African Vision and Eye Health
ISSN: (Online) 2410-1516, (Print) 2413-3183

Heterophoria, fusional vergence, and near point of convergence in Sudanese hospital-based population

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Dates:
Received: 05 July 2023
Accepted: 05 Dec. 2023
Published: 05 Feb. 2024

How to cite this article:
Alrasheed SH, Aldakhil S. Heterophoria, fusional vergence, and near point of convergence in Sudanese hospital-based population. Afr Vision Eye Health. 2024;83(1), a869. https://doi.org/10.4102/aveh.v83i1.869

Background: Fusional vergence amplitude is the amount of convergence and divergence that can be induced before fusion is lost and fusional vergence amplitude controls heterophoria.

Aim: This study aimed to investigate the relationship between near heterophoria, near fusional vergence (NFV), and near point of convergence (NPC).

Setting: Al-Neelain Eye Hospital Khartoum, Sudan.

Methods: A hospital-based prospective study from February to October 2019, included 230 patients with age range of 15–30 years and mean age and standard deviation of 19.46 ± 3.33 years. The alternate cover test with prism was used to measure near heterophoria and a prism bar was used to measure quantity of fusional vergence. All measurements were taken at near heterophoria (0.33 m). Then the associations between near heterophoria, NFV and NPC were assessed.

Results: The most common heterophoria at near among the participants was exophoria: 200 (87.0%). Reported complaints of asthenopia were commonly found among these exophoric patients: 106 (86.9%) (P = 0.735). Positive fusional vergence (PFV) to the break point varied according to the forms of heterophoria (P = 0.003). Esophoria had a higher PFV to break point than exophoria (30.83 ± 8.79Δ compared to 25.59 ± 10.07Δ). Negative fusional vergence at the break and recovery points were higher among those with exophoria and lower in esophoria (P > 0.05). The NPC differed by the type of heterophoria (P = 0.01), with exophoria and slightly receded NPC (8.38 cm ± 3.33 cm) than for participants with esophoria (6.77 cm ± 1.52 cm).

Conclusions: Exophoria was the most common type of near heterophoria, with asthenopia being the most reported complaint. Esophoria was found to be strongly associated with high PFV. Exophoria, on the contrary, is related to significant high NFV at the blur, beak, and recovery point. The NPC differed significantly by the type of near heterophoria, with exophoria having more receded NPC compared to those with esophoria.

Contribution: This study provides information on the commonest type of near heterophorias among a sample of Sudanese adolescents and young adults, namely exophoria. Near point of convergence and NFV at break and recovery points were significantly different according to forms of near heterophoria.

Keywords: heterophoria; esophoria; exophoria; positive and negative fusional vergence; diplopia.

Introduction

Heterophoria is a condition where the eyes are properly aligned when both eyes are open, but a misalignment occurs when one eye is covered. This deviation when the eyes are dissociated or fusion is lost is known as heterophoria, sometimes abbreviated to phoria.[1,2] According to the American Association for Paediatric Ophthalmology and Strabismus, heterophoria is a:

> … condition in which the eyes are normally aligned when both eyes are open, but there is a tendency for the eyes to become misaligned under certain conditions such as prolonged reading, looking at a distance, or when one eye is covered.[3]

Horizontal heterophoria can be classified as esophoria and exophoria. Vertical deviations are classified as hyperphoria and hypophoria, and torsional deviations are referred to as cyclophorias. These definitions are according to the direction of the visual axes when the eyes are dissociated.[4]

Conversely, the condition where heterophoria does not exist and the dissociated position is the same as the active position is known as orthophoria.[1]

A review of studies[5,6,7,8] on prevalence rates of heterophoria among children may vary depending on the specific populations age and diagnostic criteria used. However, exophoria appears to be the more prevalent phoria in young children and school-aged children from Australia,[5] China,[6] Tibet,[8] and South Africa.[7] Normal binocular vision needs correct alignment of both eyes, in addition to motor and sensory mechanisms of fusion.[9,10] Positive fusional vergence (PFV) and negative fusional vergence (NFV) are stimulated by retinal disparity aimed at maintaining binocular single vision.[9,10] Heterophoria can appear when the PFV or NFV is interrupted because the tendency for eye deviation is kept latent by fusional vergence (FV) amplitude.[11] Maintaining compensation for heterophoria is attributed to FV, making it crucial for eye care professionals to determine the amount of total vergence amplitude necessary to control a deviation.[12,13] Therefore, the ability to fuse two single images should be assessed for subjects with heterophoria at near and distance fixation, usually at 6 m and 0.4 m but sometimes at closer distances such as 0.33 m.[11] Sheard indicated that the opposing FV to the blur point should be at least twice the size of the heterophoria. The author supposed that complaints from heterophoria could be avoided if the FV in the opposite direction is at least twice the size of the heterophoria.[1,10,13] Near point of convergence (NPC) has been considered an essential factor in assessing the vergence system at near fixation distances and the previous study showed that NPC tends to recede with increasing age.[14] This study was conducted to investigate the relationships between heterophoria, step fusional vergence (SFV) and NPC among Sudanese participants with near heterophoria.

Research methods and design

Study design

A hospital-based prospective study was conducted at Al-Neelain Eye Hospital in Khartoum, Sudan between February and October 2019. The study involved 230 patients with near heterophoria who presented with ocular discomfort and underwent an eye examination. The participants voluntarily visited the university eye hospital to receive primary eye care services. All the subjects in this study were referred, by ophthalmologists after comprehensive eye examinations, to the binocular vision clinic with presumed binocular vision disorders.

Inclusion and exclusion criteria

The study included participants aged between 15 and 30 years with no prior history of any form of vision therapy, amblyopia, or manifest strabismus. Furthermore, participants were required to have no ocular or systemic clinical findings, not to be using any medications that could cause ocular symptoms, and to have near emmetropia, with normal vision of Snellen 6/6 or better at near distances. For the study, emmetropia was defined as a refractive error ranging from −0.50 D to 0.75 D spherical, with a cylindrical of less than 0.25 D. Subjects with ocular diseases such as external eye inflammation, cataracts, glaucoma, and retinal disease, as well as those with a history of previous surgery, were excluded from the study.

Data collection procedures

Initially, all participants underwent a case history assessment to gather information about their ocular history and any vision complaints. After that the patient symptoms were classified as the following: Visual perceptual distortion included blurred vision and distorted vision. Binocular factors included difficulty to change focus and double vision. Symptoms of asthenopia included headache, sore or aching eyes, and ocular irritation. This was followed by measuring their distance and near visual acuities (VA) using the Snellen Tumbling E-chart. Objective refractions were measured using retinoscopy (Neitz RX, Japan). To identify any heterophoria and to measure the size of deviation, the cover test was performed at 33 cm. To assess the integrity of the eye muscles, the subjects underwent ocular motility tests in the nine positions of gaze. The NPC was measured using the Royal Air Force (RAF) Rule, to the breakpoint or at a point for reporting diplopia. The FV amplitude PFV and NFV were measured using a prism bar at 33 cm. The prism bar was moved downwards at a speed of approximately one step per 2 s until the fixation object became slightly blurred. The point at which the subject was unable to see the target clearly, was the 'blur point', recorded as the first prism value. Following the determination of the blur point, the prism power was gradually increased until the fixation object appeared double, known as the 'break point'. Moving the prism bar in the opposite direction, a recovery point was recorded when the subject was able to report seeing only one object. All the clinical measurements were conducted by the same examiner, using the same methodology. The examiner performed all tests within approximately 20 min per participant. All the measurements were taken at near fixation (33 cm).

Data analysis

The data collected from the participants were entered into a Microsoft Excel spreadsheet and analysed using Statistical Package for the Social Sciences (SPSS) software (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp, USA). Descriptive analysis was performed to assess averages, standard deviations medians and modes. Including the distribution of the collected data. For categorical variables, the study used cross-tabulation and the Chi-square test. Means were compared using one-way analysis of variance (ANOVA) tests. Statistical significance was set at $P < 0.05$.

Ethical considerations

The study was conducted in accordance with the guidelines of the Declaration of Helsinki, and ethical approval was obtained from the Al-Neelain University Research Ethics Committee with reference number 19-12-01. All participants

provided informed consent for their participation in the study. For children under the age of 18, consent was obtained from their parents or guardians. The data collected were kept confidential and no personally identifiable information was obtained.

Results

Descriptive statistics

A total of 230 patients between the ages of 15 and 30 years, with a mean age of 19.46 ± 3.33 years with near heterophoria and asthenopia were sent to the binocular vision clinic. The one-sample Kolmogorov–Smirnov test revealed that patients with near heterophoria were normally distributed (P = 0.203). The mean and standard deviation of VA in decimal notation for the right and left eyes were 0.95 ± 0.14 and 0.95 ± 0.15, respectively. Exophoria (5.23 ± 4.12Δ) and esophoria (4.73 ± 4.73Δ) were observed in patients. Positive fusional vergence blur, break and recovery points were 23.84 ± 10.42Δ, 26.27 ± 10.06Δ and 20.92 ± 9.9Δ, respectively. Whereas NFV blur, break and recovery points were 15.60 ± 6.65Δ, 13.37 ± 6.37Δ and 8.17 ± 3.20Δ, respectively. For the sample, average NPC were 8.17 cm ± 3.20 cm, as displayed in Table 1.

Heterophoria and ocular symptoms

The commonest heterophoria among the 230 participants was exophoria (200% or 87.0%) for near fixation. The most reported complaints were asthenopia, commonly found among exophoric patients at 106 (86.9%). However, the association between different ocular symptoms and near heterophoria was not statistically significant (χ^2 = 1.28, df = 3, P = 0.735) as shown in Table 2.

TABLE 1: Descriptive statistics for age, visual acuities, near heterophoria, near fusional vergence and near point of convergence for 230 patients.

Variables	Minima	Maxima	Means	s.d.
Age (years)	15.00	30.00	19.34	3.33
VA Right eyes (decimal)	0.50	1.00	0.95	0.14
VA Left eyes (decimal)	0.50	1.00	0.95	0.15
Exophoria (Δ)	2.00	20.00	5.23	4.12
Esophoria (Δ)	2.00	20.00	4.73	4.73
PFV [Blur point] (Δ)	4.00	44.00	23.84	10.42
PFV [Break point] (Δ)	6.00	45.00	26.27	10.06
PFV [Recovery point] (Δ)	2.00	40.00	20.92	9.90
NFV [Blur point] (Δ)	2.00	33.00	15.60	6.65
NFV [Break point] (Δ)	3.00	35.00	18.12	6.43
NFV [Recovery point] (Δ)	1.00	30.00	13.37	6.37
NPC (cm)	2.00	21.00	8.17	3.20

s.d., standard deviation; VA, visual acuities; PFV, positive fusional vergence; NFV, near fusional vergence; NPC, near point of convergence.

Positive fusional vergence to the blur point varied according to the forms of near heterophoria and this difference was significant (P = 0.003). Esophoria had a higher PFV to blur point than exophoria (29.0 ± 9.61Δ compared to 23.07 ± 10.39Δ). While PFV at the break point differed by the type of heterophoria and was statistically significant (P = 0.007), with esophoria having a higher PFV (30.83 ± 8.79Δ) and exophoria having a lower PFV (25.59 ± 10.07Δ). Furthermore, PFV to the recovery point is higher in esophoria than in exophoria, with a significant difference (P = 0.008). On the other hand, NFV at the blur point, varied by the type of heterophoria and was extremely significant (P = 0.002), with higher NFV detected in exophoria (16.12 ± 6.21Δ) and slightly lower in esophoria (12.20 ± 8.38Δ). Regarding NFV, at the break and recovery points were found higher among exophoria condition and lower in esophoria condition and the difference was not statistically significant (P > 0.05). Near point of convergence differed by the type of heterophoria and was significant (P = 0.010), with exophoria having, on average, slightly receded NPC (8.38 cm ± 3.33 cm) and esophoria having the smallest (6.77 cm ± 1.52 cm), as shown in Table 3.

Correlation between the degree of exophoria and positive fusional vergence

The scatter plot demonstrated the relationship between near exophoria and PFV at the breakpoint. The regression equation is as follows: Exophoria = 8.68 – 0.13 PFV. As illustrated in Figure 1, the correlation coefficient between exophoria and PFV at the breakpoint was r = 0.33 (with the coefficient of determination, r^2 = 0.109).

Correlation of positive fusional vergence and near point of convergence

The scatter plot showed correlation of PFV (Δ) and NPC (cm). The regression calculation is expressed as follows: PFV in (Δ) = 34.83 – 1.10 (NPC in [cm]). Correlation coefficient between PFV at the breakpoint and NPC was r = 0.36 (see Figure 2).

Discussion

The compensation for heterophoria occurs through the mechanism of FV, which involves both sensory and motor fusion. This mechanism allows the eyes together to maintain binocular single vision and avoid diplopia. This study investigated the relationship between near heterophoria, NFV and NPC among Sudanese adolescents and young

TABLE 2: Association between symptoms and near heterophoria.

Complaints	Type of heterophoria				Total		Chi-square test
	Exophoria		Esophoria		N	%	
	N	%	N	%			
Visual perceptual distortion	23	88.5	3	11.5	26	100	χ^2 = 1.28
Binocular factors	7	100.0	0	0.00	7	100	df = 3
Asthenopia symptoms	106	86.9	16	13.1	122	100	P = 0.735
No symptoms	64	85.3	11	14.7	75	100	-
Total	**200**	**87.0**	**30**	**13.0**	**230**	**100**	**-**

TABLE 3: Near fusional vergence and near point of convergence in types of near horizontal heterophoria (0.33 m).

N = 230	Means	s.d.	s.e.	95% CI for means		Minima	Maxima	*P*
				Lower bound	Upper bound			
Heterophoria			**Positive fusional vergence [Blur point] (Δ)**					
Exophoria	23.07	10.39	0.74	21.62	24.51	4	43	0.003
Esophoria	29.00	9.16	1.67	25.58	32.42	12	44	-
Heterophoria			**Positive fusional vergence [Break point] (Δ)**					
Exophoria	25.59	10.07	0.71	24.18	26.99	6.00	45.00	0.007
Esophoria	30.83	8.79	1.60	27.55	34.12	16.00	45.00	-
Heterophoria			**Positive fusional vergence [Recovery point] (Δ)**					
Exophoria	20.26	9.91	0.70	18.87	21.64	2.00	40.00	0.008
Esophoria	25.37	8.77	1.60	22.09	28.64	10.00	40.00	-
Heterophoria			**Negative fusional vergence [Blur point] (Δ)**					
Exophoria	16.12	6.21	0.44	15.25	16.98	2	33	0.002
Esophoria	12.20	8.38	1.53	9.07	15.33	2	29	-
Heterophoria			**Negative fusional vergence [Break point] (Δ)**					
Exophoria	18.61	5.10	0.42	17.77	19.44	4.00	35.00	0.003
Esophoria	14.90	8.19	1.50	11.84	17.96	3.00	30.00	-
Heterophoria			**Negative fusional vergence [Recovery point] (Δ)**					
Exophoria	13.86	5.98	0.42	13.02	14.69	1.00	30.00	0.002
Esophoria	10.10	7.85	1.43	7.17	13.03	1.00	25.00	-
Heterophoria			**Near point of convergence (cm)**					
Exophoria	8.38	3.33	0.24	7.92	8.84	2.00	21.00	0.010
Esophoria	6.77	1.52	0.28	6.20	7.34	5.00	12.00	-

s.d., standard deviation; s.e., standard error; CI, confidence interval.

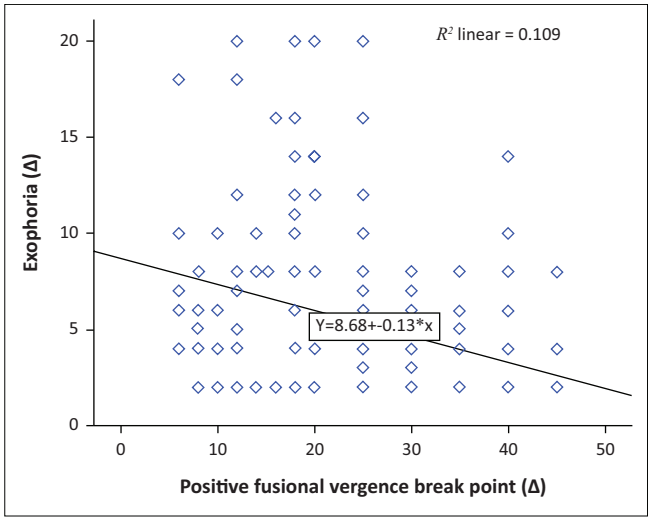

FIGURE 1: Correlation between the degree of near exophoria and positive fusional vergence breakpoints.

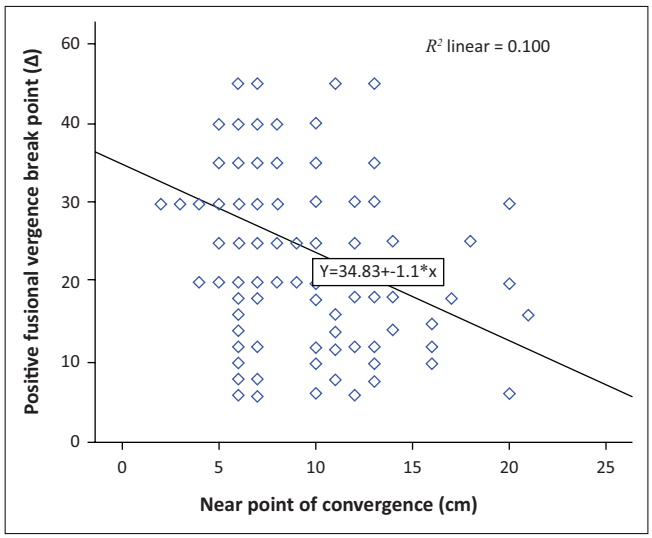

FIGURE 2: Correlation of positive fusional vergence (Δ) and near point of convergence (cm) on exophoria.

adults with near heterophoria and asthenopia. The study revealed that the most common type of near heterophoria among this Sudanese sample was exophoria, ranging from 2 to 20Δ with a mean of 5.23Δ. (This is like that commonly reported previously in the literature.) The most reported symptoms were asthenopia and were commonly found among exophoric patients (P = 0.735). Positive fusional vergence to the breakpoint is different according to the forms of heterophoria (P = 0.003), and esophoria had a higher PFV at breakpoint than exophoria. Regarding NFV, the break and recovery points were found higher among exophoria and lower in esophoria $P > 0.05$. Near point of convergence differed by type of heterophoria (P = 0.010), with exophoria having the receded NPC and esophoria having the shortest NPC.

Our study showed that exophoria at near fixation was highly prevalent among Sudanese subjects, this agreed with Leone et al.,[5] study, which reported that exophoria was the more common heterophoria among Australian children. Furthermore, East Asian populations have been associated with a wider inter-pupillary distance (IPD), and previous studies[15,16] have suggested that this could be linked to a higher occurrence of exophoria. Conversely, previous studies[17,18,19] conducted on children have consistently reported that having orthophoria, which is the state where the eyes are properly aligned and there is no latent deviation, is the most common condition observed in near fixation. These differences in findings could be because of variation in the ages; our study was conducted in adolescents and adults with mean age 19.46 (±3.33) years,

whereas the previous studies[17,18,19] were mostly conducted in young children.

This study found that PFV at near fixation was significantly lower in exophoria than esophoria, and this was consistent with a previous study[20] that indicated that during the school years, PFV ranges for both distance and near tend to decrease among myopic children as their near heterophoria, which becomes more exophoric. Our findings largely agreed with earlier studies.[10,12,21] Positive fusional vergence helps to control exophoria, which is a tendency for the eyes to deviate outwards, while NFV helps control esophoria, which is a tendency for the eyes to drift inwards.

Maddox[22] reported that FV is the motor response that is driven by feedback and serves as the final correction for any remaining retinal disparity. This correction takes place in the presence of other non-disparity-driven vergence components, such as tonic, accommodative, and proximal vergence. This means that not only FV strength plays a role in controlling heterophoria, tonic accommodation, tonic convergence and proximal accommodation and convergence, but also reflex accommodation. Our study revealed significant variations in NPC among participants with heterophoria, with exophoria exhibiting a more distant NPC compared to individuals with esophoria. These findings were supported by fusional vergence results, which indicated that esodeviation was associated with high PFV, while exodeviation was associated with low PFV.

Consequently, controlling heterophoria involves not just the strength of FV, but also the contributions of tonic accommodation, tonic convergence, proximal accommodation, and NPC, as well as amplitude of accommodation. Jampolsky[23] suggested that the shift from alignment to deviation in strabismus is associated with the relaxation of fusional convergence ranges. Researchers[24,25] have shown that there is a significant correlation between the width of the fusional range and the control of exodeviation. This suggests that the ability to maintain comfortable binocular single vision is related to the strength and flexibility of FV.

Study limitations and recommendations

This study has some limitations, such as that the sample size for individuals was relatively small (at 230) but especially so for those with near esophoria (<30). This creates uncertainties about some tables (e.g. Table 2 or Table 3) and subsequent results in this study; the readers should take this discrepancy in sample sizes (200 with near exophoria and the remainder with either orthophoria or esophoria) into consideration when assessing study results. For future research concerning this topic, it is recommended to markedly increase the sample size to ensure that enough participants with near esophoria are included to improve the validity and generalisability of the findings. Additionally, it is suggested that the Sheard and Percival criteria should be applied for the diagnosis of heterophoria, as this can provide more accurate and standardised measurements of the condition. Furthermore, future research should explore the association between FV and the NPC.

Another limitation was that only one method (cover test) was used to measure near heterophorias and possibly the use of other methods such as the Thorington might have improved the nature of the data collected for analysis. Future studies should include both objective and subjective methods for determination of the main variables of interest. Repeated measurements of the variables of interest would also have strengthened the overall analysis. A standardised questionnaire for symptomology (e.g. associated with convergence insufficiency) was not used and that might have also been a beneficial addition to the study, and certainly is recommended for future studies of this type.

Inclusion of fixation disparity and associated phorias also is recommended for future studies concerning this topic. Ocular accommodation was not included in the study and thus possible contributions of accommodative disorders to symptoms of asthenopia were unclear.

Measurements were obtained at 0.33 cm and this is not always in agreement with previous studies in this area where 0.4 m is more frequently used as the standard near testing or stimulus distance. Although this probably would not have major implications in terms of the study results, it does create some uncertainties in analysis and meaning of results.

Conclusions

Exophoria at near (0.33 m) was the most common type of decompensated heterophoria among the Sudanese in this study, with asthenopia being commonly reported. Esophoria was found to be strongly associated with high PFV. Exophoria, on the contrary, was related to significant NFV at the blur, break, and recovery points. The NPC differed significantly by type of the heterophoria, with those with near exophoria having slightly receded NPC and those with near esophoria (albeit a small group) having the smallest NPC. Clinically the difference was small (on average, 8.38 cm vs. 6.77 cm) but the difference across type of near heterophoria was significant (P = 0.01). Clinically, differences in mean results for blur, break and recovery points (Table 3) were not large (mostly < 6Δ) across type of near heterophoria, albeit the differences were found to be statistically significant, but the discrepancy in sample sizes for those with near exophoria versus those with near esophoria should be taken into consideration.

Acknowledgements

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

S.H.A. conceptualised the study and contributed to data curation, formal analysis, methodology, validation and investigation. S.A. was involved in software, writing the original draft, and review and editing the final draft.

Funding information

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability

The data that support the findings of this study are available from the corresponding author, S.H.A.., upon reasonable request.

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