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Eye preference within the context of binocular functions

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Abstract *Background:* Eye preference refers to an asymmetric use of the two eyes, but it does not imply a unitary asymmetry between the eyes. Many different methods are used to assess eye preference, including eyedness questionnaires and sighting tasks that require binocular and monocular alignment of a target through a hole in the middle of a card or funnel. The results of these coarse accounts of eye preference are useful as a first screening, but do not allow for graded quantification of the manifested asymmetry in binocular vision. Moreover, they often concern only a rather selective range of binocular functions. The aim of the present study was to further differentiate eye preference within the context of other binocular functions as measured in standard optometric tests, and to validate their relation to questionnaire data of eyedness. *Methods:* Conventional accounts of eye preference (German adaptation of Coren's questionnaire and a sighting task) were compared with various optometric tests of binocular function within a sample of 103 subjects. Examination included visual acuity and accommodation in each eye, stereoscopic prevalence, suppression due to binocular rivalry, fixation disparity (Mallett test). *Results:* Sighting dominance was leftward in 32% and rightward in 68% of the cases and was highly correlated (Kendall's τ_b=0.70) with eyedness. Further significant associations were restricted to stereoscopic prevalence which correlated with sighting dominance (τ_b=0.55), eyedness (τ_b=0.50), and rivalry dominance (τ_b=0.28). *Conclusion:* Eye preference seems to be essentially reflected by eyedness, sighting dominance, and stereoscopic prevalence, but largely unrelated to fixation disparity, accommodation, and visual acuity.

Keywords Eye preference · Binocular functions · Sighting dominance · Stereoscopic prevalence · Fixation disparity · Rivalry suppression

Introduction

As a bilateral sense organ, the eyes show asymmetries and differential preference behaviors. The unequal use of both eyes is quite complex and referred to by different, partly overlapping, partly distinctive terms, such as eye preference, eyedness, eye dominance, ocular dominance, sighting dominance and ocular or stereoscopic prevalence. *Eyedness* is usually assessed by questionnaire data. Eye dominance, as defined by sighting tasks, is determined by alignment of two objects presented at a stereo disparity far beyond Panum's area, whereas *ocular prevalence* is determined by the alignment of two objects presented at a stereo disparity within Panum's area [20].

In order to avoid confusion, we will use *eye preference* as an umbrella term to include the different aspects of eyedness, eye or sighting dominance as well as ocular preference.

The unequal use of both eyes was first mentioned by Giovanni Battista della Porta in 1593 who also described a first alignment test for determining the preferred or sighting-dominant eye [36]. The examiner holds a staff directly in front of the body. With both eyes open, the viewer aligns the tip of the staff with a mark on a distant wall. Then, the eyes are winked alternately. The tip of the staff remains in good alignment when viewing with one eye, whereas, when using the other eye, the viewer usually perceives the tip of the staff to be in misalignment shifted to one side. Obviously, the tip of the staff and the distant target are aligned by using the information from one eye's view, while the misaligned view of the other eye is ignored or suppressed. The eye for which target and staff are in alignment is the "dominant" eye [20, 33].

In a recent review, Mapp, Ono and Barbeito [23] conclude that the visual and oculomotor function of the preferred eye remains still largely unknown. Eye preference can be defined by such criteria as asymmetry in acuity, rivalry, or sighting. The degree to which these different measurements reflect the same or at least part of a common function is yet to be determined. The most reliable criterium of eye dominance is found within sighting tasks. These tasks, such as pointing a finger, are quite common in daily situations. They force the observer to align just one eye with the target and ignore visual input from the other eye [e.g. [6–8, 27]].

Despite methodological quibbles, there is a broad agreement that eye preference is a consistent behavioral pattern [9, 11, 30, 37] which is supposed to be largely genetically determined [1, 3, 31] and can be influenced by sex hormones [2]. The notion of a persistent eye dominance is corroborated by neurophysiological (fMRI) findings that the dominant eye actually activates a larger area of the primary visual cortex than the non-dominant eye [32] and that the human equivalent of primate ocular dominance columns shows a higher activity in those columns that are driven by the dominant eye [12, 26].

Although eye preference is usually found to be a consistent trait in individuals, it does not exclude a change in the preferred use of either eye. For example, in a reaching task subjects tend to align the hand to the left or the right eye depending on whether the target is located in the left or right peripheral visual field [18]; yet, the point of crossover from left-eye- to the right-eye preference varies across subjects, according to her or his eye preference. In a pointing task, the fingertip is aligned with a vertical plane located between the two eyes and the target such that eye-hand alignment is directed towards the eye with the best overall field of view [19].

The aim of the present study was twofold: first, to investigate how eye preference is embedded and might be further differentiated within the context of binocular functions, and second, to relate questionnaire data of eyedness and behavioral tasks that test for various aspects of eye preference.

Patients and methods

Subjects

A total of 103 subjects, 35 female and 68 male (16–51 years; mean=24.1, SD=4.5) was examined. Except for accommodation measurements, where test conditions were repeated, subjects were examined once in each test. Unless specified by the respective, slightly lower, number of subjects (see Results section), each of the subjects participated in all tests.

Data analysis

A comparison between the various eye-preference scores, some of which (accommodation measures) are rational-level variables, others (questionnaire data) ordinal-level data, requires a non-parametric statistics approach [4]. Therefore, contingency tables of the respective eye-preference scores were formed and statistical independence was tested by using the Chi-square test and the exact Fisher test. Multiple comparisons of the present seven different tests (see Test and procedures) resulted in 21 pairwise comparisons and a multiple significance level of 0.05/21=0.0024. In order to determine the degree of correlations or associations between the various tests, Kendall's rank correlation test was used. Kendall's measure τ_b accounts for binary or ordinal level variables defining null relationship as statistical independence and values of one as perfect association.

Tests and procedures

Visual acuity Standard Landolt rings (DIN 58220) were displayed in eight possible gap orientations: top, top-right, right, right-bottom, bottom, left-bottom, left, and top-left. Subjects orally indicated the gap orientation of the optotypes that were viewed binocularly or monocularly, with one eye shielded by a milky glass, at a distance of 5 m. Two rows, of five Landolt rings each, were presented for each level of visual acuity of 0.8, 1.0, 1.25 and 1.6. The result was the highest level reached by the observer with at least six correctly identified optotypes out of ten.

Stereoscopic prevalence The perceived deviation towards the left or right from the physical midline of aligned stereo images, stereo prevalence, was determined by using the Polatest (Zeiss, Oberkochen, Germany), see Haase [14]. Two triangles were presented stereoscopically one above and the other below a central disc (Fig. 1). Observations were made through goggles with polarizing filters. Subjects had to focus at the central disc presented at a distance of 40 cm (*near* condition) or 5 m (*far* condition). They had to judge and indicate orally the position of the stereoscopically fused apices of the triangles, shown with a stereo-disparity

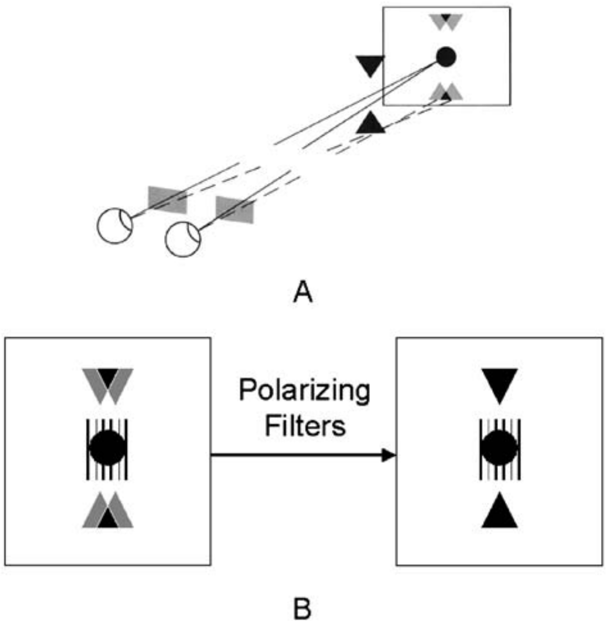

Fig. 1 Stereo prevalence test (Haase [14]). **a** Schematic representation of the test as used in the present study. Viewing through goggles with polarizing filters, subjects had to focus at the central disc shown at 4.50-m distance (far condition) or at 40 cm (near condition). The *triangles* were shown with crossed stereo-disparity, so that they appeared in front of the central disk. The task was to judge the position of the fused apices of the triangles relative to the center of the disc. (Note that an observed *leftward* displacement of the triangles indicates the prevalence of the right eye and vice versa). **b** Depiction of the condition in which the position of the fused triangles had to be judged relative to a scale added to the disc

of 13′ arc in front of the central disc (Fig. 1a; due to the crossed disparity an observed rightward displacement of the triangles indicates a left-eye prevalence, and a leftward displacement a right-eye prevalence). Three response categories were assessed: triangles at the center, displacement of the triangles from the center to the left or to the right.

Measurements were started for the far condition with a scale and were then repeated without a scale, followed by measurements for the near condition with a scale. In the without-scale condition the perceived position of stereoscopically fused triangles had to be judged relative to the central disc alone (as in Fig. 1a). For with-scale measurements a scale was added to the central disc (see Fig. 1b).

Binocular suppression To test binocular suppression, we used a modified Maddox wing apparatus (Clement Clarke Ltd, London) which allows for dissociation of the eyes by means of a septum. Both eyes receive identical stimuli (a vertical row of six crosses), except for the position at which the left eye is exposed to an arrow pointing leftwards to a green dot, whereas the right eye is exposed to an arrow pointing towards the right at a red dot (Fig. 2a). In the fused image, usually the input from one eye is suppressed and only the stimulus from the fellow eye remains visible (left eye suppression, as depicted in Fig. 2b). The task of the

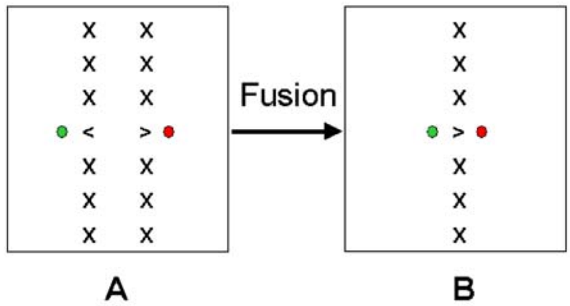

Fig. 2 Binocular suppression test. **a** Eyes, dissociated by a septum, receive identical input, except for the middle row, in which the left eye is exposed to an arrow pointing to a *green dot* (*leftward*), whereas the right eye receives an arrow pointing to a *red dot* (*rightward*). **b** In the fused image the input of one, here the left, eye is suppressed

observer was to decide and indicate orally whether the arrow is pointing to the red or green dot.

Fixation disparity (Mallett test) Fixation disparity is a condition in which the visual axes of both eyes do not intersect at the fixation point, but either in front (eso) or behind (exo) it. Fixation disparity varies among subjects and typically amounts to a few minutes of arc in the presence of central fusion stimuli [17], still within the limits of Panum's area, so that double vision does not occur [15]. A commonly used routine test to detect the fixation disparity is the Mallet test for near vision [22]. Dissociation of the monocular marks is obtained by cross-polaroid filters. A central fixation target "OXO" is seen with both eyes and two monocular marks (Nonius bars) in line with the X are seen, one with each eye (see Fig. 3). In the present study the upper Nonius bar was shown to the right eye and the lower bar to the left eye.

If a fixation disparity is present, in the left or right eye, the upper or lower (monocular) bar will be perceived horizontally displaced relative to the X. The amount of dis-

Fig. 3 Test of fixation disparity [22]. The central target "OXO" is seen with both eyes, the *upper* and *lower bar* only to one eye due to cross-polaroid filters. A fixation disparity is indicated by a displacement of the monocular bars from their alignment with the *X*

placement was judged and indicated orally by the subjects for the upper bar (right eye) and lower bar (left eye) in percent of the bar width (=100%).

Accommodation A Canon-R1 infra-red autorefractometer [24, 25] was used for objective measurement of the static accommodation separately for the left and right eye for viewing target at *far* (4.50 m) and *near* (40 cm) distance. The far target was a Landolt ring of 0.8 acuity level, the near target was a ring crossed by a thin line. Measurements were performed repeatedly in four blocks of trials. In the first and fourth block accommodation was determined 10 times for the right eye, first in the far, then in the near condition. In the second and third block, the left eye was likewise examined first in the far, then in the near condition. The median of the spherical equivalent was calculated from ten measurements per condition.

Sighting dominance (card test) The card test, also called "Dolman's peephole test" ([8], p. 478) is similar to Porta's alignment task (see above), yet with the advantage that it is less biased for handedness. Subjects have to sight a target, a black cross, shown at a distance of approximately 5 m through a hole (3 cm in diameter) in the middle of a card (20 cm wide and 12.8 cm high). To prevent a handedness bias, the card was held with both hands at arm's distance. Without moving the head, the task was to align the hole of the card with the target when viewing with both eyes. The experimenter then alternately covered the left or right eye of the subject. Subjects responded orally which eye, left or right, despite of covering the fellow eye, kept the object lined up in the hole; this eye was noted as the sighting-dominant eye.

Eyedness (questionnaire) Eyedness was assessed conjointly with ear, hand, and foot preference by a German adaptation of Coren's Lateral Preference Inventory [5, 10]. The original questionnaire consists of 16 items, four subscales with four items each, to determine the preference of eye, ear, hand and foot, respectively. It allows to determine the direction (left=−, right=+) and degree (maximal +4 and −4) of side preference. In the present study, a shortened version of this questionnaire was used. It consisted of ten items, four items for eyedness and two items each for assessing ear, hand and foot preferences; only the direction of preference, i.e. the sign resulting from the sum of scores, was evaluated.

The items to assess eyedness were as follows (see also Ref. [10]):

1. Which eye would you use to look through a telescope?
2. If you had to look in a dark bottle to see how full it was, which eye would you use?
3. Which eye would you use to peep through a keyhole?
4. Which eye would you use to sight down a rifle?

Results

Visual acuity

Measurements of static visual acuity (n=102) yielded *mean* visus levels of 1.40 for the left eye and 1.41 for the right eye, and 1.50 binocularly, while *medians* were 1.6 throughout. Acuity was found to be equal in both eyes for 74.8% of the subjects, a better performance for the left or right eye was found for 12.6% of the participants, respectively.

Stereoscopic prevalence

The three test versions conform in showing that stereoscopic prevalence is found, on average, more often for the right eye (37.6%) than for the left eye (27.5%) with a third of the subjects reporting no prevalence. Table 1 shows the relative frequencies separated for the three measurement conditions across all subjects. Measurements for the *far/without scale* condition lead to the highest percentage of no-preference judgements (45.6%), whereas for the *near/with scale* condition the no-preference scores were only 24.3%.

Binocular suppression

Suppression due to binocular rivalry (n=100) was found in 82% of the participants; 26% reported that the arrow pointed towards the left (right-eye suppression) and 56% that it pointed towards the right (left-eye suppression), while the remaining 18% reported no suppression or side preference.

Fixation disparity (Mallett test)

The Mallett test of fixation disparity revealed no clear differences between left and right eyes. No displacement was reported by 55.3% of the subjects for the left eye, and by 48.5% for the right eye. The maximal displacements ranged from 50% of the bar width to the left (eso-fixation disparity) to 100% of the bar width to the right (exo-fixation disparity); for the right eye the range was somewhat smaller, extending from 50% to the left (exo-fixation disparity) to 25% to the right (eso-fixation disparity).

Table 1 Percentages of eye prevalence obtained for the three measurement conditions of stereo prevalence (Haase test)

Test condition	Stereo prevalence (%)		
	Left	No	Right
Far, with scale	28.2	34.9	36.9
Far, without scale	23.3	45.6	31.1
Near, with scale	31.1	24.3	44.7

Accommodation

Measurements of accommodation (N=100) yielded little difference between the eyes. For the left eye, means (±SD) were 2.37 D (0.47) and 2.34 D (0.49) for the first and second measurement, respectively; for the right eye they were 2.44 D (0.44) and 2.37 D (0.45). The data of the two measurement series (test–retest) were highly correlated (Bravais–Pearson coefficient r=0.85 for the left eye; r=0.77 for the right). The correlation becomes only slightly lower if it is between the left and right eye (r=0.71), indicating an almost perfect equivalence between the eyes.

Sighting dominance (card test)

The card test resulted in a clear-cut dichotomous outcome: 32% of the participants showed a sighting dominance of their left eye and 68% of their right eye.

Eyedness (questionnaire)

Eyedness, as assessed by four items of the laterality questionnaire, yielded a preference for the left eye in 30.1% of the subjects and for the right eye in 63.1%; 6.8% reported no side preference (ambilateral). Compared to eyedness, handedness was found to be much more lateralized: 8.7% of the participants preferred the left hand, 88.4% preferred the right hand, and 2.9% were ambilateral.

Eyedness and handedness were only moderately correlated (Spearman's ρ=0.17; P<0.05). Out of 31 left-eyed persons 25 were right-handed, i.e. left-side preference for eye and hand was shared in only six persons. Conversely, out of 65 right-eyed persons, only three were left-handed and two had no preference, while 60 persons were right-handed, i.e. they showed a right-side preference for eye and hand.

Test interrelationships

A practical aspect of the present study concerns whether and to what extent questionnaire data of eyedness reflect the actual behavior shown in the card test of sighting dominance. Questionnaire and card test data yielded identical results for 83.5% of the subjects (25.2% left eye; 58.3% right eye). Since the card test was applied only once for each subject, the present data do not allow to test for variability and thus provides only dichotomous data. In case of repeated measurements, the card test might have detected "ambilateral" subjects for sighting dominance. In the present case, 6.8% of the subjects were ambilateral according to the questionnaire, i.e. they show a half-way correspondence with either a left or right score of the card test. With respect to this partial correspondence, the disagreement between both ways of determining eye preference is only 9.7%.

Table 2 Summary of the degree of associations (Kendall's τ_b) obtained among the tests employed. *1* Visual acuity, *2* stereo prevalence, *3* binocular suppression, *4* fixation disparity, *5* accommodation, *6* sighting dominance, *7* eyedness

Tests	1	2	3	4	5	6	7
1	–						
2	0.18	–					
3	0.10	0.28*	–				
4	−0.20	−0.18*	−0.22	–			
5	0.12	−0.03	0.23	−0.10	–		
6	−0.08	0.55*	0.30	−0.17	0.05	–	
7	0.01	0.50*	0.13	−0.15	0.09	0.70*	–

*Significance (p<0.002)

For further evaluation of interrelationships, contingency tables of the various eye-preference scores were formed. The seven tests with 21 pairwise comparisons resulted in a multiple significance level of 0.05/21=0.0024. The degree of association between the various tests was estimated by Kendall's τ_b, see Table 2. The highest association was found between sighting dominance and eyedness as assessed by the questionnaire (Kendall's τ_b=0.70). Further associations were restricted to stereoscopic prevalence, which correlated with sighting dominance (τ_b=0.55), eyedness (τ_b=0.50), and rivalry dominance due to binocular suppression (τ_b=0.28).

Discussion

In the present study, we compared various aspects of eye preference. We found that eyedness, as assessed by a questionnaire, is closely correlated with the behavior in a sighting-dominance task, and both measures are related to stereoscopic prevalence of visual direction as measured by the Haase test. Further, comparatively moderate correlations were found between the preference in a test for binocular rivalry suppression and stereoscopic prevalence, as well as between eyedness and handedness. Conversely, no significant correlations of these measures were found to interocular differences in visual acuity, accommodation, and fixation disparity.

A high correlation between sighting-dominance and stereoscopic prevalence was also found by Kommerell et al. [20] who used a cone-shaped funnel (Parson's monoptoscope), similar to our card test, to determine dominance and a slightly modified version of the Haase test to measure stereoscopic prevalence.

The correlation between binocular rivalry and eye prevalence, found in our study, supports the idea that suppression of one eye may be involved in the preference of the other eye. It should be noted, however, that the relationship between binocular rivalry and suppression is vague, especially with respect to eye dominance [23]. For instance, it has been assumed that the suppression of one eye in strabismic amblyopia develops in order to avoid double vision and that a similar process operates for normal vision in sighting tasks [28, 35]. However, strabismic suppression is distinct from rivalry suppression in non-strabismic persons, in that both types of suppression differ in strength and are elicited by different stimuli [23, 34].

Haase [14] proposed that the stereoscopic prevalence as determined in his test is an indicator of fixation disparity. However, we did not find a correlation between stereoscopic prevalence and fixation disparity of the left and right eye as determined by the Mallett test. This finding accords with the absence of a refixation movement of the non-prevalent eye when the fixation target for the dominant eye is switched off [13]. Such a refixation movement should have occurred in the case of a vergence error.

Are dominance and prevalence of one eye purposeful features of binocular vision? Eye preference may be important to solve the problem of diplopia that can occur in species with large overlapping monocular fields of view [16, 29]. For instance, in pointing a finger at a distant target, one cannot effectively use both eyes, since fixation on the fingertip will result in stimulation of non-corresponding retinal points by the distant target that will appear diplopic. Conversely, fixation on the target will result in double images of the fingertip. A solution is offered by attenuating or suppressing the input from the non-sighting eye under conditions of binocular stimulation in order to clear the way for single vision by admitting preferably the input from the sighting eye [11, 20, 29]. Close to the limits of Panum's area, a partial suppression of one eye, manifesting itself as prevalence of the other eye, may suffice to avoid any ambiguity in visual directions [20]. Prevalence at stereo-disparities near to the limits of Panum's area does, however, not preclude the utilization of the input from both eyes at small stereo-disparities, since ocular prevalence has been shown to be compatible with a high stereo acuity [21].

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