LATVIAN JOURNAL OF PHYSICS
AND TECHNICAL SCIENCES
2025, N 5

DOI: 10.2478/lpts-2025-0033

THE RELATIONSHIP BETWEEN EYE ASTIGMATISM AND ACCOMMODATION DISORDERS IN SCHOOL-AGE CHILDREN

I. A. Buksa [1*], E. Kassaliete [1*], A. Ganebnaya [1], E. Serpa [1],
A. Svede [1], I. Ceple [1], K. Panke [1], G. Krumina [1], P. Georgiev Ivanov [2]

[1]Department of Optometry and Vision Science,
University of Latvia,
1 Jelgavas Str., Riga, LV-1004, LATVIA
[2] External consultant (info@Peter-ivanov.com)
*e-mail: ievaancebuksa@inbox.lv

This study investigated the potential link between eye accommodation disorders and astigmatism by comparing the differences in astigmatism type – with-the-rule (WTR), against-the-rule (ATR) or oblique – and its origin (total, corneal, or lenticular) in 64 school-aged children (6–12 years; mean age 9 ± 2 years) diagnosed with accommodation disorders (hypofunction or hyperfunction) and a control group. Objective astigmatism was measured using the Huvitz Auto Ref/Keratometer HRK-1, and data from sphero-cylindrical notation were converted into Jackson crossed cylinder (JCC) vectors for further analysis. Keratometry data showed that corneal astigmatism in school-aged children was predominantly WTR. In contrast, refraction data, representing total astigmatism, revealed a more complex pattern: ATR astigmatism predominated in participants with accommodation hypofunction and in the control group, whereas WTR astigmatism was more common in participants with accommodation hyperfunction. Statistically significant differences were found in the astigmatism axis when comparing objective refractometry and the calculated lenticular astigmatism between the accommodation hyperfunction and control groups. Notably, the hyperfunction group exhibited a tendency toward oblique astigmatism. These findings suggest a possible relationship between accommodation disorders and astigmatism axis orientation. However, due to the small samples and the observational nature of the study, the results should be interpreted as preliminary.

Keywords: *Accommodation hyperfunction, accommodation hypofunction, corneal astigmatism, Jackson crossed cylinder analysis, total astigmatism.*

1. INTRODUCTION

The rapid advancement of technology has led to an increase in asthenopic complaints among school-aged children, largely due to the extensive use of electronic devices for near-vision tasks [1]. These complaints typically begin to appear around the ages of 6–7 and are often associated with accommodation disorders [1]. Previous studies have reported small but clinically significant changes in both the magnitude and axis of astigmatism during accommodation demand [2]–[4]. However, there is no clear consensus on the direction of these changes – whether they shift toward with-the-rule (WTR) or against-the-rule (ATR) astigmatism [2]–[4]. Liu & Thibos [5] observed a slight shift toward ATR astigmatism, whereas Cheng et al. [6] reported a shift toward WTR astigmatism. To detect such changes, both Liu & Thibos [5] and Cheng et al. [6] employed a Shack-Hartmann aberrometer. Liu & Thibos [5] conducted repeated measurements on 34 healthy subjects (16 emmetropic and 18 myopic), with accommodative demands ranging from 1.00 D to 6.00 D in 1.00 D increments. In contrast, Cheng et al. [6] studied 91 optometry students with good ocular health using accommodative demands of 0.00 D, 3.00 D, and 6.00 D. Other factors that may influence the development of astigmatism – though not directly related to accommodation disorders – include pupil size [2], genetic predisposition, eyelid pressure and the mechanical action of extraocular muscles on the eyeball [2], [7]. Wilson et al. investigated changes in corneal astigmatism by retracting the eyelids and found that subjects with more than 1.00 D of WTR astigmatism exhibited a reduction in astigmatism when the eyelids were lifted [8]. These findings suggest that eyelid pressure influences the axis orientation of corneal astigmatism [8]. It was initially hypothesized that accommodation could induce changes in the anterior corneal surface [9], [10]. However, more recent studies have demonstrated that the cornea maintains its curvature radius during accommodation due to the tension of the ciliary muscle [11], [12], [13].

Previous research suggests a potential link between eye accommodation disorders and changes in astigmatism, indicating that accommodation disorders may influence both the magnitude and axis of astigmatism. In studies involving university student populations, Harvey et al. [14] and Cacho-Martínez et al. [15] reported that uncorrected astigmatism was associated with accommodative disorder and increased visual symptoms. Davis et al. [16] investigated the relationship between accommodation insufficiency and WTR astigmatism in school-aged children, concluding that moderate or high degrees of WTR astigmatism did not pose a higher risk of accommodation insufficiency. However, the relationship between other accommodative disorders and total ATR or oblique astigmatism remains unknown and has not been systematically evaluated yet. Unlike previous studies that have primarily focused on changes in astigmatism during accommodation demand, our research investigates whether diagnosed accommodation disorders are associated with distinct patterns in objective astigmatism parameters. Clinical observations suggest that in cases of accommodative disorders, total astigmatism tends to be more frequently oblique or ATR, while corneal astigmatism remains predominantly WTR. This finding is supported by the results of Liu & Thibos,

[5] who demonstrated that corneal and lenticular optics interact to balance astigmatism across different accommodation states. In most cases, this interaction leads to a reduction in total astigmatism. However, in some subjects, as the demand for accommodation increases, the axial component of lens-induced astigmatism strengthens while remaining approximately orthogonal to the corneal astigmatism axis. This orthogonal relationship serves to reduce the total axial astigmatism, highlighting the need to analyse astigmatism as a vector, considering both magnitude and axis in complex optical systems such as the eye, where multiple refractive elements contribute to the overall optical outcome.

The aim of the present study is to examine whether astigmatism type – WTR, ATR, or oblique – or its origin –

total, corneal, or lenticular – is associated with accommodation hyperfunction or hypofunction in school-aged children and to interpret the clinical findings using vector analysis.

2. EXPERIMENTAL

2.1. Participants

A total of 82 children of Marupe State Gymnasium, Latvia, participated in this study. All examinations were conducted at the school over the course of one week by three licensed optometrists. Of the participants, 23 were diagnosed with accommodation disorders (70 % with accommodation hyperfunction and 30 % with accommodation hypofunction), 15 were diagnosed with vergence disorders, and three presented with combined vergence and accommodation disorders. The remaining 41 participants, whose visual functions were within the normal range for their age, formed the control group. For the final analysis, data from 64 participants were included. Children diagnosed with convergence disorders or combined vergence-accommodation disorders were excluded. The analysed sample of 64 children, aged 6 to 12 years (mean age 9 ± 2 years), is considered representative of the elementary school population in urban Riga, supporting generalization of the findings within this context. The sample included 44 % girls and 56 % boys.

Inclusion criteria: The study included participants aged 6 to 12 years who were either diagnosed with accommodation disorders (accommodation hypofunction or hyperfunction) or had normal visual functions and served as a control group. Inclusion in the accommodation disorder groups was based on diagnostic criteria outlined in Appendix A, adapted from Franco et al. [18] and Scheiman & Wick [19]. For specific accommodative and vergence disorders, additional criteria were adapted and reviewed by three independent clinical optometrist specialists. The inclusion criteria for participants with normal visual functions included:

- Normal AA (accommodative amplitude) calculated based on Hofstetter's minimum value for age;
- NRA (negative relative accommodation) between +2.25D and +2.75D;
- PRA (positive relative accommodation) greater than -3.00D;
- BAF (binocular accommodation facility) ≥ 6 cpm;
- MAF (monocular accommodation facility) ≥ 6 cpm;

- MEM (dynamic retinoscopy with monocular estimated method) between +0.50D and +0.75D;
- VF (vergence facility) > 13 cpm;
- AC/A ratio between 2:1 and 6:1;
- NPC (near point of convergence) ≤ 6 cm;
- NFV (negative fusional vergence) at far -/7/4 (±3/±2) and at near 13/21/13 (±4/±4/±5);
- PFV (positive fusional vergence) at far 9/19/10 (±4/±8/±4) and at near 17/21/11 (±5/±6/±7).

2.2. Data Collection

At Marupe State Gymnasium, objective refraction and keratometry data were obtained using a Huvitz Auto Ref/Keratometer HRK-1. All examinations were performed by licensed optometrists, without the use of cycloplegia, in accordance with Latvian regulations prohibiting its use by optometrists; ophthalmologists did not participate in this study. Subjective refraction was assessed using the fogging technique to help minimize the influence of accommodation. For each participant, five refractometry and keratometry measurements were collected, and the mean of the five measurements was used in the analysis. Corneal astigmatism was calculated based on keratometry values obtained with a biograph. Astigmatism axis classification was based on the minus cylinder form, categorized as WTR (0° ± 30°), ATR (90° ± 30°), and oblique (31°–59° or 121°–149°) [17]. This classification system is widely used in clinical optometry and represents the standard approach adopted by practicing optometrists. Visual functions assessed included:

- Visual acuity;
- Accommodation functions (accommodation amplitude, accommodation reserves, accommodative facility using a ±2.00 D lens flipper, dynamic retinoscopy, and AC/A ratio);
- Binocular functions (suppression test, stereovision, prism cover test, convergence, and fusional vergence amplitude).

2.3. Data Analysis

The normality of the data distribution was assessed using the Shapiro–Wilk test. The Chi-squared test was used to determine whether there were statistically significant differences in astigmatism type among the accommodation hypofunction group, the accommodation hyperfunction group, and the control group. To evaluate differences in total, corneal, and lenticular astigmatism across these groups, both the Kruskal–Wallis test and One-way ANOVA Multiple Comparisons Test were applied, depending on the distribution to the data. All statistical analyses were performed using GraphPad software.

2.3.1. Jackson Crosse Cylinder (JCC) Vector Analysis

Simple arithmetic subtraction of refractive (total) and corneal astigmatism cannot accurately determine residual (lenticular) astigmatism, as the orientations of refractive and corneal astigmatism axes often differ. Therefore, vector analysis is required for precise calculation. In this method, all sphero-cylindrical refractive errors – defined by sphere, cylinder [C], axis [ɑ] – are geometrically represented by three dioptric components: spherical equivalent (SE), and two JCC components J_0, and J_{45}. Astigmatism is modelled as a JCC with power J at axis α (see Fig. 1). This JCC can be further resolved into the sum of two orthogonal components: one with power J_0 at axis α = 90° = 180° and the other with power at axis α = 45° = 135°. To enable statistical analysis of astigmatism data, we adopted the method proposed by Thibos et al. [20], in which spherocylindrical data are converted into JCC vector form using Eqs. (1) and (2):

$$J_0 = -\frac{C}{2} * \cos 2\alpha. \quad (1)$$

$$J_{45} = -\frac{C}{2} * \sin 2\alpha, \quad (2)$$

where C is the negative cylinder power in dioptres and α is the cylinder axis in radians.

When astigmatism is represented as vectors, the and values can be either positive or negative (see Figs. 2 and 3). Positive values correspond to cylinder axes ranging from 0° to 90° with a maximum power at 45° and zero power at 0° and 90°. Negative values represent cylinder axes from 90° to 180°, with minimum power at 135° and zero power at 90° and 180°. Positive values indicate cylinder axes between 0° and 45°, corresponding to WTR or oblique astigmatism, while negative values correspond to axes between 45° and 135°, indicating ATR or oblique astigmatism. The component reaches its maximum power at 0° and 180°, and its minimum at 90°.

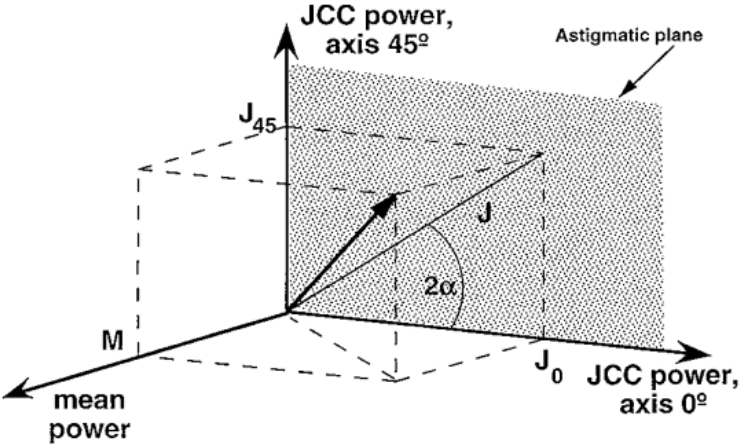

Fig. 1. Astigmatism is calculated using Eqs. (1) and (2) and represented as JCC vectors. Each vector originates from the zero-coordinate intersection point, with its length corresponding to the cylinder power in dioptres [16].

The vector coordinates (x, y) can be calculated using the following equations:

$$x = C * \cos 2\alpha. \quad (3)$$

$$y = C * \sin 2\alpha, \quad (4)$$

where C is the cylinder power in dioptres, and α is the cylinder axis in radians.

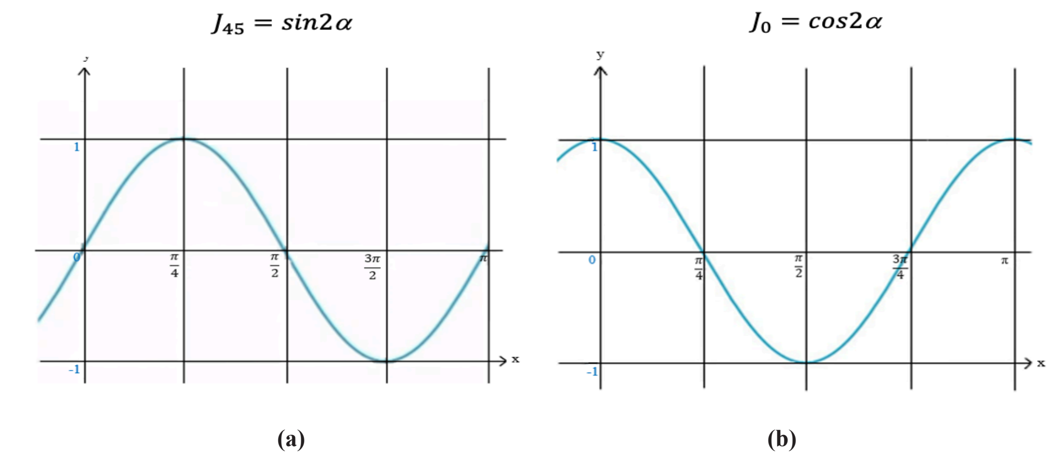

Fig. 2. Jackson crossed cylinder relevant functions: **(a)** the sin2α function used in calculating the J_{45} value, and **(b)** the cos2α function used in calculating the J_0 value.

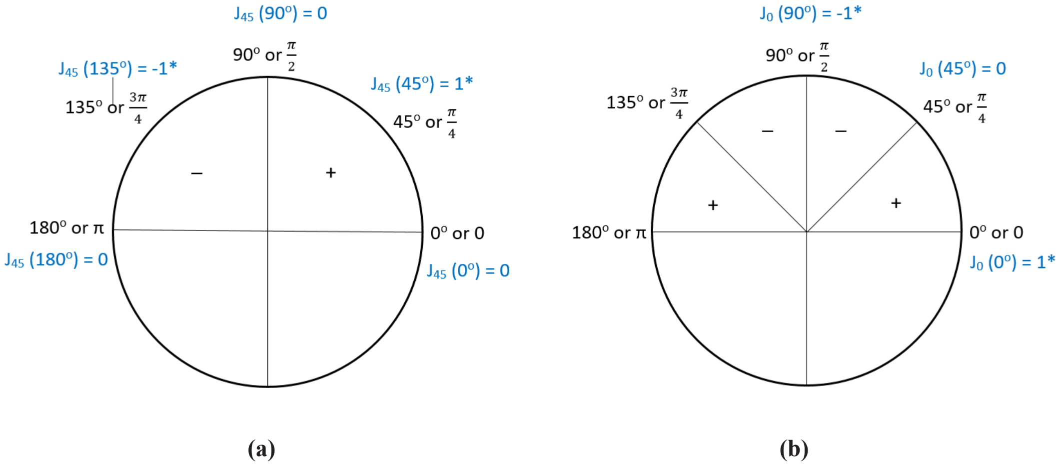

Fig. 3. Jackson crossed cylinder vector components: **(a)** J_{45} and **(b)** J_0 values.
*Both J_0 and J_{45} values can exceed ±1.00 when the cylinder power is greater than 2.00 D.

To calculate lenticular astigmatism, we used equation proposed by Hruby as cited by Liu et al. [21]:

$$LA = TA - CA, \tag{5}$$

where LA is lenticular (residual) astigmatism, TA is total (refractive) astigmatism, CA is corneal astigmatism.

JCC vector analysis treats astigmatism compensation as a linear sum of power vectors, revealing axis modulation and offering a more comprehensive understanding of astigmatism in both individual cases and population-level trends. This approach has been applied in various optometric studies [26], [32], [33] and will enhance the understanding of JCC vector analysis at our department in the future.

3. RESULTS

In the control group, the most prevalent type of astigmatism was ATR (39 %), followed by WTR (28 %) and oblique (26 %) astigmatism (see Table 1). A similar pattern was observed in participants diagnosed with accommodation hypofunction, where ATR astigmatism was the most common (57 %), followed by WTR (29 %), and oblique (7 %). In contrast, among participants with diagnosed accommodation hyperfunction, the most prevalent type of astigmatism was WTR (47 %) followed by ATR (31 %), and oblique (16 %) astigmatism. The Chi-squared test revealed statistically significant differences in both total astigmatism and corneal astigmatism among participants in the control group ($\chi^2 = 71.90$, df = 3, $p<0.01$). Similarly, significant differences were found in total and corneal astigmatism within the hypofunction group ($\chi2 = 10.44$, df = 3, $p<0.02$) and the hyperfunction group ($\chi2 = 19.93$, df = 3, $p<0.02$). However, these findings should be interpreted with caution, particularly for the hypofunction group, which included only seven participants. The small sample size limits statistical power and increases the risk of overestimating the effect size, potentially undermining the robustness and generalizability of the observed differences.

Table 1. Distribution of Astigmatism Types (WTR, ATR, Oblique) and Absence of Astigmatism Analysed for Eyes in the Control Group, the Accommodation Hypofunction Group, and the Accommodation Hyperfunction Group

Control group (n=41)	**WTR (%)**	**ATR (%)**	**oblique (%)**	**No astigmatism (%)**
Total astigmatism	23 (28 %)	32 (39 %)	21 (26 %)	6 (7 %)
Corneal astigmatism	76 (93 %)	3 (4 %)	3 (4 %)	0 (0 %)
Accommodation Hypofunction (n=7)				
Total astigmatism	4 (29 %)	8 (57 %)	1 (7 %)	1 (7 %)
Corneal astigmatism	12 (86 %)	1 (7 %)	0 (0 %)	1 (7 %)
Accommodation Hyperfunction (n=16)				
Total astigmatism	15 (47 %)	10 (31 %)	5 (16 %)	2 (6 %)
Corneal astigmatism	31 (97 %)	1 (3 %)	0 (0 %)	0 (0 %)

*$p<0.05$

To compare total, corneal, and lenticular astigmatism between the control group and the groups diagnosed with accommodation hypofunction and hyperfunction (see Table 2), a Kruskal–Wallis test was performed using both standard clinical values and JCC vector components. The analysis revealed no statistically significant differences in any of the astigmatism parameters – cylinder power, axis, Jackson values, x and y vector coordinates – across the three groups. The closest to statistical significance were the x-vector coordinate ($p=0.09$) and cylinder power ($p=0.09$) in corneal astigmatism. These trends suggest that participants with accommodation disorders may exhibit slightly higher corneal cylinder values. The difference falls within the 0.12–0.16 D range. This difference, although small, is clinically relevant when using a digital phoropter for precise measurements. The lack of statistically significant differences in the group comparisons suggests that overall variations in astigmatism parameters are subtle. This may be attributed to within-group heterogeneity, interaction effects between variables, or differences in the analytical focus. However, intersectional analyses revealed significant interaction effects, highlighting the importance of considering multidimensional relationships when evaluating astigmatism parameters. These findings suggest that the complexity of the data requires a more detailed analytical approach to uncover meaningful associations.

Table 2. Comparison of Astigmatism in School-Age Children with Diagnosed Accommodation Disorders – Accommodation Hypofunction (HYPO), Accommodation Hyperfunction (HYPER) and the Control Group, Including Group Mean Differences (Δ) Relative to the Control Group and Associated p Values (95 % Confidence Interval)

Total astigmatism:	**Control group (n=41), mean ± SD**	**HYPO (n=7), mean ± SD**	**HYPER (n=16), mean ± SD**	**p value**	**Δ Control - HYPO ±SD**	**Δ Control - HYPER ±SD**
cylinder power, D	-0.43±0.25	-0.35±0.18	-0.38±0.15	0.37	-0.08±0.03	-0.05±0.02
cylinder axis, °	80.90±48.46	72.08±41.13	60.93±48.54	0.22	8.82±3.60	19.96±8.15
Jackson 0	-0.05±0.21	-0.06±0.16	-0.01±0.16	0.48	0.01±0.00	-0.04±0.02
Jackson 45	-0.03±0.10	0.00±0.08	-0.01±0.11	0.28	-0.03±0.01	-0.02±0.01
X (vector coordinate)	-0.04±0.27	-0.06±0.17	-0.10±0.23	0.27	0.02±0.01	0.06±0.02
Y (vector coordinate)	-0.28±0.27	-0.25±0.22	-0.22±0.21	0.56	-0.04±0.02	-0.06±0.03

*p<0.05

Corneal astigmatism:	**Control group (n=41), mean ± SD**	**HYPO (n=7), mean ± SD**	**HYPER (n=16), mean ± SD**	**p value**	**Δ Control - HYPO ±SD**	**Δ Control - HYPER ±SD**
cylinder power, D	-0.73±0.34	-0.90±0.52	-0.84±0.29	0.09	0.16±0.07	0.11±0.04
cylinder axis, °	16.24±30.49	17.69±27.50	10.56±18.49	0.52	-1.45±0.59	5.68±2.32
Jackson 0	0.33±0.21	0.39±0.28	0.39±0.16	0.11	-0.06±0.02	-0.07±0.03
Jackson 45	0.08±0.09	0.11±0.09	0.10±0.09	0.48	-0.03±0.01	-0.02±0.01
X (vector coordinate)	-0.69±0.40	-0.81±0.56	-0.82±0.31	0.09	0.12±0.05	0.13±0.05
Y (vector coordinate)	-0.11±0.11	-0.12±0.09	-0.11±0.09	0.65	0.01±0.01	0.00±0.00

*p<0.05

Lenticular astigmatism:	**Control group (n=41), mean ± SD**	**HYPO (n=7), mean ± SD**	**HYPER (n=16), mean ± SD**	**p value**	**Δ Control - HYPO ±SD**	**Δ Control - HYPER ±SD**
cylinder power, D	0.75±0.32	0.86±0.50	0.79±0.26	0.88	-0.11±0.05	-0.04±0.01
cylinder axis, °	26.25±32.78	24.21±30.81	16.28±20.95	0.28	2.05±0.84	9.97±4.07
Jackson 0	-0.25±0.26	-0.31±0.38	-0.31±0.20	0.55	0.06±0.02	0.06±0.02
Jackson 45	-0.14±0.13	-0.08±0.05	-0.14±0.14	0.23	-0.06±0.03	0.00±0.00
X (vector coordinate)	0.65±0.38	0.75±0.59	0.73±0.30	0.57	-0.10±0.04	-0.08±0.03
Y (vector coordinate)	-0.17±0.26	-0.12±0.26	-0.11±0.23	0.21	-0.05±0.02	-0.07±0.03

*p<0.05

When analysing the mean differences between groups, a statistically significant distinction was observed in the total cylinder axis. In the accommodation hyperfunction group, the mean axis difference compared to the control group was 19.96° ± 8.15°, while in the hypofunction group, the mean difference was 8.82° ± 3.60°. Additionally, mathematical calculations revealed a lenticular astigmatism axis difference of 9.97° ± 4.07°. Although these findings suggest potential clinical relevance, further studies are necessary to confirm their robustness and broader applicability.

According to the Vision Council of America [42], even 3.00° difference in axis may be clinically significant in individuals with astigmatism below 2.00 D. Therefore, these results may be interpreted as both statistically and clinically significant. One-way ANOVA Multiple Comparisons Test confirmed that both the total cylinder axis and lens cylinder axis were significantly different in the accommodation hyperfunction group (see Table 3), supporting the need for further investigation into axis variations in accommodative disorders.

Table 3. One-Way ANOVA Multiple Comparisons Test Results between the Control, Accommodation Hypofunction, and Hyperfunction Groups

p value	**Control group vs. HYPO**	**Control group vs. HYPER**	**HYPER vs. HYPO**
Total astigmatism:			
cylinder power, D	ns	ns	ns
cylinder axis, °	0.13	<0.0001*	0.07
Jackson 0	ns	ns	ns
Jackson 45	ns	ns	ns
X (vector coordinate)	ns	ns	ns
Y (vector coordinate)	ns	ns	ns

p value	Control group vs. HYPO	Control group vs. HYPER	HYPER vs. HYPO
Corneal astigmatism:			
cylinder power, D	ns	ns	ns
cylinder axis, °	0.98	0.18	0.37
Jackson 0	ns	ns	ns
Jackson 45	ns	ns	ns
X (vector coordinate)	ns	ns	ns
Y (vector coordinate)	ns	ns	ns
Lenticula astigmatism:			
cylinder power, D	ns	ns	ns
cylinder axis, °	0.95	0.0035	0.25
Jackson 0	ns	ns	ns
Jackson 45	ns	ns	ns
X (vector coordinate)	ns	ns	ns
Y (vector coordinate)	ns	ns	ns

*$p<0.05$; significance levels (p values) are based on a 95 % confidence interval; non-significant results are denoted as "ns", $p \geq 0.99$.

4. DISCUSSION

Several authors have reported that corneal astigmatism (CA) in healthy eyes is predominantly WTR both in adults [22]–[24] and children [25], [26]. For instance, Heydarian et al. [27] found that the mean residual lenticular and corneal astigmatism were − 0.84 dioptres (D) and − 0.85 D, respectively. Based on and vector analysis, residual astigmatism was − 0.33 D and 0.04 D, while corneal astigmatism measured 0.38 D and 0.01 D, respectively. In their study, WTR, ATR, and oblique corneal astigmatism were observed in 67.94 %, 1.3 %, and 1.5 % of children, respectively. Residual astigmatism decreased as the spherical refractive error increased, while corneal astigmatism showed the opposite trend, increasing with higher spherical refractive errors. Among the 6–18-year-old population, there was a high prevalence and magnitude of residual astigmatism with an ATR pattern. This ATR residual astigmatism appeared to have a compensatory effect on corneal astigmatism, which predominantly exhibited a WTR pattern. These findings align with the results of the present study, in which 93 % of participants with diagnosed accommodative disorders and 93 % of control group participants exhibited WTR corneal astigmatism. The prevalence observed in our study is higher than that reported in previous studies, which mainly focused on the prevalence of astigmatism based on subjective refraction data [28]–[31]. It is important to note that our study did not include an analysis of subjective refraction. A small amount of astigmatism may be present in objective refraction measurements, which may not be clinically significant or require correction during subjective refraction, and therefore might not be classified as astigmatism in clinical practice. Furthermore, previous studies have used varying thresholds to define astigmatism. In this study, objective astigmatism was documented starting from 0.25D.

Thibos et al. [20] were the first to propose the analysis of JCC vector analysis to describe astigmatism, and this methodology has since been widely adopted by numerous authors [26], [32], [33]. According to this approach, positive values of J_0 indicate WTR or oblique astigmatism. When applying the cos2α function, positive values correspond to axis ranges of [0°–45°) and (135°–180°]. Conversely, negative values of J_0 indicate ATR or oblique astigmatism, corresponding to axis values within the (45°–135°) range (see Fig. 2). JCC vector analysis does not fully correspond to the clinical terminology traditionally used to classify astigmatism. In clinical practice, WTR astigmatism is typically defined by a negative cylinder axis positioned at 180° ± 30°, whereas ATR astigmatism is defined by a negative cylinder axis at 90° ± 30°. In our study, the mean axis of the negative cylinder was 80.90°±48.46° in the control group, 72.08°±41.13° in the group with diagnosed accommodation hypofunction, and 60.93°±48.54° in the group with diagnosed accommodation hyperfunction, indicating a predominance of ATR astigmatism (see Table 2).

Although the mean total astigmatism power was approximately equal across all three groups (around -0.40 D), the results showed a lower corneal astigmatism value in the control group (less than -0.75D) compared to the accommodation disorder groups, where corneal astigmatism was close to of exceeded -1.00 D. When examining the difference between the corneal and refractive cylinder axes, the control group demonstrated a mean axis of difference of approximately 75°, whereas this difference was reduced in the accommodation hypofunction and hyperfunction groups, averaging around 55° and 50°, respectively.

The preliminary results suggest that a clinically significant discrepancy between total and corneal astigmatism power, combined with an oblique orientation of the total astigmatism axis, may indicate the presence of an accommodative disorder. In such cases, a comprehensive assessment of accommodation is recommended. Previous studies have shown minimal impact of accommodative demand on ocular astigmatism but have not thoroughly evaluated the type and magnitude of astigmatism in relation to accommodative disorders – particularly through vector analysis. Since total astigmatism at any point in the visual field consists of both axial and oblique components, these elements may shift in opposite directions during accommodation, resulting in little or no net change in total astigmatism.

Liu & Thibos [5] demonstrated that both axial and oblique components of astigmatism remain invariant with accommodation. Furthermore, they found that these components of corneal astigmatism are partially compensated by the internal optics across the central 30° of the visual field in accommodating emmetropic or myopic eyes. This compensatory interaction between corneal and internal astigmatism influences not only the magnitude but also the axis of the resulting total astigmatism. The compensation of axial astigmatism suggests that at least one surface of the crystalline lens is toroidal, with the meridian of minimum lens power generally aligned with the meridian of maximum corneal power. The fact that total axial astigmatism remains independent of accommodation implies that changes in zonular tension during accommodation are uniformly distributed across the lens, thereby preserving its toricity.

In all groups, the most prevalent type of corneal astigmatism was WTR (see Table 2). The clinically negative cylinder was aligned at 16.24° ± 30.49° in the control group, 17.69° ± 27.50° in the accommodation hypofunction group, and 10.56° ± 18.49° in the accommodation hyperfunction group – values that are consistent with the clinical classification of WTR astigmatism. Similar observations have been raised by Bayramlar et al. [12] and Rozanova [13].

Dobson et al. [34] report that physiological lenticular astigmatism is typically ATR, with an average magnitude of approximately 0.50 D, and remains stable throughout life in individuals without ocular pathology. In our study, calculated lenticular astigmatism was also predominantly ATR, with the positive cylinder axis aligned at 26.25°± 32.78° in the control group, 24.21° ± 30.81° in the accommodation hypofunction group, and 16.28° ± 20.95° in the accommodation hyperfunction group. The group with accommodative hyperfunction showed a notable shift in lenticular astigmatism axis – closer to 90° for negative cylinders – indicating a stronger ATR tendency.

When calculating and analysing the refractive power and axis of the lens using the JCC method, the sphere and the spherical equivalent must be taken in account. Otherwise, calculation by JCC gives negative value, indicating that the lenticular astigmatism is either oblique or ATR. It should also be mentioned that there is a large scatter in the results due to the astigmatism type classification. For instance, if astigmatism clinically classifies as ATR that means that negative cylinder axis can range from 60 to 120 degrees.

Gwiazda et al. [35] explained the mechanisms of possible accommodation interaction with astigmatism and found that infantile astigmatism – particularly ATR – was associated with increased astigmatism and myopia during the school years. The mechanisms are not well understood, but two possible hypotheses have been proposed: First – *the blur hypothesis* or the inability to use blur cues appropriately, combined with extensive near work. Infantile astigmatism may disrupt emmetropization by reducing a child's sensitivity to focusing cues (spherical aberration and astigmatism, meridional amblyopia). This disruption of sensitivity may lead directly to underaccommodation, which in turn induces myopia, or it may cause eye alignment problems that inhibit accommodation, thereby creating a hyperopic blur signal that can only be corrected through the induction of myopia. Second – *the ocular growth hypothesis* – young adults' corneal astigmatism is not correlated with myopia, while total astigmatism is. The crystalline lens and vitreous become the source of myopia-associated astigmatism. The key – a crystalline lens structurally based mechanism for the simultaneous increase in astigmatism and spherical equivalent power.

The limitations of the current study are listed below.

- A small effect size: For a small effect size (d = 0.19), as observed in comparisons such as control vs. hyperfunction and hypofunction vs. hyperfunction groups, achieving 80 % statistical power at an alpha level of 0.05 would require over 400 participants per group. In contrast, for a medium effect size (d = 0.42), such as in the control vs. accommodation hyperfunction comparison, the required sample size would be approximately 60 to 100 participants per group.
- Small sample size: The hypofunction group (n=7) is extremely small, and the hyperfunction group (n=16) is also

relatively limited in size, resulting in a high risk of failing to detect true effects. While the control group (n=41) is larger, it is still insufficient to fully mitigate the impact of variability and the small sample sizes in the other groups.

- Low statistical power to detect smaller effects, meaning that subtle differences may go undetected.
- The high variability in the cylinder axis measurements – particularly in the control and hyperfunction groups – further complicates the detection of significant differences, especially given the small sample sizes.
- The findings may not be easily generalizable to the broader population of children. Larger and more diverse samples are needed to ensure the results are robust and widely applicable. There are practical constraints, such as the limited sample size due to the accessibility of school-aged children from Latvia and the limited time available for visual function evaluation. Each child's full examination takes one academic hour.
- Non-cycloplegic refraction, while commonly used, presents limitations in pediatric populations due to the potential influence of accommodation on refractive accuracy. Active accommodation can lead to an overestimation of myopia and an underestimation of hyperopia and astigmatism, potentially skewing the results. This limitation should be carefully considered when interpreting refractive data. However, to mitigate these effects, standardised procedures were implemented, including multiple measurements and fogging techniques, aiming to reduce variability and enhance the reliability of the measurements.

Assessing accommodative function is a vital component of paediatric vision examinations, alongside refraction and keratometry measurements. Our primary focus was on the relationship between astigmatism axis and power, as measured by Auto Ref/Keratometer, and the presence of binocular disorders. Future research could explore factors such as genetics, environment, and behaviour, which are crucial in the context of myopia progression. Gwiazda et al. [35] proposed that disrupted sensitivity to defocus may directly contribute to underaccommodation, positioning the crystalline lens as a potential source of myopia-associated astigmatism. In this context, recommendations concerning outdoor activity, reading habits, and hereditary factors are becoming increasingly relevant.

The study demonstrated that JCC vector analysis can be a valuable tool for assessing astigmatism. However, further investigation is necessary to broaden the understanding of how this method can be interpreted within the context of clinical astigmatism classification. Future research could benefit from including participants with higher degrees of astigmatism, as all participants in this study had astigmatism below 2.00 D, limiting the scope of conclusions. As a cross-sectional study, this research cannot establish causal relationships. Longitudinal studies would provide deeper insights into how accommodative disorders influence astigmatism and the progression of myopia within the same cohort over time. Additionally, future studies could explore the relationship between total astigmatism parameters and binocular dysfunctions by examining vergence disorders and heterophoria types.

5. CONCLUSIONS

Keratometry data in school-aged children showed predominantly WTR corneal astigmatism, while total astigmatism tended to be ATR in the control and accommodation hypofunction groups, and WTR in the hyperfunction group. Statistically and clinically significant differences in total and lenticular astigmatism axis were observed between the accommodation hyperfunction and control groups, with the hyperfunction group showing a shift toward oblique astigmatism. The difference between refractive and corneal astigmatism axes averaged approximately 50° in the accommodation hyperfunction group, and 75° in the control group. Assessing the total astigmatism axis during refraction may offer optometrists valuable insights into underlying accommodative dysfunctions, even in asymptomatic patients. In our study, a statistically significant difference in total astigmatism axis was observed between the control and accommodation hyperfunction groups. However, this finding should be interpreted with caution due to the limited sample size. Future studies should aim to include larger and more balanced cohorts, ideally with 50–100 participants per group, to enhance the reliability and generalizability of results. These preliminary findings support a potential association between accommodative disorders and astigmatism axis orientation, warranting further investigation to determine their clinical relevance.

Appendix A

Appendix A: Diagnostic criteria for accommodative and vergence disorders (all diagnostic criteria were adapted from Franco et al. [18] and Scheiman & Wick [19]. For some accommodative and vergence disorders additional criteria were adapted – as indicated in the table)

Disorders	Fundamental signs	Complementary signs
Accommodation hypo-function		
Accommodative insufficiency [36], [37]	Reduced AA – at least 2.00D lesser than the expected Hofstetter's minimal value of the age and MAF < 6 cpm (difficulty with -2.00D lenses)	BAF < 3 cpm (difficulty with -2.00D lenses) MEM ≥ +0.75 D PRA ≤1.25 D PFV < 12/15/4 – blur at near may be reduced
Ill-sustained accommodation	MAF < 6 cpm (difficulty with -2.00D lenses)	BAF < 3 cpm (difficulty with -2.00D lenses) MEM ≥ +0.75 D PRA ≤1.25 D PFV < 12/15/4 – blur at near may be reduced
Accommodative infacility [38]	MAF < 6 cpm (difficulty with ±2.00 D lenses)	BAF < 3 cpm (difficulty with ±2.00 D lenses) PRA ≤ 1.25 D NRA ≤ 1.50 D PFV < 12/15/4 – blur at near may be reduced NFV < 9/17/8 – blur at near may be reduced

Accommodation hyperfunction		
Accommodative excess	MAF < 6 cpm (difficulty with +2.00 D lenses)	BAF <6 cpm (difficulty with +2.00D lenses) MEM ≤ +0.25 D NRA ≤ 1.50 D NFV < 9/17/8 - blur at near may be reduced
Vergence, heterophoria, fusion		
Convergence insufficiency [39]	Near exophoria at least 4PD larger than at distance	NPC > 6cm AC/A ratio < 2:1 PFV < 11/14/3 (reduced finings in at least one of three) VF < 13 cpm (difficulty with base out) BAF < 6 cpm (difficulty with +2.00D lenses) NRA ≤ 1.50 D MEM ≤ +0.25 D
Convergence excess [40]	Near esophoria at least 2 PD larger than at distance	NFV < 8/16/7 (reduced findings in at least one of three) AC/A ratio > 6:1 MEM ≥ +0,75 D PRA ≤ 1.25 D VF < 13 cpm (difficulty with base in) BAF < 6 cpm (difficulty with -2.00D lenses)
Fusional vergence disorder	PFV < 11/14/3 (reduced finings in at least one of three) or NFV < 8/16/7 (reduced finings in at least one of three)	VF < 13 cpm (difficulty with BO and BI) BAF <6 cpm (difficulty with ±2.00D lenses) PRA ≤ 1.25 D NRA ≤ 1.50 D
Divergence insufficiency [41]	Far esophoria at least 4PD larger than at near	AC/A ratio < 2:1 NFV at distance < -/3/2 (reduced finings in at least one of three)
Divergence excess	Far exophoria at least 5 PD larger than at near	AC/A ratio > 6:1 PFV at distance < 5/11/6 (reduced finings in at least one of three) NFV at near < 9/17/8 (reduced finings in at least one of three)
Basic exophoria	Significant exophoria at distance and near of approximate the same amount (within 5 PD)	PFV at distance < 5/11/6 (reduced finings in at least one of three) PFV at near < 12/15/4 (reduced finings in at least one of three) VF < 13 cpm (difficulty with BO) BAF < 6 cpm (difficulty with +2.00D lenses) NRA ≤ 1.50 D MEM ≤ +0.25 D
Basic esophoria [40]	Significant esophoria at distance and near of approximate the same amount (within 5 PD)	NFV at distance < -/4/2 (reduced finings in at least one of three) NFV at near < 9/17/8 (reduced finings in at least one of three) VF < 13 cpm (difficulty with BI) BAF < 6 cpm (difficulty with -2.00D lenses) PRA ≤ 1.25 D MEM ≥ +0.75 D

NPC – near point of convergence, PFV – positive fusional vergence, NFV – negative fusional vergence, VF – vergence facility, AC/A ratio – accommodative convergence to accommodation ratio measured with gradient method, BAF – binocular accommodation facility, MAF – monocular accommodation facility, NRA – negative relative accommodation, PRA – positive relative accommodation, MEM – dynamic retinoscopy with monocular estimated method, BO – base out, BI – base in.

REFERENCES

1. Shukla, Y. (2020). Accommodative Anomalies in Children. *Indian Journal of Ophthalmology*, *68* (8), 1520–1525.
2. Gurnani, B., & Kaur, K. (2023). Astigmatism. *In StatPearls*. Available at: https://www.ncbi.nlm.nih.gov/books/NBK582142/
3. Mohammadi, S. F., Tahvildari, M., & Z-Mehrjardi, H. (2012). Physiology of astigmatism. In M. Goggin (ed.), *Astigmatism – Optics, Physiology and Management* (pp. 1–16). InTech: Iran.
4. Lara-Lacárcel, F., Marín-Franch, I., Fernández-Sánchez, V., Riquelme-Nicolás, R., & López-Gil, N. (2021). Objective Changes in Astigmatism during Accommodation. *Ophthalmic & Physiological Optics: The Journal of the British College of Ophthalmic Opticians (Optometrists)*, *41* (5), 1069–1075.
5. Liu, T., & Thibos, L. N. (2017). Variation of Axial and Oblique Astigmatism with Accommodation across the Visual Field. *Journal of Vision*, *17* (3), 24.
6. Cheng, H., Barnett, J. K., Vilupuru, A. S., Marsack, J. D., Kasthurirangan, S., Applegate, R. A., & Roorda, A. (2004). A Population Study on Changes in Wave Aberrations with Accommodation. *Journal of Vision*, 4 (4), 272–280.
7. Read, S. A., Collins, M. J., & Carney, L. G. (2007). A Review of Astigmatism and its Possible Genesis. *Clinical & Experimental Optometry*, *90* (1), 5–19.
8. Wilson, G., Bell, C., & Chotai, S. (1982). The Effect of Lifting the Lids on Corneal Astigmatism. *American Journal of Optometry and Physiological Optics*, *59* (8), 670–674.
9. Mandell, R. B., & Helen, R. S. (1968). Stability of the Corneal Contour. *American Journal of Optometry and Archives of American Academy of Optometry*, *45* (12), 797–806.
10. Yasuda, A., Yamaguchi, T., & Ohkoshi, K. (2003). Changes in Corneal Curvature in Accommodation. *Journal of Cataract and Refractive Surgery*, *29* (7), 1297–1301.
11. Schachar R. A. (2004). Effect of Accommodation on the Cornea. *Journal of Cataract and Refractive Surgery*, *30* (3), 531–533.
12. Bayramlar, H., Sadigov, F., & Yildirim, A. (2013). Effect of Accommodation on Corneal Topography. *Cornea*, *32* (9), 1251–1254.
13. Rozanova, I. O. (2023) Scheimpflug Imaging of the Anterior Eye Segment during Standardized Accommodation Stimulation in Patients with Emmetropia, Myopia and Hypermetropia. *Open Journal of Ophtalmology*, *13* (1), 73–82.
14. Harvey, E. M., Miller, J. M., Apple, H. P., Parashar, P., Twelker, J. D., Crescioni, M., … & Sherrill, D. L. (2014). Accommodation in Astigmatic Children during Visual Task Performance. *Investigative Ophthalmology & Visual Science*, *55* (8), 5420–5430.
15. Cacho-Martínez, P., Cantó-Cerdán, M., Carbonell-Bonete, S., & García-Muñoz, Á. (2015). Characterization of Visual Symptomatology Associated with Refractive, Accommodative, and Binocular Anomalies. *Journal of Ophthalmology*, 2015, 803–895.
16. Davis, A. L., Harvey, E. M., Twelker, J. D., Miller, J. M., Leonard-Green, T., & Campus, I. (2016). Convergence Insufficiency, Accommodative Insufficiency, Visual Symptoms, and Astigmatism in Tohono O'odham Students. *Journal of Ophthalmology*, *20* (16), 6963–6976.
17. Hashemi, H., Khabazkhoob, M., Peyman, A., Miraftab, M., Jafarzadehpur, E., Emamian, M. H., … & Fotouhi, A. (2013). The Association between Residual Astigmatism and Refractive Errors in a Population-Based Study. *Journal of Refractive Surgery, 29* (9), 624–628.
18. Franco, S., Moreira, A., Fernandes, A., & Baptista, A. (2022). Accommodative and Binocular Vision Dysfunctions in a Portuguese Clinical Population. *Journal of Optometry*, *15* (4), 271–277.

19. Scheiman, M., & Wick, B. (2008). *Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders.* Philadelphia: Lippincott Williams & Wilkins.
20. Thibos, L. N., Wheeler, W., & Horner, D. (1997). Power Vectors: An Application of Fourier Analysis to the Description and Statistical Analysis of Refractive Error. *American Academy of Optometry*, *74* (6), 367–375.
21. Liu, Y. C., Chou, P., Wojciechowski, R., Lin, P. Y., Liu, C. J., Chen, S. J., … & Cheng, C. Y. (2011). Power Vector Analysis of Refractive, Corneal, and Internal Astigmatism in an Elderly Chinese Population: The Shihpai Eye Study. *Investigative Ophthalmology & Visual Science*, *52* (13), 9651–9657.
22. Fledelius, H. C., & Stubgaard, M. (2009). Changes in Refraction and Corneal Curvature during Growth and Adult Life. *Acta Ophthalmologica*, *64* (5), 487–491.
23. Remón, L., Benlloch, J., & Furlan, W. D. (2009). Corneal and Refractive Astigmatism in Adults: A Power Vectors Analysis. *Optometry and Vision Science, 86* (10), 1182–1186.
24. Hoffmann, P. C., & Hütz, W. W. (2010). Analysis of Biometry and Prevalence Data for Corneal Astigmatism in 23,239 Eyes. *Journal of Cataract & Refractive Surgery*, *36* (9), 1479–1485.
25. Tong, L., Carkeet, A., Saw, S.-M., & Tan, D. T. (2001). Corneal and Refractive Error Astigmatism in Singaporean Schoolchildren: A Vector-Based Javal's Rule. *Optometry and Vision Science*, *78* (12), 881–887.
26. Shankar, S., & Bobier, W. R. (2004). Corneal and Lenticular Components of Total Astigmatism in a Preschool Sample. *American Academy of Optometry*, *81* (7), 536–542.
27. Heydarian, S., Sardari, S., Heidari, Z. Yekta, A.A., Ostadimoghaddam, H., & Khabazkhoob, M. (2020). Corneal and Ocular Residual Astigmatism in School-Age Children. *Journal of Current Ophthalmology, 32* (4), 355–360.
28. Vitale, S. (2008). Prevalence of Refractive Error in the United States, 1999–2004. *Archives of Ophthalmology*, *126* (8), 1111.
29. He, M., Huang, W., Li, Y., Zheng, Y., Yin, Q., & Foster, P. J. (2009). Refractive Error and Niometry in Older Chinese Adults: The Liwan Eye Study. *Investigative Opthalmology & Visual Science*, *50* (11), 5130.
30. Wolfram, C., Höhn, R., Kottler, U., Wild, P., Blettner, M., Bühren, J., … & Mirshahi, A. (2014). Prevalence of Refractive Errors in the European Adult Population: The Gutenberg Health Study (GHS). *The British Journal of Ophthalmology*, *98* (7), 857–861.
31. Varma, R., Torres, M., McKean-Cowdin, R., Rong, F., Hsu, C., Jiang, X., & Chinese American Eye Study Group. (2017). Prevalence and Risk Factors for Refractive Error in Adult Chinese Americans: The Chinese American Eye Study. *American Journal of Ophthalmology*, *175*, 201–212.
32. Radhakrishnan, H., & Charman, W. N. (2007). Changes in Astigmatism with Accommodation. *Ophthalmic & Physiological Optics*, *27* (3), 275–280.
33. Salvador-Roger, R., Albarrán-Diego, C., Garzón, N., García-Montero, M., Muñoz, G., Micó, V., & Esteve-Taboada, J. J. (2023). Revisiting Javal's Rule: A Fresh and Improved Power Vector Approach according to Age. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *262* (1), 249–260.
34. Dobson, V., Miller, J. M., & Harvey, E. M. (1999). Corneal and Refractive Astigmatism in a Sample of 3- to 5-Year-Old Children with a High Prevalence of Astigmatism. *Optometry and Vision Science*, *76* (12), 855–860.
35. Gwiazda, J., Grice, K., Held, R., McLellan, J., & Thorn, F. (2000). Astigmatism and the Development of Myopia in Children. *Vision Research, 40* (8), 1019–1026.
36. Hussaindeen, J. R., & Murali, A. (2020). Accommodative Insufficiency: Prevalence, Impact and Treatment Options. *Clinical Optometry, 12,* 135–149.

37. Cacho, P., García, A., Lara, F., & Seguí, M. (2002). Diagnostic Signs of Accommodative Insufficiency. *Optometry and Vision Science, 79* (9), 614–620.
38. Cacho-Martínez, P., Cantó-Cerdán, M., Carbonell-Bonete, S., & García-Muñoz, Á. (2015). Characterization of Visual Symptomatology Associated with Refractive, Accommodative, and Binocular Anomalies. *Journal of Ophthalmology*, *2015* (1), 895–803.
39. Gantz, L., & Stiebel-Kalish, H. (2022). Convergence Insufficiency: Review of Clinical Diagnostic Signs. *Journal of Optometry, 15* (4), 256–270.
40. Lara, F., Cacho, P., García, Á., & Megías, R. (2001). General Binocular Disorders: Prevalence in a Clinic Population. *Ophthalmic and Physiological Optics, 21* (1), 70–74.
41. Jacobson, D. M. (2000). Divergence Insufficiency Revisited: Natural History of Idiopathic Cases and Neurologic Associations. *Archives of Ophthalmology, 118* (9), 1237–1241.
42. The Vision Council. (2020). *Quick Reference Guide*. Available at https://thevisioncouncil.org/sites/default/files/ANSI%20Z80%201-2015_Quick%20Reference%20v2.pdf