ARTICLE

The Correlation between Reduced Binocular Vision Function and Reading Ability in Elementary School Students in Greece

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ABSTRACT

BACKGROUND

This study aimed to identify the correlation between visual performance and reading fluency, accuracy, and speed in elementary school students in Greece.

METHODS

Examination procedures were approved by the Ministry of Education for the optometric team to enter the school premises and perform the assessments. The researchers performed optometric testing according to standard protocols to evaluate near point of convergence, oculomotor function, visual acuity, stereopsis, and accommodation and vergence facility. All results were compared with the reading ability using objective measurements of reading speed, number of fixations, and number of regressions while reading standardized Greek text. Results were analyzed with IBM SPSS Statistics 25.0 setting a value of $p < 0.05$ as the level of statistical significance.

RESULTS

The 834 students that were examined came from a total number of 14 schools to enable socioeconomic stratification of high, medium, and low living standards. Study results showed a significant difference in reading speed between students who passed all visual performance tests and those who failed at least one. The number of failed vision tests was directly correlated with reading ability. Reduced reading speed and efficiency was directly correlated to the number of visual tests failed.

CONCLUSION

Poor reading performance in elementary school students in Greece was correlated with reduced visual function. Results demonstrated undiagnosed binocular and oculomotor visual deficiencies impact reading ability. A high correlation was identified between the number of visual deficiencies identified with both reading speed and regressions.

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Bollano-Lazaridis M, Chandrinos A. The correlation between reduced binocular vision function and reading ability in elementary school students in Greece Vision Dev & Rehab 2022; 8(1):41-55.

Keywords: accommodation, ocular motility, Optometry, reading regressions, reading speed, vergence, visual dysfunctions, visual skills

1. INTRODUCTION

The evolution of learning for every child starts when entering elementary school. Every year, teachers try to infuse new ideas and more complex thoughts to young students.

This learning procedure depends mainly on visual stimuli. Thus, it is very important to investigate the impact of visual restrictions on reading ability and performance.

The study aimed to identify the correlation between visual performance and reading fluency, accuracy, and speed in elementary school students in Greece.

1.1. Vision testing in Greece

Pediatric eye care in Greece is largely based on ophthalmological examination This means that every child is examined for pathological findings and refractive errors. Although this examination is very important, it neglects the assessment of visual function.

Current classroom demands require ability in tracking, focusing, binocular eye coordination, and visual processing of complex information.

1.2. Visual Skills Required in the Classroom

Neuromuscular skill is required of the visual system as both eyes must precisely point to the same point in space when tracking words on the page when reading. Oculomotility includes pursuit eye movements (accurately following a moving target, like the tip of the pencil when writing) and saccadic eye movements (short jumps from word to word when reading). Difficulties in oculomotility cause a loss of place, re-reading lines of text, and omitting words when reading. Students often guess words of similar starts because they do not see the full span of the word per glance.

The eyes must also coordinate to look at the right distance when executing eye movement. If the eyes misalign, binocular function, and depth perception are compromised. The student may make errors in reading and math calculation due to double vision. The eyes converge to view near targets at desk and computer viewing distances and diverge to see the teacher or information presented in the front of the classroom. Copying from the board requires the eyes to quickly and accurately converge and diverge, a skill called vergence facility. In addition, a modern classroom requires sustained near viewing. Maintaining accurate eye alignment for desk work requires a skill called sustained near point of convergence.

To see clearly, the crystalline lens must adjust appropriately to maintain clear vision. This occurs by activation of the ciliary body muscle and is a skill called accommodation - more commonly known as focusing. The ability to switch focus quickly and accurately between near and far distances is called accommodative facility and is another essential visual skill when copying information from far to near in the classroom setting.

Neuromuscular skills are essential to place a clear and single image on the retina of each eye so that the sensory processing of visual information is acquired accurately. Sensory functions of the visual system are to receive input from both eyes and fuse this information into a single perception. Visual information starts with the identification and localization of what is seen and where it is located. This requires the development of visual acuity, the ability to resolve fine detail. In the classroom, these skills are used to correctly identify letters, words, symbols, and numbers.

When visual information is processed binocularly, the brain avoids suppression, combines information for sensory fusion and acuity summation, and detects stereopsis.Stereopsis is used in the classroom when writing, drawing, cutting, and performing eye-hand coordination.[1]

1.3. Children's School Performance and Visual Function

Every living being develops based on sensory stimuli. As Aristotelis, the ancient Greek philosopher said "There is nothing in our mind that hasn't been firstly in our senses". Acknowledging that vision is the main sensory source of environmental information for every individual, the learning process can be directly affected by vision dysfunctions. Prior studies have proven the relationship between vision and learning.[2,3,4] Normally developed visual skills

enable efficient reading ability and academic progress.

Restricted visual skills development affects learning ability, the thinking process, and social behavior. A study by Dr. Paul Harris (2003) entitled "The prevalence of visual conditions in a population of juvenile delinquents" found that 97% of detainees had some visual impairment. An in-depth analysis of this phenomenon has revealed that children who cannot follow normal development through the learning process gradually tend to drop out, isolate, and finally may develop delinquent behaviors.[5]

2. METHODS

2.1. Children's Visual Dysfunctions

When visual skills are not developed sufficiently or synchronized properly, children may manifest functional vision problems. Visual dysfunctions may develop such complications that the whole optical system gets in a state of disorder.

Oculomotility dysfunctions are identified when an individual is unable to make accurate and synchronized saccadic movements between targets or the pursuit movement of a moving stimulus. To investigate any deficiency or restriction in this area, the Northeastern State University College of Optometry (NSUCO) test was completed.

Eye teaming dysfunctions are defined as the difficulty, interference, or inability of the binocular flow of data via neurological pathways. When the information is not able to be fused into one perception, testing can determine the presence of suppression of binocular vision and double vision. These visual restrictions were detected using the Worth 4 dot test for sensory fusion.

Difficulty in maintaining binocular alignment includes conditions such as convergence insufficiency or excess, divergence insufficiency or excess, high phorias, and strabismus. To detect those visual restrictions, a comprehensive oculomotor evaluation is necessary. In a screening scenario, the tests selected to evaluate functional binocular performance included vergence facility and near point of convergence.

Stereopsis is the "barometer" of binocularity[6] and the highest level of binocular visual function. Every individual who exhibits deficiencies in stereoscopic acuity has binocular vision problems. The ability to see accurate stereoscopic depth perception was evaluated by the Randot 3 Stereo test.

Focusing dysfunctions are characterized by the inability of an individual to achieve clarity by looking at a target. Restricted visual function includes the inability to sustain attention on near work for adequate time. Sustained accommodation is necessary for maintaining clear vision at near point including reading, writing, and drawing tasks. Changing focus between targets requires accuracy and efficiency. The binocular accommodative flexibility (BAF) and monocular accommodative flexibility (MAF) tests were selected to address this section of dysfunctions.

In all these dysfunctions visual acuity contributes significantly, assuring that the other systems will work ideally. For this reason, visual acuity was used to assess visual clarity and focusing accuracy. Symptoms commonly reported with reduced accommodation include blurred vision, headaches, and intermittent diplopia. Symptoms may worsen by the end of the day and include photophobia or nausea when traveling by car. Parents often report watching their child's eyes lose convergence, near-reading induced fatigue and sickness, and excessive head movements. Children show an inability to focus and concentrate on texts for a long time periods, drowsiness while reading, decreased comprehension of texts or loss in place when reading, fatigue when doing near work, skipping lines of text, difficulty copying from blackboard or doing mathematical computation, difficulty when they text on a computer or cell phone screen, and prefer to keep their head inclined while reading or writing. Children also mention that may see jumping words or words that are constantly mov-

ing on the page and that they also have a very poor performance in sports.

Parents first consult pediatricians and neurologists with learning concerns. These professionals are unable to explain the child's symptoms. Following exclusion of eye pathology, all functional vision problems must be evaluated by an optometrist.

2.2 Optometric Assessment Tests

Our protocol abided by the tenets of the Declaration of Helsinki. We chose to examine students of 4th and 6th grade because they should have passed at least 2 eye exams before the day of screening. Testing was designed to cover the daily living visual requirements of elementary students. Thus, we chose to evaluate visual acuity, near point of convergence, accommodation and vergence facility, stereopsis, and oculomotor function.

2.2.1 Visual Acuity

Visual acuity (VA) is a direct measure of the clarity of eyesight. A Snellen printed optotype chart consisting of numbers and graded from 20/200 to 20/15 was viewed at a testing distance of 6m and under correct lighting standards of the chart used as shown in Figure 1. The examination was completed with habitual lens correction (with glasses or without glasses if not worn). Visual acuity was recorded as the line in which more than 50% of the numbers were identified. Each eye was tested separately and then binocular visual acuity was also recorded. Visual acuity was expected to be equal to or better than 20/25 to pass this assessment. A difference between the two eyes should also not be greater than one line.[7]

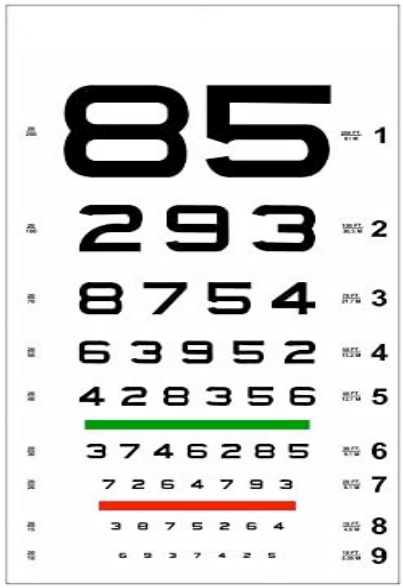


Figure 1. Acuity Chart

2.2.2 Near Point of Convergence (NPC)

To examine near point of convergence (NPC) skill, the student was instructed to maintain fixation as a Wolff wand target was brought toward the nose. The fusion break was recorded at the distance at which one of the two eyes no longer followed the target. The recovery point measurement was achieved by moving the target away from the subject's face and locating the point at which eye co-operation returned. The test is repeated five (5) times to draw an average performance and a stable response. The normative breakpoint values are between 5-8 cm and recovery 8-11cm. Fail criteria were therefore placed at measurements over 8 cm break and 11 cm recovery.[8,9,10,11,12]

2.2.3 Accommodation Facility

The amplitude of accommodation is defined as the maximum dioptric change in the power of the crystalline lens a subject can achieve. Accommodation flexibility assesses the ability to quickly acquire a clear and distinct image. In this research, we tested the ability of each individual to change focus between +/-2.00 D flipper lenses (Figure 2) known as accommodation facility.

Every child sat on a chair at a slanted desk with a 20-degree tilt and a viewing distance of 40

Figure 2. Accommodative flipper lenses

cm to control for accommodative and vergence demand. Accommodative Rock cards with words were used as targets as shown in Figure 3. (Cards with Greek words were made with the same font and size as the original ones). As the student cleared the print and accurately read the words correctly on the testing card, the examiner altered the flipper between plus and minus lens. A full cycle is considered by changing the flipper to view through +2.00 and -2.00. When the time reached 1min, the assistant stopped the procedure and the number of cycles per minute (cpm) was recorded. First, binocular accommodation facility (BAF) was executed and then monocular accommodation facility (MAF) testing was completed. Passing criteria was set at 3 cpm for binocular and 5 cpm for monocular testing.[13,14,15,16]

1	τρέχω	σπίτι	δοχείο	βάζω
2	παιδί	τραπέζι	τυρί	σπίρτο
3	θυμός	σημαία	βρύση	εργασία
4	γάντι	νίκη	ζύμη	λουλούδι
5	ποτήρι	κάστρο	ρυάκι	μπίλια
6	κοιτάω	πλήθος	χρόνος	δρόμος
7	όμορφος	κτίριο	φακός	γράμμα
8	κρύο	αυγό	περιβόλι	ήλιος
9	νόμισμα	δίκαιος	παίζω	ελιά
10	ζάρι	έδρα	κερί	ρήμα
11	γελώ	βεντάλια	φάκος	ξύστρα
12	νίκη	αγρός	ευχή	τέλος
13	τζάκι	κήπος	λόγος	κρίνω
14	σέλα	βάρος	λύπη	ρίζα
15	άλλη	φορώ	πιρούνι	δέμα
16	λύκος	φωτιά	πυλός	ζάχαρη

Figure 3. Accommodative Rock card

2.2.4 Vergence Facility

The flexibility of moving the eyes between convergence and divergence posture was tested with a prism flipper consisting of 3ΔBI /12ΔBO and targets at 40cm from the examinee. Every child sat on a chair at a slanted desk tilted 20-degrees to control for stable accommodation and vergence demand. Accommodative Rock cards with words (Figure 3) were used as targets and viewed through one side of the 3ΔBI /12ΔBO prism flipper. When the student recognized the one word correctly without double vision, the flipper was rotated. A full cycle is completed by changing the flipper to view through both 3ΔBI and 12ΔBO prism. When the time reached 1min, the assistant stopped the procedure and the number of cycles was recorded. The minimum requirements for a normal facility between convergence and divergence operation were set at 12cpm.[17]

2.2.5 Stereopsis

A Random Dot 3 Stereo test (Figure 4) was administered using Polarized glasses, the examination distance of 40 cm, and photopic conditions. The examinee was asked to wear the polarized glasses and look at the stereoscopic test. Shapes should be recognized in response to various stereoscopic objects starting at a disparity of 600 sec arc and down to 12.5 sec arc. The best stereoscopic acuity of the examinee was recorded.[18,19]

Figure 4. Random Dot 3 Stereo Test

2.2.6 Pursuit and Saccade Oculomotor Function

The purpose of the oculomotor test is to evaluate the quality and accuracy of pursuit eye movements and saccadic eye movements. A smooth pursuit describes a type of eye movement in which the eyes remain fixated on a moving object. A saccade is a quick, simul-

taneous movement of both eyes between two fixation points. The Northeastern State University College of Optometry (NSUCO) test was used to evaluate the performance of students in oculomotility.[20]

Oculomotor testing was conducted by an examiner holding the 5mm diameter fixation target at a distance of 40cm from the examinee and assessing the accuracy and ability scores according to the NSUCO testing protocol. Behind and next to the examiner, a second observer objectively evaluated body and head movements. The instruction to the examinee was "follow the target as if your eyes were connected to it with an invisible rope." The examiner performed two counterclockwise circles 20cm in diameter and then two clockwise circles of the same diameter to assess pursuit oculomotor function. Saccadic oculomotor testing was completed with two Wolff Wand targets (Figure 5) of 5 mm in diameter and the student alternated gaze between the two targets. The distance between targets was 20cm (10cm from midline).

Figure 5. Wolff Wands

2.2.7 Pass/Fail test Criteria

To evaluate the performance of each individual, the criteria were set to determine the pass/fail performance on each functional vision test. Table 1 shows the pass/fail criteria for testing VA, NPC, BAF, MAF, vergence facility, and stereoacuity.

Table 1: Pass/Fail Criteria

Fail Test Criteria		
Visual Acuity (VA)	≤ 20/25 Within 1 line	monocular
	≤ 20/25	binocular
Near Point of Convergence (NPC)	> 8cm (break)	>11cm (recovery)
Accommodative Facility	<5 cpm (monocular)	< 3 cpm (binocular)
Vergence Facility	<12 cpm	
Stereo Acuity	> 50sec	

2.2.8 Reading Assessments

In this study, the Thomson Eye-Tracker software (Figure 6) was used to record the operation of the visual system during reading. Correct operation of the program required hardware including a laptop computer and a 22" screen. Located at the lower portion of the screen, the "Tobii eye pro" device was applied to detect eye movements.

The operating interface of the Thomson Eye Tracker enables the integration of any Microsoft Word document. This makes the system compatible with any language. This integrative feature also provides the ability to zoom the text according to the needs and requirements of the exam. For this testing, letters were standardized to the same size as grade-level reading books. Text size was calibrated for the viewing distance of 45-65cm

The Thomson Eye Tracker program provided the ability to display monocular or binocular motion. It was used to record reading speed, the number of eye fixations to read the text, the number of regressions per line (re-reading or

Table 2	NSUCO	Failed Criteria		Values				
A/A STUDENT	PURSUIT EYE MOVEMENT				SACCADE EYE MOVEMENT			
	ABILITY	ACCURACY	HEAD MOV.	BODY MOV.	ABILITY	ACCURACY	HEAD MOV.	BODY MOV.
4th Grade Boys	< 5	< 4	< 4	< 4	< 5	< 3	< 3	< 4
4th Grade Girls	< 5	< 4	< 4	< 5	< 5	< 3	< 3	< 4
6th Garde Boys	< 5	< 4	< 4	< 4	< 5	< 3	< 3	< 4
6th Grade Girls	< 5	< 4	< 4	< 5	< 5	< 3	< 4	< 5

looking back), and horizontal and vertical vergences. In addition, information related to head tilt when reading, blink rate, and interpupillary distance were also recorded.

Before starting the eye movements recording, a calibration was performed to identify the movements of each eye with great accuracy. The following instruction set was then given to the examinee: "A text will appear on the screen. I would like you to read it as clearly and quickly as you can." The text that the examinee was asked to read consisted of 16 lines. Each row contained exactly 10 words.

The recording started from the second paragraph and continued for the next 50-70sec, in order for the first paragraph to be used as an adaptation to the reading conditions for all tested students. The examiner chose to stop recording when the child had finished a series of readings within the timeframes mentioned above. What was recorded were the reading speed in words per minute (wpm), the average number of fixations per line (fix/ line), and the average number of regressions per line (reg/line).

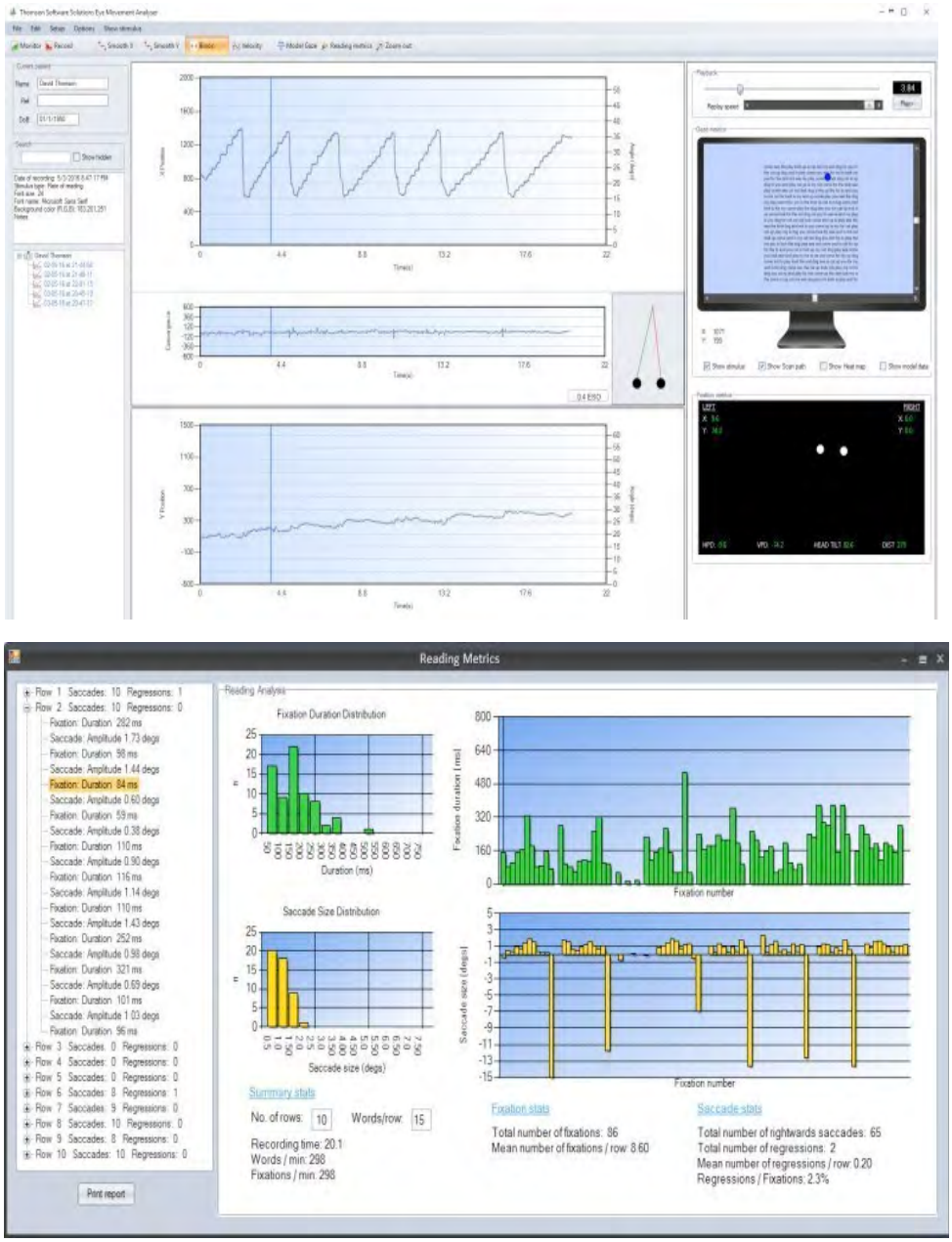


Figure 6. Thomson Eye Tracker software presentation

3. RESULTS

3.1 Test results analysis

The 834 students that were examined came from a total number of 14 schools to enable social stratification of high, medium, and low socioeconomic status. Of the students, 188 (22.5%) were boys of 4th grade, 217 (26.0%) girls of 4th grade, 197 (23.6%) boys of 6th grade, and 233 (27.9%) girls of 6th grade.

Students were classified by the number of failed visual performance tests as shown in Figure 7. This graph demonstrates the quantitative distribution of students regarding the number of failed tests. Students who passed all the tests totaled 143 (17.1%). There were 76 (9.1%) children who failed in one test, 218 (26.1%) in two tests, 192 (23%) in three tests, 152 (18.2%) in four tests, 51 (6.1%) in five tests, and 3 (0.4%) who failed all six tests showing the most significant restrictions in visual skills performance.

3.2 Hypotheses

A **first hypothesis** was made that ***students who passed all optometric testing with normal***

visual performance had a significant difference in reading speed compared to students who had restricted visual skills. Students were divided into two groups according to their visual performance testing results. The first group included the students who passed all optometric tests. The second group included the students who failed to pass at least one optometric test.

The normal visual performance (Pass all tests) and restricted visual performance (Fail ≥1 test) groups were assessed with the Thomson Eye Tracker device which measured reading speed, the number of fixations, and the number of regressions. The Thomson Eye Tracker reading speed data analysis followed the normal distribution for both groups of visual performance (p-value >0.05), leading to parametric analysis as shown in Table 3.

Table 4 shows the reading speed data analysis between students with normal visual performance (1st group) and restricted visual skills performance (2nd group) in the 4th and 6th grades. The mean reading speed of first group in 4th grade was 123.26 wpm and for the

Table 3. Statistical Test of Normality regarding Reading Speed of 4th and 6th grade students.

Test of Normality		Kolmogorov-Smirnov			Shapiro-Wilk		
Grade 4th	**Pass all tests**	**Statistic**	**df**	**p-value**	**statistic**	**df**	**p-value**
Reading	Yes	0.081	39	0.200	0.975	39	0.535
Speed	No	0.046	366	0.057	0.994	366	0.182

Grade 6th	**Pass all tests**	**Statistic**	**df**	**p-value**	**statistic**	**df**	**p value**
Reading	Yes	0.080	104	0.104	0.982	104	0.178
Speed	No	0.031	326	0.200	0.998	326	0.919

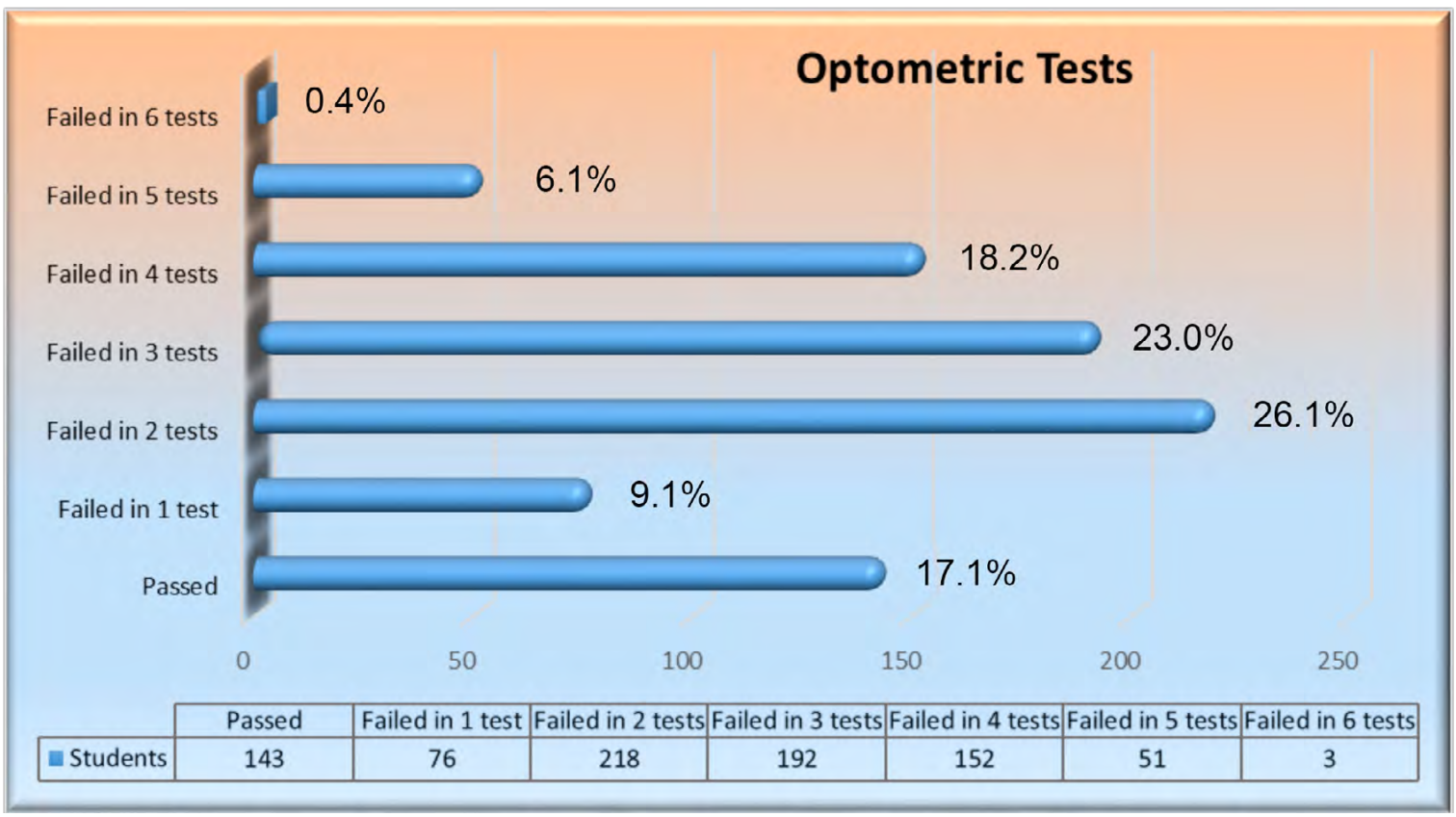


Figure 7. Quantitative distribution graph of students regarding the number of tests failed

Table 4. Statistical evaluation of reading speed per minute of 4th and 6th grade students.

Grade 4th	Pass all tests	N	Mean	Stand. Deviation	T. Statistics	p-value
Reading	Yes	39	**123.26**	13.23	10.764	**<0.001**
Speed	No	366	**85.18**	21.64	0.994	366
Grade 6th	**Pass all tests**	**Statistic**	**df**	**p-value**	**statistic**	**df**
Reading	Yes	104	**140.69**	17.16	16.471	**<0.001**
Speed	No	306	**100.96**	22.60		

Table 5. Statistical Test of Normality regarding Regressions per line of 4th and 6th grade students.

Test of Normality	Kolmogorov-Smirnov				Shapiro-Wilk		
Grade 4th	**Pass all tests**	**Statistic**	**df**	**p-value**	**statistic**	**df**	**p-value**
Regression	Yes	0.155	39	0.200	0.951	39	0.090
	No	0.109	366	<0.001	0.904	366	<0.001
Grade 6th	**Pass all tests**	**Statistic**	**df**	**p-value**	**statistic**	**df**	**p-value**
Regressions	Yes	0.084	104	0.065	0.968	104	0.012
	No	0.131	326	<0.001	0.840	326	<0.001

second group of 4th grade 85.18 wpm. Similarly, the mean reading speed of first group in 6th grade was 140.69 wpm and for the second group of 6th grade 100.96 wpm. These results show a mean deviation between the first and second groups of 37 and 40 words per minute. Study results showed a significant difference in reading speed between students who passed all visual performance tests and those who failed at least one. Reading Speed: T-Statistics 10.764 (4th), 16.471 (6th) and p-value <0.001, Regressions: M-Whitney 1.221 (4th), 4.555 (6th) and p-value <0.001).

A **second hypothesis** was made that students who passed all optometric testing with normal visual performance had a significant difference in the number of regressions while reading compared to students who had restricted visual skills.

The Thomson Eye Tracker regressions data did not follow the normal distribution for both groups of visual performance (p-value <0.05), leading to non-parametric statistical analysis to evaluate the correlation as shown in Table 5.

Table 6 shows the reading regression data analysis between students with normal visual performance (1st group) and restricted visual skills performance (2nd group) in the 4th and 6th grades. The mean regressions of the 1st group in 4th grade were 2.2 regressions per line (reg/line) and for the 2nd group of 4th grade 4.2 reg/line. Similarly, the mean number of regressions of the 1st group in 6th grade was 2.2 reg/line and for the 2nd group of 6th grade 3.5 reg/line. These results show a mean deviation between the first and second groups of 2 regressions per line (reg/line) and 1.5 reg/line accordingly. The results showed statistically significant differences between the mean values reading regressions between the 1st and the 2nd group of students.

Summarizing the research, findings we conclude that students who passed all the optometric tests showed significantly fewer regressions compared to those who did not pass at least one visual performance test.

A third hypothesis was made that there is a correlation between the reduction of reading

Table 6. Statistical evaluation of the results regarding Regressions per line of 4th and 6th grade students.

Regressions						
Grade 4th	**Pass all tests**	**N**	**Mean**	**Mean Rank**	**Mann-Whitney U**	**p-value**
Normal Vision	Yes	39	**2.20**	51.31	1.221	**<0.001**
Visual Restriction	No	366	**4.20**	218.65		
Regressions						
Grade 6th	**Pass all tests**	**Statistic**	**df**	**p value**	**statistic**	**df**
Normal Vision	Yes	104	**2.20**	96.30	4.555	**<0.001**
Visual Restriction	No	306	**3.50**	252.98		

Table 7. Statistical evaluation of results regarding the Reading Speed per minute and the Regressions per line of reading in accordance with the failed tests by the students of 4th & 6th Grade.

Test of Normality	**Kolmogorov-Smirnov**			**Shapiro-Wilk**		
Grade 4th	**Statistic**	**df**	**p-value**	**statistic**	**df**	**p-value**
Test Failed	0.167	366	<0.001	0.919	366	<0.001
Reading Speed	0.046	366	0.057	0.994	366	0.182
Regressions	0.109	366	<0.001	0.904	366	<0.001
Grade 6th	**Statistic**	**df**	**p-value**	**statistic**	**df**	**p-value**
Test Failed	0.232	326	<0.001	0.897	326	<0.001
Reading Speed	0.031	326	0.200	998	326	0.919
Regressions	0.131	326	<0.001	0.840	326	<0.001

speed and the increment of regressions depending on the number of failed tests. The greater the number of failed visual performance tests, the more visual processing areas affected across categories of accommodation, oculomotility, and binocular function.

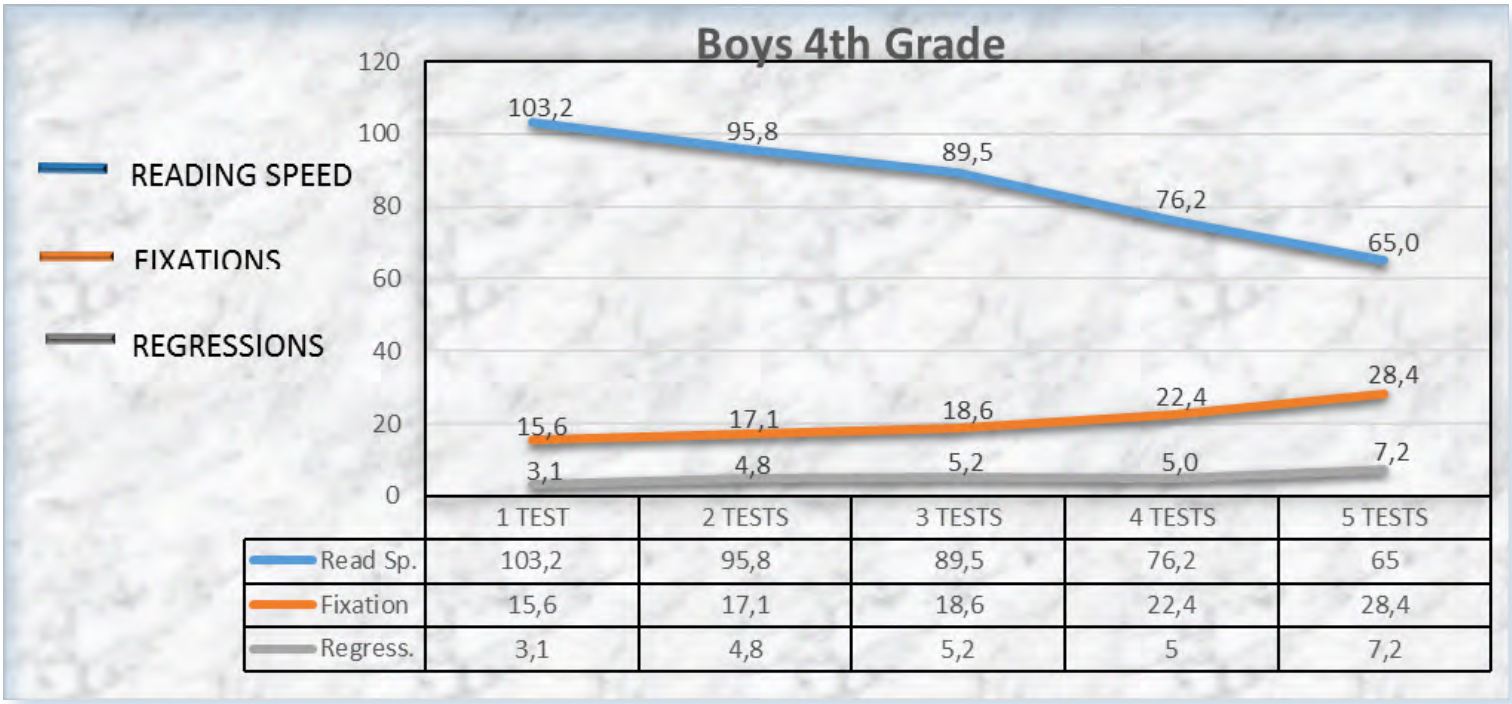
In Table 7, we can see that 3 variables did not follow the normal distribution (p-value < 0.05) and therefore we followed the non-parametric statistical evaluation for this correlation.

The Spearman coefficient was used to calculate statistical findings according to non-parametric data as shown in Table 8. Results showed that there is a medium significant correlation between Reading Speed, Regressions, and the number of failed tests.

Table 8. Statistical evaluation of results with Spearman correlation coefficient regarding the Reading Speed per minute and the Regressions per line of reading in accordance with the failed tests by the students of 4th & 6th Grade.

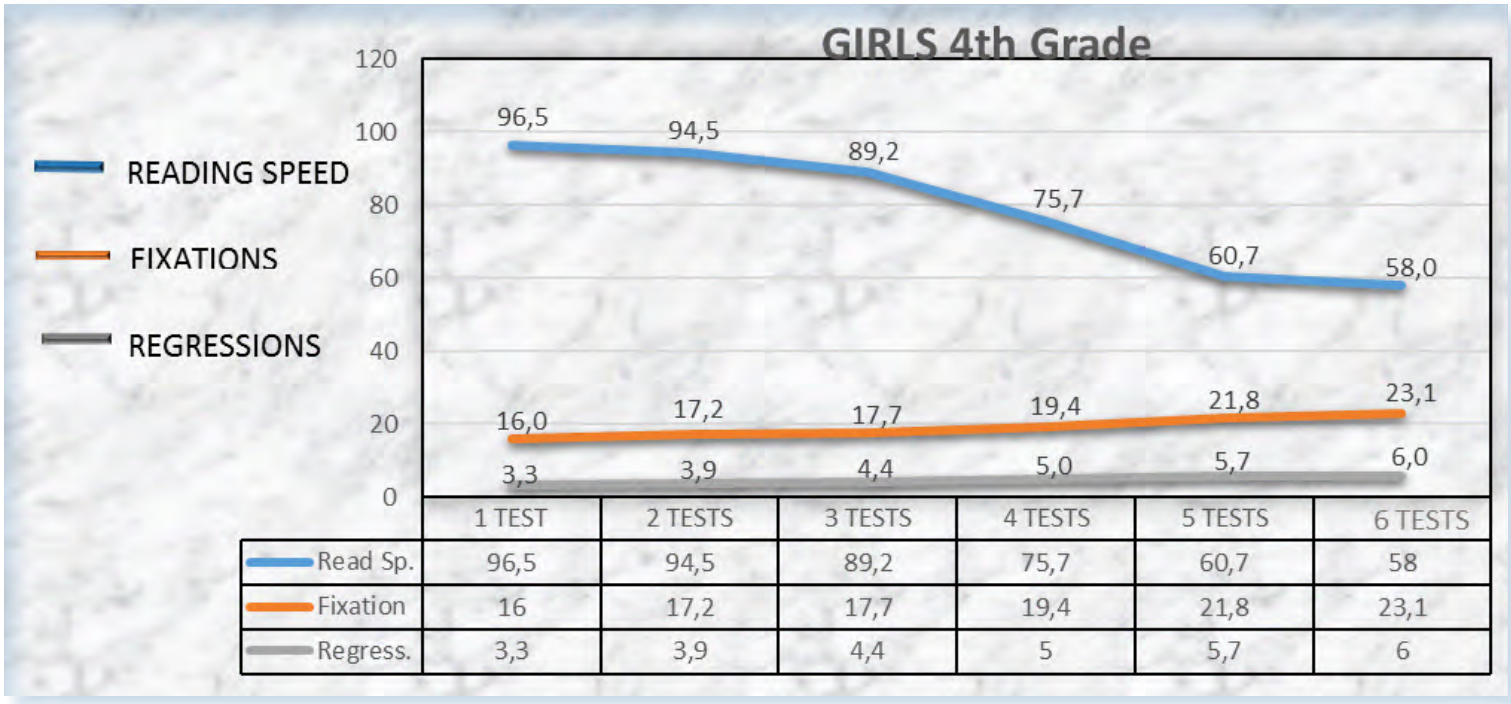
Grade 4th		**Number of failed tests**	**Reading Speed**	**Regressions**
Number of Tests Failed	**Spearmn Coefficient**	1	-0.491	0.334
	p-value		<0.001	<0.001
Grade 6th		**Number of failed tests**	**Reading Speed**	**Regressions**
Number of Tests Failed	**Spearmn Coefficient**	1	-0.302	0.366
	p-value		<0.001	<0.001

Figure 8 is a graph representing the mean reading speed, fixations per line and regressions per line compared to the number of visual performance tests failed in test subjects who were boys in the 4th grade. Test results for reading speed in this age group show decreased ability in reading speed according to the number of failed tests. Fourth-grade boys read on average 103 wpm when failing 1 test, 95.8 wpm when failing 2 tests, 89.5 wpm when failing 3 tests, 76.2 wpm when failing 4 tests, and 65 wpm when failing in 5 tests. In addition to slower



	1 TEST	2 TESTS	3 TESTS	4 TESTS	5 TESTS
Read Sp.	103,2	95,8	89,5	76,2	65
Fixation	15,6	17,1	18,6	22,4	28,4
Regress.	3,1	4,8	5,2	5	7,2

Figure 8. Mean reading speed (Read Sp.), fixations per line, and regressions (Regress.) per line compared to the number of tests failed in boys of the 4th grade.

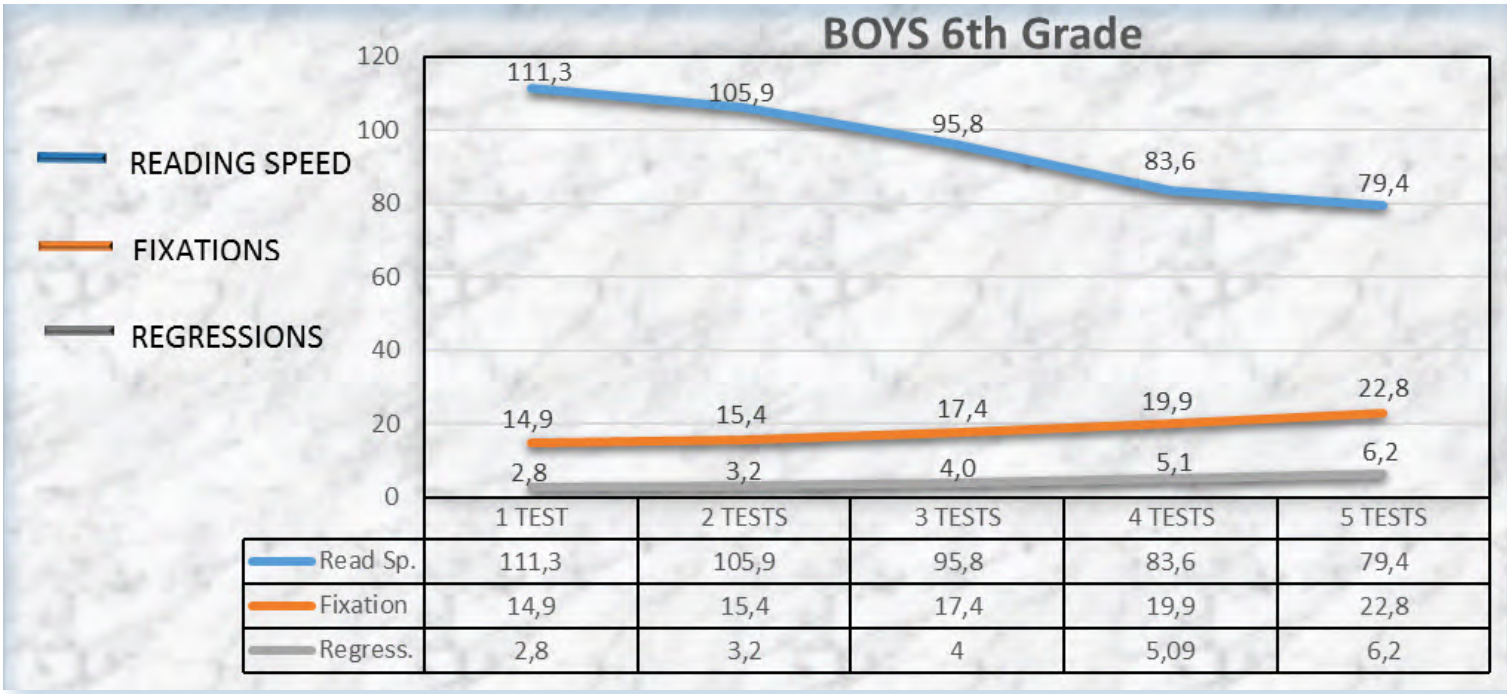


	1 TEST	2 TESTS	3 TESTS	4 TESTS	5 TESTS	6 TESTS
Read Sp.	96,5	94,5	89,2	75,7	60,7	58
Fixation	16	17,2	17,7	19,4	21,8	23,1
Regress.	3,3	3,9	4,4	5	5,7	6

Figure 9. Graph representing the mean Reading speed, Fixations per line, and Regressions per line, regarding the number of tests failed by girls of the 4th grade.

reading speeds, 4th grade boys also showed reading inaccuracy with increased fixations per line (f/line) and regressions per line (reg/line) as follows: 15.6 fixations/line and 3.1 reg/line if failing one optometric test, 17.2 fixations/line and 4.8 reg/line when failing 2 tests, 18.6 fixations/line and 5.2 reg/line if failing 3 tests, 22.4 fixations/line and 5 reg/line if failing 4 tests, and 28.4 fixations/line & 7.2 reg/line when failing to pass 5 tests.

Figure 9 is a graph representing the mean reading speed, fixations per line, and regressions per line compared to the number of visual performance tests failed in test subjects



	1 TEST	2 TESTS	3 TESTS	4 TESTS	5 TESTS
Read Sp.	111,3	105,9	95,8	83,6	79,4
Fixation	14,9	15,4	17,4	19,9	22,8
Regress.	2,8	3,2	4	5,09	6,2

Figure 10. Graph representing the mean Reading speed, Fixations per line, and Regressions per line, compared to the number of vision tests failed by boys of 6th grade.

who were girls in the 4th grade. This test group also demonstrated a decreased ability in reading speed according to the number of failed optometric tests. Fourth-grade girls averaged 96.5 wpm when failing 1 test, 94.5 wpm when failing 2 tests, 89.2 wpm when failing 3 tests, 75.7 wpm when failing 4 tests, 60.7 wpm when failing 5 tests, and 58 wpm when failing 6 tests. Fourth grade girls also showed reading inefficiencies due to increased regressions and fixations. When failing in 1 visual performance test, the subjects averaged 16 fixations/line and 3.3 reg/line. When failing 2 tests, the results were 17.2 fixations/line and 3.9 reg/line. When analyzing the results of subjects failing 3 tests, the reading performance results were 17.7 fixations/line & 4.4 reg/line. When failing 4 tests, results were 19.4 fixations/line and 5 reg/line. When failing 5 tests, results were 21.8 fixations/line and 5.7 reg/line. When failing 6 tests, results were 23.1 fixations/line & 6 reg/line.

Figure 10 illustrates that boys in the 6th grade have decreased ability in reading speed according to the number of failed vision performance tests (111.3 wpm – 1 test, 105.9 wpm - 2 tests, 95.8 wpm - 3 tests, 83.6 wpm – 4tests, 79.4 wpm -5 tests). Reading efficiency was also poorer, as the students showed increased regressions and fixations as follows: 14.9 fixations/line and 3.2 reg/line – 1 test, 15.4 fixations/line and & 3.2 reg/line – 2 tests , 17.4 fixations/line and 4 reg/line – 3 tests, 19.9 fixations/line and 5.09 reg/line – 4 tests, 22.8 fixations/line and 6.2 reg/line – 5 tests.

Figure 11 illustrates that girls in the 6th grade also have decreased ability in reading speed according to the number of failed vision performance tests. Reading speed testing was on average as follows: 108.3 wpm – 1 test, 104.7 wpm - 2 tests, 100.6 wpm - 3 tests, 93.8 wpm – 4 tests, 89.7 wpm - 5 tests. Also showing reduced reading performance, these 6th grade students showed increased numbers of regressions and fixations with higher numbers of identified visual restrictions. Data from testing is as follows: 15.3 fixations/line & 3.2 reg/line - 1 test, 16.3 fixations/line & 3.6 reg/line – 2 tests, 16.6 fixations/line & 3.7 reg/line – 3 tests, 18.8 fixations/line & 4.6 reg/line – 4 tests, 18.8 fixations/line & 4.6 reg/line – 5 tests.

The number of vision tests failed was directly correlated with reading ability across

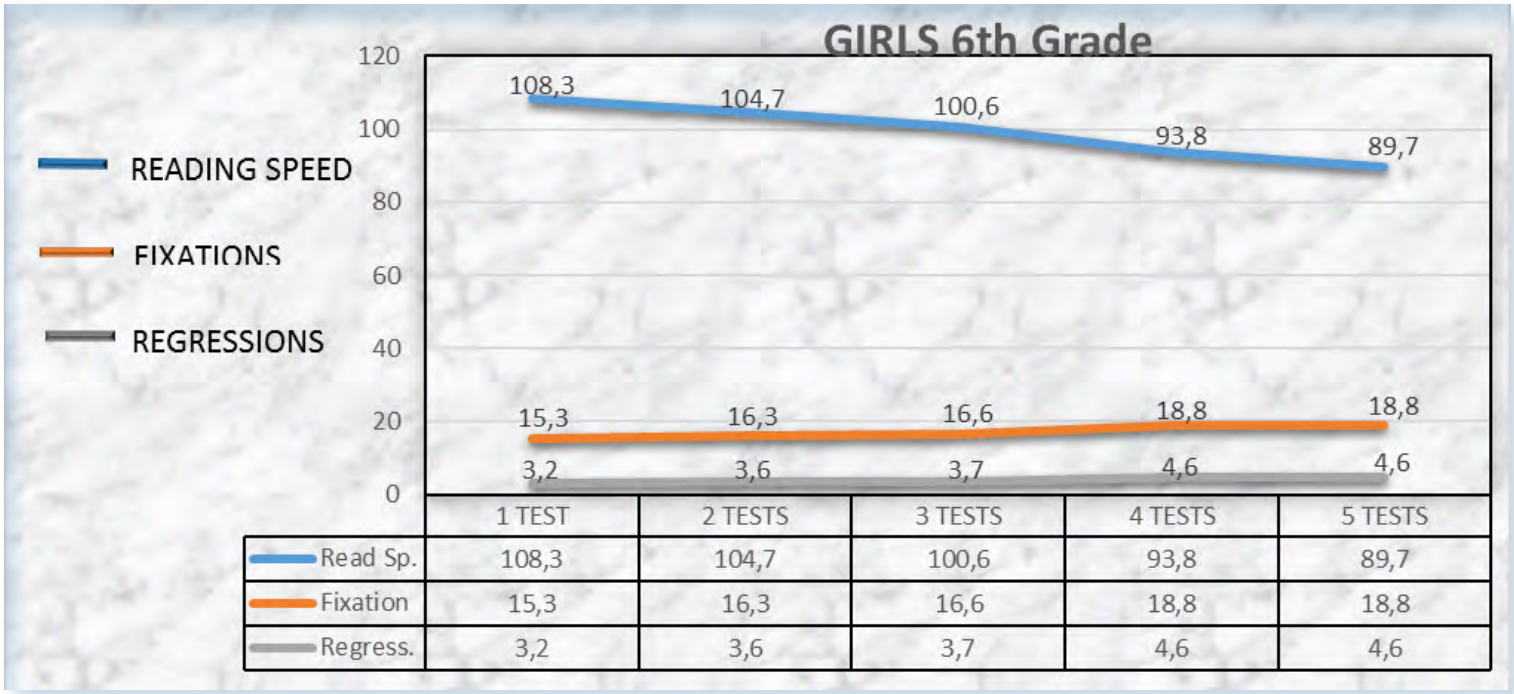


Figure 11. Graph representing the mean Reading speed, Fixations per line, and Regressions per line compared to the number of tests failed by girls in the 6th grade.

boys and girls of both grade cohorts. Reduced reading speed and efficiency were directly correlated to the number of visual tests failed.

4. DISCUSSION

Limitations of this research included:

1. The time available for each student to perform a reading task on the Thompson Eyetracker was a maximum of 70 seconds due to the restrictions on the time limit in our school presence.
2. For NPC measurement a Wolff wand was used. Although the instruction to every student was "Look at the sphere trying to see yourself on it" some of them may not have fully activated accurate accommodation.
3. Worth 4 Dot was performed before the Binocular Accommodative Facility (BAF) test for detecting suppression, but other techniques for investigating central suppression were not included.
4. On the Vergence facility test, the instruction given was "say the word when it is clear". This suggests that some students could answer "clear" even though it was blurry.
5. We were unable to compare relations between specific failed tests and reading performance individually because correlations would be numerous and create difficulties in statistical analysis. The study was limited to comparing correlations between the total number of failed tests and reading performance.

Despite the above-mentioned limitations, the data shows reduced visual efficiency directly correlated to reading ability across all testing groups. The mean reading speed difference between those who passed all of the tests (17.9%) and those who failed at least in one area of visual performance (82.1%) was 40 words per minute. This significant difference in reading speed impacts the learning process, forcing children to spend more time trying to read and comprehend every text. The difference in frequency of regressions during reading was also significant. A student with a visual restriction had to make more corrective eye movements to succeed in word recognition. This impact on reading makes the required span of attention longer and reduces the available time for higher-order thinking, analysis, and processing of written information.

A review of the literature shows that there is a lack of research in Greece concerning the

expected values of reading speed in Elementary aged students. Oral reading fluency norms established by Hasbrouck and Tindall (2006)[22] for the English language set the appropriate mean value for 4th grade students at 112 wpm and 6th grade students at 140 wpm. Comparing these values with the research findings shows that the students who had normal visual performance (passed all optometric testing) achieved this standard in reading speed. Students who had restricted visual function had an almost 40 wpm reduction in performance.

According to a study by Rayner & Pollatsek contained in the book *Psychology of Reading,*[23] regressions should not exceed 25% of the number of fixations. The first study group of students with normal visual skills tested at the expected level and had acceptable regression scores. The 2nd group of students with restricted visual performance had more regressions than normal.

Reading ability was directly related to the number of visual restrictions identified. The higher the number of vision restrictions, the less the speed of reading and the higher the number of regressions. This is a very important result that could support the hypothesis that every visual restriction directly impacts the reading ability of children. Testing showed performance in oculomotility, accommodation, and vergence played a decisive role in reading performance.

Areas of oculomotor and binocular function were evaluated in this clinical study. Further research should also include visual perception and sensory integration ability to further investigate the complexities of reading for comprehension and learning. Visual perception skills must be highly accurate, consistent, and also be performed quickly. Visual processing speed is developed through the visual learning process. These areas of visual processing should be also be considered and evaluated for their impact on classroom performance.

5. CONCLUSION

Poor reading performance in elementary school students in Greece was correlated with reduced visual function. Results demonstrated that undiagnosed binocular and oculomotor visual deficiencies impact reading ability. A high correlation was found between the number of visual deficiencies identified with both reading speed and regressions. The study confirmed a significant correlation between visual restrictions and reading performance. Students with normal vision performed impressively better than those who had at least one visual restriction in reading speed. They also had fewer regressions per line compared to students with restrictions.

This data demonstrated that reading performance was connected with the number of visual restrictions affecting every individual. As the number of failed visual tests increased, the reading speed decreased and the regressions increased. The high number of previously unidentified visual restrictions indicates that students do need optometric care in Greece. Optometric care to improve vision skills can be achieved by prescribing the correct lenses, prisms, or tints and implementing optometric vision therapy.

Detection and treatment of visual disorders would aim to both alleviate symptoms and strengthen learning ability.

Acknowledgments

I would like to express sincere gratitude to Savvas Lazaridis, BSc Optometrist, FCSO, for providing invaluable guidance, comments, and suggestions throughout the course of this project. His supervision ensured the appropriate execution of every optometric test under ideal conditions and selection of the examination procedures.

Special thanks to Dr. Jennifer Simonson, OD, FCOVD for her invaluable guidance in writing and submitting this research. —Melinta Bollano

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When she is not working, Melinta enjoys reading and spending time with her husband and their two children.