ARTICLE

The King-Devick Reading Acceleration Program Significantly Improves Reading Performance in Students with Dyslexia

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ABSTRACT

Background

Reading is a complex task and for students who are not proficient in reading, intervention and remediation is frequently necessitated. Previous literature has shown support for the inclusion of in-school oculomotor training using the King-Devick Reading Acceleration Program (K-D RAP) to supplement current reading curriculums. The aim of this study was to evaluate the effect of the K-D RAP intervention in students with dyslexia.

Methods

Participants with dyslexia diagnosed by a licensed professional were recruited and enrolled (n=7). Participants performed a total of six hours of K-D RAP intervention which was parent-supervised in their homes. A test of reading fluency and the King-Devick Eye Movement Test for Reading were administered before and after the intervention.

Results

Participants demonstrated a median 14 WCPM increase in fluency following intervention with K-D RAP, which was significant (50 to 64 WCPM; p = 0.0178). Greater reading fluency improvements were observed in younger participants compared to older participants (under age 10: 51.2% vs. ages 10 and above: 3.2% improvement; p = 0.0339). Participants with other learning disability diagnoses in addition to dyslexia were likely to impact progress in reading achievements.

Conclusion

Similar to prior research of randomized, controlled trials examining the effect of K-D RAP in the general school curriculum, students with dyslexia in this study achieved significant reading gains following six hours of practice. There is an urgency for implementing K-D RAP, as findings indicate that older students do not improve to the same degree as younger students, which is coincident with research demonstrating earlier intervention is more effective for reading enhancement.

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INTRODUCTION

Developmental dyslexia was originally defined as a hereditary deficit selectively affecting the visual processing of words, with intact oral and non-verbal reasoning ability.[1,2] Following Noam Chomsky's development of

generative phonology in the 1980's, dyslexia was redefined as a language disorder or a failure to acquire phonological skills.[3] Just before then in 1976, Jerome Rosner, O.D. wrote and presented on the basic aptitudes for reading, which he defined as visual and auditory analysis skills.[4] He recognized the essential link between visual processing and reading, while at the same time educated that the ability to differentiate sounds of language is also a key factor for proficient reading.[5] The phonological theory states that children with dyslexia have difficulty learning to read due to a reduced ability to separate sounds in a word, or phonemic awareness.[6] The theory is supported by imaging studies demonstrating cortical abnormalities in the left hemisphere language centers.[7,8] However, these imaging findings are not consistently reproducible.[9] Richlan et al found that the most reproducible site of hypoactivation in both adults and children with dyslexia appears to be the left occipitotemporal cortex, at the site of the visual word form area, according to the meta-analysis examining fMRI and PET study findings.[9]

The key symptoms of dyslexia include difficulty with decoding or single word reading and/or reduced reading fluency and spelling.[10] According to the International Dyslexia Association, it is best practice to evaluate a student after determining his or her response to intervention (RTI) or multi-tiered systems of support (MTSS). Appropriate early intervention in kindergarten through 3rd grade is key for effectively improving reading ability, when the gap is smaller and the child can maximize brain plasticity advantages.[10] If a student is not reading proficiently after intervention, this is when students should be formally evaluated for a specific learning disorder (SLD) or dyslexia by a licensed professional.[10] Early screening assists in providing intervention sooner, which results in better student performance. Drs. Griffin and Walton, developmental optometrists, created the Decoding-Encoding Screener for Dyslexia (DESDTM) to aid optometrists in quickly screening for dyslexia.[11]

Factors that contribute to the failure of a child learning to read effectively include a child's family structure and support system, quality of teaching in the classroom, learning style, ability of the child among other factors.[12] Children with dyslexia experience difficulty with sequencing sounds in words,[13,14] temporal processing (correct timing of visual and auditory inputs),[15] and impaired magnocellular development as shown by imaging and electrophysiological studies of the lateral geniculate nucleus.[16,17] The magnocellular pathway is an important contributor of eye movement control. During reading, the magnocellular pathway responds to fixation slip and signals the extraocular muscles to move back on target. Additionally, the magnocellular pathway detects the appearance of a new target location and initiates a saccadic eye movement to the target.[12] Many studies have demonstrated that children with dyslexia also have impaired eye movements,[18–22] with reports of 62% with oculomotor deficits compared to 15% in the general pediatric population.[21] Therefore, reading-related eye movements can be predictive of reading difficulties and be helpful in an initial dyslexia evaluation.[22,23]

There have been few studies examining the effect of treating aspects of vision in children with dyslexia. Oculomotor, motion processing, and visual search training has been shown to significantly improve phonological awareness in children with dyslexia.[24–26] The King-Devick Reading Acceleration Program (K-D RAP; King-Devick Technologies, Oakbrook Terrace, Illinois) is a computerized oculomotor and visual processing intervention that has been shown to significantly improve reading fluency and comprehension in large randomized-controlled trials.[27-30] The largest study published to date included over 600 students in 1st through 4th grade. To study the effect of this intervention in high needs students, a subpopulation which included students with

an active Individual Education Program (IEP), enrolled in reading recovery programs, and/or were English language learners, was analyzed as a separate group. While the entire group as a whole significantly improved in reading fluency and comprehension following K-D RAP intervention, the high needs group improved to a greater degree, indicating that by enhancing oculomotor skills and visual processing speed, struggling readers were able to improve their reading performance significantly after only six hours of practice. According to Raja and Arockiasamy, 80% of students with an IEP are below level in reading performance and 85% of those students have a diagnosis of dyslexia.[31] Therefore, it is likely that many students in the high needs group had dyslexia or other reading impairments. Due to student confidentiality, specific diagnoses, such as dyslexia, were not known in prior K-D RAP studies.

This study's aim was to expand on current K-D RAP research. We examined the effect of K-D RAP on reading performance in a group of students with clinically diagnosed dyslexia.

METHODS

Study Design and Participants

A case series was conducted from August 2018 to January 2019. Children with clinically diagnosed dyslexia (n=7) were recruited from web-based flyers. Participants were from the following countries: United States, Canada, New Zealand, England, and South Africa. Informed written assent and consent was respectively obtained for each participant and parent or guardian. The inclusion criteria for the group was a proven diagnosis of dyslexia by a licensed professional, reading ability, as provided by the parent, at or below a fourth-grade level, and English as a first and primary language. Participants were diagnosed by clinicians, SLD specialists, dyslexia therapists, or speech-language pathologists, who were licensed to diagnose dyslexia in their respective geographic region. Individuals with a history of concussion or the inability to identify and read numbers zero through nine aloud were excluded. Enrolled participants performed K-D RAP at home and practice sessions were monitored remotely by the study team. No participants were receiving vision therapy. Participants continued current reading remediation programs as recommended by their dyslexia specialist as ongoing intervention, which began about two years prior to this study.

All participants underwent assessments before and after the intervention of K-D RAP. The pre- and post-assessments included the King-Devick Eye Movement Test for Reading (K-D Test; King-Devick Technologies, Inc, Oakbrook Terrace, Illinois) and the Scholastic Fluency Formula Assessment (Scholastic Press; New York, New York).

King-Devick Eye Movement Test for Reading (K-D Test)

The K-D Test is an objective assessment of saccadic functioning and rapid number naming. Better performance on the K-D Test has been correlated with higher reading fluency scores[32] and academic achievement test scores.[33] Standardized instructions required the participant to read aloud a series of randomized single digits, zero through nine, in a left to right, top to bottom direction as quickly and accurately as possible as time and errors are monitored. The K-D Test contains one demonstration screen and three test screens which increase in difficulty due to changes in spacing between lines and numbers (increased visual crowding). The total cumulative time and the total number of errors constitute the summary score and are compared to age-matched norms.[34] Passing the K-D Test occurs when the participant's score is within one standard deviation of the average score based on the participant's age. The K-D Test score was recorded for each participant before and after the intervention.

Reading Assessment

Reading performance was assessed with the Scholastic Fluency Formula Assessment (Scholastic Press, New York, New York). The Scholastic Fluency Formula Assessment is an individually administered oral fluency test. Participants read aloud two reading-level appropriate passages for one timed minute each. The total number of words read, and errors are recorded. Scoring is based on the number of words correct per minute (WCPM). Scholastic assessments also provide WCPM to percentile rank range conversion. The percentile rank ranges include <10th, 10-25th, and 25-50th, 50-75th, 75-90th, >90th. To avoid passage memorization, different passages were used for pre- and post-intervention assessments. There is no standardized reading comprehension score with the Scholastic Fluency Formula Assessment. All reading assessments were completed by a licensed and trained test administrator.

Intervention

The King-Devick Reading Acceleration Program is a computerized oculomotor and visual processing intervention which presents single randomized numerical targets zero through nine, in a left to right then top to bottom direction to simulate reading-related eye movements. K-D RAP was performed on a desktop or laptop computer over the course of treatment. During K-D RAP practice, subjects are instructed to read aloud the single digit number targets as they appear dynamically on the screen. The speed at which the number targets appear is increased over time based on the child's ability and progress. Starting speed varied and was determined by initial K-D Test performance. The parents were instructed to increase the speed by 5 numbers per minute (npm) after completing three rounds of practice with high accuracy, which was 95-100% accuracy. The speed can be varied from 0 to 300 npm. The aim is to perform K-D RAP at the fastest speed possible without errors. The intervention for this study was completion of six total hours of practice at home over a 6 to 12-week period. Parents were trained on how to supervise practice and increase the K-D RAP target speed at regular intervals based on the participant's ability. Participant compliance to the intervention protocol was monitored remotely by the study team two days per week to ensure regular practice times and practice speed was appropriately adjusted for the participant.

Statistical Analysis

Statistical analyses were performed using STATA 14.0 software (StataCorp, College Station, Texas). Descriptive statistics were used to summarize the continuous measures of the diagnosed dyslexia group. Due to a small sample size, a non-parametric statistical approach was used with calculations of median and range. The primary outcome measure was reading fluency, and pre- and post-intervention differences in reading fluency scores were compared using the Wilcoxon signed-rank sum test. Percent change between pre- and post-intervention scores was calculated. Given previous data supporting greater gains in reading performance in earlier grade levels[27,29] (i.e. 2nd grade compared to 4th grade), we wanted to explore if there were similar trends in this population. A younger subgroup (9 years of age and under) and an older subgroup (10 years of age and older) was further compared using Wilcoxon rank sum analysis. Additionally, to evaluate the role of multiple diagnoses, comparisons were made between participants with dyslexia only and those with concurrent diagnoses using Wilcoxon rank sum analysis. A p value less than 0.05 was considered statistically significant.

RESULTS

Seven participants (ages 8-11; 2 males, 5 females) completed the study protocol and were included in the analysis. The demographic data is shown in Table 1. Enrolled grade levels

Table 1. Participant Demographics

Age (yrs), median (range)	9 (8-11)
Other Diagnoses	
ADHD	4
Auditory Processing Disorder	1
Autism	1
Anxiety	1
Gender (% female)	60%
Grade Level	
3rd Grade	1
4th Grade	3
5th Grade	2
6th Grade	1
Race (%)	100% Caucasian
Hispanic (%)	0

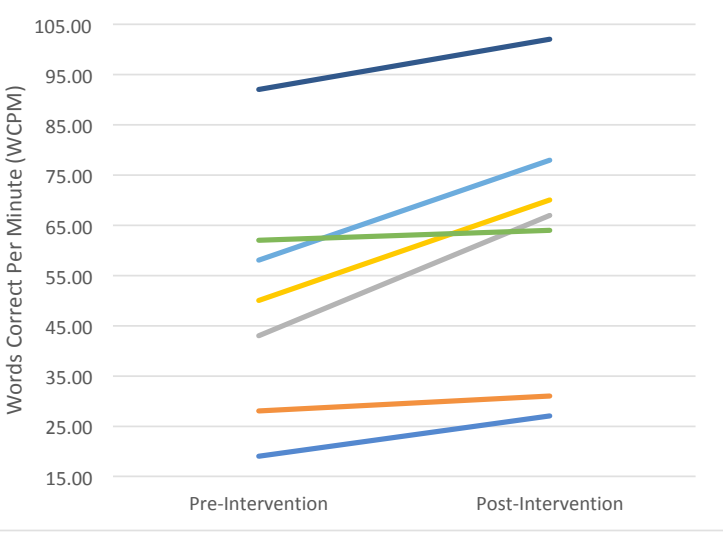

Figure 1. **Pre- and Post-Intervention Reading Fluency Scores by Diagnosed Dyslexia Participant.** Pre- and post-intervention reading fluency scores in Words Correct Per Minute (WCPM) by diagnosed dyslexia group participant. All diagnosed dyslexia group participants demonstrated an improvement in reading fluency.

ranged from 3rd to 6th grade and reading ability levels ranged from one to three grades below the participant's enrolled grade level. Some participants had concurrent diagnoses including attention deficit hyperactivity disorder (ADHD) (n=4), autism (n=1), anxiety (n=1), and auditory processing disorder (n=1).

Reading fluency scores are displayed in Table 2. Pre- and post-intervention oral reading fluency scores by participant are shown in Figure 1. All participants demonstrated an improvement in reading fluency following the intervention. There was a median increase in reading fluency of 14 WCPM (50 vs. 64 WCPM; p =0.0178; Table 2). Five of seven participants improved to a higher-level percentile rank range.

Differences in reading fluency gains were observed by age range. When dividing this group into younger (9 years of age and younger) and older (10 years of age and older) subgroups, greater change in reading fluency was observed in the younger subgroup (51.2% vs 3.2% change; p = 0.0339; Table 3). Three

Table 3. Reading Fluency Scores by Age Range

Age Range	Combined Reading fluency Scores median (range), WCPM		Percent Change
	Pre-Intervention	Post-Intervention	
Younger (≤9 years)	42 (19-58)	63.5 (27-78)	51.2%
Older (≥10 years)	62 (28-92)	64 (31-102)	3.2%[a]

[a]*Younger vs Older Group percent change comparison, p = 0.0339*

Table 2. Pre- to Post-Intervention Reading Fluency Scores

			Reading Fluency (WCPM)			Reading Fluency (Percentile Rank Range)	
Participant	**Age**	**Grade Level (Reading Level)**	**Pre-Intervention**	**Post-Intervention**	**Percent Change**	**Pre-Intervention**	**Post-Intervention**
A	8	3 (1)	19	27	42%	<10th	10th
B	9	4 (1)	34	57	56%	<10th	10-25th
C	9	4 (3)	50	70	40%	10th	25th
D	9	4 (3)	58	78	34%	10-25th	25-50th
E	11	5 (3)	28	31	11%	25th	25th
F	11	5 (4)	62	64	3%	10th	10th
G	11	6 (4)	92	102	11%	25th	25-50th
OVERALL (median)			50	64a	34%	10th	25th

[a]*Post-Intervention fluency scores were significantly higher than pre-intervention fluency scores, p = 0.0178*

participants who had additional diagnoses of autism, anxiety, and auditory processing disorder did not improve to a similar degree as the other four participants with ADHD (11% vs 37% change).

Overall, the median K-D Test time improved and was faster by 38 seconds (range: 9 to 76 seconds faster) and the number of errors remained the same (4 errors pre- and post-intervention). K-D Test results by participant are detailed in Table 4. Similar to reading fluency trends by age subgroup, the younger group improved in K-D Test to a greater degree compared to the older group (younger group: 31 sec faster, 5 less errors vs older group: 9 sec faster, 1 less error). The percentage of participants that failed the K-D Test following intervention was less than before the intervention (86% vs. 100% failed; Table 4).

DISCUSSION

This study examined the effect of K-D RAP on reading performance in a group of students with clinically diagnosed dyslexia. Participants demonstrated significant reading fluency gains, with a median improvement of 14 WCPM in reading fluency following intervention. According to normative reading fluency data, the typical range of weekly improvements in reading fluency in the absence of intervention can range from 0.4 to 2.2 WCPM depending on grade and initial reading fluency performance for the general population.[35] In this study, dyslexia participants' reading level was approximately two grades below their actual grade level. Hasbrouk and Tindal determined that students who read below average within their given grade level progress in reading fluency less than students who fall in an average or above average range for reading (e.g. 2nd grade WCPM expected progress per week: 10th PR = 0.6 WCPM improvement vs 90th PR = 1.1 WCPM).[35] Given this group is not reflective of the general student population and that struggling readers tend to progress at a slower pace than proficient readers, it is likely that our participants would achieve smaller gains week-to-week.[36] By calculating the typical improvement on the lower end of 0.4 per week, we would expect an improvement of 4.8 WCPM after 12 weeks within the general population. This cannot be applied directly to students with dyslexia in this study but can help provide a reference for what reading fluency gains to expect over time.

Prior studies have examined the impact of K-D RAP on reading performance for struggling readers. High needs students, who were students with active IEPs, in reading

Table 4. Pre- to Post-Intervention King-Devick Test scores

		K-D Test Time (sec)			K-D Test Errors			K-D Test Result	
Participant	**Age**	**Pre-**	**Post-**	**Change[a]**	**Pre-**	**Post-**	**Change[b]**	**Pre-**	**Post-**
A	8	209	133	-76	4	12	8	F	F
B	9	146	94	-52	17	6	-11	F	F
C	9	173	163	-10	29	14	-15	F	F
D	9	91	108	17	1	2	1	F	F
E	11	154	159	5	7	4	-3	F	F
F	11	90	81	-9	0	2	2	F	F
G	11	65	55	-10	1	0	-1	F	P
OVERALL (median)		**146**	**108**	**-38a**	**4**	**4**	**0**	**100% Failed**	**86% Failed**

[a]A negative value indicates improvement and faster speed.
[b]A negative value indicates improvement and less errors.
Pre- = Pre-Intervention Test, Post- = Post-Intervention Test
F= failed K-D Test, P=passed K-D Test

remediation programs, and/or were English language learners, from the overall student population were evaluated to examine how K-D RAP affected performance for students who had already been identified with poor reading skills. Following intervention, the high needs group demonstrated significant improvements in reading fluency and a median increase of 16.6 WCPM, compared with participants in this study who saw an increase of 14 WCPM. Similarly, the high needs group scored better on the time and error components of the post-intervention K-D Test. This may be due to some of the high needs students having less severe reading and oculomotor deficits than the diagnosed dyslexia participants in this study. Many of the students in the high needs group were able to read at grade level passages, however, they scored in a below average range for their grade level, whereas the dyslexia participants were consistently at a reading level approximately two grade levels below their enrolled grade level. Our results suggest that dyslexia may be associated with greater oculomotor and rapid number naming deficits than other reading disorders.

Children ages 9 and younger made larger improvements in reading fluency compared with children 10 years and older. This finding coincides with the recommendation by the International Dyslexia Association that early intervention for reading difficulties is imperative for best results.[10] Previous studies on K-D RAP have shown similar age-related differences in performance changes, with greater improvements occurring for students in 2nd and 3rd grade compared with higher grade levels.[29,30,32] While 4th grade students improved, they improved to a lesser degree students in earlier grades. These results therefore further support early reading intervention for the greatest gains.

Other studies have indicated that as below-level readers move up grade levels, reading fluency becomes more challenging as they continue to fall behind and miss a great deal of reading practice performed by their peers.[37] Additionally, there is a strong psychosocial component in reading and academic performance.[38] A 2016 review of reading interventions over the last century, stated that factors like motivation to read, anxiety around reading, the need to overcome mental blocks created by previous experiences of reading failure, and student interest level are essential when intervening with struggling readers.[38] Perhaps these factors also played an important role in the differences in degree of improvement among younger versus older participants.

Participants with additional diagnoses of autism, anxiety, and auditory processing disorder did not improve to the degree as those with dyslexia and ADHD. Four participants had a concurrent diagnosis of ADHD, two of which were in the younger group and two in the older group. The ADHD diagnosed participants in the younger group improved reading fluency scores by 36% and 42% as compared to participants in the older group improved by only 3% and 10%. Given these results, despite the concurrent ADHD diagnoses, the younger age at the time of intervention had a meaningful influence on the amount of reading improvement. As gains tend to lessen when the intervention is given in later grade levels, it is important to consider the time sensitive implementation of reading interventions like K-D RAP to occur before the end of 4th grade. In addition, progress with K-D RAP may be impacted by the presence of certain comorbid disorders as it did for participants with autism, anxiety, and auditory processing disorder found in this study.

Previous studies have demonstrated that most students improve significantly in reading fluency and comprehension after six total hours of practice.[27-30] Yet some students require a longer period of practice in order to normalize their eye movement skills as compared to the majority of the general student population.[27] Progress with K-D RAP depends on where

the students begin (pre-assessment result) and how much progress they achieve with practice. Dodick et al examined the effect of extra training beyond the standard six hours of practice, with an additional 11 practice sessions for students who failed the post-intervention K-D Test. Results showed that this subgroup of students continued to benefit from additional practice, as results were significant when comparing the post-intervention of six weeks and post-extra training reading fluency and comprehension.[27] Participants in this current study would likely benefit from additional practice sessions since despite significant gains, they continued to struggle with reading and most failed the post-intervention K-D Test.

We attributed improvement in reading performance following K-D RAP to changes in visual processing speed, oculomotor efficiency, and visual attention. Other studies have noted that reading relies heavily on proficiency in visual processing speed and visual attention.[39,40] A study of students with reading disabilities who performed a program of eye movement therapy found that there were significant improvements in reading comprehension.[40] Following an analysis of reading performance changes following visual span tasks, Lobier et al found that visual attention span facilitated adequate visual processing speed and that visual processing speed predicted reading speed.[39] Multiple studies have linked developmental immaturity in visual attention and reduced visual information processing skills with oculomotor deficits in children with dyslexia.[41-44] Fischer and Hartnegg studied performance of children with dyslexia and oculomotor dysfunction after completing orientation and saccadic techniques. Results showed the children improved in perceptual ability, saccadic control in only three to eight weeks, and children with dyslexia were not statistically different from the control group following the intervention.[26] To further support the close relationship between attentional aspects in oculomotor control, studies have found substantial neural activation representing attentional aspects of eye movements during eye tracking tasks within fMRI findings.[45]

There are a lack of brain imaging studies examining changes in brain activity during and after a program of oculomotor training. It has been found that areas including the dorsolateral prefrontal cortex, areas of the frontal lobe, cerebellum, and brain stem demonstrated greater functional activity after successful completion of vision therapy.[46] Likewise, the dorsolateral prefrontal cortex also controls advanced saccadic planning.[47] Voluntary saccades begin with signaling within the frontal and supplementary eye fields that travel to the superior colliculus, then the brainstem gaze centers.[47] Similar studies could be considered for examining brain imaging before, during, and after oculomotor training to pinpoint areas of the brain that correspond with improvements in the oculomotor system which translate to reading performance gains. There have been studies examining changes in fMRI maps that correspond with language centers in response to phonemic remediation for children with dyslexia.[48,49] Imaging studies would be helpful in understanding neurological adaptations following K-D RAP intervention.

Limitations of this study were the small sample size, the presence of other learning-related disorders, and lack of longitudinal follow-up assessments. Students with dyslexia commonly have other diagnoses that impact their reading and academic performance. Since other developmental disorders likely affect reading ability, future studies should explore progress in reading intervention examining both individual and concurrent diagnoses that impair learning. In addition, there was no reading comprehension data for the dyslexia group, due to the lack of standardized reading comprehension scoring within the Scholastic Fluency Assessment. The advantage of using the Scholastic Fluency Assessment is that it offers multiple passages and is repeatable within a short time ..frame, which is why it was

utilized for this study. Longitudinal studies on K-D RAP have previously shown that reading fluency scores following six hours of K-D RAP practice remained stable and even improved after one and two years following the intervention.[30]

Another limitation of this study was that the diagnoses were made by different clinicians and specialists within varying geographic regions. Consideration for utilizing specific criteria of dyslexia testing and diagnosis should be made for improved consistency when examining this population. Additionally, information on the type and severity of dyslexia for each participant was unknown. Future studies examining the type of dyslexia and severity would provide further details. Although none of the participants were enrolled in reading intervention programs or vision therapy during the study, alternative non-formal reading support may have occurred given this international cohort. Future research may consider gathering more details on participants' previous and current reading support and how that may have an influence on reading gains observed during the study period.

The assessment of other visual skills (including binocular, accommodative, and other aspects of visual processing) were not assessed or addressed in this study. Other studies exploring the connection between oculomotor ability, reading performance, and the other essential visual skills would provide a more complete picture on how vision relates to reading ability as a whole. Comparing results from this study to other studies that evaluate reading performance after vision therapy or other vision-based interventions could also provide valuable insights.

Findings demonstrated that children with diagnosed dyslexia children successfully completed K-D RAP at home under parent supervision. Reading performance gains were substantial in this dyslexia population and comparable to prior studies that examined students who were below-level in reading. The results of this study support the use of K-D RAP as an effective, supplemental intervention to improve reading performance in students with dyslexia.

CONCLUSION

K-D RAP intervention resulted in significant improvements in reading performance for these participants with dyslexia. Age and timing of the intervention appears to be a substantial factor in the degree of improvement. Based on the results of this study and previously published studies, K-D RAP implementation is an evidence-based reading intervention beneficial for students of all reading levels from proficient readers to students who read below-level, including those with dyslexia. There is an urgency for implementation, as findings indicate that older students do not demonstrate the same improvements seen in younger students.

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