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The Effect of In-School Saccadic Training on Reading Fluency and Comprehension in First and Second Grade Students: A Randomized Controlled Trial

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Abstract

Efficient eye movements provide a physical foundation for proficient reading skills. We investigated the effect of in-school saccadic training on reading performance. In this cross-over design, study participants (n = 327, 165 males; mean age [SD]: 7 y 6 mo [1y 1 mo]) were randomized into treatment and control groups, who then underwent eighteen 20-minute training sessions over 5 weeks using King-Devick Reading Acceleration Program Software. Pre- and posttreatment reading assessments included fluency, comprehension, and rapid number naming performance. The treatment group had significantly greater improvement than the control group in fluency (6.2% vs 3.6%, $P = .0277$) and comprehension (7.5% vs 1.5%, $P = .0002$). The high-needs student group significantly improved in fluency ($P < .001$) and comprehension ($P < .001$). We hypothesize these improvements to be attributed to the repetitive practice of reading-related eye movements, shifting visuospatial attention, and visual processing. Consideration should be given to teaching the physical act of reading within the early education curriculum.

Keywords

reading, eye movements, saccadic training, intervention, randomized controlled trial

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Reading ability is essential to a child's academic success. Children who read proficiently in the third grade are more likely to graduate from high school and achieve greater economic success later in life.[1] In the United States, 66% of all fourth-graders are not proficient in reading.[1,2] Poor readers tend to have more behavioral and social issues in school and higher rates of repeating grade levels.[3] The pivotal transition from third to fourth grade proves difficult for children who are behind in reading as fourth-grade students are required to derive meaning and learn from text.[4] Children in the initial stages of learning to read would greatly benefit from implementing an effective program aimed at improving reading performance.

Reading is a complex task requiring appropriate eye movements, attention, and information processing. There are 3 eye movement tasks essential to the physical act of reading: (1) saccades, a quick movement from one target to the next; (2) vergence, inward or outward movement of the eyes to sustain binocular alignment; and (3) accommodation, focusing and maintaining clarity of the target. More than 50% of the brain is devoted to visual function.[5] Brain areas involved in saccadic control include the frontal eye fields, supplementary eye field, dorsolateral prefrontal cortex, parietal lobes, superior colliculus, oculomotor nuclei in the brainstem, and the cerebellum.[5,6] These areas also contribute to visual attention and processing.[7]

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Saccadic control involves numerous neurologic pathways and synchronization with extraocular muscles for precise muscle movement. Saccadic function is highly complex and has been shown to be an effective performance measure in monitoring the quality of life in individuals with multiple sclerosis,[8,9] Parkinson disease,[10] Alzheimer disease,[11,12] and amyotrophic lateral sclerosis.[13] Decrements in saccadic performance can be seen in hypoxia[14,15] and extreme sleep deprivation.[16] Multiple studies provide evidence of saccadic disruption as a result of mild traumatic brain injury.[6,17-19]

Efficient eye movements may not be fully developed at the time a child learns to read, resulting in inaccurate saccades, longer fixation, and slower reading.[20-22] Furthermore, children with reading disabilities have reduced saccadic accuracy and speed compared with normal readers.[23,24] Eye movements, like any motor task, can be trained for improved execution[25-28] and multiple studies report successful outcomes following training.[25-29] Eye movement training is an integral part of rehabilitation following acquired brain injury.[27-29] A recent study of individuals with mild traumatic brain injury observed more accurate saccades, faster reading rates, reduced symptoms, and improved visual attention following 6 weeks of oculomotor rehabilitation, which included saccadic, vergence, and accommodative training.[28]

Eye movement training has been shown to improve reading fluency in grade school students as well.[25,26] A 2014 study[25] published in *Clinical Pediatrics* of first- through third-grade students found significantly higher scores in standardized oral reading fluency assessments following a 6-week in-school program, using the King-Devick Reading Acceleration Program software (King-Devick Test, Inc, Oakbrook Terrace, IL). A previous pilot study of second- through fourth-grade students demonstrated a similar significant improvement in oral reading fluency scores following eye movement training.[26] Oral reading fluency improved to a greater degree for second-grade students compared with fourth-graders,[26] suggesting there may be an optimal age during development for students to benefit the most from the eye movement training program. Although a significant treatment effect was demonstrated, these studies are limited by demographic variability and study size.

Although oral reading fluency correlates with reading comprehension,[30,31] and is a crucial component of reading, comprehension is the main objective in reading and was not tested in either of the prior studies. Additionally, reading comprehension reflects higher educational achievement. A longitudinal study of 26 000 third-graders from Chicago Public Schools who were at or above grade level in reading were significantly more likely to attend college than below-level readers,[4] and third-grade reading level was also a predictor of high school graduation rate.[4]

The purpose of this study was to investigate if an in-school eye movement training program improves reading fluency and comprehension in first- and second-grade students. We hypothesized that a rigorous eye movement reading acceleration program would have a positive impact on reading fluency and comprehension in early school-aged children.

Subjects and Methods

Study Participants

Subjects in this study were students from 2 rural elementary schools in Illinois. All students in first and second grade (n = 327) were enrolled in the spring season. If students were unable to read numbers, they were to be excluded from the study. No students were excluded (refer to Figure 1). The parent or guardian of each student received study information and an invitation to participate. Recruited subjects were randomized, using a random number generator, into 2 intervention groups in a 3:1 ratio: treatment and placebo. A separate group of high-needs students (n = 79) with Individualized Education Programs were identified prior to the study. This group underwent the active treatment protocol and was analyzed as a separate group. Other than students identified with Individualized Education Programs, other clinical diagnoses related to cognitive development and learning disabilities were not available to the study team because of student and school district privacy policies. Each participant's assent, along with a written informed consent from a parent or guardian, was obtained. All study procedures were approved by the Illinois College of Optometry's Institutional Review Board.

Reading Fluency and Comprehension Assessment: The Wechsler Individual Achievement Test Third Edition (WIAT)

The Reading Fluency and Reading Comprehension subtests of the Wechsler Individual Achievement Test Third Edition (WIAT) (Pearson, San Antonio, TX) were used for the standardized reading assessment. In the Reading Fluency subtest of the WIAT, participants are timed while reading aloud 2 grade-level-specific passages. Reading Fluency assesses and scores the subject's reading speed and accuracy and reflects overall reading performance. Total time, number of words read, and word errors are recorded. The score is based on an average number of words read correctly per minute and a standard score and percentile ranking by grade level is determined. Standard score is based on a scale with a mean (average) of 100 and a standard deviation of 15. If a student's standard score is 100, the student performed average. Percentile ranking represents the student's relative standing to other students who are the same grade. A percentile ranking of 50 indicates that the student performed better than 50% of children in the same grade.

In the Reading Comprehension subtest of the WIAT, participants read 3 grade-level-specific passages and then answer a series of questions. Reading Comprehension measures literal and inferential reading comprehension skills using a variety of item sets. The questions are scored on accuracy, and a standard score and percentile ranking by grade level is then determined.

The King-Devick Test

The King-Devick Test is based on performance of rapid number naming. Better performance on the King-Devick Test has

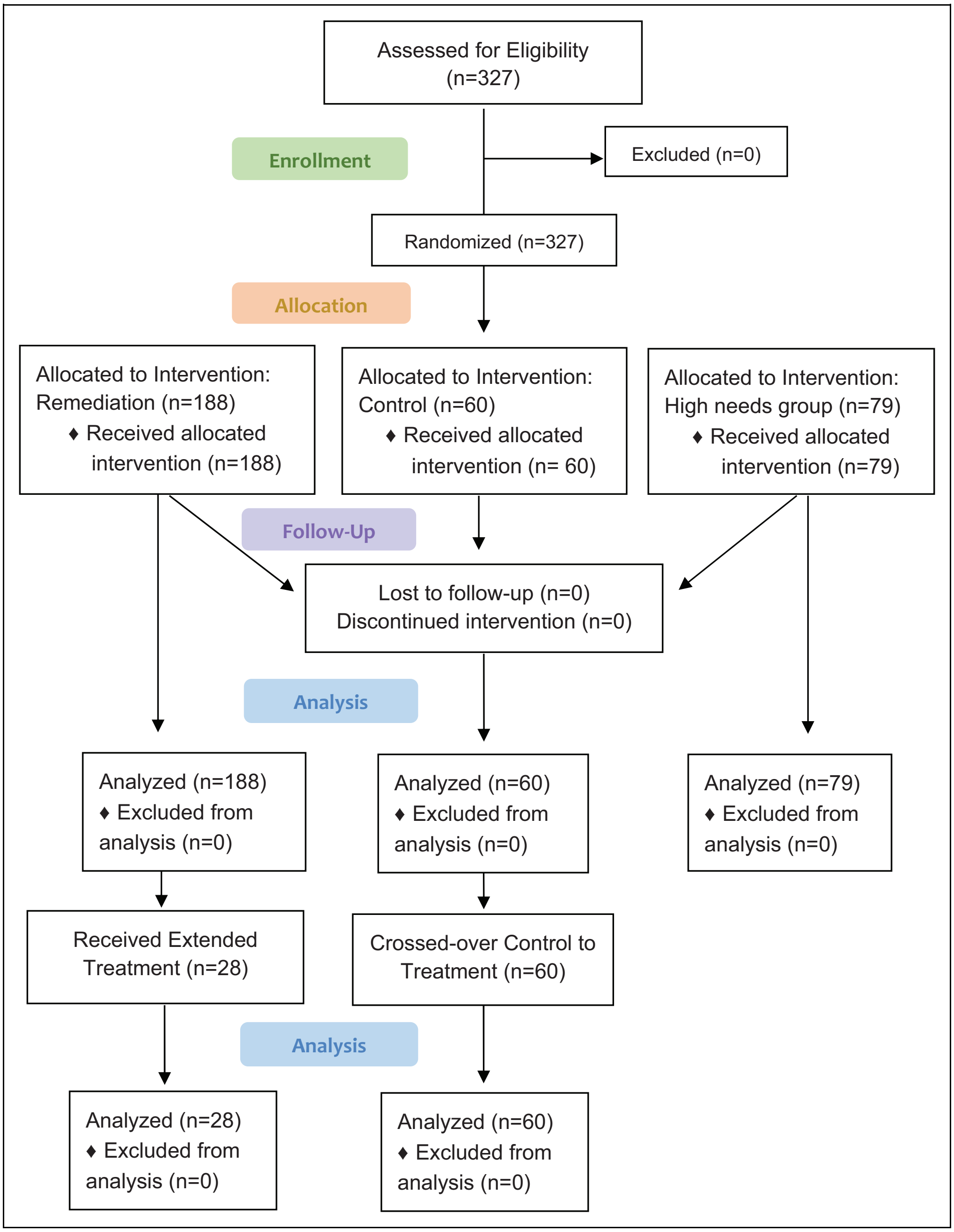

Figure 1. CONSORT diagram.

been correlated with higher reading fluency scores[26] and achievement test scores. Worse performance predicts lower academic status.[32] Standardized instructions require the student to read aloud a series of randomized single digits, 0 through 9, in a left to right, top to bottom direction as quickly and accurately as possible. The test contains 1 demonstration card and 3 test cards, which increase in difficulty. The total cumulative time and the total number of errors of the 3 test cards constitute the summary score. The time and errors are compared to age-based norms.[33] The criterion for below-expected performance on the King-Devick Test was scoring beyond 1 standard deviation from the age-based average on time and/or errors.

The King-Devick Reading Acceleration Program Software

The King-Devick Reading Acceleration Program software presents single randomized numerical stimuli, in a left to right and top to bottom direction to simulate reading-related eye movements. The subjects are instructed to read aloud the number targets as they appear. The speed at which the number targets appear is varied based on the student's performance and is measured as a numbers per minute speed. Reading Acceleration Program is available in computer and companion tablet–based platforms. The computer-based software was used on standardized laptops in this study.

Treatment Protocol

For this prospective, participant-masked, randomized, crossover study, all study participants completed pre- and posttreatment assessments. All testing was conducted at the subjects' school by a trained administrator and was masked to students and school personnel. Objective assessments included (1) the WIAT Reading Fluency, (2) WIAT Reading Comprehension, and (3) the King-Devick Test.

Treatment protocol consisted of eye movement training using Reading Acceleration Program. All treatment sessions were carried out in the subjects' school. Each student participated in 18 training sessions of 20 minutes each, for a total of 6 hours of training across a 5-week period.

The treatment group read aloud single, randomized numerical targets 0 through 9 that were presented in a left to right direction, top to bottom orientation on the computer screen. The speed of number presentation can be varied from 10 to 500 numbers per minute depending on the subject's performance level. The subjects read the numbers aloud as quickly and accurately as possible. The presentation speed was increased over time based on the subject's ability and progress. The aim was to perform the training at the fastest speed possible without errors.

The control group read aloud single, randomized numeric targets 0 through 9, positioned in the center of the screen, which did not change positions and did not simulate the left to right saccadic eye movements used during reading. The speed of presentation could be varied from 10 to 500 numbers per minute. The speed of presentation was similarly increased as subjects' ability improved.

After the 18 sessions, subjects in both the treatment and control group were retested with the standardized assessments. All testing procedures were identical to pretreatment testing. The control group then crossed over to complete the same 18-session treatment protocol of the treatment group and assessed posttreatment.

At the posttreatment assessment, all subjects who scored below average on the King-Devick Test (based on age-related King-Devick normative data[33]) following the initial treatment protocol of 18 sessions (n = 28) were enrolled in an extra training group and continued on with treatment for an average of 11 additional sessions. The extra training group underwent repeat testing identical to previous test procedures following their additional training sessions.

Statistical Analysis

Statistical analyses were performed using the Stata 12.0 software (StataCorp, College Station, TX). Percent change between individual pre- and posttreatment scores were calculated. Descriptive statistics of mean and standard deviation were used to summarize the continuous measures of the cohort. Normality assumption for variables of interest was checked using the Shapiro-Wilk test. Pre- and posttreatment scores were compared using paired *t* tests. Percent changes between groups were compared using 2-sample *t* tests. One-way repeated measures analysis of variance was performed on the extra training group. All tests were 2-sided and *P* values less than .05 were considered statistically significant.

Table 1. Characteristics of the Cohort.

	Control (n = 60)	Treatment (n = 188)	High needs (n = 79)
Age (y), mean (SD)	7.2 (0.6)	7.3 (0.7)	7.0 (0.7)
Male (%)	50	53	44
Grade 1 (%)	50	47	56
Grade 2 (%)	50	53	44
Race (%)			
Caucasian	90	92	86
African American	5	4	6
Asian/Pacific Islander	3.3	0.5	3
American Indian/Alaskan	0	0.5	0
Other	1.7	2.7	5
Hispanic	6.7	6.5	20

Results

Characteristics of the study cohort (n = 327) are displayed in Table 1. Age, gender, grade level, and racial background were similar between the treatment and control groups. The high-needs group characteristics are also displayed in Table 1.

The control and treatment groups had similar pretreatment scores for reading fluency and comprehension. Both groups demonstrated a significant improvement in fluency (percentile ranking and standard score, $P < .001$; Table 2); however, the treatment group had a greater improvement in fluency than the control group (percentile ranking: 26% vs 16%, $P = .0428$; standard score 6.2% vs 3.6%, $P = .0277$, Table 2). Both groups also demonstrated improvements in reading comprehension. This was not statistically significant for the control group (percentile ranking: $P = .051$, standard score: $P = .0837$) but was statistically significant for the treatment group (percentile ranking & standard score: $P < .001$; Table 3). Compared with the control group, the treatment group had a greater improvement in comprehension (percentile ranking: 37% vs 9%, $P = .0014$; standard score: 7.5% vs 1.5%, $P = .0002$, Table 3). Within the treatment group, there was no significant difference in improvement by grade (standard score: $P = .08$).

When the control group (n = 60) crossed over into active treatment, there was a significant improvement in reading fluency (percentile ranking: 76th vs 84th, $P < .001$; standard score: 113 vs 118, $P < .001$), resulting in a 32% change in percentile ranking (9% change in standard score). Similarly, comprehension improved significantly (percentile ranking: 72nd vs 82nd, $P < .001$; standard score: 111 vs 117, $P < .001$), resulting in a 28% change in percentile ranking (7% change in standard score).

Treatment group students who performed below age expectations on the King-Devick Test and continued on for extra training (n = 28) received an average of 11 additional sessions.

Table 2. Wechsler Individual Achievement Test Third Edition (WIAT) Reading Fluency Score by Group.

	Percentile rank, mean (SD)				Standard score, mean (SD)			
	Pretreatment	Posttreatment	Change	*P*	Pretreatment	Posttreatment	Change	*P*
Control (n = 60)	69th (21)	76th (18) $P < .001^a$	16% (27)	$.0428^b$	109 (13)	113 (12) $P < .001^a$	3.6% (6)	$.0277^b$
Treatment (n = 188)	67th (25)	78th (22) $P < .001^a$	26% (43)		109 (14)	116 (15) $P < .001^a$	6.2% (10)	

[a]Pretreatment versus posttreatment comparison using paired *t* test.
[b]Control versus treatment group percent change comparison using 2-sample *t* test.

Table 3. Wechsler Individual Achievement Test Third Edition (WIAT) Reading Comprehension Score by Group.

	Percentile rank, mean (SD)				Standard score, mean (SD)			
	Pretreatment	Posttreatment	Change	*P*	Pretreatment	Posttreatment	Change	*P*
Control (n = 60)	68th (20)	71st (19) $P = .051^a$	9% (27)	$.0014^b$	109 (11)	110 (11) $P = .0837^a$	1.5% (7)	$.0002^b$
Treatment (n = 188)	63rd (20)	78th (17) $P < .001^a$	37% (71)		106 (10)	114 (10) $P < .001^a$	7.5% (12)	

[a]Pretreatment versus posttreatment comparison using paired *t* test.
[b]Control versus treatment group percent change comparison using 2-sample *t* test.

Table 4. Extra-Training Subgroup (n = 28) Fluency and Comprehension Scores.

	Percentile rank, mean (SD)				Standard score, mean (SD)			
	Pretreatment	Posttreatment	Post–extra training	Change[c]	Pretreatment	Posttreatment	Post–extra training	Change[c]
Fluency	55th (22)	67th (21)	74th (23) $P = .007^b$	42% (32)	102 (10)	109 (11)	113 (13) $P = .003^b$	10.0% (6)
Comprehension	62nd (19)	81st (15) $P < .001^a$	81st (17) $P < .001^b$	39% (43)	105 (8)	115 (9) $P = .001^a$	116 (10) $P < .001^b$	10.3% (10)

[a]Statistically significant pretreatment versus posttreatment comparison using paired *t* test.
[b]Statistically significant pretreatment versus post–extra training comparison using paired *t* test.
[c]Pretreatment to post–extra training percent change using paired *t* test.

These students saw significant improvements in reading comprehension both in the initial treatment period ($P < .001$) as well as following the extra training ($P < .001$ for fluency and comprehension; Table 4). Overall, these students demonstrated a 42% change in percentile ranking (10.0% change in standard score) for reading fluency and a 39% change in percentile ranking (10.3% change in standard score) for reading comprehension.

Analysis of the high-needs student group (n = 79) was conducted (Table 5). These students had significantly lower initial reading scores than the rest of the treatment group (26th percentile ranking reading fluency vs 67th, $P < .001$; 40th percentile ranking reading comprehension vs 63rd, $P < .001$) and demonstrated significant percentile ranking and standard score improvements in fluency and comprehension during the treatment period.

During the course of the 5-week training period, there were 16 students following treatment (5% of the entire cohort) who did not improve in reading fluency and 60 students (18% of the entire cohort) who did not improve in reading comprehension.

Students who had below expected performance (beyond 1 standard deviation of age-based norms[33]) on the King-Devick Test assessment also scored significantly lower in reading fluency (percentile ranking and standard score: $P < .001$; Table 6) and comprehension (PR: $P < .001$; standard score: $P = .0015$; Table 6) in their pretreatment reading assessments than students who scored at or above expected King-Devick test performance. Students in the treatment group who performed significantly below expectation on the King-Devick assessment (n = 133) had a significantly greater improvement in fluency percentile ranking after treatment than students who performed at or above expectation on the King-Devick Test (73% vs 31% increase in percentile ranking, $P < .001$). There was a similar improvement in reading comprehension scores across both groups (54% improvement in percentile ranking for the below King-Devick Test expectation group and 51%

Table 5. High-Needs Group (n = 79) Fluency and Comprehension WIAT Subscale Scores.

	Percentile rank, mean (SD)			Standard score, mean (SD)		
	Pretreatment	Posttreatment	Change	Pretreatment	Posttreatment	Change
Fluency	26th (40)	40th (24) $P < .001^a$	114% (256)	89 (95)	95 (11) $P < .001^a$	8% (9)
Comprehension	40th (23)	56th (25) $P < .001^a$	90% (245)	95 (11)	102 (12) $P < .001^a$	5% (20)

[a]Statistically significant pretreatment versus posttreatment comparison using paired *t* test.

Table 6. Performance on the Pretreatment King-Devick (K-D) Test.

	Below expected K-D performance (n = 156)	At or above expected K-D performance (n = 171)	*P*
Fluency percentile rank, mean (SD)	47th (28)	64th (27)	<.001[a]
Fluency standard score, mean (SD)	99 (14)	108 (15)	<.001[a]
Comprehension percentile rank, mean (SD)	54th (25)	62th (22)	<.001[a]
Comprehension standard score, mean (SD)	102 (12)	106 (10)	.0015[a]

[a]Statistically significant below expected versus at or above expected K-D performance comparison using 2-sample *t* test.

improvement in percentile ranking for the group that performed at or above the expected level).

Discussion

Our results provide further evidence that teaching the physical act of reading through eye movement training with King-Devick Reading Acceleration Program improved early reading outcomes. Reading fluency and comprehension scores were significantly improved following treatment, and the treatment group had significantly higher overall improvement in both reading assessments than the control group. Additionally, gains were observed by the control group once they crossed over into the active treatment. Extra training for poorer-performing students further improved reading performance, with the high-needs student group demonstrating the greatest improvements.

Our findings also support the previous observations that students with reading difficulties commonly have eye movement disorders.[23,24,32] Students who performed below age expectation on the King-Devick Test based on normative data[33] initially had lower average fluency and comprehension scores than students who performed at or above expected norms for the King-Devick Test. However, the students with significantly worse King-Devick Test performance showed markedly improved reading outcomes than students who performed the King-Devick Test within age expectations. The King-Devick Test of rapid number naming may be a quick screening tool to aid in identifying the students with eye movement disorders that would benefit the most from eye movement training.

An overall increase in reading test scores was expected in both groups because students were actively learning reading skills in school for the duration of the study. Additionally, the control protocol exercises involve rapid number naming and visuospatial attention. Both of these tasks are involved in reading performance which may also explain some of the improvements. Because both groups demonstrated improvements, a comparison between treatment and control groups was important to quantify the effect of the saccadic intervention. It should be noted that the control group had no worsening of reading scores during the control period. When crossed over into the active eye movement training protocol, this group showed significantly improved reading fluency and comprehension scores. In comparison, in the extra training group, who similarly had additional total training sessions beyond the initial 18, there was a greater change in reading outcomes (fluency: 42% vs 32% percentile ranking, 10% vs 9% standard score; comprehension: 39% vs 28% percentile ranking, 10% vs 7% standard score). This group received continuous eye movement training compared with the crossover group, which first received placebo and then eye movement training. This finding supports that the active eye movement training results in better outcomes.

Although previous studies[25,26,34] included all enrolled students and likely included students that were considered high-needs as defined in this investigation, this was the first study to include high-needs students as a separate group and conduct an analysis on their performance. This group showed the largest change during the treatment period, which provides evidence that the high-needs student population is likely to benefit the most from eye movement training.

In contrast to previous studies, this investigation included a period of extended treatment. This group demonstrated better reading fluency and comprehension both in the initial treatment protocol and with additional training. The additional improvements seen in the extra training subgroup suggest that they did not experience a plateau effect of the eye movement training and students may benefit from longer training programs than the 18 sessions that our study originally proposed. Also, students who saw no improvement in fluency and comprehension may benefit from a longer program beyond an initial 18 sessions. Further follow-up study on this subgroup will examine if future improvements develop.

We hypothesize that the positive reading outcomes following the training protocol with King-Devick Reading Acceleration Program is attributed to the repetitive practice of eye movements, shifting visuospatial attention, and visual processing. These tasks are components of the physical act of reading. Individuals use saccades, vergence, and accommodation to perform King-Devick Reading Acceleration Program. Early education widely accepts teaching the physical act of writing through practicing fine motor movements, in-hand manipulation, and visual-motor control.[35] Similarly, teaching the physical act of reading through increasing the efficiency of eye movements should also be considered.[36] By training saccades, vergence and accommodation are also exercised, because these eye movements work in conjunction. The data on accommodative and convergence training provides further evidence that eye movement skills can be trained and improved.[25-28,34,37] The results of this study show that early reading skills improved with the implementation of King-Devick Reading Acceleration Program, an in-school eye movement training, to teach the physical act of reading. Improving reading skills in youth is essential to building the foundations for future academic success.

Although this is the largest study to date examining the effect of eye movement training on reading performance, there was a relatively limited study population. Students were from 2 schools with a similar racial and socioeconomic demographic. The fact that the testers were not masked to the group allocation of the students was another study limitation. Future studies should focus on expanding across multiple schools with more diverse demographics; including more grade levels and masking the reading fluency and comprehension test administrators. Comparing academic test scores before and after King-Devick Reading Acceleration Program would also provide further insight into how this type of eye movement training may translate into overall academic success. Future research is needed to explore appropriate length and timing of training to maximize reading outcomes. Long-term follow-up for the students in this study is not yet available. Prior studies have shown reading performance stability over the course of 1- and 2-year follow-up[25]; therefore, ongoing follow-up of this cohort will provide useful longitudinal information in order to monitor reading fluency and comprehension and the effectiveness of King-Devick Reading Acceleration Program over time.

Conclusion

The King-Devick Reading Acceleration Program significantly improved reading fluency and comprehension over the course of 5 weeks (6 hours) of in-school training, which was flexibly incorporated into the daily classroom schedule. Efficient eye movements are one necessary component of proficient reading that integrate with visual processing, word decoding, and attention span; cognitive processing also contributes to successful reading. King-Devick Reading Acceleration Program improves aspects of reading that are not currently addressed in schools. Based on the positive reading outcomes found in this study and prior studies, there is increasing evidence to support the inclusion of teaching the physical act of reading in the early education curriculum.

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Author Contributions

DD, AJS, JW, YP, LVM, CS, CLM, RBHS, BBV, JMB, AT, and DL conceived and designed the study. All authors took part in analysis and interpretation of data, drafting and revising the article, and final approval of the submitted version and are accountable for this work.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: DL is employed as the Senior Director of Research at King-Devick Test, Inc. AT is employed as the Associate Director of Research at King-Devick Test, Inc. All other authors have declared that there are no conflicts of interest.

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Ethical Approval

All study protocols were approved by the Illinois Eye Institute and Illinois College of Optometry's Institutional Review Board (#14021).

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