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Association of Symptoms with Refractive, Accommodative, and Vergence Anomalies in a Sample of Black High School Students in South Africa

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ABSTRACT

Background: Symptoms in refractive, accommodative, and vergence anomalies are similar, which may pose some challenges with differential diagnosis. The aim of conducting this study was to explore associations among symptoms and refractive, accommodative, and vergence anomalies.

Methods: Using a multi-stage random cluster sampling, 1211 children (481 males and 730 females) between 13 and 19 years of age, with a median age of 16 years, were selected. The preliminary visual functions evaluated included visual acuity, stereo-acuity, and suppression; refractive errors were measured objectively using the autorefractor and then refined subjectively. Other tests performed included measurement of accommodative (amplitude, accuracy, facility, and relative) and vergence functions (near point of convergence, heterophoria, and fusional vergences). Symptoms were evaluated using the Convergence Insufficiency Symptom Survey.

Results: The prevalence of the respective refractive errors were: myopia (≥-0.50 D) 4.4%, hyperopia (≥+0.50 D) 4.8%, and astigmatism (≥-0.75 DC) 3.2%; the prevalence of anisometropia (≥±0.75 D spherical equivalent refraction between both eyes) was 1.3%. The prevalence estimates for accommodative anomalies were: accommodative infacility 12.9%, accommodative insufficiency 4.5%, and accommodative excess 2.8%. Accommodative infacility was associated with more symptoms than accommodative insufficiency, whereas accommodative excess was not associated with any symptoms. The prevalence estimates for convergence insufficiency were: low suspect 11.8%, high suspect 6%, definite 4.3%, and pseudo-convergence insufficiency 1.9%. The prevalence of convergence excess was 5.6%, and that of fusional vergence dysfunction was 3.3%. The mean symptom scores for pseudo-convergence insufficiency, convergence excess, and fusional vergence dysfunction were higher than those for any severity of convergence insufficiency. Overall, the mean symptom scores for accommodative insufficiency, infacility, and pseudo-convergence insufficiency were significantly higher than other anomalies. For all types of anomalies, the mean symptom scores for females were significantly higher than for males (p=0.001), older students were significantly higher than younger students (p=0.001), and higher grade levels were significantly higher than lower grade levels (p=0.001).

Conclusion: Our findings suggest that astigmatism is the most symptomatic refractive error, while accommodative infacility, accommodative insufficiency, and pseudo-convergence insufficiency are the most symptomatic accommodative-vergence anomalies. Accommodative excess, convergence insufficiency, convergence excess, and heterophoria are least likely to produce symptoms. Female students are more likely to be symptomatic than males, as are students in upper school grade levels compared to students in lower grade levels. Identification of symptoms that are specific to each anomaly is useful for differential diagnosis and treatment.

Keywords: accommodative-vergence anomalies, high school students, refractive errors, symptoms

Introduction

Refractive errors, accommodative mechanisms, and vergence mechanisms constitute part of the visual efficiency system (VES),[1] and refractive errors play a dynamic role in the etiology and treatment of binocular vision anomalies.[1] Accommodative anomalies are syndromes of clinical signs,[2] which are classified into patterns of inadequate responses to stimulation: accommodative insufficiency (AI), accommodative excess (AE), or both (accommodative infacility, AIF).[3] Vergence anomalies, including convergence insufficiency (CI), convergence excess (CE), and fusional vergence disorders (FVD), result in either a failure of fusion or an inability to sustain comfortable bifoveal fixation.[2] Convergence insufficiency is characterized by the eyes' inability to converge accurately or to sustain convergence for a considerable period of time when a near task is performed.[4,5] In CE, there is a tendency for the eyes to over-converge at near,[4,5] while in FVD, there are deficiencies in the fusional vergence dynamics[4] and an inability of the fusional vergence system to respond efficiently to changing vergence demands over time.[6]

Anomalies in the refractive-accommodative-vergence (RAV) result from deficiencies in the interactions among the components.[2,4] Such anomalies and associated symptoms are primarily aggravated by prolonged visually demanding, near-centered tasks such as reading, writing, or computer-based work.[2,4] The symptoms include blurred vision at near, diplopia, eye strain, tearing, eyes tiring, and headaches. They affect visual efficiency, create discomfort, and impair efficient near tasks and may negatively impact on a child's academic performance and intellectual development.[4,5] The negative consequences of the anomalies of the RAV on learning are experienced more especially at the upper school grade levels when visual demands increase and there is a greater demand for sustained clear, binocular vision.[1,3,7] Symptoms in the visual efficiency parameters may appear similar, although there could be unique features among them. The similarities in symptoms may create challenges related to diagnosis and treatment of the associated anomalies and symptoms. There are also challenges in delineating symptoms associated with specific anomalies, and various studies[6,8-28] that have investigated association of symptoms with visual parameters yielded diverse findings. Sheedy and Saladin,[18] Yekta et al.;[20] as well and Gall and Wick[6] found heterophoria to be a poor indicator of symptoms. School children with myopia and astigmatism reported asthenopia more often than those with hyperopia.[8] In the study by Hendricks et al.;[22] headache was found to be associated with both myopia and hyperopia, while Iribarren et al.[19] and Hennessey et al.[17] found AIF to be better indicators of asthenopic symptoms in school children.

The aim of conducting the present study was to explore the association of symptoms with RAV anomalies among participants. In contrast to previous studies,[6,8-28] we investigated which symptoms could differentiate among RAV anomalies by using the means and percentages and by analysing specific associations of anomalies with symptoms. The findings will be beneficial in the differential diagnosis of refractive and non-strabismic accommodative-vergence anomalies.

Methods

Study Design

A cross-sectional descriptive and analytical study was designed to determine the prevalence of RAV anomalies and their associations with symptoms. Overall, the conduct of the study complied with the Declaration of Helsinki[29] regarding research on human subjects, and the study protocol was approved by the Biomedical Research Ethics Committee of the University of KwaZulu-Natal Durban, South Africa (BE 177/12).

Sample and Study Setting

The study sample comprised high school students selected from 13 out of a total of 60 high schools in the uMhlathuze Municipality in KwaZulu-Natal province, South Africa. The sample comprised 1211 children (481 males and 730 females)

Table 1. Classification Criteria for All Anomalies

Refractive errors
Myopia: ≥ -0.50 D
Hyperopia: ≥ +0.50 D
Astigmatism: ≥ 0.75 DC in minus cylinder notation
Anisometropia: plus or minus 0.75 D difference in spherical equivalent refraction between both eyes

Accommodative anomalies
Accommodative Insufficiency
Minimum of clinical signs (1) and (2) or (1) and (3), or all clinical signs
(1) Reduced AA. Push-up monocular AA at least 2 D below Hofstetter's calculation for minimum amplitude: 15- 0.25 x age (years)
(2) High values on MEM retinoscopy >0.75 D
(3) Fails monocular AF testing with -2.00 D (<6 cycles per minute (cpm)).

Accommodative Excess
Clinical signs (1) and (2) or (3)
(1) Low MEM <0.25
(2) Difficulty clearing 2 D with monocular AF (<6 cpm)
(3) Fails binocular AF test with 2 D (<3 cpm)

Accommodative Infacility
Clinical sign (1) and (2) or (1) and (3)
(1) Fails binocular and monocular AF using ±2 D lenses (monocular <11 cpm, binocular <8 cpm)
(2) Positive relative accommodation (PRA) <-2 D
(3) Negative relative accommodation (NRA) <+2.37 D

Vergence anomalies
Clinical signs
(1) Exophoria at near
(2) Exophoria at near ≥4 prism diopter (pd) greater than at far
(3) Insufficient fusional vergence: (i) fails Sheard's criterion or (ii) poor PFV at near ≤12 pd. Base out (BO) to blur or ≤15 pd BO break. Poor BO break was used for PFV criteria.
(4) Receded NPC ≥7.5 cm break or ≥10.5 cm recovery

Convergence insufficiency diagnostic groups
(1) Low suspect CI (exophoria greater at near than at far of ≥4 pd and clinical sign one)
(2) High suspect CI (exophoria at near and 2 signs, or clinical sign (1) and (2) plus (3) or (4)
(3) Definite CI (all clinical signs must be present)
Using the CISS, the cut-off point for "symptomatic" was ≥16 scored on the CISS
Psuedo-convergence insufficiency was defined as convergence insufficiency with underlying accommodative insufficiency and the clinical signs applied were a minimum of two from accommodative insufficiency and reduced NPC plus any other sign from convergence insufficiency

Convergence excess
Minimum of 2 clinical signs
(1) Significant esophoria at near ≥2 pd
(2) Reduced NFV at near <8/16/7 for blur/break/recovery (1 of 3)
(3) High MEM (≥ +0.75; may show high lag)

Fusional vergence dysfunction
(1) Reduced fusional vergences
(2) Normal phoria
(3) Minimal refractive errors

Heterophoria (prism diopters)
Exophoria (prism diopters (pd))
Orthophoria (0)
Mild (1-7)
Moderate (8-13) Severe (>13)

Esophoria (pd)
Eso ≤2
Eso >2

between the ages of 13-19 years. Participants were selected using stratified, multistage cluster, random sampling, and only those who were of African descent (either gender) were eligible to participate in the study. Students were excluded from the study if they had any systemic conditions, were on any systemic medications, or had amblyopia, suppression, strabismus, ocular diseases, nystagmus, or vertical phoria.

Materials and Procedure

The sample size for the study was derived from our earlier publication, where the study materials and procedures are described in detail.[30] The screening techniques comprised two main stations, with the techniques performed in the first station by trained personnel including case history and visual acuity (VA) measurements at distance and near. The case history comprised information on the history of ocular and systemic conditions, as well as the history related to near tasks, which was based on the Convergence Insufficiency Symptom Survey (CISS)[10,15] (part 1). The symptom list for part two was compiled from and was as used in previous studies.[6,14-23,26]

The CISS is a validated reliable symptom survey developed to study the frequency and severity of symptoms and to distinguish between symptomatic and asymptomatic CI in children.[10,15] It uses a Likert-type scale (a scale that uses fixed choice response formats and is designed to measure attitudes or opinions), with responses from 15 questions regarding the symptoms participants experienced when reading or doing close work.[10,15] The CISS allows a recording for whether the symptom is present and how often. The 15 items are summed to obtain an overall CISS score, with symptom severity ranging from 0 (asymptomatic) to 60 (most symptomatic).[10,15] To administer the CISS, the examiner reads each of the 15 questions aloud while the child views a card listing the five possible responses (never, infrequently, sometimes, fairly often, or always) which are assigned corresponding scores of 0, 1, 2, 3, and 4.[10,15] Although the CISS was validated for CI, the inventors[10] suggested that it could be applied to investigate symptoms in other anomalies.

Station two comprised measurement of the binocular functions by an optometrist. To minimize bias, the assistant who collected the student's demographic details worked independent of the optometrist, therefore the optometrist was not aware of the symptoms reported by the learners. To eliminate inter-examiner variability, all tests were performed by one optometrist who was experienced in conducting the techniques but who was not familiar with the classification criteria applied in the study. All vision testing was performed in the morning between 8:30 am and 1:30 pm and over a period of one year between March 2013 and May 2014. The tests described below were all performed under similar conditions, including the same test distances and constant room illumination, as described in our recent study.[30]

For the preliminary tests, suppression was evaluated at near using the Worth 4-dot test (Bernell Corporation, Mishawaka Inc, USA). Stereo acuity was assessed using the Randot stereo test (Vision Assessment Corporation, USA). Ocular health status was evaluated using a direct ophthalmoscope. Refractive errors were determined objectively using an autorefractor (MRK-3100; Huvitz, Gunpo, Gyeonggi, South Korea) and were refined subjectively to the best visual acuity with maximum convex (positive) monocularly and binocularly. Spherical lenses (2 D) were used to screen for latent hyperopia as cycloplegia was not applied. Cycloplegic refraction was not performed as it would have disrupted the sequence of testing for near vision functions and it was not always easy as school principals were always unwilling to permit students to leave class frequently.

Accommodative-vergence tests: the near point of convergence (NPC) was measured using the Royal Air Force (RAF) Rule. All near tests were performed at 40 cm, and the following tests were performed with distance correction in place. Heterophoria was evaluated using the von Graefe technique, and fusional vergences were measured using a horizontal prism bar. For accommodative functions: amplitude of accommodation (AA) was measured using the RAF rule. Accommodative facility was assessed using a ±2 D lens flipper, while accommodative accuracy was evaluated using monocular estimation method (MEM) retinoscopy. Relative accommodation was measured with positive and negative lenses on the phoropter in a specially designed tripod stand. All outcome variables (Table 1) were classified based on criteria applied in previous studies.[11,12,24,27,30] The criteria for convergence insufficiency were based on the Convergence Insufficiency and Reading Study (CIRS) group's system,[11,24,30] those for accommodative anomalies were based on criteria from other studies,[25,27] the criteria applied to define exophoria was modified from Bade et al.,[15] and esophoria was defined according to Borsting et al.[12] Refractive errors were defined based on a study by Wajuihian and Hansraj.[27]

Data Analysis

All data were entered into Microsoft Excel, checked by the first author, and thereafter imported into and analyzed by a statistician using the Statistical Package for Social Sciences (SPSS) version 21. Descriptive statistics were presented as mean, standard deviation, and median. The one-way analysis of variance (ANOVA) and independent t-test were used to analyze differences in means between groups, while the Pearson chi-squared test was performed to test for differences in proportions for categorical variables between and among groups. Logistic regressions were used to examine multivariate associations. Distributions of variables were presented using tables and percentages, with the corresponding 95% confidence intervals presented as an estimate of the prevalence. A significance level of less than 0.05 was considered significant.

Table 2. Prevalence of Refractive, Accommodative, and Vergence Anomalies

Anomalies	n(frequency)	Percent	95% CI
Refractive errors			
Myopia	52	4.4	3.3-5.6
Hyperopia	58	4.8	3.6-6.2
Anisometropia	16	1.3	0.7-2.0
Astigmatism	38	3.2	2.2-4.2
Emmetropia	1037	86.7	84.3-88.2
Amount of astigmatism			
Low astigmatism	108	9.0	7.3-9.7
Moderate astigmatism	26	2.2	1.4-3.1
High astigmatism	1	0.1	0.00-0.2
No magnitude astigmatism	1066	88.7	82.8-88.7
Sphero-astigmatism			
Simple myopic astigmatism	62	5.2	3.9-6.5
Compound myopic astigmatism	42	3.5	2.4-4.7
Mixed astigmatism	26	2.2	1.4-3.1
No astigmatism	1071	84.9	82.80-87.0
Axis-astigmatism			
With-the-rule	57	4.7	3.6-6
Against-the-rule	44	3.7	2.6-4.8
Oblique astigmatism	30	2.5	1.7-3.4
No axis astigmatism	1070	89	87-92.30
Accommodative anomalies			
Accommodative insufficiency	54	4.5	3.4-5.8
Accommodative excess	34	2.8	1.9-3.8
Accommodative infacility	154	12.9	10.9-14.7
Vergence anomalies			
Convergence insufficiency			
Low suspect	141	11.8	10.1-13.7
High suspect	72	6	4.8-7.4
Definite	51	4.3	3.2-5.4
Pseudo-convergence insufficiency	23	1.9	1.2-2.7
Convergence excess	67	5.6	4.2-6.8
Fusional vergence dysfunction	40	3.3	2.4-4.4
Heterophoria			
Exophoria			
Orthophoria	592	49.2	47.1-51.2
Mild (1-7)	522	43.1	42.1-46.2
Moderate (8-13)	76	6.3	5.1-8.0
Severe (>13)	11	1.4	0.4-1.5
Esophoria			
0-2 pd	1141	96.3	94.1-98.6
>2 pd	43	3.6	2.6-4.8

RESULTS

Participants' Characteristics

A total of 1211 out of 1230 students returned their consent forms. Ten participants were excluded as seven had amblyopia, one was diabetic, one had glaucoma, and one had corneal scars due to trauma. Thus, data was analyzed for 1201 children, giving a response rate of 97.6%. The participants' mean age was 16.27 ± 1.79 years, and the median age was 16 years. Of the 1201, 476 (39.5%) were males, and 725 (60.5%) were females; 631 (52.5%) were aged 13-16 years (younger age group), while 570 (47.5%) were 17-19 years old (older age group). The sample comprised 803 (66.86%) students from grades 8-10 (lower grade level) and 398 (33.14%) from grades 11-12 (higher grade level), with 810 (67.4%) being from eight suburban schools and 391 (32.7%) from five rural schools.

The descriptive statistics for all variables are detailed in our recent report.[30]

Prevalence of Refractive, Accommodative, and Vergence Anomalies

The prevalence and 95% confidence interval (CI) estimates for refractive and accommodative-vergence anomalies are shown in Table 2. The prevalence of refractive errors was relatively low. Accommodative infacility was the most prevalent accommodative anomaly, whereas CI was the most prevalent vergence anomaly (Table 2).

Part 1: Association of Symptoms and Refractive, Accommodative, and Vergence Anomalies

Three approaches were applied to determine the association of symptoms with anomalies for parts 1 and 2 symptom questionnaires and consisted of:

1. The mean symptom scores for those with anomalies were compared with those without to determine which anomalies were likely to be symptomatic. The anomaly was considered symptomatic if those with anomalies had higher symptom scores than those without anomalies.
2. The association of each anomaly with each symptom question was examined to enable an inference to be made on which symptoms were most likely to be specific to an anomaly.
3. The mean symptom scores for all anomalies were compared to determine which anomaly was likely to be most symptomatic.

Symptoms, Refractive Errors, and Accommodative-Vergence Anomalies: Part 1 Symptom Survey

In Table 3 (Part 1 survey), the mean, standard deviation (SD), and percentages of symptom scores and the p-values for participants with and without anomalies were compared for Part 1 symptom survey. Their significance levels are also indicated. The percentage of symptomatic patients was derived from the CISS cut-off score of ≥16, as detailed in the methods

section. The mean, standard deviation, and percentage of symptoms for participants according to gender, age group, grade level, and study location were also compared.

Astigmatism, myopia, and anisometropia had higher mean symptom scores than hyperopia and emmetropia (Table 3) [ANOVA, F (4, 1180) = 3.034, p=0.017)]. However, there was no significant difference in the percentage of symptomatic participants (p=0.135). The trend for mean symptom score was similar for Part 2 symptom survey [(ANOVA, F (4, 1176) = 4.92, p=0.001)].

For accommodative anomalies, the t-test showed that the mean symptom score was significantly higher for participants with AI than those without AI (p=0.001) and significantly higher for participants with AIF than those without AIF (p=0.001). However, there was no significant difference between those with AE and those without AE (p=0.390). There were significant differences in percentages of symptomatic participants for those with and those without AI (p=0.043, Table 4), while there were no significant differences for those with AE and those without AE (p=0.510), as well as for those with AIF and those without (p=0.070; Table 4).

The distribution of symptoms in Part 2 was similar to Part 1, where the mean symptom score for participants with AI was significantly higher than those without AI, (t=5.13, p=0.001), as was mean symptom score for those with AIF compared to those without AIF (t=4.86, p=0.001). However, in symptom survey Part 2, participants with AE had significantly higher mean symptom score than those without AE (t=2.07, p=0.001).

On vergence anomalies, the mean scores between participants with and without CI were similar, while there was a significant difference in mean scores of those with and those without PCI (p=0.020). Similarly, there was a significant difference in mean score for those with and without CE (p=0.001), as well as those with and without FVD (p=0.001). Overall, the mean symptom scores for CE and FVD were significantly higher than CI, whereas that for PCI was highest for all vergence anomalies [(ANOVA, F (4.309) = 2.13, df = 20, p=0.001 logistic regression)].

There was no significant difference in the proportion within the CI types and those without CI (p=0.580). There was a significant difference between the participants with PCI and those without (p=0.017; Table 4), whereas there were no significant differences between those who had CE and those without (p=0.37) and with FVD and without (p=0.140).

For heterophoria, the means and proportions for orthophoria were compared with exophoria and esophoria. There was no significant difference in the mean [(ANOVA, F (2, 1182) = 0.194, p=0.430)], and proportions (p=0.200)of symptoms for exophoria. Similarly, there was no significant difference in mean (p=0.080) and proportions (p=0.670) for esophoria and orthophoria. The trend was similar for symptom survey Part 2, where there was no significant difference in means between those with CE and those without (p=0.890), those with FVD and those without FVD [(p=0.001; ANOVA, F (2, 1178) =1.15, p=0.520)]. Futhermore, the participants with esophoria greater than 2 pd had significantly higher mean symptom scores than those with esophoria below 2 pd (t=2.911, p=0.004).

On gender, age, grade level, study site, and symptoms, the mean symptom scores for female students were significantly higher than for males (p=0.001), older participants scored significantly higher than younger ones (p=0.001), those in higher grades scored significantly higher than those in

Table 3. Association of Refractive, Accommodative, and Vergence Variables with Symptoms: Means and Proportions (Part 1 Symptoms).

Anomalies	Mean	SD	F/t	P
All	1.90	0.72		
Refractive errors				
Anisometropia	2.09	0.52		
Astigmatism	2.14	0.6	3.03	0.01
Emmetropia	1.88	0.71		
Hyperopia	1.86	0.87		
Myopia	2.14	0.69		
Accommodative anomalies				
Accommodative insufficiency	2.30	0.61	4.90	0.001
No accommodative insufficiency	1.88	0.72		0.001
Accommodative excess	2.00	0.71	0.85	0.390
No accommodative excess	1.89	0.72		
Accommodative infacility	2.17	0.71	5.01	0.001
No accommodative infacility	1.86	0.70		
Vergence anomalies				
Low suspect CI	1.88	0.78	0.22	0.88
High suspect CI	1.83	0.76		
Definite CI	1.90	0.83		
No convergence insufficiency	1.90	0.70		
Pseudo-convergence insufficiency	2.38	0.80	3.13	0.020
No pseudo-convergence insufficiency	1.89	0.82		
Other vergence anomalies				
Convergence excess	2.17	0.76	3.20	0.001
No convergence excess	1.88			
Fusional vergence dysfunction	2.21	0.75	2.83	0.001
No fusional vergence dysfunction	1.89	0.72		
Heterophoria				
Orthophoria	1.90	0.71		
Exophoria				
Mild	1.96	0.76		
Moderate	1.81	0.82	0.91	0.430
Severe	2.17	0.51		
Esophoria				
0-2	1.89	0.72		0.080
>2	2.01	0.74		

Table 4. Associations of Refractive, Accommodative, and Vergence Variables with Symptoms (Part 1 only)

Anomalies	Symptomatic	Asymptomatic	χ2	P
All	**1038 (87.6)**	**147 (12.4)**		
Refractive errors				
Anisometropia	15 (93.8)	1 (6.3)		
Astigmatism	34 (94.4)	2 (5.6)	7.01	0.130
Emmetropia	897 (87.5)	128 (12.5)		
Hyperopia	45 (78.5)	12 (21.1)		
Myopia	47 (92.2)	4 (7.8)		
Accommodative anomalies				
Accommodative insufficiency	53 (96.4)	1 (3.6)	4.08	0.040
No accommodative insufficiency	985 (87.2%)	145 (12.8)		
Accommodative excess	31 (91.2)	3 (8.8)	0.41	0.510
No accommodative excess	1005 (87.5)	144 (12.5)		
Accommodative infacility	140 (92.1)	12 (7.9)	3.26	0.070
No accommodative infacility	898 (86.9)	135 (13.1)		
Vergence anomalies				
Low suspect CI	119 (85.0)	21 (15.0)	1.94	0.580
High suspect CI	61 (85.9)	10 (14.1)		
Definite CI	42 (84.0)	8 (16.0)		
No convergence insufficiency	808 (88.2)	108 (11.8)		
Pseudo-convergence insufficiency	22 (100.0)	0 (0.0)	3.17	0.017
No pseudo-convergence insufficiency	1016 (87.4)	147 (12.6)		
Other vergence anomalies				
Convergence excess	61 (91.0)	6 (9.0)	0.77	0.370
No convergence excess	977 (87.4)	141 (12.6)		
Fusional vergence dysfunction	38 (95.0)	2 (5.0)	2.08	0.140
No fusional vergence dysfunction	1000 (87.3)	145 (12.7)		
Heterophoria				
Exophoria				
Orthophoria	592 (87.9)	128 (12.1)		
Mild	522 (87.0)	6 (13.0)		
Moderate	76 (82.7)	13 (17.3)	3.14	0.200
Severe	11 (100.0)	0 (0.0)		
Esophoria				
0-2	1038 (87.6)	147 (12.4)		
>2	103 (88.8)	13 (11.2)	0.182	0.670

lower grades (p=0.001), and suburban participants scored significantly higher than rural participants (p=0.017). For the proportions of symptomatic participants, female students were significantly more symptomatic than males (p=0.002), older participants were significantly more symptomatic than younger ones (p=0.002), participants in higher grades were significantly more symptomatic than those in the lower grades (p=0.006), and suburban participants were more symptomatic than rural participants, although this difference was not significant (p=0.210).

Similar trends were observed for symptom survey Part 2 for gender, age, grade level, and study site. However, Part 2 was not applied to evaluate symptoms in convergence insufficiency, as the Part 1 questionnaire was validated specifically for convergence insufficiency. In addition, percentages of symptomatic participants were not analyzed for the Part 2 symptoms, as the cut-off score of ≥16 was specifically validated for CI only, and therefore could not be applied.

Anomalies and Specific Associations: Symptom Questionnaire Part 1 and 2

The chi-squared test was used to determine the association of anomalies and symptoms for the categories, and the significance levels are as indicated (Table 5).

Part 1:

In summary, for refractive errors, myopia was associated with two symptoms (symptoms number 10 and 12), anisometropia with 6 symptoms (3, 11, 12, 13, 14, and 15), astigmatism and its subtypes with 10 symptoms (1, 2, 3, 8-12, 14, and 15), and hyperopia with only symptom number 14.

Accommodative insufficiency was associated with seven symptoms (1, 3, 4, 7, 8, 10, and 15), accommodative infacility with eight symptoms (1, 4, 8, 10, 11, 13, and 15), whereas accommodative excess was not associated with any symptoms.

For vergence anomalies, CI was associated with 4 symptoms (1, 2, 5, and 6), PCI with 3 symptoms (7-9) and FVD with two symptoms (8 and 10), whereas CE and heterophoria were not significantly associated with any symptoms.

Part 2:

Myopia was associated with three symptoms (16, 18, and 21). Anisometropia was associated with one symptom (24), astigmatism with seven symptoms (16-21 and 24). Hyperopia was not expressed as most degrees of hyperopia were mild, which may not have had much impact given the students' age and active accommodation ability. For other RAV anomalies, AI had 4 symptoms (17, 19, 21, and 22), and AIF was associated with seven symptoms (16 and 18-23), whereas CE, AE, and heterophoria were not significantly associated with any symptoms.

Overall, to determine which anomalies were likely to have the highest mean symptom scores, one-way ANOVA was used to compare all the means, using Bonferroni and Kodak techniques for multiple mean separation tests to which a p-value of less than 0.05 was considered significant. For Part 1, AI (p=0.022), AIF (p=0.007), and PCI (p=0.001) had significantly higher mean symptom scores than the other anomalies. For Part 2, AI (p=0.001), FVD (p=0.037), AIF

Table 5. Anomalies and Specific Associations: Symptom Questionnaire Parts 1 and 2

SN	SYMPTOMS	ASSOCIATED ANOMALIES	SPECIFIC TO:
1.	Do your eyes feel tired when reading or doing close work?	LA and MA, p=0.001; WTR, ATR and OA, p=0.040; CMA and MXA, p=0.001; CI, p=0.041; AI, p=0.001; AIF, p=0.002.	Astigmatism, CI, and AIF
2.	Do your eyes feel uncomfortable when reading or doing close work?	LA and MA, p=0.030; WTR, ATR and OA, p=0.001; CMA and MXA, p=0.001; CI, p=0.040.	Astigmatism and CI
3.	Do you have headaches when reading or doing close work?	SMA, CMA and MXA, p=0.021; WTR, ATR and OA, p=0.004; anisometropia, p=0.024; AI, p=0.005.	Astigmatism, anisometropia, and AI
4.	Do you feel sleepy when reading or doing close work?	SMA, CMA, MXA, p=0.001; AI, p=0.05; AIF, p=0.001.	Astigmatism, AI, and AIF.
5.	Do you lose concentration when reading or doing close work?	CI, p=0.037.	CI
6.	Do you have trouble remembering what you have read?	CI, p=0.020	CI
7.	Do you have double vision when reading or doing close work?	PCI, p=0.001; AI, p=0.010	PCI and AI
8.	Do you see the words move, jump, swim, or appear to float on the page when reading or doing close work?	SMA, CMA, MXA, p=0.001; AI, p=0.001; AIF, p=0.020; PCI, p=0.05; FVD, p=0.001.	Astigmatism, AI, AIF, PCI, and FVD
9.	Do you feel like you read slowly?		
10.	Do your eyes ever hurt when reading or doing close work?	WTR, ATR and OA, p=0.012; LA and MA, p=0.001; AI, p=0.020; AIF, p=0.015; PCI, p=0.050; myopia, p=0.050; SMA, CMA, MXA, p=0.001.	Astigmatism, myopia, AI, AIF, and PCI
11.	Do your eyes ever feel sore when reading or doing close work?	WTR, ATR and OA, p=0.033; anisometropia, p=0.000; AIF, p=0.020; FVD, p=0.001.	Astigmatism; anisometropia, AIF, and FVD.
12.	Do you feel a "pulling" feeling around your eyes when reading or doing close work?	WTR, ATR and OA, p=0, 040; myopia, p=0.001; anisometropia, p=0.001.	Astigmatism, myopia, and anisometropia
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?	AIF, p=0.001; anisometropia, p=0.001.	AIF and anisometropia
14.	Do you lose your place while reading or doing close work?	SMA, CMA, MXA, p=0.031; WTR, ATR and OA, p=0.022; anisometropia, p=0.05; hyperopia p=0.01; AIF, p=0.001.	Astigmatism, anisometropia, hyperopia, and AIF
15.	Do you have to re-read the same line of words when reading?	LA and MA, p=0.001; AI, p= 0.011; AIF, p=0.041; anisometropia, p=0.040.	Astigmatism, anisometropia, AI, and AIF
PART 2 SYMPTOMS			
16	Do you tend to hold books too close while reading?	Myopia, p=0.016; SMA, CMA, MXA, p=0.001; low and moderate astigmatism, p=0.020; AIF, p=0.001.	Myopia, astigmatism, and AIF
17.	Do you hold books away while reading?	AI, p=0.001.	AI
18.	Do you see things as blurry (not clear) when you read or use the computer?	Myopia, p=0.031; low and moderate astigmatism, p=0.010; WTR, ATR, OA, p=0.042; AIF, p=0.001.	Myopia, astigmatism, and AIF
19.	Do you feel dizzy when you read?	AI, p=0.001; AIF, p=0.004.	AI and AIF
20.	Do your eyes water when you read?	AIF, p=0.001.	AIF
21.	Do you have problems when you look on the chalkboard, back to your textbook, and back to the chalkboard again?	CMA, MXA, SMA, p=0.012; myopia, p=0.001; low and moderate astigmatism, p=0.020; AI, p=0.010; AIF, p=0.001; WTR, ATR, OA, p=0.020.	Astigmatism, myopia, AI, and AIF
22.	Do you suffer from headaches after school?	AI, p=0.010; AIF, p=0.001.	AI and AIF
23.	Does your eye turn red after reading?	AIF, p=0.001.	AIF
24.	Do you frown or "squeeze" your face when you read?	Anisometropia, p=0.001; SMA, CMA, MXA, p=0.010.	Astigmatism and anisometropia

(p=0.024), and PCI (p=0.030) had significantly higher mean symptom scores than the other anomalies.

Discussion

In this study, we examined the possible association of symptoms with refractive, accommodative, and vergence anomalies and found symptoms to be associated with various anomaly types. Astigmatism, myopia, and anisometropia were more symptomatic than hyperopia and emmetropia, and the REs were significantly associated with various specific symptoms. Similar to the present study, Abdi et al.[8] found that school children with myopia and astigmatism reported asthenopia more often than school children with hyperopia, whereas another study[9] found a correlation between hyperopia and asthenopic symptoms. Ips et al.[21] studied eye disorders in 6-year-old Australian children with complaints of eyestrain and reported that the prevalence of REs was similar in children with or without symptoms of eyestrain, although hyperopia was slightly more frequent among children with eyestrain. In a study by Hendricks et al.,[22] headaches were significantly associated with myopia and hyperopia. Unexpectedly, we found a relatively higher frequency of symptoms among myopes. According to Grosvenor,[31] myopes may squint to see clearly and feel that their eyes are under strain when doing so, therefore they may report symptoms.

Clinically, in patients with astigmatism, the unaided acuity and the presence of symptoms are dependent on the type of astigmatism present.[31,32] We found different types of

astigmatism to be associated with various symptoms. Low-magnitude astigmatism has been reported to be the most common refractive cause of ocular headaches in young people.[32] With high astigmatism, the ciliary muscles may make minimal effort to correct the error, which could result in asthenopia.[32,33] However, if the degree of astigmatism is low to moderate, the patient makes unconscious effort to compensate for the error, and the ciliary muscle contracts irregularly, causing more asthenopia.[33] Thus, low-magnitude RE, especially astigmatism, often causes more severe headaches than high amounts.[31,33]

Against-the-rule astigmatism produces more blur than WTR, and in ATR astigmatism, symptoms of asthenopia may result from small astigmatic errors even if visual acuity is normal.[31,32] In oblique astigmatism, the blur is even greater, and compensating for the astigmatic error may significantly improve visual acuity.[31,32] In simple or compound myopic astigmatism, no amount of accommodation is able to prevent blurred vision at distance; therefore, such errors may cause symptoms of asthenopia at near because accommodation may place the circle of least confusion closer to the retina.[31,33] Accordingly, the association of astigmatism with symptoms may be warranted.

On accommodative anomalies and symptoms, a higher mean and proportion of symptoms, as well as associations with more specific symptoms compared to other accommodative anomalies, suggests that AI is the most likely to cause symptoms of all accommodative anomalies, while AE is the least. Similar to our findings, Borsting et al.[11] found that AI is related to subjective symptoms reported, and participants who had AI scored significantly higher than those with normal binocular vision. Gall and Wick[6] found accommodative infacility to be the most likely to show symptoms.

A high proportion of participants (87.2 to 96.4%) in our study reported various symptoms. A comparison of proportions for symptomatic participants in accommodative anomalies is limited by a lack of studies that used the CISS to measure them. However, in comparison with studies that applied the non-CISS symptom questions (compiled list of symptoms), Abdi et al.[8] found that 23.1% of school children who had refractive, accommodative, and vergence anomalies manifested symptoms of asthenopia. In Ips et al.,[21] 15.2% of 6-year-old children with refractive errors reported symptoms of asthenopia, while Sterner et al.[14] found a prevalence of asthenopia of 34.7% among 6- to 10-year-old school children with accommodative problems. On specific association with symptoms, two studies[17,19] found a significant association between AIF and asthenopic symptoms in school children.

The findings on vergence anomalies and symptoms are diverse. Rouse et al.[24] found that the percentage of children rated as symptomatic increased with the number of CI-related clinical signs present, and 72% of definite CI was rated as symptomatic, compared to 84% in our study. Approximately 71.9% of symptomatic primary school children aged 9-13 years in South Korea had non-strabismic accommodative-vergence anomalies.[25] Krakta and Krakta[28] found that 75% of participants who presented with at least one-sign CI were symptomatic. In Borsting et al.,[10] children with three-sign CI scored higher than the normal binocular vision (NBV) group, and the severity of the condition was associated with an increase in the symptom scores. In contrast, Maran et al.[13] found that children with CI-only had similar symptom scores to children with normal binocular vision, which corroborates our findings of no significant difference in mean scores between participants with and without CI. Specifically, the mean symptom scores for PCI were significantly higher than in other vergence anomalies. A lower mean symptom score, as well as lower proportion of symptomatic responses for all severities of CI than other vergence anomalies, suggests that CI is less symptomatic than other vergence anomalies. Thus, our findings agree with descriptions by Marran et al.,[13] who suggested that the asthenopic symptoms in CI may be due to the associated AI. Furthermore, CI may be symptomatic only when comorbid with AI, resulting in the score being higher than in children with normal binocular vision. It has been suggested that previous reports of high scores on the CISS survey are likely the results of preselecting symptomatic cases of CI.[13]

Table 6. Characteristics of Symptoms in Convergence Insufficiency

- Signs can exist for years without any symptoms
- Symptoms may not disappear
- Cure of the signs does not necessarily produce disappearance of the symptoms
- Symptoms may disappear entirely while the signs remain unaltered
- Relapse and recurrence of the symptoms may occur without reappearance of the objective signs
- Cases exist with all the classical symptoms and no objectively demonstrable signs at all

Lack of symptoms in CI may also result from an abnormal suppression on first-degree targets, which is a common feature of CI.[34] Suppression is a sensory adaptation to eliminate diplopia and visual confusion by creating functional monocular vision in CI.[34] Thus, the more severe the CI is, and the longer the duration of onset of CI, the greater the probability of suppression, with a resultant lack of symptoms.[34] However, in some cases, the patient may be highly symptomatic even though the clinical signs may be relatively within normal limits.[35] Such cases correspond with our findings of a high percentage of symptomatic participants with relatively low prevalence of anomalies. Shipman et al.[35] described such cases as CI with normal parameters, and they correspond with the descriptions of CI by Mann[36] (Table 6).

The association of CE and FVD has not been studied extensively. Only one study[12] examined the relationship between CE and symptoms and found that the CE group scored higher than the normal binocular vision group, which agrees with our findings.

On symptoms and gender, age and grade level, mean symptom scores were significantly higher in females than in males, which corroborates the findings by Rouse et al.[24] and Hennessy et al.,[17] whereas Marran et al.[13] and Borsting et al.[11] found no significant gender difference in the distribution of CI.

On heterophoria and symptoms, although mild exophoria was significantly more symptomatic than the moderate and severe categories, there was no significant association between heterophoria and individual symptoms. Similarly, other studies[18,20] found no association between heterophoria and symptoms, as symptoms in heterophoria may not be found reliably by only a measurement of the phoria.[18] Accordingly, Sheedy and Saladin[18] found failure of the Sheard's criterion to be a better predictor of symptoms.

Overall, our findings suggest that AI, AIF, and PCI are the binocular anomalies most likely to cause symptoms compared to CI, CE, and AE. For refractive errors, astigmatism is most likely to manifest symptoms compared to hyperopia, myopia, anisometropia, and emmetropia. Taken together, our findings on the relations between symptoms and RAV anomalies may be interpreted from various perspectives. The low mean scores and proportion of symptomatic participants, lack of difference in symptom scores between those with an anomaly such as AE and CI and those without AE and CI, and a lack of association with specific symptoms as in AE suggest that the anomalies may not present with symptoms. It also implies that such anomalies may not be distinguished based solely on the presence or absence of symptoms. Alternatively, the symptoms may be non-specific and not differentiated on the basis of the causative factor.[23,37]

For anomalies most likely to manifest symptoms, (AI, AIF, and PCI), the associated symptoms can distinguish them from other anomalies. In addition, a lack of association with specific symptoms suggests that CE and AE could present without symptoms. It may be argued that the findings of lack of symptoms between those with and without AE, for example, may be due to an increased level of symptoms in the without AE group compared to other binocular anomalies such as eye movements.[6] However, it is important to note that the without AE group had relatively lower mean symptom scores and were least associated with symptoms.

The differences in the frequency level of symptoms across studies may be related to the ways symptoms were recorded; some studies used validated, standard questionnaires,[10,11,13,15] whereas others did not.[8,14,21] The subjectiveness of the responses in the symptom questionnaires may also have influenced the percentages of participants who reported symptoms. In addition, participants' age differences may have introduced differences in the frequency estimates, as younger children may have less near visual demand to trigger symptoms.[34]

Analyses of patients' symptoms are important for decisions regarding diagnoses and treatment. However, our findings suggest that the presence of symptoms may not be an absolute indication for the presence of an anomaly. Such asymptomatic cases may be due to avoidance of near work and other factors, as detailed earlier. In general, visual symptoms and their intensities may vary from day to day among persons. Thus, associations with anomalies may depend on predisposing conditions such as duration and intensity of near tasks performed, and snapshot records of symptoms may not reveal a conclusive manifestation of such associations. Besides differences in the design of questionnaires, environmental factors such as illumination and contrast may contribute to differences in symptoms reported. Lastly, it may also be that such conditions resemble the cases as stated in Table 6. In general, a lack of association may indicate that the participants either avoided near tasks or developed suppression as the convergence ability worsened.[15] Individuals who have high pain thresholds may also not manifest symptoms.[34]

In summary, evaluating patients' symptoms plays a fundamental role in vision care practice, as most patients consult the eye care practitioner because their symptoms bother them. As some visual efficiency anomalies may present without symptoms, vision screening for anomalies and symptoms is a strategic way to detect refractive, accommodative, and vergence anomalies in school-aged children who are less likely to consult an independent optometrist. The existence of binocular anomalies predisposes the student to develop symptoms with increasing near point visual demands. Identifying anomalies and initiating treatment plans before the high school student enrols for tertiary education, which has even greater near task demand, will be beneficial.

Our study has some limitations that may affect the interpretation of the study findings. Due to the difficulty in understanding marked differences in the options (never, infrequently, sometimes, fairly often, or always), even in the children's indigenous isiZulu language, some questions on the questionnaires were left unanswered. This may have affected the value of the mean symptom scores. The lack of cycloplegia could have influenced the prevalence of hyperopia and accommodative anomalies. However, the use of cycloplegia remains largely controversial,[37] especially in a study on near vision functions with the logistics of its use in a school setting being questionable. After all, cycloplegia may not yield a significantly different outcome,[38] noting that we screened for latent hyperopia using a plus 2.00D lens. According to Laudon,[37] "Since binocular anomalies are the second most common visual problem after refractive error, minimizing the use of cycloplegic refraction will allow us to search for the real cause of many of our patients' visual problems."

Lastly, it must be acknowledged that research investigating associations of symptoms with anomalies poses a unique challenge. Although most studies evaluated symptoms by comparing those with and without anomalies, that approach could be flawed, as it may be impossible to perform all near tests to rule out binocular anomalies and derive a no-binocular-vision-anomaly group, as well as to detect subtle

ocular abnormalities. However, continuing discourse on the topic will enhance further understanding of the relationship among symptoms and visual efficiency anomalies.

Possible strengths of the study include a relatively large sample size and the systematic analysis of the associations between anomalies and symptoms. Our study has implications for clinical practice and research in vision care, as the ability to distinguish symptoms in various anomalies could enhance differential diagnoses.

Conclusion

Our findings suggest that astigmatism is the most symptomatic refractive error among students who participated in the study. Accommodative infacility, insufficiency, and pseudo-convergence insufficiency are most likely to produce symptoms compared to AE and CE. Female students are more likely to be symptomatic than males; students in upper school grade levels are more likely to be more symptomatic than those in lower grade levels. Screening for near vision anomalies and associated symptoms is an important way to detect the binocular anomalies. An understanding of symptoms specific to anomalies will enhance proper diagnosis and treatment.

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