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Exploring the association between asthenopia, vergence measures and the interpupillary distance

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Background: Exploring the possible association between Interpupillary distance (IPD), and vergence parameters (VPs) and asthenopia may give an impression of a vergence disorder (VD).

Aim: To investigate the association between asthenopia, VPs, VDs, and IPD among junior high school (JHS) students.

Setting: The study took place in JHSs in Cape Coast, Ghana.

Methods: A cross-sectional study design and a multi-stage sampling technique was employed. Five hundred and forty-six (546) students enrolled completed oculo-visual screening, Convergence Insufficiency Symptom Survey (CISS) administration, IPD measurements, and VPs assessments [near point of convergence (NPC), lateral heterophoria, positive fusional vergence (PFV), negative fusional vergence (NFV) amplitudes, Gradient AC/A ratio and relative accommodation] over maximum plus for best corrected visual acuity refractive correction.

Results: The IPD status (small [OR] = 0.542, CI = 0.200 – 1.470, p = 0.229), medium (OR = 1.182, CI = 0.818 – 1.708, p = 0.373), large (OR = 0.920, CI = 0.630 – 1.344, p = 0.668) was not a risk for asthenopia. Small (p = 0.598), medium (χ^2 = 0.046, p = 0.831), and large (χ^2 = 2.875, p = 0.090) IPD was not associated with VDs. There were significant correlations between IPD, and NPC break (r_s = 0.101, p = < 0.018); distance PFV blur (r_s = 0.106, p = 0.014) and break (r_s = 0.129, p = 0.003); near NFV blur (r_s = 0.096, p = 0.025) and break (r_s = 0.103, p = 0.016); near PFV blur (r_s = 0.111, p = 0.010) and break (r_s = 0.125, p = 0.003).

Conclusion: VD and asthenopia cannot be predicted with IPD

Contribution: The IPD is not diagnostic sign for vergence disorder.

Keywords: interpupillary distance; facial asymmetry; asthenopia; vergence disorders; vergence parameters.

Introduction

The distance between the pupil centres of the two eyes, commonly referred to as interpupillary distance (IPD), facilitates the alignment of optical centres of ophthalmic lenses with pupil centres (primary visual axes) of each eye to eliminate unwanted prismatic effect during vision examination and spectacle fitting.[1] The IPD serves as an initial measure relevant to achieving reliable results in most optometric procedures such as subjective refraction (setting the correct IPD in the trial frame), objective refraction (retinoscopy and automatic refractometry) and binocular vision (BV) assessment using the phoropter. The correct IPD needs to be set in instruments for the above procedures to achieve reliable results. The IPD is also used to compute vergence in most eye or gaze-position trackers.[2] The anatomical IPD (horizontal separation of the two eyes) geometrically makes each eye receive slightly different retinal images; however, motor and sensory fusional mechanisms act to produce a single binocular perception.[3] The IPD, thus, is a key determinant of binocular function and is expressed in the determination of the accommodative convergence over accommodation (AC/A) ratio in the relation, $AC/A\ ratio = IPD + (n - d)/D$, where IPD is in centimetres, n, d and D represent near phoria, distance phoria and accommodative demand at near, respectively.[3,4] Determination of the AC/A ratio is important in the analysis of optometric data, especially in the diagnosis and management of vergence disorders (VDs). A reduced AC/A ratio is a major sign of convergence insufficiency or divergence insufficiency, and a greater AC/A ratio is a major sign of convergence excess or divergence excess.[4]

Only a few studies[5,6,7] have reported associations between IPD and vergence parameters (VPs). Filipovic found that IPD does not affect the near convergence and distance ratio in subjects from Croatia.[6] Cunha and Correia[5] studied IPD and convergence in a Brazilian presbyopic population and found variations in convergence because of differences in IPD, as the two were directly correlated. Dag et al.[7] reported differences in fusional vergence amplitudes and stereoacuity levels among normal ophthalmology residents and juniors in Turkey with varying IPDs. The association between IPD and other BV parameters such as heterophoria, near point of convergence (NPC), relative accommodation and AC/A ratio has not been investigated. Moreover, because an anomaly in the vergence system may result in eyestrain,[3,4] exploring the association between IPD and asthenopia symptoms clarifies the relationship with VDs. Furthermore, there is a physiological increase in IPD because of normal growth,[8] and BV anomalies are anecdotally common in children; therefore, it is necessary to investigate whether the reduced IPD in younger individuals influences the frequency of VDs. Understanding the association of IPD with VPs may impact perceptions of VDs and/or lead to their inclusion in the diagnostic criteria for VDs. The aim of this study was to examine the vergence system of junior high school (JHS) students in Ghana to explore possible associations between asthenopia, VPs and IPD.

Research methods and design

Study design, population and sampling

The study was a school-based cross-sectional design, and a multi-stage sampling technique was used to enrol JHS children aged 12 years – 17 years in Cape Coast, Ghana. The JHSs in Cape Coast were clustered into the north and south. Three JHSs within each cluster were selected using a random sampling method to participate. Within the chosen schools, 100 students were selected using a random sampling method to participate in the study. The Cochran formula (Equation 1):

$$n = \frac{z^2 pq}{e^2} \quad \text{[Eqn 1]}$$

where n is the minimum sample size, p is the prevalence of VDs in Cape Coast children (14.8%),[8] q is $1–p$ $(1 – 0.148)$ and e is the desired level of precision (5%), and $z^2 = 1.96$ was used to calculate for a minimum sample size (424.6), using a confidence interval of 95%, accounting for an attrition rate of 10% and a design effect of 2.

Data collection procedure

Oculo-visual screening

The oculo-visual screening included visual acuity measurement using the LogMAR chart, the Broad-H test to assess ocular motility, the unilateral cover test to check for heterotropia and an ocular health assessment using a hand-held slit lamp, penlight and a direct ophthalmoscope.

Exclusion criteria

We excluded JHS students with unilateral or bilateral blindness (defined as no perception of light), amblyopia, heterotropia, nystagmus and acute external and internal ocular diseases. Excluded participants were referred to the neighbouring eye hospitals for full visual examination.

Questionnaire administration

The reliable (Cronbach's alpha, 0.867 for participants) convergence insufficiency symptom survey (CISS), a revised and validated 15 asthenopia symptom questionnaire,[9] was administered to quantify the symptom level of participants who passed the ocular screening. In children, a CISS score of greater than or equal to 16 indicates the presence of symptoms.[9] The questionnaire was read verbatim to the students, and they ticked the level of severity (never, infrequently, sometimes, fairly often and always) of any of the 15 symptoms (link:https://da4e1j5r7gw87.cloudfront.net/wp-content/uploads/sites/3704/2022/01/CISS.pdf) they experienced. Participants whose CISS score was greater than or equal to 16 were classified as having asthenopia.[9]

Interpupillary distance

Monocular and binocular distance and near IPDs were measured and recorded using the cornea reflex pupilometer (model: New Century NCE-90 K Digital PD). For distance IPD and near measurements, the fixating light of the pupillometer was set for distance and near, respectively. The distance and near IPDs were recorded after taking the average of three readings from the instrument in millimetres (mm). The difference in distance IPD for the right and left eyes represents the magnitude of facial asymmetry.

Refraction

An objective refraction was performed using the Keeler 3.6V streak retinoscope (Matronix India Corporation). A non-cycloplegic refraction was performed using trial lens sets, and the maximum plus correction for best visual acuity (MPBVA) after subjective refraction was recorded for each participant.

Vergence

Vergence measurements included NPC, lateral heterophoria, positive fusional vergence (PFV) and negative fusional vergence (NFV) reserves.

Near point of convergence

The Royal Air Force (RAF) rule (Harlow, Essex, CM20 2TT, Clement Clarke International, UK, CE0120) was positioned on the sides of the nose under the two eyes, with the line targets seen midway, and the participant was instructed to fixate on the smallest dot in the line. The participant was instructed to keep looking at the smallest dot as it was moved gradually towards their eyes and to say 'double' when the line appeared two. When participants reported double, they were encouraged to try and keep it single again. The target was slowly but steadily moved towards the eyes until the patient reported a sustained double (breakpoint). When the participant reported doubling, the target was slowly moved away from the face until the participant reported it became single again. This distance was recorded as the recovery point. The test was repeated three times for every participant, and the averages were recorded as the break and recovery points in centimetres.

Heterophoria

Heterophoria was measured employing the alternate cover test with the prism neutralisation technique. The procedure was explained to the participant. For near testing, the participant fixated on the N6 letters on a fixation card positioned at 40 cm; for far testing, the participant fixated on the 6/6 letters on the Snellen visual acuity chart at 6 m. The occluder was placed before one eye for 2 to 3 seconds and then transferred quickly to the other eye, without pausing. The occluder was kept in front of the eye for 2 to 3 seconds for the other eye to take up fixation, and the cycle was repeated. The examiner watched out for any movement of the eyes from the just unoccluded eye as the occluder was switched to the other eye. The prism bar was positioned base-out or base-in in front of the eye to measure the horizontal deviation only if the just un-occluded eye moved out or in, respectively.

Fusional vergence reserves

Positive fusional vergence and NFV amplitudes were measured at far and near using the step vergence (prism bar) technique. Participants were instructed to fixate on the 6/6 and N6 letters for distance and near testing, respectively, after explaining the test to them. For PFV and NFV testing, the horizontal prism bar was placed base-out and base-in before the participant's right eye, respectively, and slowly increased until they reported the target became blurred, doubled and became single again. The test was repeated thrice, and the averages of the amount of prism powers for blur, break and recovery points were recorded for each base-out and base-in measure, respectively.

Gradient accommodative convergence over accommodation ratio

A +1.00 DS lens was placed over the participant's MPBVA correction in a trail frame, and the near phoria was determined again employing the alternative cover test with prism neutralisation. This AC/A ratio was determined by subtracting the habitual phoria at near over MPBVA from that with an additional +1.00 DS lens.

Relative accommodation

The participant's MPBVA refractive correction was set in the phoropter. The near card was set at 40 cm on a near-point rod fitted to the phoropter. The participant was set up behind the phoropter and was instructed to fixate on the vertical line of 20/30 letters on the near card. Plus and minus lenses in the phoropter were added in +0.25 D and –0.25 D step increments, respectively, until the participant reported the first sustained blur. The amount of additional plus and minus lenses was recorded as the negative relative accommodation (NRA) and positive relative accommodation (PRA), respectively. The test was repeated thrice and the averages were recorded for NRA and PRA, respectively.

Each optometric test described above was performed by one examiner throughout the study to prevent inter-examiner variations in results. All testing was performed in the school setting.

Diagnostic criteria for vergence disorder

The diagnostic criteria for VDs are described in Table 1.[4] To strengthen the diagnosis of VD, other signs that check interactions between the vergence and accommodative system, namely the gradient AC/A ratio, NRA and PRA, were also measured.

Data analysis

Data were analysed using the IBM SPSS version 22. The Chi-square, Fisher's exact and binary logistic regression models were used to investigate associations between categorical variables. The Mann–Whitney U test was used to determine the differences in some parameters based on gender. The paired samples Wilcoxon test was used to test differences in IPD between right and left eyes. Kruskal–Wallis one-way analysis of variance (ANOVA) was used to compare various VPs between IPD statuses. Spearman's rho correlation test was used to determine the relationship between IPDs and VPs. All testing was performed at a significance level of < 0.05.

Ethical considerations

The study was approved by the institutional review board of the University of Cape Coast (reference number: UCCIRB/CHAS/2018/51). The heads of various schools sampled gave permission, parents gave written informed consent, and children gave assent.

Results

A total of 600 participants were enrolled in the study, and 54 were excluded with amblyopia (n = 27), strabismus (n = 9), external ocular disease (n = 7), internal ocular disease (n = 10) and nystagmus (n = 1). The remaining participants (546) with a median age of 15 years (interquartile range [IQR] = 2) and comprising 258 males (47.3%) and 287 females (52.6%) completed all procedures. The distribution of the clinical VPs and IPD anthropometric measures is indicated in Table 2; only binocular distance IPD was approximately normally distributed (Table 2). In a Mann–Whitney U test, males (mean rank = 296.04) were significantly older than females (mean rank = 252.29) (U = 31079, Z = –3.300, P = 0.001).

The frequency of IPDs, asthenopia and VD is indicated in Table 1. There was a significant positive correlation between distance binocular IPD and near binocular IPD (r_s = 0.882, P < 0.0001); thus, distance IPD was used in further analysis. Distance binocular IPD increased with age among

TABLE 1: Diagnostic criteria for variables.

Variables	Diagnostic criteria	Frequency	%
Small IPD	56 mm to 62 mm IPD	19	3.5
Medium IPD	63 mm to 68 mm IPD	360	65.9
Large IPD	69 mm to 75 mm IPD	167	30.6
Asthenopia	CISS score of more than 16.†	296	54.2
Vergence disorders	First two and either 3 or 4 of signs of specific vergence disorders below:	92	16.8
Convergence insufficiency	Receded NPC: break > 7 cm; recovery > 9 cm	59	10.8
	High exophoria at near (> 6$^{\Delta}$)	-	-
	Low or decompensated PFV at near (< 12/ < 16/ < 7)	-	-
	Low AC/A ratio (< 3/1)	-	-
	Low NRA (+0.25 D to +1.50 D)	-	-
Basic exophoria	Equal exophoria at distance and near of ≥ 5$^{\Delta}$	5	0.9
	Low PFV at distance (< 7/< 15/< 8) and near (< 14/< 18/< 7)	-	-
	Low NRA (+0.25 D to +1.50 D) Normal AC/A ratio (3–5/1)	-	-
Divergence excess	High exophoria at distance (> 2$^{\Delta}$)	1	0.2
	High AC/A ratio (> 5/1)	-	-
	Low NFV at near (< 11/< 19/< 10)	-	-
	Low PFV at distance (< 7/< 15/< 8)	-	-
Convergence excess	Near esophoria > Distance esophoria	4	0.7
	Low NFV at near (< 11/< 19/< 10)	-	-
	Low PRA (-0.25 D to -1.50 D)	-	-
	High AC/A ratio (> 5/1)	-	-
Basic esophoria	Equal esophoria at distance and near of ≥ 5$^{\Delta}$	0	0.0
	Low NFV at distance (-/< 5/< 3) and near (< 11/< 19/< 10)	-	-
	Low PRA (-0.25 D to -1.50 D)	-	-
	Normal AC/A ratio (3–5/1)	-	-
Divergence insufficiency	Distance esophoria > Near esophoria	1	0.2
	Low AC/A ratio (< 3/1)	-	-
	Low NFV at distance (-/< 5/< 3)	-	-
Fusional vergence dysfunctions	Orthophoria or a low degree of esophoria or exophoria at distance and near	22	4.0
	Low FVA at distance and near (Distance PFV: < 7/< 15/< 8; Near PFV: < 14/< 18/< 7; Distance NFV: -/< 5/< 3; Near NFV: < 11/< 19/< 10)	-	-
	Low PRA (-0.25 D to -1.50 D)	-	-
	Low NRA (+0.25 D to +1.50 D)	-	-

IPD, Interpupillary distance; CISS, convergence insufficiency survey; NPC, near point of convergence; PFV, positive fusional vergence; AC/A, accommodative convergence over accommodation ratio; NRA, negative relative accommodation; NFV, negative fusional vergence; PRA, positive relative accommodation.

†, Anderson H, Stuebing KK, Fern KD, Manny RE. Ten-year changes in fusional vergence, phoria, and near point of convergence in myopic children. Optom Vis Sci. 2011;88(9):1060–1065.

participants (r_s = 0.302, P < 0.0001). In a Mann–Whitney U test, distance binocular IPD for males (mean rank, 306.42) was significantly higher than for females (mean rank, 242.95) (U = 28 400, Z = –4.702, P < 0.0001. In a paired samples Wilcoxon test, there was a significant median difference between monocular near IPD for right and left eyes (Z = –3.550, P < 0.0001), a mean difference of 0.16 mm; also, there was a significant median difference in monocular distance IPD between right and left eyes (Z = –3.425, P = 0.001), a mean difference of 0.18 mm.

Participants with small (odds ratio [OR] = 0.542, confidence interval [CI] = 0.200 – 1.470, P = 0.229), medium (OR = 1.182, CI = 0.818 – 1.708, P = 0.373) and large (OR = 0.920, CI = 0.630 – 1.344, P = 0.668) IPDs were not likely to experience asthenopia. There was no statistically significant correlation between distance binocular IPD and CISS score (r_s = –0.058, P = 0.177). There was no statistically significant correlation between facial asymmetry and CISS score (r_s = 0.001, P = 0.988).

There was no significant association between the small distance IPD (P = 0.598), medium distance IPD (χ^2 = 0.046, P = 0.831) and large distance IPD (χ^2 = 2.875, P = 0.090) and VDs. There were significant differences in certain VPs between participants with small, medium and larger IPDs (Table 3). Table 4 indicates the correlation between specific VPs and facial asymmetry magnitudes. There were significant correlations between IPD and NPC and some FVRs (Table 5).

Discussion

This study found no association between IPD ranges and asthenopia and VDs. There were, however, significant positive correlations between IPD and some VPs, namely NPC break, NPC recovery and some FVR (distance PFV break, near NFV break and recovery, near PFV blur and break). Again, there were differences in the VPs between the different IPD ranges: small, medium and large.

The increased IPD is associated with receded NPC; receded NPC is a direct sign of convergence insufficiency[4] (the common VD among African populations[8,10]). The positive correlation between IPD and some FVR, but with no significant relationship between distance and near phoria, indicates that fusional amplitudes increase in patients with

TABLE 2: Interpupillary distance anthropometric measures for population and descriptive measures of vergence parameters.

Parameters	Mean	s.d.	95% CI	5th percentile	25th percentile	Median	IQR	75th percentile	95th percentile	SW *P*
VA (RE)	-0.02	0.04	-0.02 to -0.01	-0.10	0.00	0.00	0.00	0.00	0.00	< 0.0001
VA (LE)	-0.02	0.04	-0.02 to -0.01	-0.10	0.00	0.00	0.00	0.00	0.00	< 0.0001
DIPD (RE)	32.75	1.65	32.62 to 32.89	30.00	31.70	32.80	2.30	34.00	35.00	< 0.0001
DIPD (LE)	32.57	1.80	32.41 to 32.72	29.60	31.70	32.45	2.60	34.00	35.00	0.0020
DIPD (BE)	65.32	3.20	65.06 to 65.60	60.00	63.20	65.00	4.02	67.23	70.57	0.1090
NIPD (RE)	30.77	1.85	30.61 to 30.92	27.90	29.50	30.70	2.50	32.00	34.00	< 0.0001
NIPD (LE)	30.61	1.87	30.45 to 30.76	27.50	29.28	30.60	2.73	32.00	34.00	0.0130
NIPD (BE)	61.37	3.50	61.07 to 61.66	56.00	59.00	61.05	5.00	64.00	67.65	0.0050
CISS	19.04	12.02	18.00 to 20.08	2.30	9.00	17.00	19.00	28.00	40.65	< 0.0001
NPC break	6.44	2.12	6.26 to 6.62	3.00	5.00	8.00	3.00	8.00	10.00	< 0.0001
NPC recovery	8.52	2.26	8.33 to 8.71	5.00	7.00	8.00	3.00	10.00	13.00	< 0.0001
Distance phoria	-0.17	1.46	-0.05 to -0.29	-2.00	0.00	0.00	0.00	0.00	1.00	< 0.0001
Near phoria	-2.23	2.76	-2.00 to -2.46	-7.00	-4.00	-2.00	4.00	0.00	1.65	< 0.0001
DBI break	11.01	5.27	10.57 to 11.46	4.00	8.00	10.00	6.00	14.00	20.00	< 0.0001
DBI recovery	6.12	4.00	5.79 to 6.46	2.00	4.00	5.00	4.00	8.00	15.00	< 0.0001
DBO blur	11.44	5.61	11.00 to 11.91	4.00	7.00	10.00	7.00	14.00	22.65	< 0.0001
DBO break	18.00	7.66	17.46 to 18.75	6.00	12.00	18.00	13.00	25.00	30.00	< 0.0001
DBO recovery	10.31	5.02	9.89 to 10.73	2.00	6.00	10.00	8.00	14.00	20.00	< 0.0001
NBI Blur	11.77	5.79	11.29 to 12.26	4.00	8.00	11.00	7.00	15.00	22.65	< 0.0001
NBI break	18.86	8.42	18.15 to 19.57	6.00	12.00	18.00	13.00	25.00	35.00	< 0.0001
NBI recovery	10.94	5.40	10.48 to 11.39	3.35	6.00	10.00	8.00	14.00	20.00	< 0.0001
NBO blur	13.57	6.33	13.04 to 14.10	4.00	8.00	12.50	10.00	18.00	25.00	< 0.0001
NBO break	21.10	8.78	20.36 to 21.84	6.00	14.00	20.00	16.00	30.00	35.00	< 0.0001
NBO recovery	12.77	5.70	12.30 to 13.25	4.00	8.00	12.00	9.00	16.00	22.00	< 0.0001
NRA	3.25	1.82	3.10 to 3.41	1.00	2.25	3.00	1.75	4.00	6.00	< 0.0001
PRA	-3.46	1.86	3.31 to 3.62	1.00	2.50	3.50	1.50	4.00	6.00	< 0.0001
AC/A	2.70	1.01	2.71 to 2.88	1.00	2.00	3.00	1.00	3.00	4.00	< 0.0001
MFAssy	0.91	0.93	0.83 to 0.99	0.00	0.00	1.00	1.40	1.40	2.70	< 0.0001

SW, Shapiro-Wilk; IQR, interquartile range; CI, confidence interval; NPC, near point of convergence, DBI, distance base-in; DBO, distance base-out; NBI, near base-in; NBO, near base-out; rec, recovery; DIPD, Distance interpupillary distance; NIPD, Near Interpupillary distance; NRA, negative relative accommodation; PRA, positive relative accommodation; AC/A, accommodative convergence over accommodation; MFAssy, Mag Asymmetry face in millimetres; VA, visual acuity; RE, right eye; LE, left eye; BE, both eyes; CISS, convergence insufficiency survey, s.d., standard deviation.

TABLE 3: Differences in vergence parameters between interpupillary distance statuses using Kruskal–Wallis one-way analysis of variance.

Vergence parameter	Ranks of IPD status			Kruskal–Wallis H	*df*	*P*
	Small	Medium	Large			
NPC break	251.25	261.30	302.50	8.342	2	0.015*
NPC recovery	255.23	262.17	300.14	7.036	2	0.030*
Distance phoria	318.59	272.97	268.69	3.260	2	0.196
Near phoria	294.57	281.55	253.52	4.116	2	0.128
Distance BI break	311.02	267.14	282.14	2.362	2	0.307
Distance BI recovery	303.77	273.41	269.71	0.933	2	0.627
Distance BO blur	248.84	264.86	295.21	4.816	2	0.090
Distance BO break	221.52	263.09	302.60	9.683	2	0.008*
Distance BO recovery	242.77	268.76	287.78	2.534	2	0.282
Near BI blur	261.39	262.64	298.32	6.012	2	0.049
Near BI break	243.73	261.32	303.51	9.003	2	0.011*
Near BI recovery	255.05	259.84	305.13	9.779	2	0.008*
Near BO blur	267.48	260.49	302.11	8.006	2	0.018*
Near BO break	254.27	259.26	306.48	10.628	2	0.005*
Near BO recovery	254.39	263.87	296.60	5.275	2	0.072
NRA	272.11	276.83	266.54	0.492	2	0.872
PRA	259.70	263.78	296.09	5.020	2	0.081
AC/A ratio	271.50	278.40	263.29	1.136	2	0.567
CISS	294.61	272.28	273.32	0.416	2	0.812

NPC, near point of convergence; BI, base in; BO, base out; NRA, negative relative accommodation; PRA, positive relative accommodation; AC/A, accommodative convergence over accommodation; IPD, interpupillary distance; *df*, degrees of freedom;CISS, convergence insufficiency symptom survey.

*, statistical signficance at 95% confidence interval.

larger IPDs to compensate for possible vergence demands. The convergence and divergence demand for individuals with larger IPD may be greater; thus, higher relative NFV and PFV range will increase the starting point for convergence and divergence, respectively. It is also possible that the oculomotor system's innervation for convergence compensates for the increase in IPD[6]; objects can be seen as single and with stereopsis if the IPD remains within Panum's

TABLE 4: Correlation between facial asymmetry and specific vergence parameters.

Parameter of vergence	r_s	*P*
NPC break	-0.174	< 0.0001*
NPC recovery	-0.163	< 0.0001*
Distance phoria	0.011	0.8060
Near phoria	-0.084	0.0510
Distance BI break	-0.032	0.4580
Distance BI recovery	0.026	0.5380
Distance BO blur	-0.053	0.2150
Distance BO break	-0.088	0.0400*
Distance BO recovery	-0.040	0.3550
Near BI blur	-0.055	0.1980
Near BI break	-0.104	0.0150*
Near BI recovery	-0.030	0.4780
Near BO blur	-0.078	0.0690
Near BO break	-0.083	0.0540*
Near BO recovery	-0.048	0.2600
NRA	0.078	0.0690
PRA	-0.101	0.0180*
AC/A ratio	0.005	0.8980

NPC, near point of convergence; BI, base in; BO, base out; NRA, negative relative accommodation; PRA, positive relative accommodation; AC/A, accommodative convergence over accommodation.

*, statistical significance at 95% confidence interval.

TABLE 5: Correlation between near and distance binocular interpupillary distance and specific parameters of vergence.

Parameter of vergence	Near IPD		Distance IPD	
	R_s	*P*	r_s	*P*
NPC break	0.216	< 0.0001*	0.101	0.018*
NPC recovery	0.210	< 0.0001*	0.097	0.024*
Distance exophoria	0.094	0.0280*	0.051	0.237
Distance esophoria	0.176	0.2040	0.138	0.321
Near exophoria	0.059	0.1700	0.074	0.086
Near esophoria	-0.062	0.1490	-0.047	0.277
Distance BI break	0.077	0.0700	-0.002	0.964
Distance BI recovery	-0.033	0.4480	-0.033	0.437
Distance BO blur	0.128	0.0030*	0.106	0.014*
Distance BO break	0.202	< 0.0001*	0.129	0.003*
Distance BO recovery	0.077	0.0730	0.062	0.146
Near BI blur	0.155	< 0.0001*	0.096	0.025*
Near BI break	0.198	< 0.0001*	0.103	0.016*
Near BI recovery	0.150	< 0.0001*	0.112	0.009*
Near BO blur	0.187	< 0.0001*	0.111	0.010*
Near BO break	0.229	< 0.0001*	0.129	0.003*
Near BO recovery	0.136	0.0010*	0.076	0.077
NRA	-0.152	< 0.0001*	-0.031	0.469
PRA	0.227	< 0.0001*	0.047	0.276
AC/A ratio	-0.071	0.0960	-0.009	0.828

IPD, interpupillary distance; NPC, near point of convergence; BI, base in; BO, base out; NRA, negative relative accommodation; PRA, positive relative accommodation; AC/A, accommodative convergence over accommodation.

*, statistical significance at 95% confidence interval.

fusional area.[3] This result is comparable to a study by Anderson et al.[11] who found a positive relationship between IPD and NFV at near. The positive correlation between IPD and NPC is consistent with a study among a presbyopic population in Brazil.[5]

The increased IPD with age in this study is consistent with a study by AlAnazi et al.[8] The positive correlation between IPD and FVR may thus imply that, possibly with smaller IPD in children, phoria demands on the vergence system become decompensated because FVRs are smaller. This may be especially so when phorias do not change significantly with age[12] and may explain why BV problems are common in children. A study[11] indicates that a significant positive correlation exists between age and horizontal phoria among myopes. This implies that smaller heterophorias in children with myopia may not put greater demands on the BV systems, even with reduced FVR in the younger age group. A longitudinal study among participants with myopia, however, found no association between IPD and vergence measures at distance.[11] Also, heterophoria has been reported to be positively associated with changes in age and near IPD.[8] The increased FVR with increased IPD, as determined in this study, may compensate for the higher phoria demands on the visual system with ageing. According to AlAnazi et al.,[8] there may be more esophoria and more exophoria at near for patients with smaller than 62.5 mm near IPD and ones with larger near IPD, respectively. With the positive correlation between IPD and FVR, it may suggest that near esophoria may become decompensated in individuals with smaller NIPD; exophoria at near, on the other hand, may become compensated as FVR increases with increased IPD.

The differences in certain VPs (Table 2) among participants with small, medium and large IPDs further emphasise their associations. This indicates that vergence amplitudes are influenced by variations in IPDs, comparable to the findings of Dag et al.[7] The positive correlation between IPD and fusional vergence amplitude in this study is inconsistent with Dag et al.,[7] who found that individuals with larger IPDs exhibit lower fusional vergence amplitudes.

The IPD facial anthropometry measures for school children in the Cape Coast metropolis are comparable to those for children in the Kumasi metropolis of Ghana[12,13] and Malawi.[14] The higher IPD for males compared to females aligns with other studies on African populations.[13,14,15] Kumah et al.[13] attributed this difference to the potentially larger craniofacial skeletons in males than in females. This IPD data can inform the design of spectacle frames for Ghanaian JHS students.

The role of IPD in the vergence system and its association with other parameters needs further clarification (before findings can be applied in the clinic) and should be explored in future studies. A limitation of our study is the failure to exclude participants with reduced stereopsis and suppression, as these two parameters affect the vergence system and can influence the results. Future studies should consider excluding participants with reduced stereopsis and suppression.

In conclusion, IPD may not predict asthenopia and VDs in JHS students in Cape Coast, Ghana. NPC and fusional vergence amplitudes (distance PFV break, NFV break and recovery at near, near PFV blur and near PFV break) correlated positively with IPD. This implies that the increasing demand on the BV system because of large IPD may be compensated by the corresponding increase in fusional reserves. Authors, however, do not seem to imply causation or impact from correlations in this cross-sectional study.

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Competing interests

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Authors' contributions

C.D.-T. contributed to conceiving, designing, collecting and analysing data and drafting the article. S.A.A., E.K.A., M.N., C.H.A., F.L.O. and S.O. contributed equally in designing, data collection, data analysis and writing the article.

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Data availability

The raw data were generated at study sites (basic schools in Cape Coast). The derived data of this study are available from the corresponding author, C.D.-T., on reasonable request.

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