STANDARDIZED READING PERFORMANCE AND OBJECTIVE EYE MOVEMENT EFFICIENCY IN CHILDREN – A QUANTITATIVE CORRELATIONAL STUDY DESIGN

by

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A THESIS

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Primary Thesis Advisor

Binocular vision screenings conducted in academic settings have determined that nearly 20% of all children are identified with a binocular or accommodative disorder (Bodack et al., 2010). Strikingly, without binocular and accommodative testing, only about 40% of these students would have been identified as having a functional vision disorder based on distance visual acuity alone. Functional vision is defined as "how the person functions [visually] and indicates deficits in higher-order cerebral mechanisms" (Roberts et al., 2016). Binocular and accommodative disorders occur at much higher rates among students that have been identified as poor readers (two or more grade levels below expected), with nearly 80-85% of poor readers diagnosed with at least one binocular or accommodative disorder (Dusek et al., 2010; Grisham et al., 2007). The significant prevalence of vision disorders in academic settings warrants investigation into accurate and accessible screening tools to identify students who may have functional vision deficits that impact their academic performance, and whether objective measures of eye movement efficiency correlate with standardized measures of reading comprehension.

One hundred and fifty students from grades three through five will be sampled from three elementary schools in the Eugene-Springfield area. These students will undergo a visual health screening and the RightEye Reading Skills Module. The visual screening will consist of near and distance visual acuity testing, as well as a cover test to determine if the student presents visual misalignment. The RightEye Reading Skills module will consist of a simulated reading task in which eye movement patterns will be recorded using video retinoscopy, producing outcome measures of reading visual efficiency, including reading rate, fixations per 100 words, average fixation duration, regression per 100 words, regression fixation ratio, gaze disparity, and Grade Level Equivalent (GLE) will be compared to performance on the Oregon State English Language Arts Examination Reading subsection. Statistical analysis will focus on how closely differences in performance correlate between these component measures of visual efficiency and the Oregon State English Language Arts Examination. If there is a moderate to strong correlation between these measures, this study could provide the basis for functional vision as a part of visual health screenings in academic settings, as well as further studies of academic subgroups.

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Introduction

Poor readers are defined as students who read an average of two or more grade levels below their expected grade level (Hussaindeen et al., 2017). Schools use this threshold when conducting standardized testing to identify students who may require additional resources and accommodations to be successful academically. However, standardized testing has limited means to identify the underlying reasons why students may struggle with reading. Demographics, geography, and academic resources have been explored as contributing factors. However, research concerning the visual system has posited that the efficiency of eye movements when tracking words across a page may have significant effects on reading comprehension and scores on standardized examinations.

Primary binocular eye movements can be divided into vergence, versional, saccadic, fixational, and pursuit eye movements, with additional influences including the optokinetic and vestibular ocular reflexes. Vergence eye movements involve the eyes moving in opposite directions to maintain a single image for objects at a variety of distances. Versional eye movements consist of the eyes moving in the same direction to track objects as they move across our field of vision. Saccadic eye movements involve rapid, coordinated movements of the eyes to move between targets. Fixational eye movements involve the eyes maintaining focus on a stationary target, and pursuit eye movements are slower eye movements intended to maintain a moving target on the center of the fovea (Purves et al., 2001). These eye movement skills, as well as the accommodative system that changes lens power to maintain image clarity, comprise the informational basis on which we process visual information. Eye movement skills typically follow a developmental trajectory. However, when a child experiences developmental delays, injury, or binocular vision issues, these eye movement skills can be compromised.

Causal study designs in the field have primarily centered around interventions to improve these component eye movement skills. However, these studies face construct validity challenges, including participant sampling, study design and comparison to controls, intervention design and length of treatment, as well as broader applicability to populations of interest. Additionally, these studies are often meta-analyses of clinical treatment, and are subject to confounding variables, such as individualized treatment programs and participant attrition and noncompliance. Therefore, though causal study designs investigating links between eye movement skills and higher-order visual functions such as reading would be preferable, establishment of associations between component eye movement skills and measures of reading performance and comprehension are needed prior to pursuing interventional designs.

Reading is one of the most visually demanding tasks that we perform daily, involving the complex integration of attentional, cognitive, and visual systems (Palomo-Álvarez & Puell, 2009). Reading eye movements are primarily saccadic, versional, and fixational in nature, and enable rapid jumps between lines and accurate tracking across lines. Additionally, the accommodative system and ocular reflexes maintain the clarity of text as the head and reading object move. The binocular and accommodative systems are critical to the accurate and efficient interpretation of written information, with delays in the development of these skills resulting in potentially significant impacts on academic performance.

In fact, studies evaluating saccadic reading eye movements found that poor readers had significantly slower horizontal saccades than normative data (Palomo-Álvarez & Puell, 2009), and there was a significant association between saccadic dysfunction and slow reading speed, as well as comprehension. In fact, in a study by Powers, poor readers scored an average of five grade levels below expected levels in saccadic efficiency (Powers et al., 2008). However, the correlational studies listed previously employ skilled observers, are costly and time consuming to conduct, and produce results that are not easily understood by educators, policymakers, and students. Additionally, a portion of studies rely on subjective symptom surveys, which have been found to be an inconsistent diagnostic tool for near visual tasks such as reading (Clark & Clark, 2015). Further, they often rely on either outdated normative data or determine statistical significance thresholds based on the data collected within the study.

To address these concerns, this study will employ the RightEye Vision System to produce objective recordings of eye movement efficiency. These recordings will be used to calculate component measures of visual reading efficiency that will be compared to student performance on the Oregon State English Language Arts Examination Reading subsection (Figure 1). These measures of eye movement efficiency and reading rate will be used to determine with what significance these measures can predict a child's performance on state standardized examinations. This is intended to demonstrate the correlative validity of this screening tool, and foster awareness of the impacts of the visual system on academic and reading performance outside of the field of optometry.

Materials and Methods

Oregon State English Language Arts Examination

The Oregon State English Language Arts/Literacy Examination for grades three through five consists of four primary subsections: reading, writing, speaking/listening, and research (*ELA/Literacy Summative Assessment Blueprint*, 2018). For comparison to the results of this study, we will focus on the Reading subsection, which is made up of the content categories literary and informational. Student scores are presented as continuous scale scores across all grade levels and are expected to increase year over year. Student English Language Arts report scores are presented as an overall score, as well as the previously mentioned subscores (Figure 1). We will focus on the Reading subscore and use the raw student score to compare to the outcome variables of our study. Because we will be making comparisons between continuous variables, there is no need to subdivide scores based on the Oregon State examination cut scores (levels 1-4), or to compare the results of either examination to normative data based on expected grade level performance. This ensures that study results are not influenced by outdated normative data, and regression analysis determining the relative effect of eye movement efficiency on reading performance can be performed.

School Meetings

My thesis committee and I will hold virtual meetings with administrators of three elementary schools in the Eugene-Springfield area to explain the testing methodology and outcome goals of the study, as well as approximate date ranges to conduct the study. We will inform administrators that we will require the use of a school library or other medium to large-size space on school grounds, as well as the issuance of student hall passes to attend the study during the participating students' first class of the day. Once approval is obtained for the study to be conducted at a particular school, we will collect student data, including names, grade levels, and scores on the previous year's state standardized examinations for sampling and examination purposes.

Sampling Methodology and Power Analysis

Our power analysis was conducted using GPower 3.1 and used Webber's Pearson correlation coefficients for reading rate in words per minute (Webber et al., 2011). Therefore, based on an effect size of 0.336, an alpha error probability of 0.005 (0.05 divided by 10 for the eight separate Pearson correlations to be conducted), a power of 90%, and a two-tailed test, we reach a sample size required of 113 (Figure 4). Therefore, we will randomly sample 50 students from each of the three schools selected within grade levels three through five. This would result in an initial sample size of 150 students, ensuring an adequate sample size that can account for attrition and exclusion based on diagnosed or undiagnosed visual health conditions.

Parental Consent

Students will be asked to obtain a signature from a parent or guardian to participate in the study. The parental consent form will contain information about the study procedures and outcome goals, including the time commitment from students, location of the study, and data analysis. Parents will also be informed that personally identifying information will be removed from their student's testing results. Protocols and procedures for the study will be reviewed by the University of Oregon Institutional Review Board to ensure compliance with data security and breach of confidentiality requirements. Once a student obtains a signature from a parent or guardian, they will also be asked to complete a screening survey.

Screening Survey

The screening survey parents and students will be asked to complete prior to participation in the study will include three primary sections: visual health, demographic information, and diagnosed attentional and behavioral disorders.

The visual health portion of the screening will focus on previously diagnosed visual conditions that could potentially impact the accuracy of eye movement recordings. These include ocular misalignment such as amblyopia and strabismus, as well as conditions such as cataracts. Additionally, questions will be asked concerning previous eye surgeries or ocular trauma (Hussaindeen et al., 2018). Students with pre-existing ocular health conditions will be excluded from participating in the study, as ocular misalignment or trauma could potentially disrupt eye movement recordings, invalidating the data that the student would provide.

The demographics section of this study will include information such as race (Asian, Black/African American, Hispanic/Latino, American Indian/Alaskan Native, Multi-Racial, Pacific Islander, White), gender (male, female, non-binary), parental income, as well as academic status (talented and gifted, students with disabilities, students requiring extended assessment time).

The final section of the screening will focus on previously diagnosed attentional and behavioral disorders, such as ADHD, depression, anxiety, and bipolar disorder. Parents will be asked if their child has been previously diagnosed by a medical professional with any of the above conditions. Rouse states that there may be a correlative relationship between parent-reported ADHD and higher incidence of symptomatic convergence insufficiency and other binocular vision disorders (Rouse et al., 2009). Students with diagnosed attentional and behavioral disorders will be flagged to determine if they score significantly differently on state standardized testing or GLE eye movement efficiency. This flagging differs from other studies in the field that exclude students based on potentially confounding neurological conditions. We view that including these students is important to ensuring that the study provides a representative sample of the Eugene-Springfield community, and that its results can be used to justify broad policy and practice changes. Students will be separated into three groups: those with diagnosed attentional disorders, those with diagnosed behavioral disorders, and students with both diagnosed attentional and behavioral disorders.

Permission Slips

Students will turn in their parental consent and screening surveys to their school administrative office no less than one day prior to their scheduled date of participation in the study and will obtain hall passes/permission slips to participate. If a student identifies that they have previously diagnosed visual health conditions that serve as exclusionary criteria, the student will be notified that they will be excluded from the study and will not be issued a hall pass/permission slip.

Visual Health Screening

Students will report to their school's library/gymnasium during their first class of their scheduled participation date. Students will be asked to present their hall passes and confirm their name and date of birth. Students will be given a slip with their unique student identifier to present to both the attending optometrist and research assistant for data entry. Students will also be asked if they wear habitual correction (e.g. glasses or contacts), and whether they are wearing that habitual correction upon their arrival. If students wear habitual correction, and either do not have it or refuse to use it during the examination, their response will be noted. The first examination the student will undergo will be conducted by the attending optometrist.

The student will be asked to sit in a screening chair, which will be placed ten feet from a computer monitor (Broderick, 1998). The attending optometrist will then trigger a randomly generated series of letters of decreasing size on the monitor, and the student will be asked to read the series of letters of smallest size they can perceive. The optometrist will record the student’s approximate distance visual acuity in their chart (Minnesota Department of Health, 2017). Next, the student will undergo the near visual acuity test. The near visual acuity test will consist of the child holding a near visual acuity chart 14 inches from their eyes and reading the lowest series of letters they can perceive (*Home Visual Acuity Testing*, 2020). The attending optometrist will record the student's approximate near visual acuity. Following the completion of these two tests, the attencing optometrist will then perform a cover test to determine if one eye deviates when visual stimulus from the other eye is restricted. The student will be asked to focus on a target on the computer monitor in the distance. The attending optometrist will then cover one eye with a handheld occluder and determine if there is movement of fixation of the exposed eye. The attending optometrist will then remove the occluder and determine if the covered eye deviated from the target (Broderick, 1998). If either eye deviates, there is potential presence of strabismus which may invalidate eye movement recordings.

Following the completion of these evaluations, the attending optometrist will determine whether the student presents clinically significant visual acuity or ocular misalignment deficits. The visual acuity threshold for the study will be 20/40 near and distance best corrected visual acuity with no clinically significant ocular misalignment. Students who fail to meet these criteria will be asked to return to their first period or study hall class. Students will also be given a note from the attending optometrist notifying their parents of their uncorrected visual health condition.

RightEye Vision System

We will use the RightEye Vision System to record student eye movements and calculate their corresponding component eye movement efficiency values. The RightEye Vision System is made up of the Tobii Dynavox IS4 eye tracker that allows for head movement compensation, calibration, and the use of habitual correction (either glasses or contacts) and RightEye software used to interpret the recordings of the Tobii system. The IS4 is designated as a nystagmograph by the FDA (Cunningham, 2018), and uses video retinoscopy to track movements of the retina by reflecting infrared light off the retina. RightEye produces software and testing tools including the Vision EyeQ and Reading Skills modules. This study will focus on the Reading Skills module, which involves a simulated reading task in which the Tobii IS4 system will be used to track a student's eye movements as they progress through the task. This recording will be used to calculate component measures of eye movement efficiency, including reading rate, fixations per 100 words, average fixation duration, regression per 100 words, regression fixation ratio, gaze disparity, as well as Grade Level Equivalent (GLE). Grade Level Equivalent, for the RightEye Vision System, is based solely on reading rate and is compared to normative data collected by Taylor (T. Radford, personal communication, April 29, 2021; Taylor, 1965). This GLE score is reported in integers ranging from 1-12 for the primary and secondary grade levels, college (coded as 13), and advanced reading levels from

1-5 (coded as 14-18). The eye movement efficiency variables previously mentioned (reading rate, fixations per 100 words, average fixation duration, regression per 100 words, regression fixation ratio, gaze disparity) and student GLE scores will serve as the primary outcome measures of the study and will be compared to student scores on the Oregon State English Language Arts Examination Reading subsection.

RightEye Reading Skills Module

Following completion of the visual health screening, students will move to the next station to undergo the RightEye Reading Skills Module examination. Students will sit in a height-adjustable chair so their feet can be grounded, ensuring head movement stability during the examination. Student distance from the RightEye Vision System will be ensured by a calibration prior to the examination, in which eye distance and head tilt will be evaluated to ensure accuracy in data collection. Students will be required to sit approximately 55-60cm from the screening device and correct their head positioning to +/- 3 degrees of left and right head tilt (T. Radford, personal communication, April 29, 2021).

Once the calibration is completed, the research assistant will select a reading passage based on the student's prior year grade level performance on the Oregon State English Language Arts Examination Reading subsection. For instance, if a student scored within the level 2 cut score range for the previous year's examination, they will be selected a reading passage that is one grade level below their current grade level. The same standard will be applied to students reading above their grade level average, with students within the level 4 cut score range reading a passage one grade level above their actual grade level (*2019-2020 Achievement Standards Summary*, n.d.). Students will be informed to read the passage as they would normally read any other text and will be instructed to place their right hand on the enter key of the keyboard sitting in front of them. Students will be instructed to press the enter key, read the entire passage, and press the enter key again immediately after finishing the reading passage. The first simulated reading task will serve as a practice recording, ensuring that students understand how to complete the reading task and do not engage in additional movements that could interfere with eye movement tracking results (e.g. head movements, looking away from the reading passage). Once the research assistant has determined that the student is prepared, and their practice recording falls within acceptable reliability measures (analysis reliability of greater than 80%), the student will undergo the simulated reading task, in which they will read the selected passage while the RightEye Vision System records their eye movements.

Once a student indicates they have completed reading the passage, they will be asked a series of ten comprehension questions concerning the reading passage. If a student answers 70% of the questions (7 out of 10) or higher correctly, they will have completed the simulated reading task. If the student does not meet this comprehension threshold, the research assistant will select a reading passage that is one grade level below the student's previous passage. Once the student has completed the reading task and met the comprehension threshold, they have completed the reading task. If a student completes the reading task two times, but does not meet the comprehension threshold, their testing results will be excluded from the study. If a student chooses not to repeat the reading task, their results will be excluded from analysis. Additionally, if a student's results are below the analysis reliability threshold of 80%, meaning that their head position varied outside of the distance range or the student tilted or moved their head in a way that disrupted tracking results, students will be retested with the same reading passage. If the student's results fail to meet this threshold a second time, their results will be excluded from analysis (T. Radford, personal communication, April 29, 2021).

Statistical Analysis

Reading Eye Movements

The primary statistical analysis of the study centers around Pearson's correlations between student scores on the Oregon State English Language Arts Examination Reading subsection and component measures of eye movement efficiency. Each student's score on the Oregon State ELA Examination Reading subsection will be compared in a Pearson's correlation to each of the seven previously mentioned component measures to determine the overall correlation between the measures across grade levels.

The R-value (how tightly measures cluster around the regression line) and P-value (how likely you would find the same R-value with another sample) will be the two primary outcome measures of these correlations. A proposed data table of the results of our analysis can be found in Figure 6. We expect to find weak to moderate positive and negative correlations between the component measures and a student's score on the Oregon State ELA Examination Reading subsection. We will then seek to determine which component scores best predict a student's performance on the ELA Reading subsection. Following this, we will perform a post-hoc power analysis to determine whether, based on the number of students whose data was included in the final data set, we have adequate power to generalize our results.

Health Information

In addition to the study's primary correlative analysis, we would also like to perform t-testing to determine whether previously diagnosed attentional or behavioral health conditions significantly correlate with student scores on the Oregon State English Language Arts examination and component eye movement efficiency scores. Statistical analysis for this section will split students into four separate groups: students with no diagnosed attentional or behavioral disorders, students with attentional disorders, students with behavioral disorders, and students with both attentional and behavioral disorders. Averages for all component measures of eye movement efficiency will be calculated, and two tailed t-tests at a 95% confidence level will be conducted to determine whether average scores in the attentional and behavioral disorder, as well as combined groups, score outside of the 95% confidence interval for component measures of eye movement efficiency and reading subsection scores within the neurotypical group.

Impacts and Continuing Research

The goal of this research is to determine whether objective eye movement tracking hardware can be used to screen for decreased visual efficiency that may indicate the presence of binocular and accommodative disorders impacting academic and reading performance. If multiple significant correlations are shown between student reading subsection scores and their component eye movement efficiency measures, future studies can evaluate the relationship between additional academic variables and these measures, such as academic GPA. Most importantly, evaluations using the RightEye Vision System can be used by educational institutions to screen for potential visual dysfunction in students identified as poor readers through standardized testing and academic performance. This gives institutions additional tools to better serve their students, informing parents of confounding factors that could interfere with academic performance.

Further, studies can begin to focus on specific populations, such as students with a diagnosed attentional condition such as ADHD, or poor readers who are consistently scoring two grade levels or below expected on statewide testing. This testing would seek to determine, based on the results of this study, whether there is a significant difference in component measures of eye movement efficiency within these groups versus the general population of students, and whether they score consistently lower on state standardized testing. If correlations are found, these results will provide the basis for interventional study designs for poor readers and students with undiagnosed binocular and accommodative disorders to improve their eye movement efficiency and determine resulting impacts on academic performance. More broadly, incorporating functional vision testing in annual vision screenings would be an efficient means of directing students to accessible education and optometric resources to accommodate for and remediate their visual dysfunction, potentially aiding in their academic performance.

Study Considerations

There are several limitations of this study that will be discussed subsequently. First, the study is correlational in nature, and cannot draw causative links between a child's performance on the Oregon State English Language Arts Examination and their eye movement efficiency. Additionally, the study design does not account for confounding variables that could influence results, including age, diet, sleep patterns, near work demands, as well as undiagnosed neurotrauma. The study will be conducted in a variety of settings (e.g. school libraries, gymnasiums, etc.) that could potentially introduce confounding variables such as lighting, background setting, and distracting noises that may influence study results based on the environment in which the study is being conducted.

There is also a potential for our measurement criteria (component eye movement efficiency) to misrepresent the reading skills of participants. For instance, participants could read quickly, achieving a high words per minute score but only meeting the minimum comprehension threshold of 70%. Alternatively, a student could read slowly while achieving high levels of comprehension but would be penalized in data analysis. This difference in reading strategies has the potential to produce results that are not representative of the skills we are attempting to measure. We will attempt to mitigate this issue by instructing students to read the passage as they normally would any other reading passage, and not informing the student they will be completing a series of comprehension questions following the reading task.

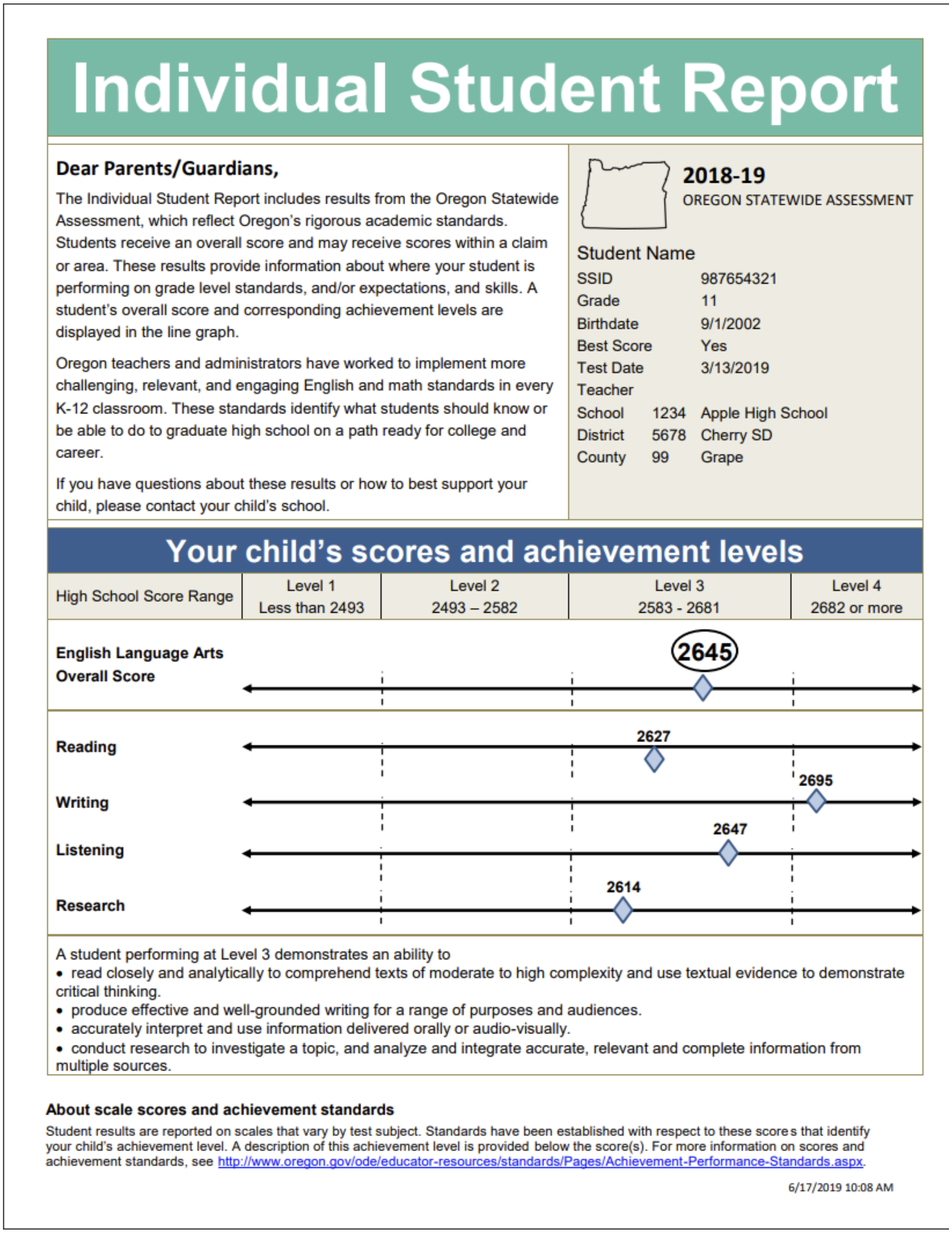
Our study uses skilled observers to reduce the variability of study data, excluding students who have identified visual acuity or visual alignment issues that would impact data accuracy. However, the participation of skilled observers adds logistical complexity and additional time to participate in the study. Additionally, despite the participation of skilled observers, comprehensive binocular and accommodative examinations will not be conducted prior to participation in this study, meaning that there will be no indication as to the specific type of binocular or accommodative disorder a student may present if they are identified with visual efficiency deficits by the RightEye Vision System.

There are also concerns about the accuracy of eye movement tracking data provided by the RightEye Vision System, as statistics concerning the deadzone, latency, and correlation with other clinical eye movement tracking devices have not been published by RightEye to the extent of this author's knowledge. Factors such as head movement, postural alignment, and head tilt have the potential to skew or invalidate tracking results in a way that would be challenging to deduce in later analysis.

Component eye movement efficiency can also be difficult to explain to educators and students without normative data to provide a reference as to expected performance based on grade level. I have chosen to largely avoid normative data in this study, as the primary data used for Grade Level Equivalent comparison was collected by Taylor in the 1960's and may not be applicable to modern students. As a result, there is potential for weak correlations between eye movement efficiency and standardized reading performance, as attention, cognition, and interest in the reading task may play a more significant role in eye movement efficiency than prerequisite eye movement skills.

However, despite the study's limitations, we view the potential benefits of collecting normative data and investigating this potentially significant impact on reading performance as outweighing its downsides.

List of Figures



Individual Student Report

Dear Parents/Guardians,

The Individual Student Report includes results from the Oregon Statewide Assessment, which reflect Oregon's rigorous academic standards. Students receive an overall score and may receive scores within a claim or area. These results provide information about where your student is performing on grade level standards, and/or expectations, and skills. A student's overall score and corresponding achievement levels are displayed in the line graph.

Oregon teachers and administrators have worked to implement more challenging, relevant, and engaging English and math standards in every K-12 classroom. These standards identify what students should know or be able to do to graduate high school on a path ready for college and career.

If you have questions about these results or how to best support your child, please contact your child's school.

2018-19
OREGON STATEWIDE ASSESSMENT

Student Name

SSID		987654321
Grade		11
Birthdate		9/1/2002
Best Score		Yes
Test Date		3/13/2019
Teacher		
School	1234	Apple High School
District	5678	Cherry SD
County	99	Grape

Your child's scores and achievement levels

High School Score Range	Level 1 Less than 2493	Level 2 2493 – 2582	Level 3 2583 - 2681	Level 4 2682 or more

A student performing at Level 3 demonstrates an ability to
- read closely and analytically to comprehend texts of moderate to high complexity and use textual evidence to demonstrate critical thinking.
- produce effective and well-grounded writing for a range of purposes and audiences.
- accurately interpret and use information delivered orally or audio-visually.
- conduct research to investigate a topic, and analyze and integrate accurate, relevant and complete information from multiple sources.

About scale scores and achievement standards

Student results are reported on scales that vary by test subject. Standards have been established with respect to these scores that identify your child's achievement level. A description of this achievement level is provided below the score(s). For more information on scores and achievement standards, see http://www.oregon.gov/ode/educator-resources/standards/Pages/Achievement-Performance-Standards.aspx.

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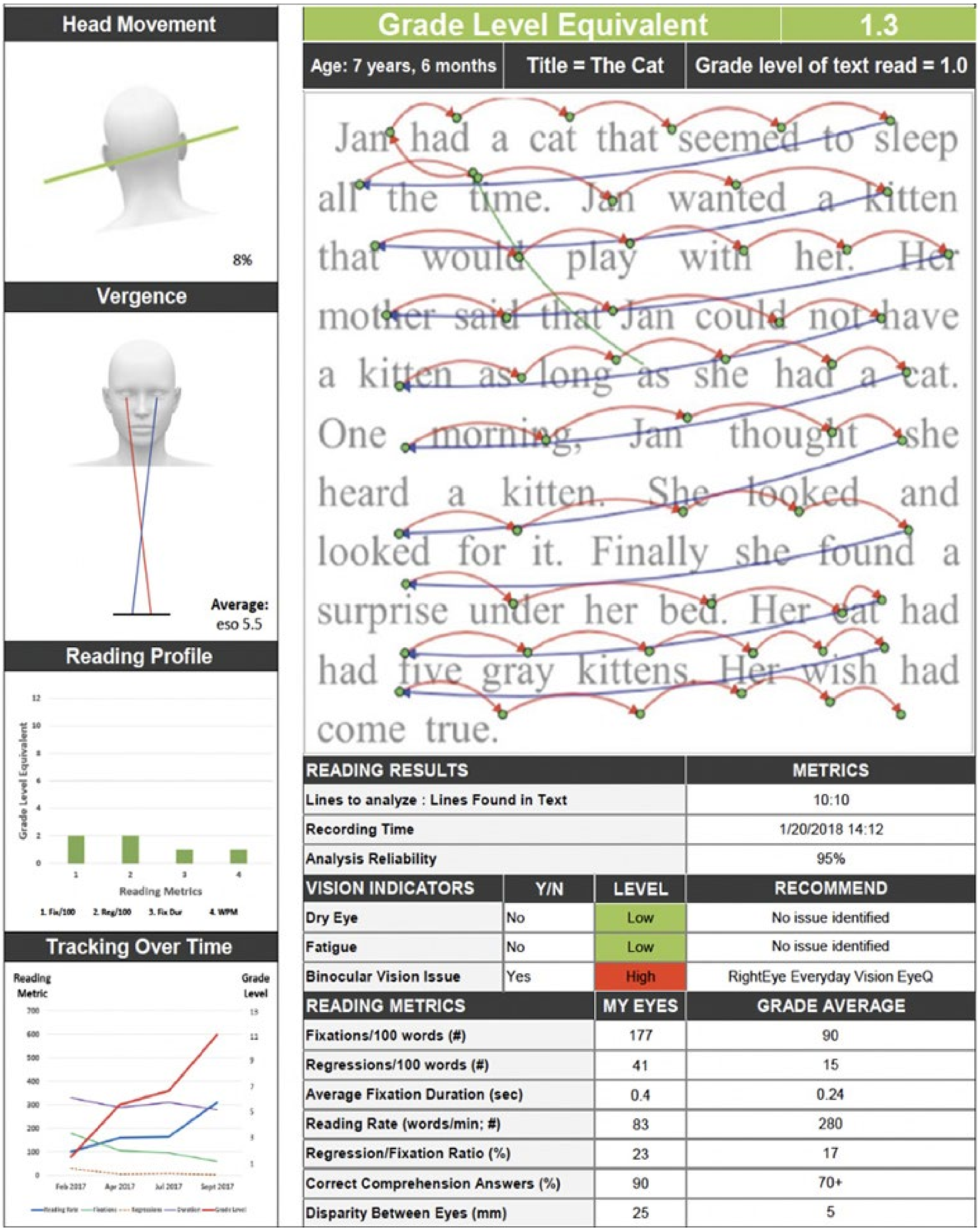
Figure 1: Oregon State English Language Arts Examination Individual Student Report



READING RESULTS	METRICS
Lines to analyze : Lines Found in Text	10:10
Recording Time	1/20/2018 14:12
Analysis Reliability	95%

VISION INDICATORS	Y/N	LEVEL	RECOMMEND
Dry Eye	No	Low	No issue identified
Fatigue	No	Low	No issue identified
Binocular Vision Issue	Yes	High	RightEye Everyday Vision EyeQ

READING METRICS	MY EYES	GRADE AVERAGE
Fixations/100 words (#)	177	90
Regressions/100 words (#)	41	15
Average Fixation Duration (sec)	0.4	0.24
Reading Rate (words/min; #)	83	280
Regression/Fixation Ratio (%)	23	17
Correct Comprehension Answers (%)	90	70+
Disparity Between Eyes (mm)	25	5

Figure 2: RightEye Reading Skills Module Sample Report

Table 3. Pearson correlation co-efficients calculated between Reading Progress Test scores and DEM and Visagraph outcomes.

		Reading Progress Test Standard Score
Developmental Eye Movement Test Outcomes	Vertical Adjusted Time	-.015 (0.912)
	Horizontal Adjusted Time	-.048 (0.724)
	Number of Errors	.052 (0.702)
	Ratio (Vertical Time /Horz Time)	-.111 (0.411)
Visagraph recording Eye Movement Pattern Parameters	Number of Fixations	-.139 (0.302)
	Number of Regressions	.080 (0.556)
	Span of Recognition	.109 (0.420)
	Duration of Fixation	***-.403 (0.002)***
	Reading Rate (WPM)	***.366 (0.005)***

Bold Italics indicates correlation is significant at the 0.01 level (2-tailed).

Figure 3: Reprinted from Webber, A., Wood, J., Gole, G., & Brown, B. (2011). DEM Test, Visagraph Eye Movement Recordings, and Reading Ability in Children. *Optometry and Vision Science*, *88*(2), 295–302. https://doi.org/10.1097/OPX.0b013e31820846c0

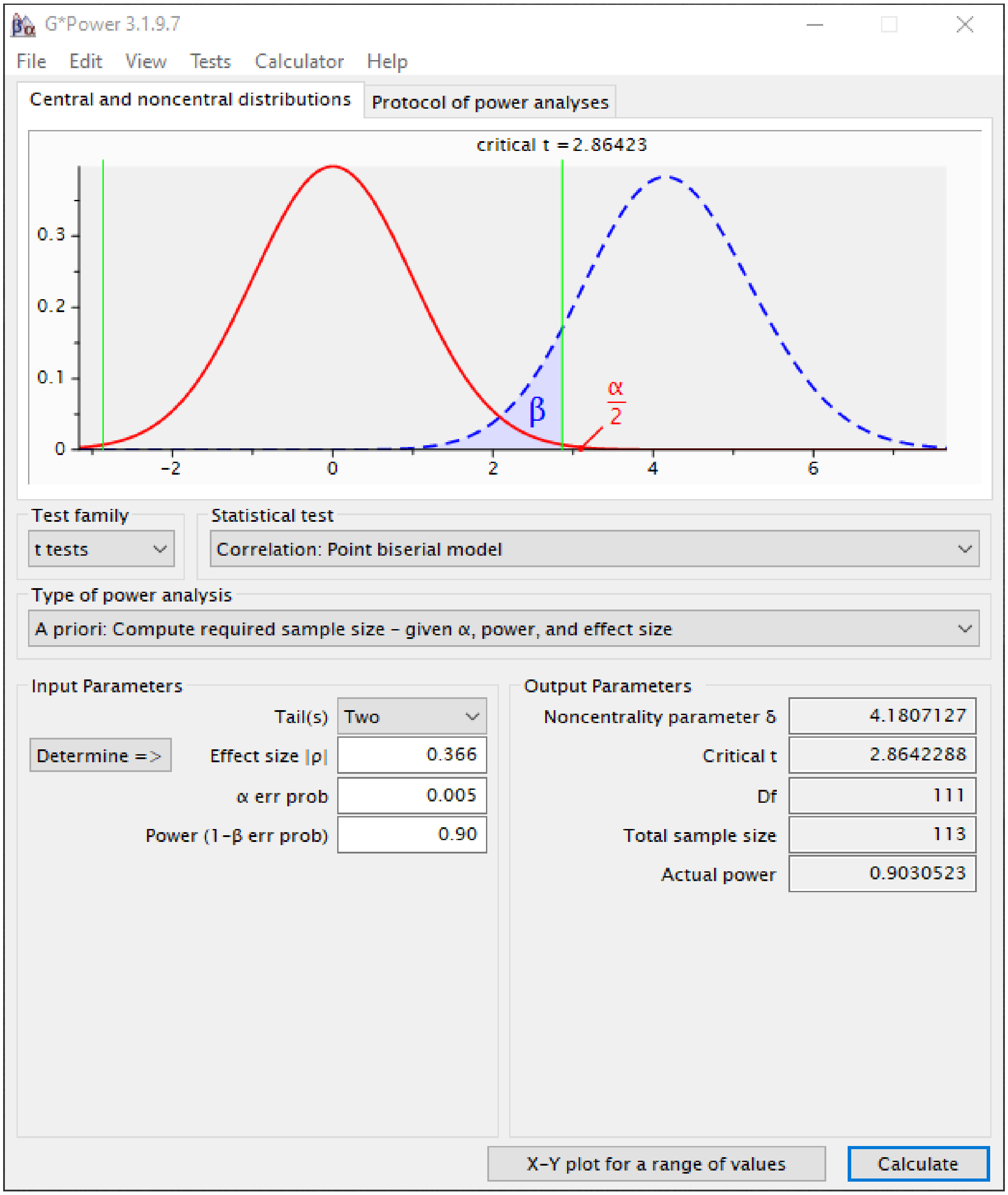


Figure 4: GPower Study Power Analysis

Grade Level	Fixations/100 Words	Regression/100 Words	Fixation Duration	Reading Rate (WPM)
1	224	52	0.33	80
2	174	40	0.3	115
3	155	35	0.28	138
4	139	31	0.27	158
5	129	28	0.27	173
6	120	25	0.27	185
7	114	23	0.27	195
8	109	21	0.27	204
9	105	20	0.27	214
10	101	19	0.26	224
11	96	18	0.26	237
12	94	17	0.25	250
13 (College)	90	15	0.24	280
14 (Adv 1)	77	11	0.23	340
15 (Adv 2)	65	8	0.23	400
16 (Adv 3)	57	5	0.22	480
17 (Adv 4)	48	4	0.22	560
18 (Adv 5)	44	2	0.22	620

Figure 5: RightEye GLE Normative Data (reprinted from Taylor, S. E. (1965). Eye Movements in Reading: Facts and Fallacies. *EYE MOVEMENTS IN READING*, 16.)

Component Measure	Pearson's Correlation (r)	Statistical Significance (p)
Reading Rate		
Fixations per 100 words		
Average fixation duration		
Regressions per 100 words		
Regression fixation ratio		
Gaze disparity		
Grade Level Equivalent (GLE)		

Figure 6: Proposed analysis results table (Pearson's correlations between component measures of visual efficiency and performance on Oregon State ELA Examination Reading subsection)

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