The Effect of Saccadic Training on Early Reading Fluency

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Danielle F. Leong, OD[1], Christina L. Master, MD[2], Leonard V. Messner, OD[3], Yi Pang, OD, MD, PhD[3], Craig Smith, MD[4,5], and Amaal J. Starling, MD[6]

Abstract

Background. Eye movements are necessary for the physical act of reading and have been shown to relate to underlying cognitive and visuoattentional processes during reading. The purpose of this study was to determine the effect of saccadic training using the King-Devick remediation software on reading fluency. *Methods*. In this prospective, single-blinded, randomized, crossover trial, a cohort of elementary students received standardized reading fluency testing pre- and posttreatment. Treatment consisted of in-school training 20 minutes per day, 3 days per week for 6 weeks. *Results*. The treatment group had significantly higher reading fluency scores after treatment ($P < .001$), and posttreatment scores were significantly higher than the control group ($P < .005$). *Conclusion*. Saccadic training can significantly improve reading fluency. We hypothesize that this improvement in reading fluency is a result of rigorous practice of eye movements and shifting visuospatial attention, which are vital to the act of reading.

Keywords

eye movements, reading fluency, saccades, remediation

Introduction

It is estimated that only 34% of fourth graders in America are proficient readers.[1] This rate does not improve with subsequent years in school as the reading proficiency rate of eighth graders in America is unchanged at 34%.[1] Therefore, it is critical to implement a program to improve the reading foundations of our youth.

Reading is a higher cognitive process depending on multiple elements. In particular, the physical act of reading requires fundamental, accurate, and rapid eye movements called saccades.[2] Saccadic ability is a complex task involving an estimated 50% of the brain's pathways.[3] It involves precise synchronization of intra- and extraocular muscles and multiple areas of the brain.[3] Saccadic coordination is so intricate that recent studies have correlated disrupted saccadic function with mild traumatic brain injury,[4-9] severe sleep deprivation,[10,11] Parkinson's disease,[12,13] hypoxic incapacitation,[14,15] and multiple sclerosis.[16,17] Eye movements, both saccades and vergence, are necessary for the physical act of reading and have been shown to be related to the underlying cognitive and visuoattentional processes that occur during reading.[18,19] The frontal eye fields, the lateral intraparietal region, and the superior colliculus are among the many areas of the brain that control eye movements, however, these areas are also involved in visual attention.[20] Saccadic eye movements are essential to this process. Saccadic generation requires the allocation of attention to the target before the saccade is initiated, which is a form of visuospatial attention. Vergence refers to the ability of both of our eyes to simultaneously move in opposite directions to obtain singular binocular vision. Attention and vergence appears to be strongly interconnected.[19] Not surprisingly, both attention and the control of vergence originate from the frontal cortex.[21,22] Previous studies have shown that the ability to perform these complex tasks are not fully developed at the age when children begin learning to read and are significantly deficient when compared with the saccadic abilities of older children and adults.[23-26] Saccades in younger children are imprecise requiring more regressions in

[1]King-Devick Test, LLC, Oakbrook Terrace, IL, USA
[2]Children's Hospital of Philadelphia, University of Pennsylvania, Philadelphia, PA, USA
[3]Illinois Eye Institute, Illinois College of Optometry, Chicago, IL, USA
[4]Aegis Creative, Lakewood, CO, USA
[5]Bill and Melinda Gates Foundation, Seattle, WA, USA
[6]Department of Neurology, Mayo Clinic, Phoenix, AZ, USA

Corresponding Author:
Danielle F. Leong, King-Devick Test, LLC, Two Mid America Plaza Suite 110, Oakbrook Terrace, IL 60181, USA.
Email: dleong@kingdevicktest.com

which the eyes need to go back to reread text resulting in slower performance.[26] When translated into the task of reading, it slows the reading rate and leads to poor reading fluency and may affect reading comprehension and academic performance.[27-30]

Many studies have demonstrated that poor saccadic function can be remedied with training.[31-36] A recent study of the saccades of surgeons revealed that novice surgeons who underwent saccadic training mimicking expert visual control patterns were able to learn surgical skills more quickly than those who had not undergone saccadic training.[31] Saccadic training has been incorporated into low vision rehabilitation and shown to be clinically successful.[33-36] Prior research on training saccades and the effect on reading ability have not been thoroughly investigated as many have relied on empirical evidence to guide patient therapy.[37] However, one study implementing a 12-hour saccadic training program resulted in improved reading eye movement efficiency. Subjects showed less regressions as well as faster and fewer required saccades when reading.[37] This study, however, did not quantitatively evaluate the effect of the saccadic training program on reading fluency outcomes with a standardized test.[37]

A previous pilot study of students in grades 2 through 4 (n = 20) following a 6-week training protocol showed improvements in standardized reading fluency testing. This study used King-Devick (K-D) remediation software that allows subjects to practice number naming and saccades in a left to right orientation. The treatment group showed significantly higher improvements ($P < .001$) in their reading fluency scores compared with the control group. Additionally, there was a significantly greater percentage improvement in the younger subjects (second grade, 38.6%, $P < .05$) as compared with older subjects (fourth grade, 0.95%) potentially indicating an ideal age for eye movement training for maximal increase in reading fluency ($P < .05$). Although a small study, these results suggest a significant treatment effect.[38]

The purpose of this study was to determine the effect of 6 weeks of in-school training using the K-D remediation software on reading fluency in a larger cohort of students. We hypothesized that reading fluency could be improved through systematic training in saccadic function, efficiency, and accuracy.

Subjects and Methods

Study Participants

Subjects in this pilot study were students from a private urban elementary school. All students enrolled in kindergarten through third grade completed a school vision screening. Information about the study and an invitation to participate was provided to the parent or guardian of students whose binocular habitual near point acuity was 20/20. Recruited subjects were randomized into 2 groups with an approximately 3:1 ratio: treatment (n = 56) and placebo (n = 20). Written informed consent was obtained from all participants' parent or guardian, and child assent was obtained from all participants.

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

For the standardized reading fluency assessment, the Reading Fluency subtest of the Wechsler Individual Achievement Test Third Edition (WIAT) was used in this study for students in grades 1 through 3. In the Reading Fluency subtest of the WIAT, participants are timed while reading two grade-level specific passages aloud. It is designed to assess the speed and accuracy of the participant's reading ability and identify academic weaknesses. The total number of words read, number of errors made, and total time are recorded. The WIAT reading score is based on an average word read correctly per minute objective measurement and a percentile ranking is determined.

The King-Devick Test

The K-D test was used in this study for kindergarten students because of the unavailability of a reading fluency assessment for this age group. The K-D test is based on a measurement of saccadic and number naming speed. The test involves reading aloud a series of randomized single numbers from left to right. The K-D test includes 1 demonstration card and 3 test cards that increase in difficulty. The score is based on the cumulative time taken to read each card. The number of errors made in reading the test cards is also recorded. In this study, standardized instructions were used, and participants were asked to read the numbers from left to right as quickly as they could without making any errors. A K-D composite score was calculated by adding the time score and error score together. A lower K-D composite score indicated higher efficiency and accuracy.

The King-Devick Remediation Software

The K-D remediation software is similar in format to the K-D test. It is available on a computer or a mobile (iPad). Randomized numerical stimuli are presented at variable speeds from left to right. Participants were asked to read aloud the numbers from left to right as quickly as they

could without making errors. The computer based K-D remediation software was used in this study.

Treatment Protocol

In this prospective, single-blinded, randomized, crossover trial, subjects were assessed pre- and posttreatment to determine reading fluency performance. Subjects were tested using the WIAT and K-D tests. A previous study has shown that the K-D test can be completed by kindergarteners and that the performance on the K-D test is related to academic performance in kindergarteners.[26] Because of the unavailability of a reading fluency measurement for the kindergarten-age and school-level students, only the K-D test was used for pre- and posttreatment assessments in kindergarteners. Pretreatment testing was conducted in the subjects' respective school classrooms by trained test administrators masked to the sequence of intervention.

The treatment consisted of 6 weeks of saccadic training using K-D remediation software conducted by independent teachers, teaching aides, and graduate students all trained to use the K-D remediation software with students. All treatment sessions were conducted in the school computer room. The treatment protocol consisted of 20-minute individual training sessions, 3 days each week for 6 weeks for a total of 6 hours of training.

In the treatment group, numerical stimuli were presented in a left to right orientation on the computer screen, and the speed of presentation was varied from 1600 to 250 milliseconds. Subjects were instructed to read the presented number aloud as quickly as they could without making errors. As subjects improved, the speed of rapid number presentation was regularly increased.

The control group was presented with individual numbers positioned in the center of the computer screen, which did not change positions. The speed of presentation was varied from 1600 to 250 milliseconds. Subjects were instructed to verbalize the presented number in the same manner as the treatment group. As subjects improved, the speed of number presentation was regularly increased.

At the conclusion of the 6-week training, subjects in both treatment and placebo groups were retested with the WIAT and K-D tests by trained test administrators masked to the sequence of intervention. All testing procedures were identical to pretreatment testing. Control group subjects were subsequently crossed over to complete the same 6-week treatment protocol of the treatment group then tested posttreatment.

To evaluate the long-term effects, a convenience sample of subjects still enrolled at the school at a 1-year follow-up (n = 25) were evaluated with identical testing procedures used during the pretreatment testing.

Table 1. Characteristics of the Cohort.

	Treatment (n = 76)	Control (n = 20)
Age in years, mean ± SD	6.58 ± 1.27	6.48 ± 1.12
Male, %	45	40
Race, Black, %	100	100
Kindergarten, %	36	40
Grade, %		
Grade 1	26	25
Grade 2	22	25
Grade 3	16	10

Statistical Analysis

Statistical analyses were performed using Stata 12.0 software (StataCorp, College Station, TX). Differences in reading fluency percentile rank from pre- and posttreatment were calculated and compared using 2-sample *t* tests. Differences in the K-D time score from pre- and post-treatment were calculated for kindergarteners and compared using 2-sample *t* tests. Statistical significance was set at $P < .05$.

Results

Characteristics of the study cohort are shown in Table 1. Age, gender, ethnicity, and grade distributions were similar between the treatment and control groups.

Reading fluency score data are shown in Table 2. Subjects in the treatment group had significantly higher reading fluency scores after treatment ($P < .001$, Figure 1), and posttreatment scores were significantly higher compared with the control group ($P < .005$, Figure 1). At the 1-year follow-up, reading fluency scores were significantly higher than posttreatment scores for subjects in grade 1 ($P = .037$, Figure 2). Additionally, these 1-year follow-up scores were higher than pretreatment scores across all grades, with an average improvement of 17 percentile rank points across all grades in the treatment group.

Kindergarten K-D composite score data are shown in Figure 3. The treatment group had a significant improvement (lower score) in their posttreatment K-D composite score compared with pretreatment ($P < .001$) and compared with the control group ($P = .0435$). Subjects in the treatment group also had a greater percentage change ($P < .001$) in their K-D composite scores compared with the control group. Additionally, at the 1-year follow-up, K-D composite scores demonstrated improvement compared

Table 2. Reading Fluency Scores Grades 1 Through 3.

	Reading Fluency Percentile Rank, Mean (SD)			
	Pretreatment	Posttreatment	1-Year Follow-up	*P*
Control (n = 12)	42 (33.9)	48 (37.4)	—[a]	<.005[b]
Treatment (n = 49)	45 (29.9)	59 (31.1)	62 (33.3)	
Grade 1 (n = 20)	38 (24.4)	52 (29.5)	62 (33.1)	<.001[c]
Grade 2 (n = 17)	55 (34.6)	65 (33.2)	77 (29.8)	<.001[c]
Grade 3 (n = 12)	39 (29.4)	59 (31.2)	56 (35.8)	<.001[c]

Abbreviation: SD, standard deviation.
[a]No 1-year follow-up data on control group because of crossover design.
[b]Control versus treatment group posttreatment comparison.
[c]Pretreatment and posttreatment percentile rank comparison.

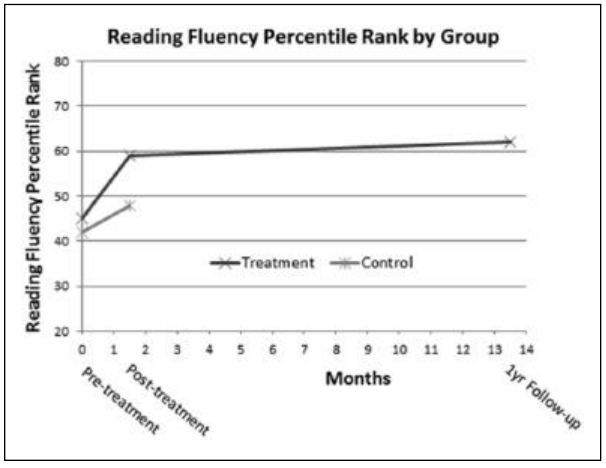

Figure 1. Reading fluency scores by group.
Plots show the mean reading fluency scores from pre- to posttreatment and at the 1-year follow-up for treatment and control groups. The treatment group demonstrated significantly higher posttreatment reading fluency scores compared with pretreatment ($P < .001$) and compared with the control group at posttreatment ($P < .005$). *No 1-year follow-up data on control group because of crossover study design.

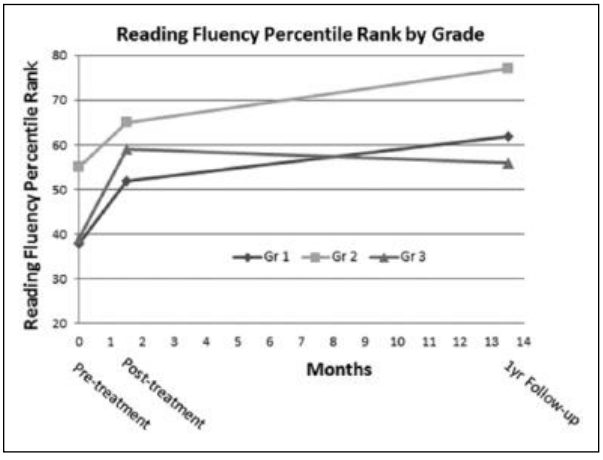

Figure 2. Reading fluency scores by treatment grade.
Plots show the mean reading fluency scores from pre- to posttreatment and at the 1-year follow-up for grades 1, 2, and 3. Posttreatment reading fluency scores were significantly higher than pretreatment across all grades ($P < .001$). One-year follow-up reading fluency scores were not significantly different from posttreatment scores in grades 2 and 3, however, they were significantly higher in grade 1 ($P = .037$).

with posttreatment scores ($P < .005$). The first grade–level reading fluency scores of these students at the 1-year follow-up was 5 percentile points higher than the naive first-grade students' pretreatment reading fluency scores (43rd vs 38th percentile rank).

Discussion

The results of this study demonstrate that the K-D remediation training has the ability to improve reading fluency in a 6-hour program across 6 weeks of training. We hypothesize that this improvement in reading fluency is a result of rigorous practice of eye movements, both saccades and vergence, and shifting visuospatial attention, all of which are vital to the act of reading.

The treatment group subjects in grades 1 through 3 had higher posttreatment standardized reading fluency scores compared with the control group, demonstrating that the training protocol improved reading fluency. Subjects in the control group did not significantly improve in their standardized reading scores after the 6 weeks. Additionally, kindergarteners had improvement in their K-D composite scores compared with controls. Furthermore, the 1-year follow-up results indicate that the treatment effect persisted with no significant worsening of reading fluency scores across all grades and in fact students had on average higher 1-year follow-up reading fluency scores when compared with students of the same grade before treatment. Subjects who received training during kindergarten had higher reading fluency

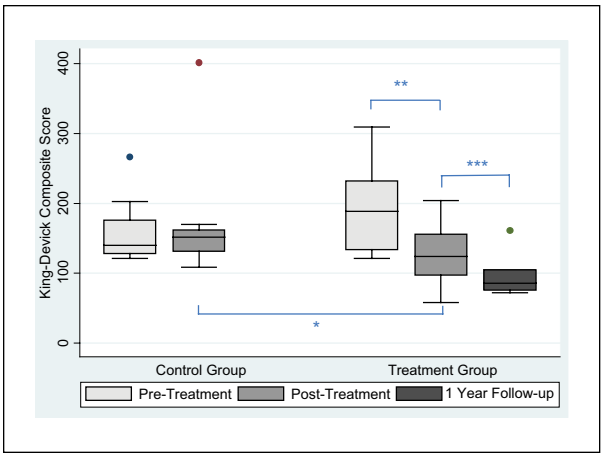

Figure 3. Kindergarten King-Devick (K-D) composite scores.
Box plots show the distributions of K-D composite scores from pre- to posttreatment and at the 1-year follow-up for kindergarten. A decrease in K-D composite score indicates improvement.
*$P < .05$; **$P < .001$; ***$P < .005$.
The lines in the box represent the medians. The boxes delineate the interquartile range (25th to 75th percentiles). Whiskers represent the range of observations minus outliners (outliers are represented by single plots).

scores in first grade at the 1-year follow-up compared with first-grade students who had not yet received training. This demonstrates that early intervention with K-D remediation may help improve reading fluency, which may be explained by a critical learning period during brain development and correlates with previous study findings of greater improvements in reading fluency observed in grades 2 and 3 compared with grade 4 following a 6-week training regimen.

Limitations of this study include small sample size, limited subject demographics, lack of double-blinding, and absence of 1-year follow-up on control subjects because of the crossover design. Future research should expand across a larger cohort, include a variety of demographics across multiple schools, use a double-blind study design, and study the long-term performance of control subjects for comparison. Also, history of learning disability and other clinical conditions that may affect reading performance should be evaluated concurrently to determine if there are correlations with amount of improvement. Additionally, the training course used in this study was 6 weeks in length. Further study should determine an optimal training length to maximize reading fluency outcomes.

Improving reading fluency is critical to American youth as the National Assessment of Educational Progress recently reported that children who are not reading proficiently by grade 4 are 4 times likely to drop out of high school.[1] Additionally, it is estimated that only 75% of America's high school students graduate leaving behind approximately 1.3 million students annually who are failing to complete high school.[1] These staggering dropout rates translate to significant social and economic costs to the rest of the nation. Those who do not have a high school diploma will earn over the course of their lifetime less than a high school graduate.[39] Also, it is estimated that dropouts from the class of 2010 alone will cost the nation more than $337 billion in lost wages over the course of their lifetimes.[40]

Conclusion

In this pilot study, the K-D remediation software has shown to improve reading fluency in a 6-week therapy program conducted in a school setting without requiring any additional use of specialized teachers. Eye movements only represent one facet of reading comprehension. There are many other factors that are involved, such as cognitive processing, attention span, and intellectual ability, which may play different roles in an individual student's reading success. Nonetheless, the results of this pilot study suggest that the K-D remediation software may be effective in significantly improving reading fluency through rigorous practice of eye movements, visuospatial attention, and oculomotor integration in a 6-week therapy program. The K-D methodology merits further testing as a tool to improve reading fluency of our youth in a larger clinical trial.

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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: Dr Leong is employed as Director of Research at King-Devick Test, LLC. All other authors have no conflicts of interest to disclose.

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