participate in the experiments. The study followed the tenets of the Declaration of Helsinki and was approved by the local ethics review board.

2.2. Stimulus, instruction and procedure

The stimulus was generated by a PowerMacintosh G4 and presented at a distance of 4.5 m on a Philips GD403 CRT monitor. By means of liquid crystal shutter goggles (ELSA 3D Revelator), separate images were presented to the two eyes. The goggles were synchronised to the CRT refresh such that the frames were alternately presented to the right and left eyes. The refresh rate of 120 Hz resulted in a rate of 60 Hz for each eye, just above the flicker fusion frequency.

The stimulus consisted of two vertical Vernier lines, one above the other (Fig. 1). The lines were 4.5′ wide and 20′ high. They were separated by a vertical gap of 4.5′. A frame with a height of 69′, a horizontal extension of 92′ and a thickness of 1.4′ surrounded the lines. The frame was divided in the middle by a horizontal bar of 1.4′ thickness. A pattern with random black and white squares with an edge length of 3′ surrounded the frame. The luminance of the "black" features on the monitor was 1.8 cd/m^2, and the luminance of the "white" features was 40 cd/m^2.

The upper line was located in the same plane as the surrounding pattern. The lower line was presented at

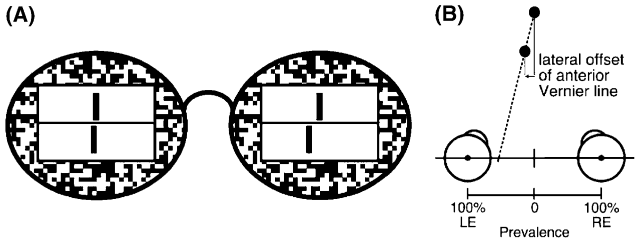

Fig. 1. Stimulus condition. (A) Observer's view. The upper (posterior) Vernier line and the frame appeared in the plane of the CRT monitor at 4.5 m, the lower (anterior) Vernier line at discrete stereodisparities in front of the CRT monitor, with a variable lateral offset, determined by the threshold estimation strategy described in Section 2.3. (B) View from above. The lateral offset at which the observer perceived the two Vernier lines as being aligned allowed geometrical calculation of the individual's ocular prevalence: the line that connects the posterior and the anterior object crosses the interocular line. Depending on the crossing point, ocular prevalence could vary between 100% prevalence of the left eye and 100% prevalence of the right eye. A prevalence of 0% meant that both eyes contributed equally to the visual directions. The figure exemplifies an observer who had a 50% prevalence of the left eye.

discrete stereodisparities, ranging from 30″ to 430″, such that it appeared closer to the observer than the upper line and the frame, and also in the same plane as the surrounding pattern, i.e. at zero stereodisparity. At each stereodisparity, the lower line was shown with a variable lateral offset, either to the right or to the left of the upper line. This offset was determined by the threshold estimation described in Section 2.3. The smallest step for the lateral offset was 8.5″.

In a two-alternative forced-choice task observers had to indicate by pressing the appropriate one of two buttons whether they perceived the lower line to the right or to the left of the upper line. If either the upper or the lower line appeared double, observers were told to base their judgement on the centre between the doubled line, and to report their double vision to the experimenter, who kept an appropriate record (“bow–tie” in Figs. 4 and 7). We did not instruct the observers to fixate either the upper (posterior) or the lower (anterior) line. The frame and the Vernier lines remained in place until the observers had pressed one of the two buttons. After an interval of 0.5 s in which the whole field was filled by random black and white squares (to mask any after-images and ensure binocular fusion), the frame and the Vernier lines reappeared. The observers wore an appropriate spherical and cylindrical correction and looked at the target with their trunk and head directed straight ahead.

All 20 observers were tested binocularly with stereodisparities of zero, 30″, 270″, and 430″. Ten of the observers were also tested with 62″ and 130″. In addition, all 20 observers were tested monocularly, both with the right and the left eye. To accustom the observers to the procedure, two training blocks with a stereodisparity of 30″ and 430″, respectively, preceded the actual experiment.

To balance sequential (e.g., learning) effects, we randomised the order of all test conditions between observers. In addition, we estimated perceptual learning by a spot check: observers who had performed the test with the stereodisparity of 30″ in the first half of the randomised sequence were compared with those who had performed the test in the second half.

2.3. Data acquisition and analysis

2.3.1. Threshold estimation

At each stereodisparity, a psychometric function was derived from a block of 160 trials (Fig. 2). To save time, each block started with 10 trials, in which the point of subjective alignment (=50%) was estimated based on a coarse variation of the lateral offset. This value was then used as the starting point for three randomly interleaved staircase procedures, targeting (according to a variant described by Leek, 2001) the 21%, 50%, and 79% probabilities of “right side” responses with the remaining 150 trials. Combining the trials of all three staircase procedures, the psychometric function for each stereodisparity was fitted by a cumulative Gaussian through weighted linear regression. Fitting errors were estimated with a bootstrapping procedure suggested by Foster and Bischof (1991); we used their C code provided at http://www.cs.ualberta.ca/~wfb/software.html. The difference between the positions of the lower line that changed the response probability from 50% (point of subjective alignment) to 79% was taken as the Vernier threshold.

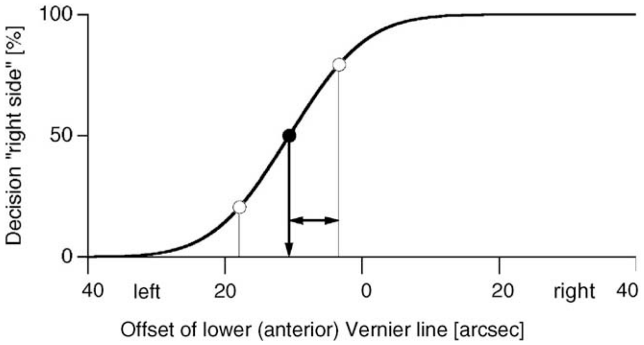

Fig. 2. Psychometric function of the right/left decision as a function of the physical offset of the lower (anterior) Vernier line. Filled circle: 50% = point of subjective alignment. Open circles: 21% and 79% points. The double arrow marks the difference between the positions of the lower Vernier line that changes the response probability from 50% to 79%. This difference is taken as the Vernier threshold. The depicted psychometric function was derived from the responses of observer SH at a stereodisparity of 30″.

2.3.2. Ocular prevalence

As depicted in Fig. 1B, the relative position in which the far and near objects appear aligned allows to calculate ocular prevalence. A 100% prevalence of one eye means that the observer perceives a physical alignment of the objects to that eye as being aligned. Intermediate values between 100% prevalence of the right and 100% prevalence of the left eye can be read on a linear scale, neglecting the tiny tangens deviation from linearity, due to the stimulus presentation at 4.5 m, instead of infinity.

The stereodisparity between the two Vernier lines determines the factor by which ocular prevalence can be calculated: 1/2 of the stereodisparity corresponds to 100% prevalence of one eye. For example, at the smallest stereodisparity of 30″, a lateral offset of the anterior Vernier line by only 15″ corresponds to 100% ocular prevalence, whereas, at the largest stereodisparity of 430″, a lateral offset of the anterior Vernier line by 215″ corresponds to 100% ocular prevalence.

2.3.3. Coefficients and regression lines

Across observers, correlation coefficients and regression lines were computed with Igor Pro (Wavemetrics, Inc., Lake Oswego, USA).

3. Results

3.1. Monocular and binocular Vernier threshold without stereodisparity

The binocular Vernier threshold of the 20 observers ranged between 3.0″ and 12.1″. As expected from previous work (Banton & Levi, 1991; Frisén & Lindblom, 1988), there was no significant difference between the binocular threshold and the monocular threshold obtained with the "better" eye ($p = 0.90$).

3.2. Binocular Vernier threshold at various stereodisparities

For disparities up to 130″, all observers were able to fuse the stereo-target without seeing double. At 270″ disparity 14 of the 20 observers and at 430″ disparity all observers saw either the anterior or the posterior Vernier line double. At 430″ disparity, one observer gave erratic responses so that no psychometric function could be fitted.

Fig. 3A demonstrates the Vernier thresholds for each of the 20 observers in relation to the stereodisparity between the upper and lower Vernier lines. Averages across the 20 observers are shown in Fig. 3B. When the two Vernier lines were presented at the same viewing distance (stereodisparity ±0), the mean threshold for perceiving a lateral offset was 7″. With stereodisparities of 30″ and 62″, the threshold remained in the same small range. When the stereodisparity was increased to 130″ and 270″, the Vernier threshold increased significantly to 11″ and 34″. The increase saturated at stereodisparities beyond 270″.

To calculate the mean thresholds for Fig. 3A and B, the single values were first logarithmised, then averaged arithmetically and finally delogarithmised. To assess significant differences at the 5%-level, paired *t*-tests were performed between the logarithmised thresholds obtained at the six stereodisparity steps, based on all trials of all 20 observers. Avoiding inflation of significance by multiple testing, the sequential Bonferroni correction was applied (Holm, 1979).

The spot check to estimate perceptual learning revealed that the observers who had performed the test with the stereodisparity of 30″ *early* showed a mean Vernier threshold of 7.4″, and the observers who had performed the test *late* showed a mean Vernier threshold of 8.3″. The difference between the two thresholds was not significant ($p = 0.40$, computed on a log scale).

3.3. Ocular prevalence at various stereodisparities

As demonstrated in Fig. 4, ocular prevalence differed significantly from 0% in most observers: at the stereodisparity of 30″ in 13/20 observers, at 62″ in 9/10, at 130″ in 9/10, at 270″ in 18/20, and at 430″ in 14/19. Significance was determined here from the error estimates for the fit of the psychometric functions, using a critical value of 5% and a sequential Bonferroni correction.

Regarding each observer individually, ocular prevalence changed considerably over the whole spectrum of

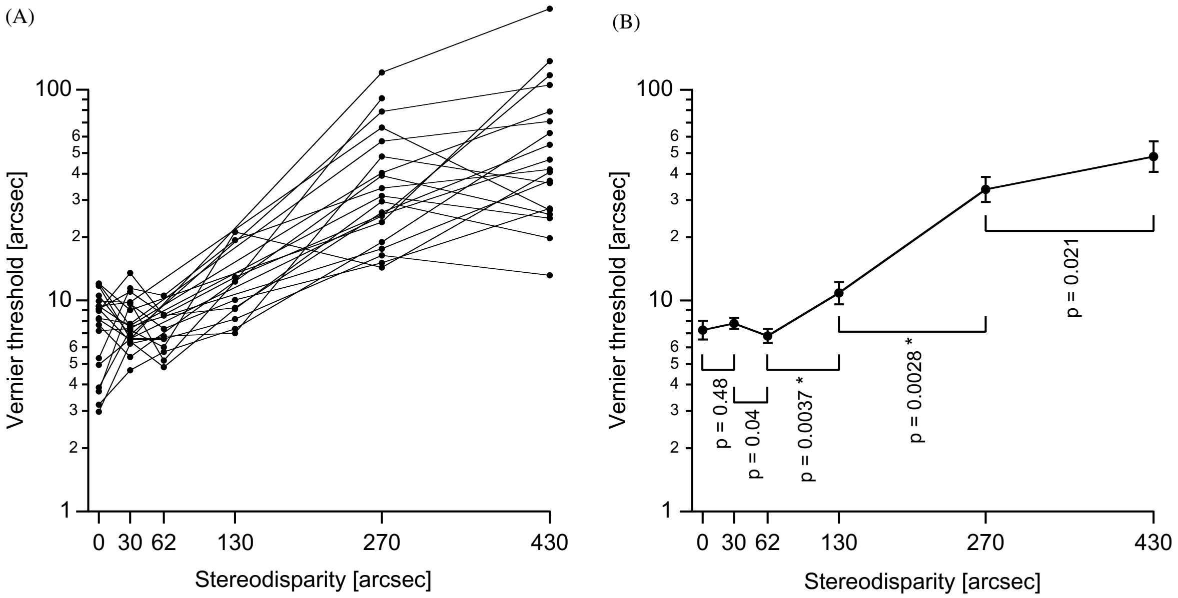

Fig. 3. (A) Vernier thresholds for each of the 20 observers in relation to the stereodisparity between the upper and lower Vernier lines. (B) Mean thresholds across the 20 observers with standard errors of the mean (SEM). The asterisks indicate significant differences after sequential Bonferroni correction.

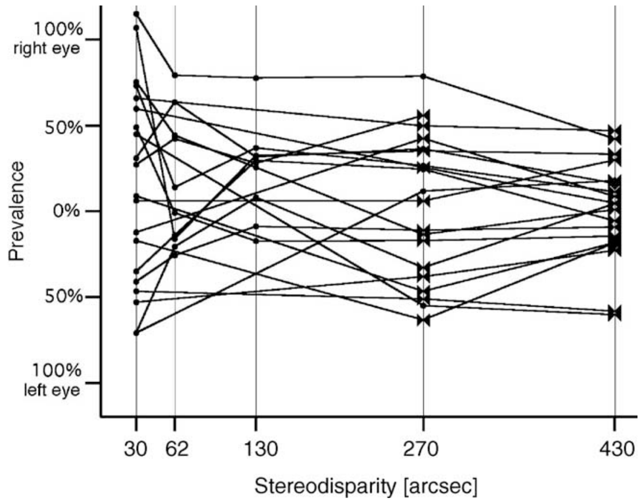

Fig. 4. Ocular prevalence versus stereodisparity. Each line connects the values obtained from one of the 20 observers. Round dots signify single vision, "bow–ties" double vision.

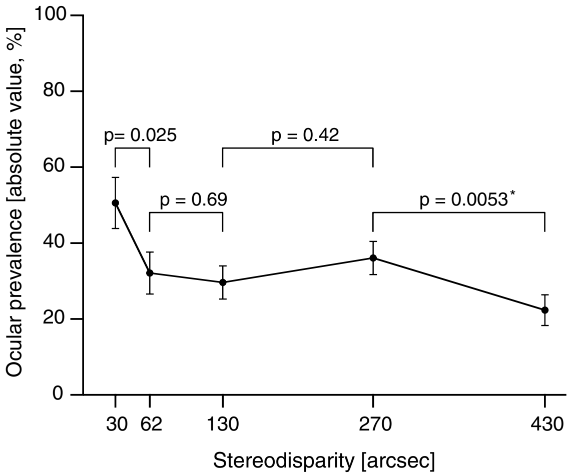

Fig. 5. Ocular prevalence in relation to stereodisparity. Mean values and standard errors relate to all observers. *P*-values relate to the 10 subjects who were tested at all stereodisparities.

stereodisparities. A shift of $\geqslant 30\%$ (on the ±100% scale) occurred in 16 and a switch to the other eye in nine of the 20 observers.

The maximal prevalence of the left eye was 71%, and the maximal prevalence of the right eye was 115%. We can only speculate on the reason, why one observer exceeded the theoretical limit of 100%. The 115% value occurred at the smallest stereodisparity of 30″. This means that the observer perceived the two Vernier lines as being aligned when the lower Vernier line was physically offset to the right by 17.3″. Taking a detailed look at the data obtained at zero disparity, we noticed that the observer perceived a similar physical offset to the right as alignment: with the right eye alone by 4.2″, with the left eye alone by 15.8″, and with both eyes together by 8.8″. The reason could be that the observer had a motor bias for pushing the right button (a suggestion put forward by one of the reviewers). Alternatively, the observer might have a retinal bias of visual directions: the visual directions pertaining to the upper halves of the retinae might be biased to the right with respect to the lower half of the retinae. For geometrical reasons, both types of a bias would play a minor role at large stereodisparities. Accordingly, the observer's ocular prevalence was markedly below 100% at the stereodisparities of 62%, 130%, 270% and 430%.

Fig. 5 shows the absolute values of ocular prevalence (neglecting the distinction between prevalence of the right and the left eye), averaged across all observers. Taking all values of all 20 observers into account, ocular prevalence decreased significantly with increasing stereodisparity, from 50% at 30″ to 22% at 430″ (calculation of significance: the slopes of straight lines fitted on a per-subject basis were on average negative, $p = 0.013$).

Considering the single steps between the various stereodisparities, the 10 observers who had been tested at all stereodisparities (also at 62″ and at 130″) showed significant changes. Between 30″ and 62″, the mean ocular prevalence decreased from 63% to 32% ($p = 0.025$). Between 270″ and 430″, the mean ocular prevalence decreased from 33% to 15% ($p = 0.005$). (Note that all observers became diplopic at this step.) After Bonferroni correction for multiple testing, the step between 30″ and 62″ did not reach the 0.05 significance level. Only the step between 270″ and 430″ remained significant.

3.4. Ocular prevalence and monocular Vernier acuity

Can ocular prevalence be explained on the basis of a better Vernier acuity of the prevalent eye? We calculated the ratio between the Vernier thresholds of the right and the left eye and related the logarithmised quotient to ocular prevalence, averaged across all tested stereodisparities (Fig. 6). The correlation was low and far from being significant ($r = -0.15$, $p = 0.54$).

3.5. Does ocular prevalence increase the Vernier acuity for stereodisparate objects?

As indicated in Section 1, we considered that ocular prevalence might be beneficial for Vernier acuity. With a marked prevalence of one eye, Vernier acuity might even reach the level obtained with one eye alone. The data represented in Fig. 7 refute this possibility for our observers: at all tested stereodisparities the correlation between ocular prevalence and Vernier threshold was weak, and after Bonferroni correction for multiple testing even the smallest *p*-value (0.028 at 430″) was not significant.

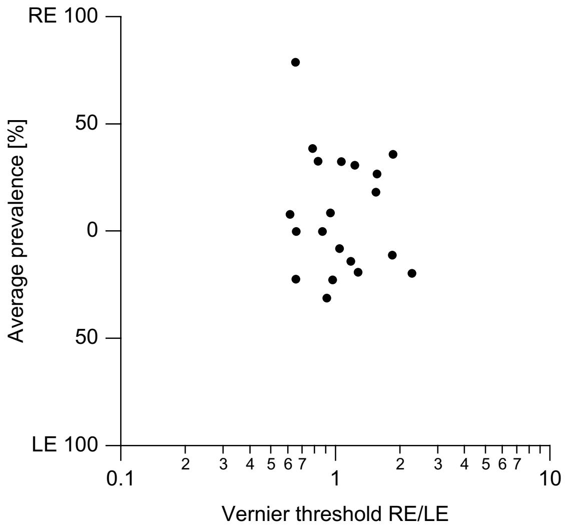

Fig. 6. Ocular prevalence versus the ratio between the Vernier thresholds of the right and the left eye.

4. Discussion

Our study revealed that the "hyperacuity" with which objects can be aligned in the same visual direction decreases when the objects are presented in different depth planes and are viewed with both eyes. With our stimulus conditions, the threshold for perceiving a misalignment of Vernier lines was about 7″ at zero stereodisparity. The threshold increased as the stereodisparity exceeded 62″, and reached 34″ at a stereodisparity of 270″ (Fig. 3). This increase of the threshold means that the Vernier acuity decreased by a factor of about four. With stereodisparities beyond 270″, the Vernier acuity did not decrease further.

What is the mechanism that impairs Vernier acuity when the objects are presented with a stereodisparity larger than 62″? Apparently, fusion of binocularly disparate objects degrades the more precise monocular signals for relative position (as measured with conventional tests for Vernier acuity).

The degradation cannot be due to the summation of noise that originates in the two eyes because, in this case, binocular Vernier acuity would be worse than monocular Vernier acuity at all stereodisparities, even at those smaller than 62″. This was, however, not the case (Section 3.1). Rather, the degradation appears to be a by-product of the cortical fusion of disparate images. This interpretation follows the suggestion of McKee and coworkers, who coined the term "fusional suppression" of monocular position signals on the basis of their finding that the increment threshold for stereodisparity is worse than the threshold obtained by a similar monocular disparity (McKee & Harrad, 1993; McKee, Levi, & Bowne, 1990).

Why did "fusional suppression" saturate at stereodisparities beyond 270″? The reason is probably the gradual appearance of double images that provide monocular position signals. (Remember that the observers had to base their judgement on the "empty" centre between the double images.)

The diplopic percepts cannot be taken as a simple summation of the two monocular percepts. Rather, there is interaction between the signals of the two eyes: as Rose and Blake (1988) have shown, diplopic bars are perceived as being closer together than they really are. Our finding that Vernier acuity for diplopic objects is worse than monocular Vernier acuity suggests that the interaction between the signals of the two eyes does not only influence the visual directions, but also degrades the precision with which objects can be aligned.

"Fusional suppression" is not limited to horizontal disparity. As Sheedy and Fry (1979) have shown, "fusional suppression" also occurs with vertical disparity (of horizontal bars), implying that perceived depth is not a necessary condition for an increase of the Vernier threshold.

In addition, Sheedy and Fry (1979) observed that, for the perceived visual direction of vertically disparate horizontal bars, some observers weight one eye more than the other. This phenomenon will be discussed in the following section.

4.1. Ocular prevalence

The reference point from which our observers judged the relative visual directions was not midway between the eyes; rather, it was decentred towards the right or the left eye. This means that our observers exhibited "ocular prevalence".

What is the mechanism that underlies ocular prevalence? A superiority of the right eye's or the left eye's Vernier acuity can hardly be invoked, because the correlation between ocular prevalence and the quotient of the monocular acuities was low and far from being significant (Fig. 6, $r = -0.145$, $p = 0.54$). The suggestion of Haase (1995) that prevalence of one eye might be due to a fixation disparity of the other eye has been refuted by search coil recordings of the eye position (Gerling, de Paz, Schroth, Bach, & Kommerell, 2000). As the most likely explanation we assume, in accordance with Lang (1994), that prevalence of one eye is due to a partial suppression of the fellow eye. Hence, we regard ocular prevalence as another facet of the "fusional suppression" that manifests itself as a reduction of Vernier acuity for stereodisparate objects. Ocular prevalence shows that the fusional suppression is more pronounced in one eye than in the other.

The marked intraindividual variability of ocular prevalence, seen in Fig. 4, is compatible with the suppression hypothesis, considering other instances that show instability of suppression with dissimilar images on corresponding retinal areas. Stereodisparity repre-

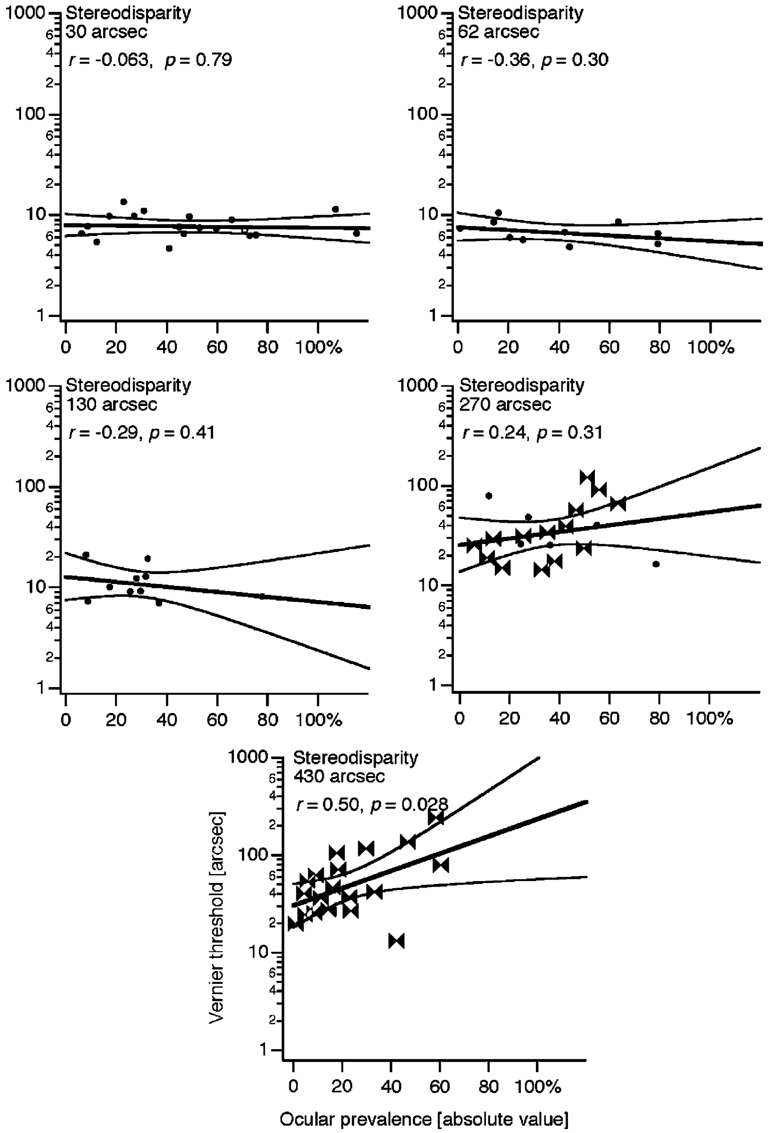

Fig. 7. Relationship between ocular prevalence and Vernier threshold. Each panel shows the data obtained at one of the stereodisparities. As can be seen from the grouping of the data points near the horizontal, the relationship between ocular prevalence and Vernier threshold was weak. Round dots signify single vision, bow–ties "double vision". The thick line shows the least squares fit, the thin lines delineate the 95% confidence band.

sents only a slight dissimilarity. Nevertheless, stereodisparity may be compared with pronounced dissimilarities that can lead to binocular rivalry, a phenomenon in which the percept swaps between the inputs from the two eyes (Helmholtz, 1867; Nguyen, Freeman, & Alais, 2003).

Is ocular prevalence advantageous to Vernier acuity for stereodisparate objects? In our observers who all had normal eyes, ocular prevalence was not strong enough to have an effect: ocular prevalence was neither beneficial nor detrimental (Fig. 7). Under pathological conditions like strabismic amblyopia, the relative position between Vernier lines would be perceived almost exclusively through the leading eye. In this case, one would expect that the binocular Vernier acuity reached the monocular "hyperacuity" level, irrespective of any depth difference between objects.

4.2. What are the practical inferences of our results for everyday viewing?

Vernier acuity for stereodisparate objects should be important for goal-directed actions. Although this assertion does not apply for ballistic, pre-programmed actions, it should be true for actions that require constant visual feedback, like guiding a hand-held instrument. Typical tasks are to insert a screwdriver into the slot of a screw or to put a key into a keyhole. Our finding that the position acuity is impaired when the stereodisparity exceeds 62″ means, for a typical working distance of 40 cm, that workers have to come up with their instrument as close as 0.4 mm to the target to utilise their maximal position acuity. At larger stereodisparities, they have to put up with a weaker position acuity, unless they choose to close an eye.

Acknowledgement

The Deutsche Forschungsgemeinschaft (Ko 761/1-3) and the Ernst und Berta Grimmke–Stiftung supported this research.

References

Banton, T., & Levi, D. M. (1991). Binocular summation in Vernier acuity. *Journal of the Optical Society of America A, 8*, 673–680.

Erkelens, C. J., Muijs, A. J. M., & van Ee, R. (1996). Binocular alignment in different depth planes. *Vision Research, 36*, 2141–2147.

Foster, D. H., & Bischof, W. F. (1991). Thresholds from psychometric functions: superiority of bootstrap to incremental and probit variance estimators. *Psychological Bulletin, 109*, 152–159.

Frisén, L., & Lindblom, B. (1988). Binocular summation in humans: evidence for a hierarchical model. *Journal of Physiology, 402*, 773–782.

Gerling, J., de Paz, H., Schroth, V., Bach, M., & Kommerell, G. (2000). Ist die Feststellung einer Fixationsdisparation mit der Mess- und Korrektionsmethodik nach H.-J. Haase (MKH) verlässlich? *Klinische Monatsblätter für Augenheilkunde, 216*, 401–411.

Haase, H.-J. (1995). *Zur Fixationsdisparation*. 3-922269-17-6. Heidelberg: Optische Fachveröffentlichung GmbH.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics, 6*, 65–70.

Kommerell, G., Schmitt, C., Kromeier, M., & Bach, M. (2003). Ocular prevalence versus ocular dominance. *Vision Research, 43*, 1397–1403.

Lang, J. (1994). Die sensorischen und standespolitischen Schwachstellen der Prismenverordnung am Polatest. *Klinische Monatsblätter für Augenheilkunde, 204*, 378–380.

Leek, M. R. (2001). Adaptive procedures in psychophysical research. *Perception & Psychophysics, 63*, 1279–1292.

Mapp, A. P., Ono, H., & Barbeito, R. (2003). What does the dominant eye dominate. A brief and somewhat contentious review. *Perception & Psychophysics, 65*, 310–317.

McKee, S. P., & Harrad, R. A. (1993). Fusional suppression in normal and stereoanomalous observers. *Vision Research, 33*, 1645–1658.

McKee, S. P., Levi, D. M., & Bowne, S. F. (1990). The imprecision of stereopsis. *Vision Research, 30*, 1763–1779.

Nguyen, V. A., Freeman, A. W., & Alais, D. (2003). Increasing depth of binocular rivalry suppression along two visual pathways. *Vision Research, 43*, 2003–2008.

Rose, D., & Blake, R. J. (1988). Mislocalization of diplopic images. *Journal of the Optical Society of America A, 5*, 1512–1521.

Sachsenweger, R. (1958). Sensorische Fusion und Schielen. *Graefes Archiv fur klinische und experimentelle Ophthalmologie, 159*, 502–528.

Sheedy, J. E., & Fry, G. A. (1979). The perceived direction of the binocular image. *Vision Research, 19*, 201–211.

von Helmholtz, H. (1867). In J. von Kries (Vol. Ed.). *Handbuch der Physiologischen Optik: Band: 3. Die Lehre von den Gesichtswahrnehmungen* (1910, 3rd ed., pp. 402–409).

Westheimer, G., & McKee, S. P. (1977). Spatial configurations for visual hyperacuity. *Vision Research, 17*, 941–947.