Final Report on Neuralign© Reading Intervention

Report #5

Heather Douglas, Shradha Dixit, Taeko Bourque, Jo-Anne LeFevre

September 2023

MATH LAB
CACR Centre for Applied Cognitive Research
Department of Cognitive Science
Department of Psychology
Neuralign
Carleton University

Table of Contents

List of Tables iii

List of Figures iv

List of Appendices v

Acknowledgements vi

Executive Summary 1

Introduction 5

- Reading Difficulties and Dyslexia 5
- Interventions to Improve Reading 6
- Neuralign© 6
- Goals of the Research Project 7

Measures and Methods 9

- Participants 10
- Procedure 10
- Apparatus 12

Results 12

- Evaluation of the Neuralign© Experience 12
- Skill Development 16
- Case Studies 22

Conclusions 26

Appendices 28

References 42

List of Tables

Table 1. Measures Administered in the Current Study 9

Table 2. Student Comments 14

Table 3. Reading Anxiety Questionnaire 31

Table 4. Reading Self-Concept 32

Table 5. Math Anxiety 33

Table 6. Neuralign© Star Game Rating Survey 38

Table 7. Neuralign© Post Intervention Parent Survey 39

Carleton University

List of Figures

Figure 1. The Structure of the Neuralign© Intervention 7

Figure 2. Study Design 8

Figure 3. Students' Opinions of the Neuralign© Online Games 13

Figure 4. The Number of Students Choosing Each Star Rating Across the Games 15

Figure 5. Parents' Feedback After the Intervention 16

Figure 6. Expected Patterns of Results. 17

Figure 7. Grade-level Changes in Phonological Processing Skills 18

Figure 8. Grade-level Changes in Decoding Skills 19

Figure 9. Grade Level Changes in Sentence Fluency 20

Figure 10. Grade-level Changes in Reading Comprehension and Spelling 21

Figure 11. Grade-level Changes in Arithmetic Fluency 22

Figure 12. Spatial Span Task 29

Figure 13. Rapid Automatized Naming Stimuli (Form A – Letters, Numbers, Quantities) 30

Figure 14. Children's Reading Anxiety Questionnaire Scale 31

Figure 15. Children's Math Anxiety Questionnaire Scale – CMAQ (Ramirez et al., 2016). 33

Figure 16. Number Line Estimation App 37

List of Appendices

Appendix A. Description of Measures Used in the Study..28

Appendix B. Survey Questions 38

Acknowledgements

This research was jointly funded by Neuralign© and MITACS©. Neuralign© (formerly LSWorks©) contributed money that was matched by MITACS© to provide funding for interns to conduct the research. The project was supervised by Dr. Jo-Anne LeFevre, Professor of Cognitive Science and Psychology. The funding was used to hire a postdoctoral fellow (Dr. Heather Douglas) and two graduate students (Taeko Bourque and Shradha Dixit) and to buy materials (e.g., standardized tests) and implement the research. Several undergraduate students also participated and used data from the project in their honours theses (Haily Rioux, Camryn Webb, and Mikayla Perrier). These students were also hired to help with data collection for Time 3 testing. Several other students volunteered to help with the project (Tru Gamble, Isa Godoy, and Nikki Ermuth) or received course credit for their contributions (Lara Russo). None of the Carleton Team has any financial interest in Neuralign©.

Executive Summary

Purpose

Learning to read is a basic human right (Ontario Human Rights Commission, 2022). However, between 5% and 20% of students have difficulty learning to read. Some have a specific learning difficulty, such as dyslexia, whereas others may have received inadequate instruction. Children who have not learned to read need remediation options. The Neuralign© reading intervention provides intensive and structured practice decoding words, reading sentences, and comprehending short texts. The goal of this research project was to determine whether the Neuralign© experience helped children to improve their reading beyond what would be expected in a regular school year.

Design

The study was conducted in the 2022-2023 school year. Students from three different sites were randomly assigned to one of two conditions ($N = 58$). The **intervention-first** group did the Neuralign© program in the Fall of 2022 and the **wait-listed group** did the intervention in the Winter of 2023. All students were tested three times on nine subtests from the Woodcock Johnson IV (i.e., segmenting, sound blending, word attack, letter-word reading, sentence reading fluency, spelling, passage comprehension, picture vocabulary, and math facts fluency). Time 1 testing occurred before the intervention-first group started the intervention (October-November), Time 2 testing occurred after the intervention-first group completed the program (February-March), and Time 3 testing occurred at the end of the school year (May-June). Parents and students were asked about their experiences with the Neuralign© activities.

Participants

At the start of the year, students varied from 6 to 15 years old, with a mean of 10.5 years. The grade levels of the students varied from 2 to 8. Students were recruited from three sites, an urban private school (41%), a Learning Centre (38%), and a private school in a small town (21%). Most children (94%) spoke English as their first language. Most students (72%) were reading at least one year below grade level.

Results

Evaluation of the Neuralign© Experience

Students were moderately positive about the program: 32% of students enjoyed the program, 50% 'sort of' enjoyed it, and 18% did not enjoy it. Students appreciated the computerized format and game-like features of the Cognitive Therapy. Many students found that the games which involved reading were the least enjoyable. Some children spontaneously stated that they felt their reading had improved. Over 60% of parents agreed that their child had benefitted from the program. Concerns included the fit between the students' level of skill and the program content, as well as the amount of time needed for the Cognitive Therapy.

Skill Improvement

Overall, we expected to find that the intervention-first group should improve more between Time 1 and Time 2 than the wait-listed group whereas the wait-listed group improve more from Time 2 to Time 3. The results across the reading measures showed this general pattern of improvement, with statistically significant effects for phonological processing and word decoding. Passage comprehension showed a different pattern, where the intervention-first group improved more than the wait-listed group from Time 2 to Time 3, suggesting a delayed advantage for the intervention.

Limitations

There were several issues which limited data the conclusions that can be drawn from this study. First, recruitment was difficult. The Carleton team contacted all private schools in Ottawa that cater to students with learning difficulties, but only two agreed to participate. Similarly, we contacted many learning centres, but only one (which had a prior relationship with Neuralign©) agreed to facilitate the study through their centre. Second, although 60 students were initially recruited, two students could not be tested at Time 1 and 10 others dropped out during the study, resulting in a final sample of 48 students who completed all three rounds of testing. Third, due to one school moving physical location and extended holiday breaks, the wait-listed groups in the two schools did not start the intervention soon enough to fully complete the Speeded Reading and the Reading Exercises. Fourth, the wide range of grades (2 through 8) added to the variability in program completion and performance. These issues of fidelity and variability work against finding clear results. Finally, other aspects of the program that are intended to engage visual processes, for instance, activation of magnocellular pathways with the goal of improving reading, were not evaluated in the present research. In general, results in a multi-dimensional intervention may be hard to link directly to specific components of the intervention.

Recommendations For Further Research

- Establish a strong relationship with schools or school districts so that the intervention can be implemented in many schools and where the schools agree to administer the intervention as required.
- Build more systematic and accurate evaluation into the program. The digital implementation should allow for consistent and continuous assessment. Allow teachers (or tutors or parents or the students themselves, whoever is managing the process) to have access to accurate information about student's progress and guide them to use the information. This evaluation should include reliable and valid pre- and post-test evaluations (including longer term follow ups). These data could be used, over time, to build up a database of performance that could

be analyzed to better understand the relations between aspects of the program and reading improvement.
- Calibrate the dosage of both Cognitive Therapy and Reading Exercises to the specific needs of students.
- Evaluate whether extending the Cognitive Therapy over a longer period of time, with less intensity (perhaps after an initial intense period) increases the impact of the training and the students' willingness to participate.
- Follow students for several years; benefits of the program may occur over a long period of time (as suggested by the reading comprehension data).
- Limit the amount of time students spend on the games which do not involve reading. Although the games which were included mainly to motivate students probably did support motivation, because students liked those games more than the reading games, time spent on those games may need to be adjusted in relation to time spent improving reading.
- Increase the amount of time spent on reading fluency and reading aloud. More emphasis on reading fluency is warranted to ensure that reading accuracy gains are consolidated. It was difficult to judge whether the repeated reading component of the program was implemented as intended.
- Consider revising/improving the Reading Exercises. The value of reading connected texts and testing comprehension is supported by research, however, there was a great deal of variability in the extent to which students participated in the Reading Exercises portion of the intervention. For example, although 90% of students completed the Cognitive Therapy sessions, only 49% and 43% of students completed Speeded Reading and Reading Exercises, respectively. Some of this variability was related to timing, but in other cases, students didn't persist with the intervention.
- Determine which of the Cognitive Therapy games lead to most learning and whether the visual and auditory distractions included are generally beneficial. Possibly allow these features to be customized to the specific needs of the students.
- Use smaller-scale evaluations (i.e., rather than holistic evaluations, as was done in this project) to evaluate program benefits and help to guide further program development.

Conclusions

In summary, we found some evidence that phonological processing, word reading, and reading comprehension improved in response to the Neuralign© program. Many core aspects of the program are consistent with the literature on reading acquisition for dyslexic students (or those with reading difficulties), such as an emphasis on phonics, practicing sounding out words, and repeated exposure to words and word families (see Report 4). The results were not strong, however, for a variety of reasons. Some aspects of the program may have produced learning gains for some students, but many issues interfered with implementation of the intervention. More data collected from all program users may be particularly helpful in understanding how students use the program and which aspects are most beneficial.

Introduction

According to the Ontario Human Rights Commission, learning to read is a basic human right (Ontario Human Rights Commission, 2022). However, between 5% and 20% of students have difficulty learning to read. Some have a specific learning difficulty, such as dyslexia, whereas others may have received inadequate instruction. Children who have not learned to read need remediation options. The Neuralign© reading intervention provides intensive and structured practice decoding words, reading sentences, and comprehending short texts. The Cognitive Therapy portion of the intervention engages children in phonological and lexical activities designed to strengthen word access. The Speeded Reading component builds fluency through reading practice and Reading Comprehension provides structured practice interpreting texts. The goal of this research project was to determine whether the Neuralign© experience helped children to improve their reading beyond what would be expected in a regular school year. In this report, we provide detailed information about the implementation of the study and the results.

Reading Difficulties and Dyslexia

Best practices for identifying children with reading difficulties remains a topic of debate because there is no consensus on how to define reading difficulties (Spencer et al., 2014). In this report, the term *reading difficulties* refers to the challenges experienced by a heterogenous group of children that display low-level reading skills (McArthur & Castles, 2017). The term *dyslexia* is used when the research that is discussed used that term. Children with reading difficulties typically are slow or inaccurate when it comes to decoding words, but they may also have weak cognitive skills (e.g., problems with short-term memory, auditory processing, or visual attention; Galuschka et al., 2014; Hulme & Snowling, 2013; Rayner et al., 2001; Snowling et al., 2020). Often, labels such as dyslexia and reading disability are applied to students with severe cases of reading difficulties whereas terms like poor reading, reading problems, or reading struggles are used to describe less severe levels of low reading achievement (Quinn & Org, 2018).

In the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM–5; American Psychiatric Association, 2013) dyslexia is described as a neurodevelopmental disorder, which means it has an early onset, is heritable, and has life-long consequences. For a person to receive a diagnosis of dyslexia, they must have had problems with reading accuracy and fluency, poor decoding, and poor spelling that persisted for a minimum of six months despite targeted interventions. Although difficulty connecting sounds and letters is considered a central issue in dyslexia, it is possible to have dyslexia without having phonological deficits (Hulme & Snowling, 2013; Pennington, 2006; Rayner et al., 2001; Snowling et al., 2020). Other possible causes of dyslexia include problems with vision (e.g., tracking or focusing), attention, working memory, and/or processing speed (Alt et al., 2022; Pasqualotto & Venuti, 2020; Rayner et al., 2001; Sala & Gobet, 2020; Snowling et al., 2020). Dyslexia and reading difficulties often co-occur with other learning difficulties or disorders. Approximately 40% of children with dyslexia have co-occurring difficulties such as dyscalculia, ADHD, anxiety, depression, or language disorders (Moll et al., 2020; Peters & Ansari, 2019). Importantly, because children who experience reading difficulties may not have a formal diagnosis of dyslexia, conducting research with children with low reading skills can provide valuable information about reading development and the effectiveness of interventions (Peters & Ansari, 2019).

Interventions to Improve Reading

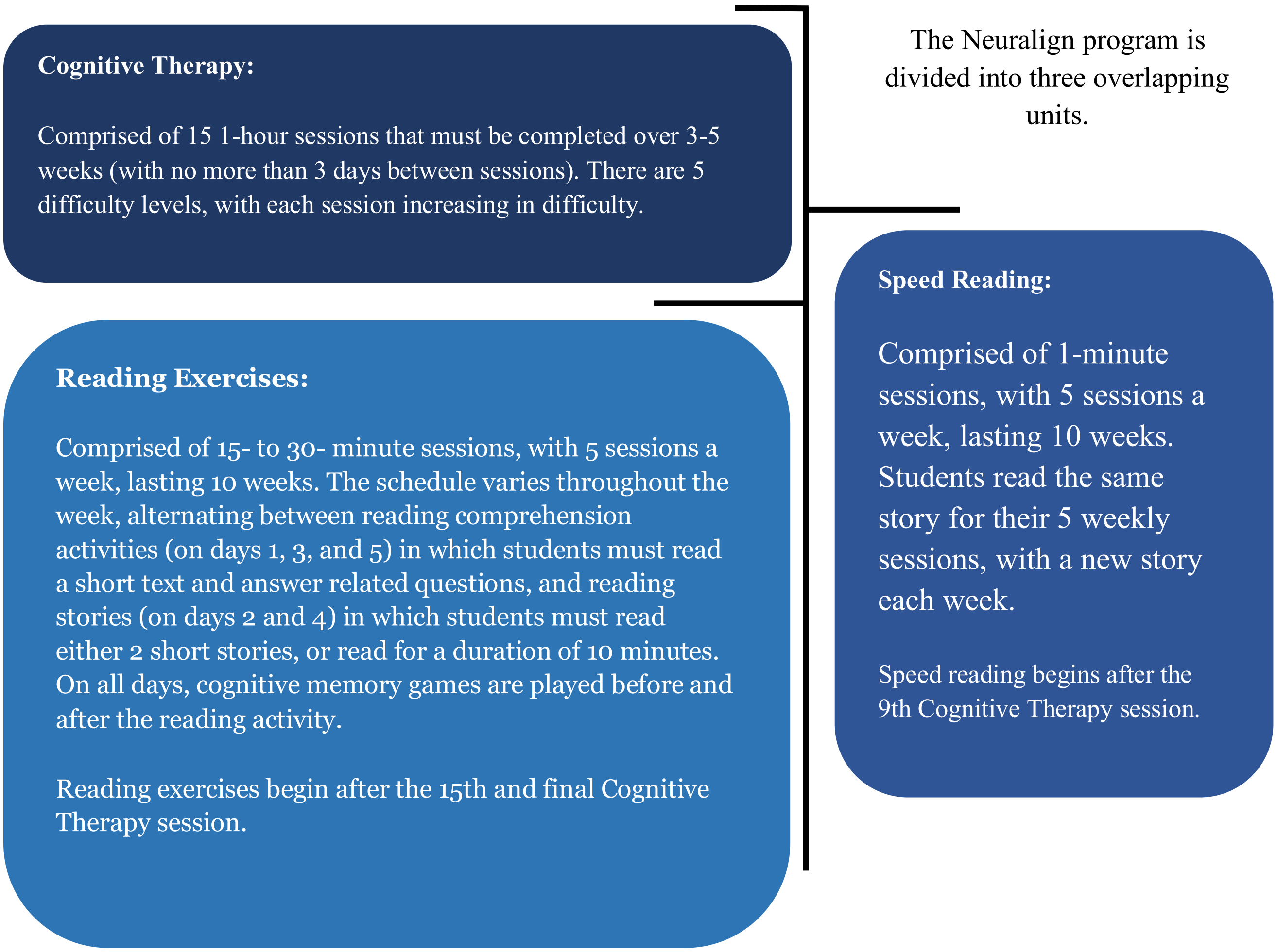
Despite the plethora of research, there is a wide gap between research on learning to read and the use of that research to develop effective reading instruction for struggling readers (Castles et al., 2018; Moats, 2007; Ontario Human Rights Commission, 2022). Finding effective interventions is critical and timely. In 2022, the Ontario Human Rights Commission found that for 2018-2019, 26% of Ontario students in Grade 3 were not meeting provincial education quality standards for minimum reading achievement (Ontario Human Rights Commission, 2022). This number is far from the 10% that would be expected if early screening and science-based instruction was widely available (McArthur & Hogben, 2012). Overall, early diagnosis and targeted intervention are critical because reading difficulties affect all areas of life. For example, an inability to comprehend text causes difficulties in day-to-day activities as diverse as completing school homework to passing driver's licencing exams (Hasselbring & Goin, 2004).

Yuzaidey et al. (2018) reviewed current intervention methods for children with dyslexia. They identified many types of interventions that are intended to target different skills for students with reading difficulties or dyslexia (e.g., multisensory methods, phonological intervention, and cognitive training methods). However, few interventions combined cognitive functions (e.g., attention and working memory) and essential reading skills. Because reading difficulties have multiple causes and correlates, struggling readers may benefit from interventions that train a combination of phonological processing, cognitive, and attentional skills. Additionally, digital interventions (i.e., that are available on computers, tablets, or online) may be an effective way to deliver accessible but high-quality instruction of core reading skills. Digital interventions may also engage students who are used to fast-paced media experiences, increasing motivation for those who have had longer-term difficulties. Finally, digital interventions may be more cost-effective than private tutoring. Yuzaidey et al. (2018) concluded that although few interventions combine both cognitive training and literacy skill-building, combined interventions are a promising area for future research.

Neuralign©

The Neuralign© program is a 13- to 15-week digital game-based intervention designed to train phonological, cognitive, reading, and attentional skills in an engaging and motivating environment. To support reading, the program provides intensive and structured practice decoding words, reading sentences, and comprehending short texts. There are three overlapping portions to the intervention as shown in Figure 1. The **Cognitive Therapy** portion of the intervention engages children in phonological and lexical activities design to strengthen word access. Fluency and comprehension are built through the **Speed Reading** practice and **Reading Exercises**. Neuralign© is intended to support the learning of neurodiverse children who are below their age-appropriate reading level. The program is designed to provide structured practice on core skills, with the goal of increasing persistence, confidence, and reading success.

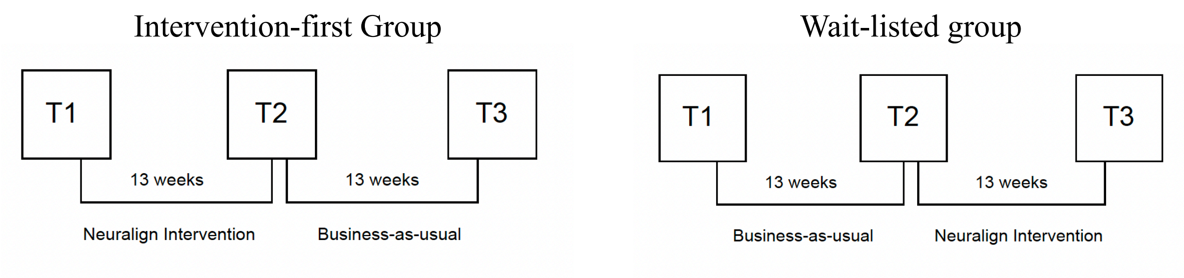
Figure 1. *The Structure of the Neuralign© Intervention*



Goals of the Research Project

The goal of the research described in this report was to evaluate the Neuralign© program, specifically, to determine whether use students show improved reading over the 15-week intervention. The study was designed as a randomized control trial, where the control group was given the intervention after the experimental group had completed it. This wait-listed control design ensures that all students are given the opportunity to benefit from the intervention. It also allows the researchers to compare two groups who have a similar experience, increasing the power of the design. The structure of the study is shown in Figure 2. After recruitment and pre-testing, students were randomly assigned, either by class (in the two schools) or grade (in the learning centre), to the intervention-first group or the wait-listed group.

Figure 2. *Study Design*



Note. Squares indicate testing timepoints (T1 = Time 1, T2 = Time 2, T3 = Time 3).

Measures and Methods

The complete list of measures is shown in Table 1. Details are in Appendix A. Children were assessed using four types of measures: general cognitive, affective, reading, and mathematics. Note that Applied Problems was replaced by the Number Line during post-test and delayed post-test because of time constraints. Testing started in October of 2022 and was completed by June of 2023.

Table 1. *Measures Administered in the Current Study*

Measures	Pretest (T1)	Post-test (T2)	Delayed Post-test (T3)
General Cognitive Measures			
Working Memory (Digit Forward, Backward, Spatial Span)	√	√	√
Matrix Reasoning (WISC-5)[1]	√		
Rapid Automatized Naming (digits, letters, quantities)	√		
Picture Vocabulary (WJ-IV Oral Language)[12]	√		
Affective Measures			
Reading affect (Reading anxiety and self-concept)	√	√	√
Math Anxiety	√	√	√
Reading Skills from the WJ-IV (Achievement)[2]			
Auditory Processing (Segmentation, Sound Blending)	√	√	√
Decoding (Word Attack, Letter-word Identification)	√	√	√
Sentence Reading Fluency	√	√	√
Spelling	√	√	√
Passage Comprehension	√	√	√
Mathematical Skills			
Math Facts Fluency (WJ-IV Achievement)[2]	√	√	√
Applied Problems[3](WJ-IV Achievement)[2]	√		
Number Line Estimation		√	√

[1]Subset of the Weschler Intelligence Scale for Children-5 (Weschler, 2014). [2]Subtests of Woodcock-Johnson IV Tests of Oral Language and Tests of Achievement (Mather & Wendling, 2014).

Participants

Demographics

Sixty students were initially recruited; 58 completed Time 1 testing; 50 completed Time 2 testing, and 48 completed Time 3 testing. Eight children dropped out of the study before post-test at Time 2 (i.e., three in the wait-listed group, five in the intervention-first group). Finally, two students from the intervention-first group dropped out of the study before post-test at Time 3. Of the 58 students, 33 were boys, 23 were girls, and no gender was reported for 2 students. At the start of the year, students varied in age from 7 to 14 years, with a mean of 10.5 years. The grade levels of the students varied from 2 to 8. Overall, there were 31 children in the wait-listed group and 27 children in the Neuralign© intervention-first group.

Students were recruited from three sites, an urban private school (41%), a Learning Centre (38%), and a private school in a small town (21%). Most of the children (93.6%) spoke English as their first language, two spoke French, and one each spoke Russian and Hebrew. All children spoke English fluently. All students were schooled in English.

Academic Characteristics

Most students (72%) were reading at least one year below grade level. Overall, 57% (n = 27) of parents reported that their children had completed a psychoeducational assessment. The most common psychoeducational diagnoses were ADHD (38.2%), dyslexia/reading difficulties (27.5%), anxiety-related conditions (17.0%), and dyscalculia (14.8%). Other diagnosis included sensory processing difficulties (n = 2), dysgraphia (n = 2), Down Syndrome (n = 1), Tourette's Syndrome (n = 1), and autism spectrum disorder (n = 1). Out of the remaining children, 23.4% (n = 11) of parents reported that they suspected their child had a learning difficulty but had not been diagnosed. Suspected diagnoses included dyslexia, anxiety-related conditions, attentional difficulties, autism spectrum disorder, and auditory processing difficulties. In summary, most children (82%; n = 38) had a formal diagnosis or suspected diagnosis contributing to difficulties in learning, and these difficulties were heterogenous. Only 18% (n = 9) of the children had no formal or suspected diagnosis.

Procedure

Time 1

Prior to beginning testing, parents provided consent and answered a background survey that took approximately 10 minutes to complete. This survey provided details about student's educational history, math and reading experiences, and the home literacy environment. For children in the learning centre (Site 1), a suitable time after school hours was arranged with the parents to bring the student to the learning centre to conduct baseline testing. In the two schools (Site 2 and 3), baseline testing was conducted during school hours with a break in-between testing after first half of the measures were administered to prevent children from being fatigued.

Baseline testing sessions lasted for up to two hours in each of the three sites. Children were tested individually at the relevant testing site by a trained researcher in a quiet environment. After baseline testing was complete, children at the learning centre were matched by age and then, randomly assigned to either the intervention-first group or the wait-list control group. At the schools, assignment to intervention versus waitlist was done by randomly assigning classrooms to intervention or wait-list control conditions. Random assignment of individuals to treatment and control groups is considered the gold standard for intervention designs (Sella et al., 1970).

All instructions were presented orally to the children. For standardized tests, the use of large print, fewer items per page, and increased space between items allowed children to focus on individual items without being overwhelmed by simultaneous presentation of numerous test items. Audio instructions were used for required subtests (i.e., sound blending) to ensure standardized item presentation. Testers followed the recommended order as outlined by the testing checklist while administering the tasks but had autonomy to present the tasks in different order to maximize interest and performance of children. When children could not sustain their optimal performance for long periods of time, then these tests were administered over multiple days (Mather & Wendling, 2014). Canadian pages/forms of tests were used for appropriate tests which included Spelling, Applied Problems, and Passage Comprehension (e.g., spell the word 'litre' in Canadian version instead of 'gallon' in the U.S. version).

Time 2

After the experimental group had completed the Neuralign© intervention, children in both the intervention and waitlist-control group were tested again. Testing procedures were the same as pre-test procedures however the total testing time was shortened to approximately 1.5 hours. After the intervention and post-test testing was complete, parents were emailed a second online feedback survey that took approximately 10 minutes to complete. Parents were asked about other reading interventions their child was receiving. The survey also included questions about their child's reading experiences and for children in the intervention-first group questions relating to the intervention.

Time 3

After the waitlist-control group had completed the Neuralign© intervention, children in both the intervention and waitlist-control group were tested again. Testing procedures followed the same format at testing during Time 2, post-test. After the control group completed the intervention parents for those children were also emailed the same online feedback survey used during Time 2. Parents received a $10 gift card as a compensation for completing the surveys.

Apparatus

The materials children used to complete the intervention consisted of varying devices such as computers, laptops, or Chromebooks, and a stable connection to the internet so that children can access the program online. The experimenters used iPads to display relevant stimuli and response booklet materials. Experimenters sat diagonally across from the child to ensure the child could view and hear the stimuli. When available, children used a mouse to enable them to click on the answers and navigate the browser of the program.

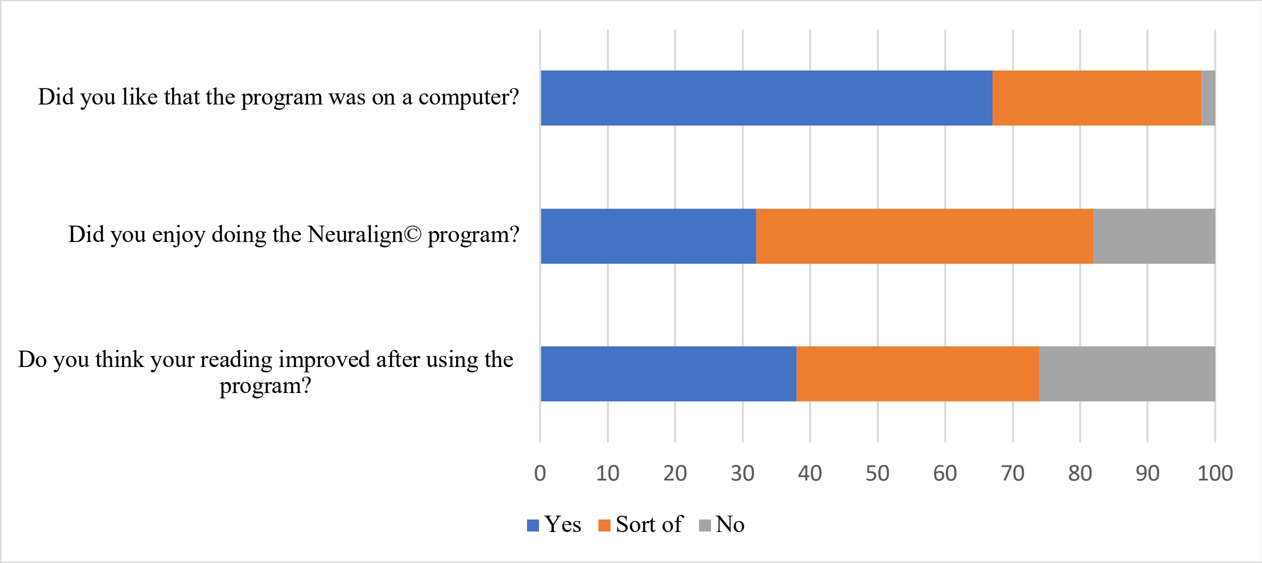
Results

Evaluation of the Neuralign© Experience

Feedback from Students

After the intervention, student feedback was gathered through surveys to better understand their experiences and opinions with the Neuralign© intervention (see Appendix B, Table 6). As shown in Figure 3, 74% of the students felt that their reading had improved, to some degree, from using the Neuralign© program. Ninety-eight percent liked that the program was on a computer, and 82% enjoyed the program, to some degree, although just 32% responded with an unqualified "yes". Although enjoyment is not necessarily the most important feature of an intervention, if students are not engaged, it may reduce their motivation to continue learning. These data are encouraging, in that the program activities were often challenging for students with reading problems. The game-like structure (e.g., animated characters like Panda, games with moving graphics, embedded text) and positive reinforcement in the form of scoring bonus points appeared to motivate some of the students. In particular, 7% of students volunteered that earning "bonus points" was a positive aspect of their experience and 16% specifically mentioned that they enjoyed the memory games.

Figure 3. *Students' Opinions of the Neuralign© Online Games*



Note. Students responded on 'Yes', 'Sort of', or 'No'.

Comments made by individual students show the range of reactions to the program. For example, one student stated: "I enjoyed the moving shapes (triangles, squares, and bees). It helped me read a little bit better"! whereas another said: "What I liked least was all the stuff moving on the screen"! Attending to the important information while blocking out auditory or visual distractions is an inherent aspect of the program's design. It might be useful, however, to do some research on whether the combination of reading/decoding practice and distractions is beneficial to all students, given that this was a concern for some students.

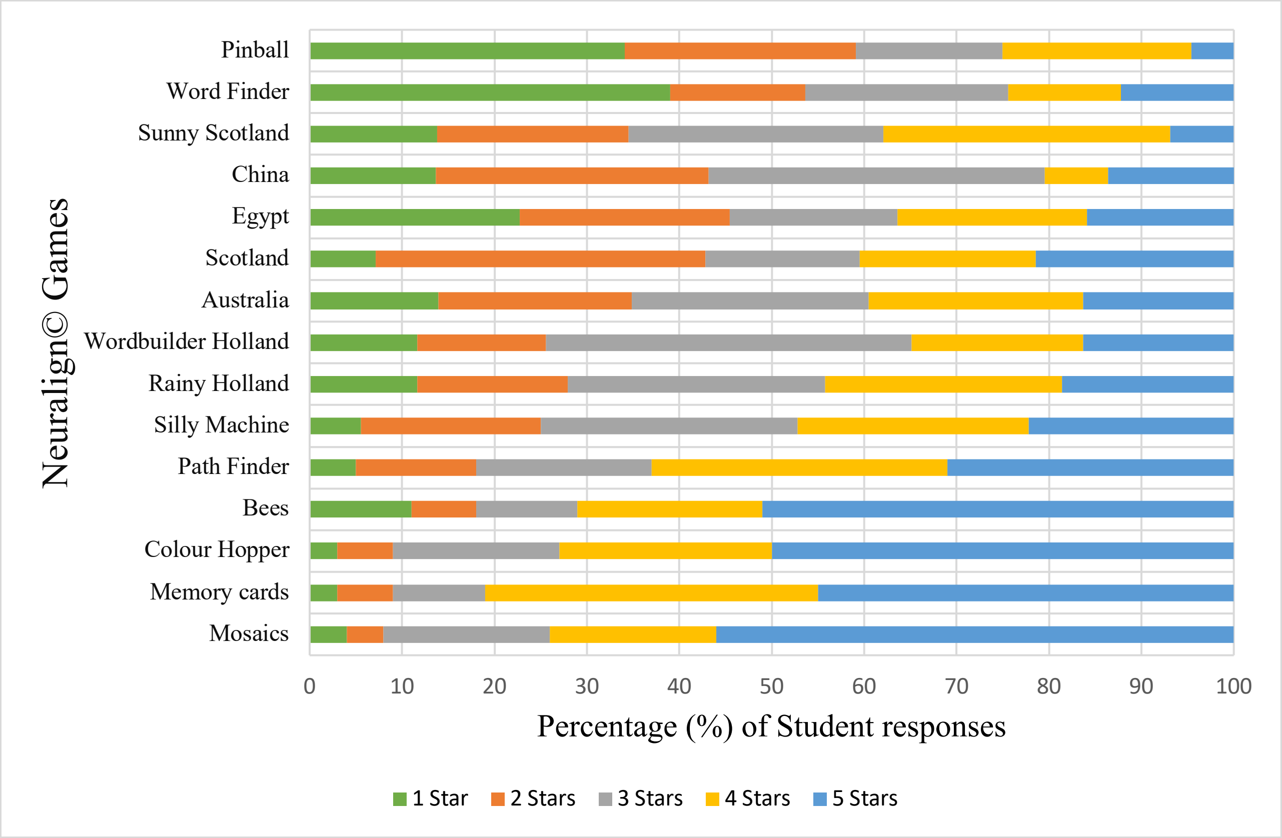
Other comments, as shown in Table 2 (see comments S1 to S3), suggested that students were aware of how the Neuralign© training was beneficial to their overall reading progress. In contrast, some students did not appreciate the program (see comment S4). Some students experienced too many operational difficulties (see comment S5), especially those at Site 2, because they were using a range of hardware and because the internet connection was weak. When using the program, it is important to follow the hardware specifications that are outlined by Neuralign©. Most of the operational problems were remediated in time for the second group to start the intervention and the teachers were more familiar with the program and thus better able to support the students.

Table 2. *Student Comments*

S1, Grade 4, Female	"I liked the China game a lot because it helped me learn how to spell some words that I always make mistakes with. For example, pen instead of pan."
S2, Grade 8, unreported	"It was very good language practice and it educated me on things I did not know before."
S3, Grade 4, Male	"I am learning more about reading!"
S4, Grade 3, Female	"The audio was too hard to understand because it was slow. Sometimes there were glitches, and it was hard to understand the program. It was too repetitive and long."

Students were asked to provide a "star" rating for each Neuralign© game they played; ratings ranged from one and five stars. As shown in Figure 4, over 70% of students gave 4- or 5-star ratings to the games that involved spatial or memory activities reading (e.g., Mosaics, Memory Cards, Colour Hopper, and Bees). In contrast, the word-based games were rated less favourably, although there was also variability across the word games, as shown. In sum, students found reading-related games less enjoyable than the games that didn't involve reading.

Figure 4. *The Number of Students Choosing Each Star Rating Across the Games*

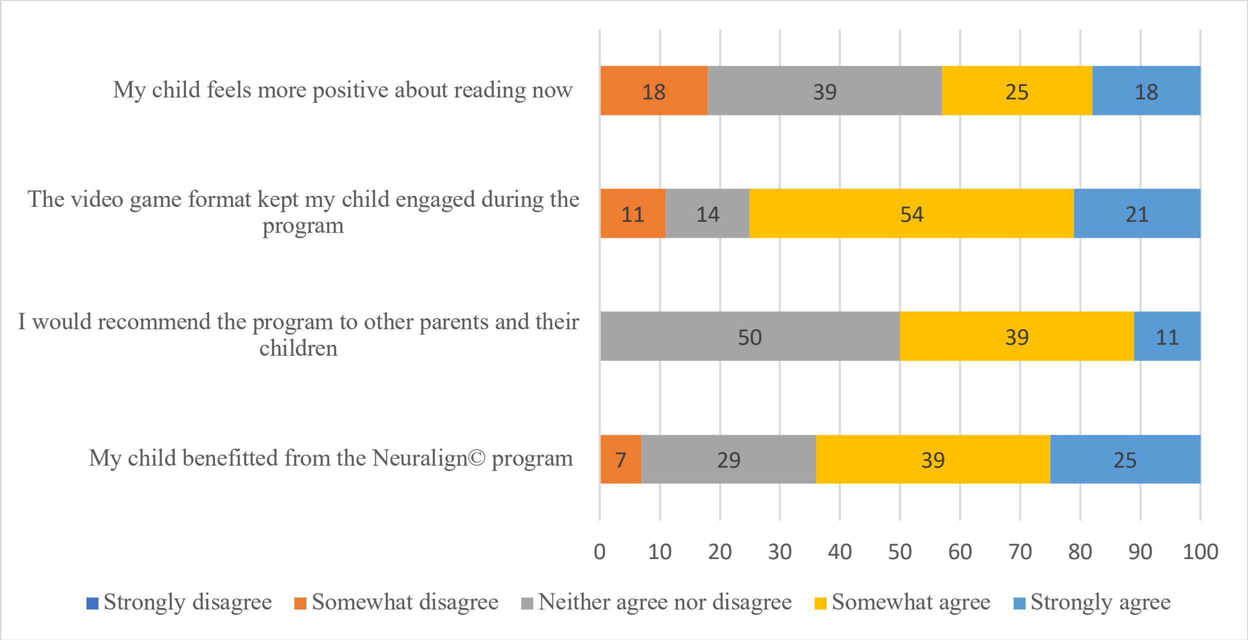


Note. The five-point scale consisted of one to five stars: (1) Don't like very much, (2) Don't like, (3) Neither like nor dislike, (4) Like, (5) Loved it. The number of responses varied depending on which games the student had played (n = 32 to 45).

Parent Feedback

Parents were asked to rate their agreement with a series of statements about the Neuralign© experience (see Appendix B, Table 7. for the full list of questions). As shown in Figure 5, 84% agreed that the game format kept their child engaged; only 12% disagreed. Further, 68% of parents agreed that their child benefitted from the program and only 8% disagreed. This finding is similar to results of a Neuralign© user survey where over 75% of parents gave Neuralign© at least 4 out of 5 stars and 56% of parents reported that their child's reading skills had improved considerably after using the intervention (Douglas et al., 2022). Thus, many parents felt that the Neuralign© experience was useful for their child.

Figure 5. *Parents' Feedback After the Intervention*



Note. The number of responses were 28.

Skill Development

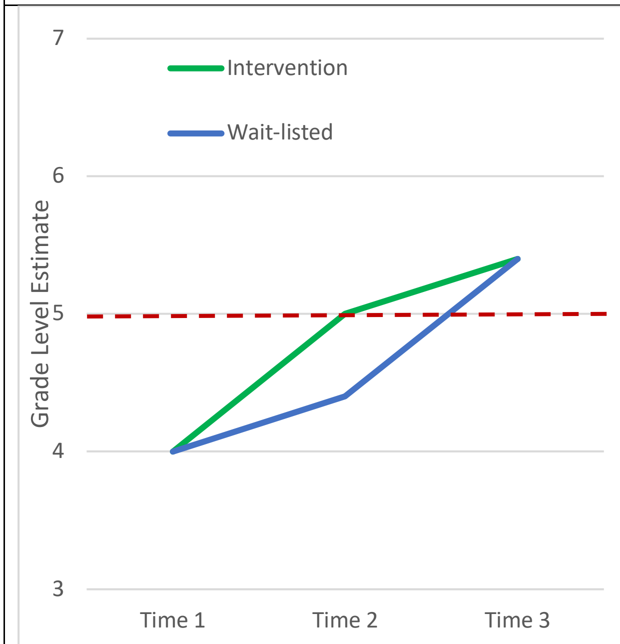
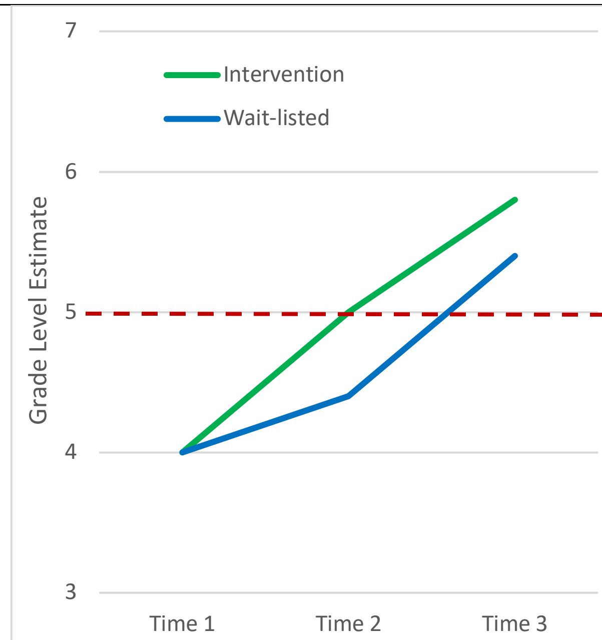
Descriptive Analyses

The sample graphs shown in Figures 6a and 6b illustrate two possible patterns of results if there was an effect of the intervention on skill development. Specifically, students in both groups would, at Time 1, be reading below grade level. The red dotted line is the average starting grade of the students. One pattern is shown in Figure 6a. If the intervention was effective, reading skills in the intervention-first group should grow faster from Time 1 to Time 2 whereas reading skills in the wait-listed group should grow more from Time 2 to Time 3. This pattern seems most likely to occur for skills that are targeted directly by components of the intervention (e.g., word level reading practice).

The other possible pattern is shown in Figure 6b. Here, we see improvement from Time 1 to Time 2 for the intervention-first group, but that improvement continues from Time 2 to Time 3. From Time 2 to Time 3, skills of students in the wait-listed group (who did the intervention after Time 2) would show faster improvement. However, if the intervention had longer-term effects, the intervention-first group may continue to improve.

To statistically compare the changes across time for the two groups, we use planned comparisons that corresponded to the predicted pattern of results for each time period for each group. Specifically, we tested whether group each improved from Time 1 to Time 2 and from Time 2 to Time 3, for a total of four comparisons per measure.

Figure 6. *Expected Patterns of Results.*

a. Intervention-first Group Improves then Stabilizes "Increase-then-stabilize"	b. Intervention-first Group Shows Continuous Improvement "Continued Improvement"
	

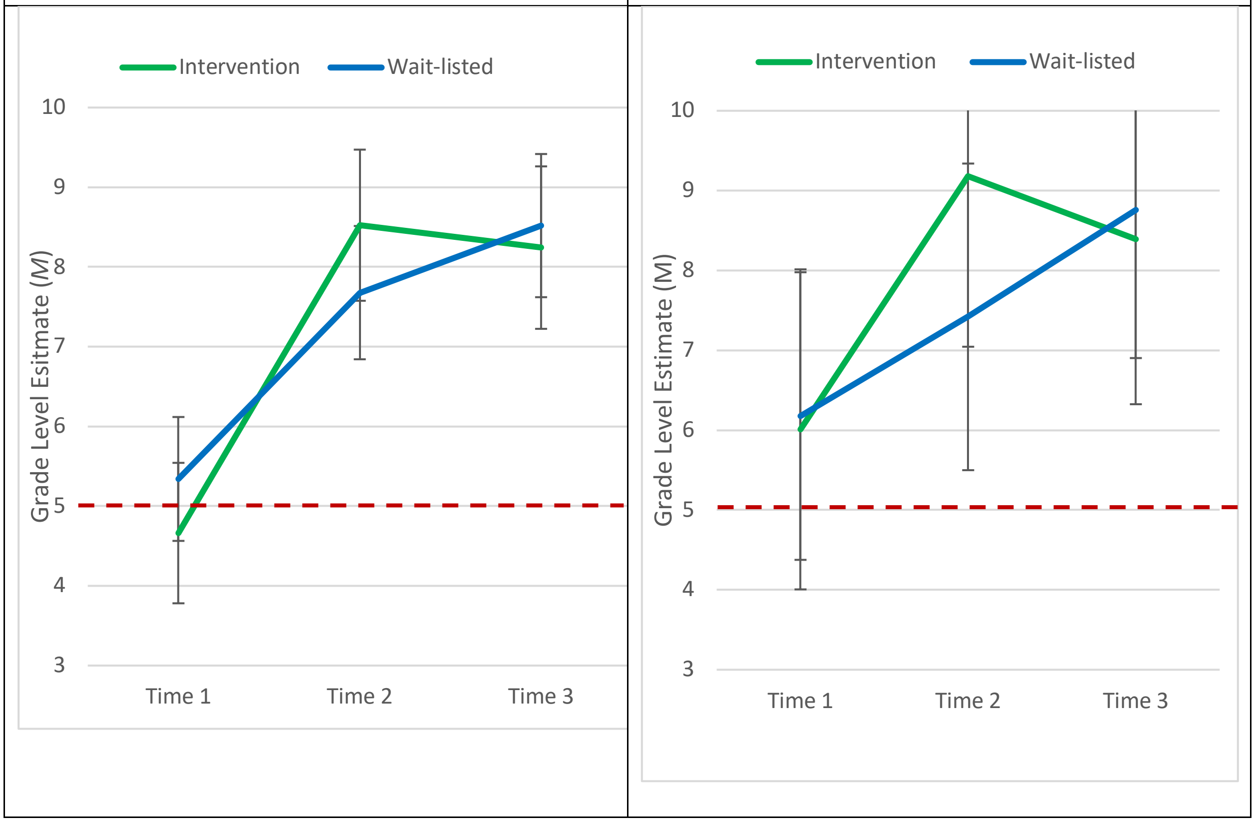
The following series of graphs (Figures 7 to 10) show the growth in student skills on the reading measures. These graphs generally follow a similar pattern as our predicted patterns in Figures 6a and 6b, with some exceptions.

Phonological Skills. The pattern of growth in students' phonological skills (Figure 7) is like the pattern shown in Figure 6a. For sound blending (Figure 7a), the intervention-first group improved significantly from T1 to T2 ($p < .001$) but not from T2 to T3 ($p = .621$). The wait-listed group also showed significant improvement from T1 to T2 ($p = .003$), but not from T2 to T2 ($p = .098$).

For segmentation, (Figure 7b), the intervention-first group improved significantly from T1 to T2 ($p < .015$) but not from T2 to T3 ($p = .389$). In contrast, the wait-listed group did not show significant improvement from T1 to T2 ($p = .277$) or from T2 to T3 ($p < .123$), despite an overall improvement from T1 to T3 (p = .015). Overall, both groups showed substantial improvement over the course of the study. However, it is likely that this test reached ceiling levels for many of the students.

Figure 7. *Grade-level Changes in Phonological Processing Skills*

(a) Sound Blending   (b) Segmentation

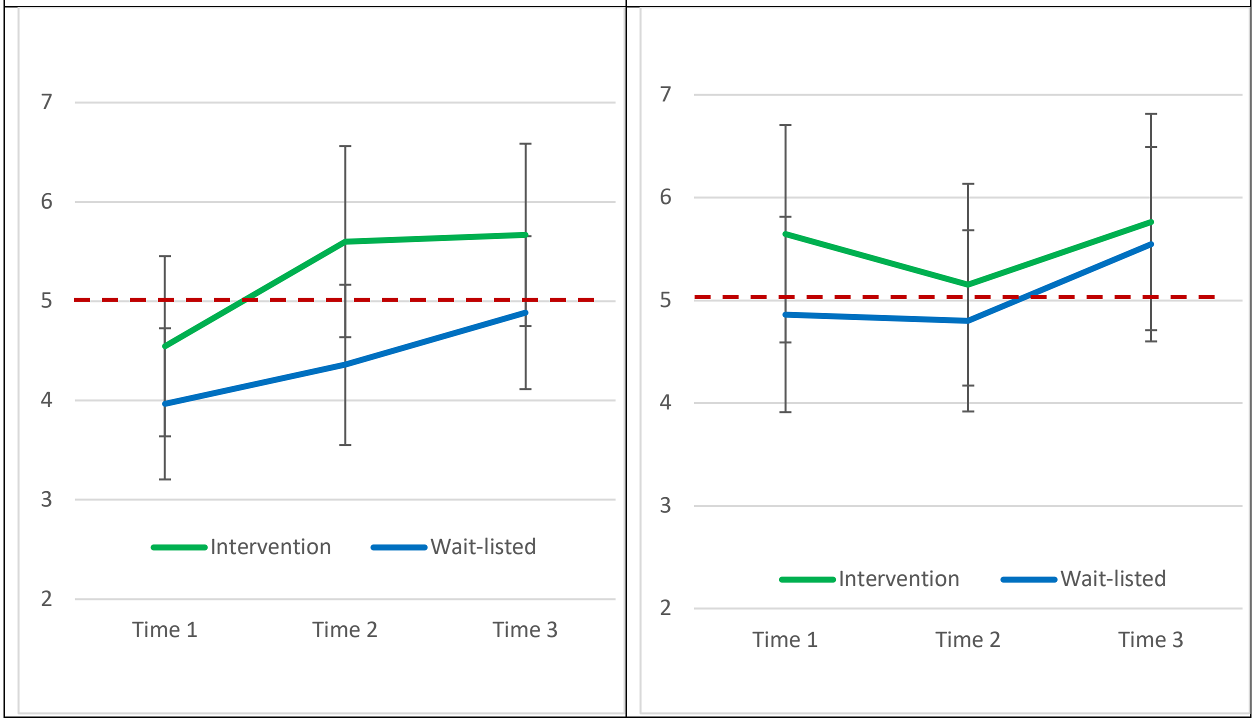


Decoding Skills. Students' word reading skills followed the predicted increase-then-stabilize pattern. As shown in Figure 8a, students began the year at or slightly below grade level. The students in the intervention-first group improved from T1 to T2 (p = .008) and then stabilized after the intervention (p = .813). In contrast, students in the wait-listed group did not show significant improvement from T1 to T2 (p = .22). They did improve from T2 to T3 (p = .035), although the amount of improvement was smaller than for the intervention-first group. Recall that the wait-listed group did not have as much time to complete the Fluency or Reading Exercises as the intervention-first group. In summary, these data suggest that there was improvement in students' word reading skills related to the intervention.

In contrast, students' word attack skills (i.e., nonword reading) did not show significant improvements from T1 to T2 or from T2 to T3 for either group. Moreover, there was no overall improvement from T1 to T3 for either group. Nonword reading is one of the most difficult skills for students with dyslexia, such that even adult dyslexic students attending university continue to show marked deficits in this skill (Bruck, 1990)

Figure 8. *Grade-level Changes in Decoding Skills*

(a) Word Reading	(b) Word Attack

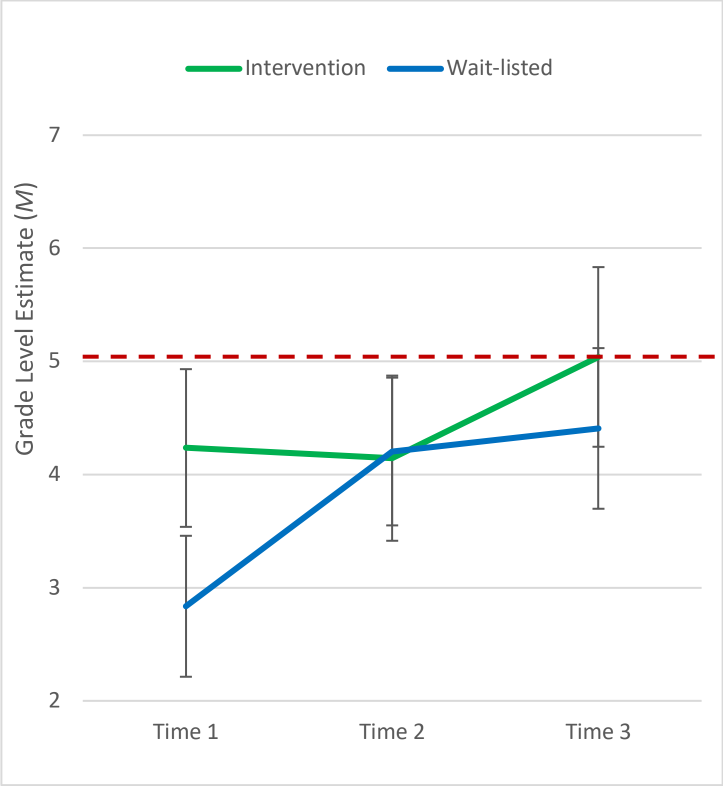


Notes. Error bars represent standard errors of the means.

As shown in Figures 9 through 11, students started out below grade level on spelling, reading fluency, and arithmetic skills. Although they improved over the year, at the end of the year they were still about one year below grade level.

Reading fluency scores did not show a pattern that suggested any influence of the intervention. The intervention-first group did not show significant improvement in either T1 to T2 (p = .874 and p = .056), whereas the wait-listed group showed significant improvements in both time periods (p = .010 and p < .001). It is possible that the wait-listed group was doing different types of practice in the non-intervention portion of the study.

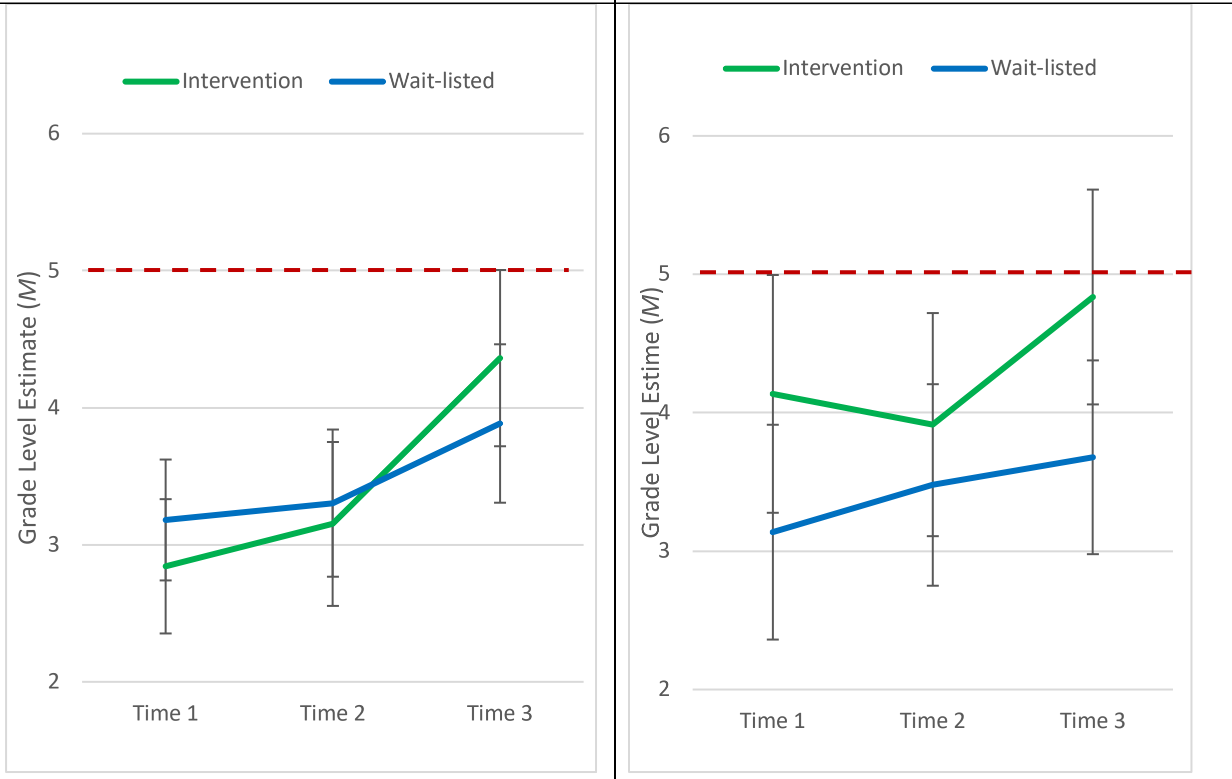
Figure 9. *Grade Level Changes in Sentence Fluency*



Comprehension and Spelling. The results for passage comprehension showed a different pattern than those for the other measures, one more like the predicted pattern in Figure 6b. Neither group of students improved much from T1 to T2 (*p*s of .647 and .303). However, from T2 to T3, students in the intervention-first group improved significantly ($p < .001$) as did those in the wait-listed group ($p = .02$). This trend suggests that there may have been a delayed effect of the intervention. Despite this improvement of just over one grade level for the intervention group, both groups were still almost two grade levels behind at the end of the study. Anecdotally, one of teachers reported that her students in the intervention-first group had more success with their in-class reading comprehension after the structured practice in the Neuralign© reading exercises. It is also important to note that, because of time constraints, the intervention-first group completed more of the reading exercises than the wait-listed group (56.4% versus 29.0%, $t(54) = 2.59$, $p = .012$. Thus, the dosage of the intervention for the wait-listed group may have been insufficient to have much influence on their comprehension.

Figure 10. *Grade-level Changes in Reading Comprehension and Spelling*

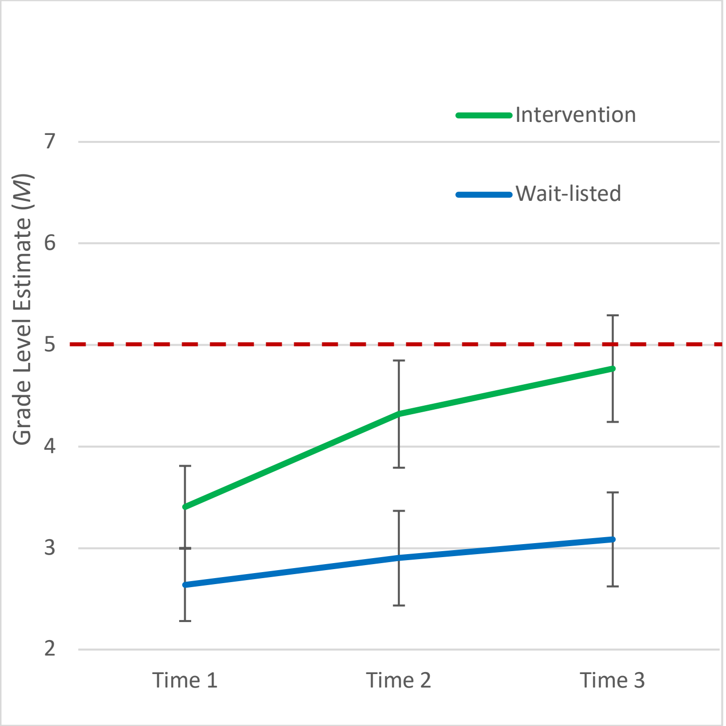
a. Passage Comprehension	b. Spelling



The results for spelling (see Figure 10) were somewhat similar to those for reading comprehension, in that the largest improvement was for the intervention-first group from T2 to T3 (p = .049). None of the other differences were significant for either group. There was considerable variability in the spelling scores at all three time points. For both spelling and reading comprehension, students were well below grade level.

Arithmetic Fluency. At the start of the year, students in both groups were, on average, below grade level. Fluency skills for intervention-first group improved from T1 to T2 (p = .002) and from T2 to T3 (p = .008). However, students in the wait-listed group did not show significant improvement in either time period (ps > .05). The initial difference between the two groups at T1 was not significant (p = .16), although objectively the intervention-group first had higher scores. It is possible that the intervention did influence the acquisition of fluency skills, but only for those students with an initially higher level. At T1, arithmetic fluency scores were two to three years below grade level, on average. More detailed information about students' math skills would be helpful in understanding the patterns of improvement for this test.

Figure 11. *Grade-level Changes in Arithmetic Fluency*



Notes: Error bars represent standard errors of the mean.

Case Studies

Averaged data across the diverse group of students obscures some of the more impressive successes. We explored the progress of several students who showed reading improvements in more detail. **The names and some details about the students were changed so that they were not identifiable.**

Jamie: Typical Pattern of Improvement

Jamie (not her real name) showed a learning trajectory that was similar in many ways to the overall pattern of change we observed for the whole sample. Jamie is a grade 5 student who has been diagnosed with dyslexia and attentional difficulties. She is getting reading support at school, and daily (30 mins/day) extra support at a local learning centre, where Jamie's parents learned about the Neuralign© study and where Jamie worked on the program. She completed all the cognitive training sessions and the majority (75%) of the reading exercises and speed-reading sessions. Jamie really liked some games, giving most of them 5-star ratings. For example, she liked the games focused on decoding (such as: *Silly Machine* and *Word Builder*), and working memory (such as: *Scotland*, *Holland, Memory Cards,* and *Colour Hopper*). In contrast, Jamie only gave 1 star to the patterning games (such as: *Bees* and *Mosaic*) and commented that she found the shifting patterns in the games distracting. Jamie's parents agreed. When asked about the program, Jamie's parents wrote:

> *She did find the first portion of the programming difficult, as the background was often very busy and that is something that she struggles with (her eyes tend to 'jump' because she has binocular emergence) however, we actually saw an improvement in her vision. She was in vision therapy and was able to complete that faster than anticipated and we wonder if it's because of the reading program.*

At the start of the year, Jamie was reading at a grade 3 level (two years behind her peers). After completing the Neuralign© program, Jamie's word reading improved by three whole grade levels. Jamie finished the year reading words at grade level. She also demonstrated strong growth in her phonological processing skills and was well above grade level in these areas (blending and segmenting sounds). Jamie had greater than expected growth (more than one grade level) in her reading comprehension and spelling skills but remained below grade level in these areas at the end the year (grades 4.6 and 2.9 respectively). Like the overall pattern of results, Jamie showed no improvement in reading nonwords or in sentence reading fluently.

Notably, Jamie's parents felt positive about Jamie's growth in reading skills, *"We are noticing that she is able to read much quicker and with more accuracy than before."* In spite of Jamie's reading difficulties, she was not anxious about her reading, and she reported positive feelings about her reading skills. Jamie's parents noticed this positive attitude and felt that the intervention and extra support was making Jamie more positive towards reading. They wrote, "*We are seeing her picking up novels to read when, before, she would have only picked up graphic novels or very small books."*

In summary, Jamie experienced more than expected growth in her foundational reading skills and her comprehension and fluency skills are continuing to develop but at a slower rate. Jamie enjoyed some of the Neuralign© games. She found the shifting patterns distracting but her parents felt that her vision had improved. Her parents believed the program and the extra support Jamie was getting through the learning centre were helping her to move forward with her reading. With on-going support, Jamie's reading skills should continue to grow.

Johnny: Growth in the Face of Variability

Johnny (not his real name) was a grade 8 student and a native, monolingual English speaker. He had three diagnosed learning difficulties, including ADHD, but had not been diagnosed with reading difficulties. Johnny's parents moderately agreed with statements that Johnny was a good reader (3.5 on a scale from 1=strongly disagree to 5 = strongly agree). Johnny was not receiving extra reading support outside of the classroom. He completed the Neuralign© Cognitive Therapy and the majority of the Reading (94%) and Speeded Reading exercises (78%). His favourite part of the intervention was the Cognitive Therapy, but he gave the full program only 2 out of 5 stars. That said, Johnny gave some of the memory games a 5-star rating (Colour Hopper and Mosaics) but in general, most games got 2 or 3 stars, similar to the patterns across the sample.

Although Johnny had no reported reading difficulties, when he started the Neuralign© program at school his word-reading skills were assessed as four years behind grade level. Johnny's skill development over the year was inconsistent. Although his word reading improved by four grade levels and his reading fluency by five grade levels (taking him to a grade 12 level), he did not show improvement in phonological processing, spelling, or nonword reading. Moreover, there was no consistency in his scores across the three testing sessions, with some improving and then declining. Considering these inconsistencies in the context of Johnny's ADHD and other learning difficulties, the assessments may not be a valid assessment of Johnny's reading skill development. It is possible that his attentional difficulties contributed to his poor performance.

In spite of the inconsistent testing results, when surveyed post-intervention, Johnny's parents reported that he was sounding out words and reading new words much better than before. They also reported that he was much more confident in reading and was spending more time reading for pleasure. These reports suggest that the Neuralign© experience supported Johnny's learning journey.

Alex: Very Strong Growth in Reading

Alex (not his real name) is a grade 4 student with two suspected learning difficulties: math and attention. Alex's parents were neutral (neither agreed nor disagreed) when asked if Alex was a good reader and they felt the same about his math skills. However, they did believe that his reading skills were slightly worse than his peers. Alex was not receiving out of school reading support. He started the Neuralign© program in the Fall and completed all components of the program, Cognitive Therapy, the Reading Exercises, and the Speeded Reading. Alex enjoyed the games, rating them between 3 to 5 stars. His favorite (5-star) games were the memory and patterning games (e.g., Bees, Mosaics, Pathfinder, Silly Machines, and Colour Hopper). When asked what he liked best about the Neuralign© program, Alex said, "*that I'm learning more about reading.*"

Alex was indeed learning. He showed strong growth in all areas of reading over the course of the school year. At the start of the year, Alex's word reading was at a grade 2 level (two years behind his peers) and his nonword reading was at a 2.8 grade level – that is, end of grade 2. By the end of the year, Alex's word reading and nonword reading were above grade level in both areas (i.e., grades 5.3 and 9.9 respectively). He had similar growth in his phonological processing skills. Alex's improved decoding and phonological processing skills are reflected in his gains in reading comprehension. Alex started the year with weak comprehension (grade level 2.6) and finished the year understanding reading at a grade 5 level. In a typical year, students are expected to grow by a grade level. The Neuralign© experience may have contributed to Alex's exceptional gains in both decoding skills and reading comprehension.

Alex's parents suspected that he had difficulties with math. Consistent with this view, Alex started the year with low math fluency (grade 1.3 level) and he finished the year at a grade 1.7 level. In spite of his poor math skills, Alex rated his math anxiety very low.

In summary, after completing the Neuralign© program and the year of school, Alex's reading skills improved substantially more than expected. His math skill however remained weak.

Summary

In summary, these three students all showed improvements in their reading skills that appeared to be linked to their experience with Neuralign©, based both on their own perceptions and those of their parents. They also demonstrate the extreme variability that we saw in the students, variability that contributed to large standard deviations in group performance. This variability and consequent low power are clearly an inherent feature of this diverse group of learners. We suspect that more frequent and detailed assessments of students' progress, as well as a longer-term commitment to continuing the various aspects of the Neuralign© intervention, would help to reduce variability and reveal the specific effects of program elements on students' learning progress.

Conclusions

The goal of this research was to evaluate the effect of Neuralign©, a reading intervention that embeds cognitive training in reading skill practice, on student reading skill development. The students involved in the study were diverse and had complex learning histories. They were either attending private schools that was focused on supporting students with special needs or they were receiving afterschool support at a private learning centre. The students were quasi-randomly assigned to one of two experimental conditions; one group received the 15-week intervention at the start of the study (i.e., the intervention-first group) and the second group received the intervention approximately half-way through the study (i.e., the wait-list control group). A range of reading skills were assessed three times. These skills included phonological processing, decoding, reading fluency, reading comprehension and spelling. Growth in skills were compared between the groups.

We predicted that, if the intervention had a positive impact on students' reading, the intervention-first group would show greater skill improvement at between Time 1 and Time 2 (i.e., after they finished the intervention) compared to the wait-listed group. Further, we anticipated two possible trends from Time 2 to Time 3, that is, the intervention-first group would either see continued skill improvement or their skills would level off. We also expected the wait-listed control group to show more improvement from Time 2 to Time 3.

We found some evidence that the Neuralign© intervention led to predicted improvements in three areas of reading: phonological processing, word reading, and reading comprehension. First, phonological processing, that is, segmenting and blending sounds improved. Specifically, students' processing skills in the intervention-first group improved between Time 1 and Time 2 and then levelled out. The wait-listed students showed less improvement between Time 1 and Time 2, as anticipated, but they caught up by the end of the study. Thus, the intervention seems to have given these phonological skills a boost. Second, word reading skills improved between Time 1 and Time 2 for the intervention-first group but did not improve much after the intervention (Time 2 to Time 3). The wait-listed group showed gradual improvement over the year and did not catch up to the intervention-first group. Overall, they had less exposure to reading because time for the intervention was limited. Third, reading comprehension improved from Time 2 to Time 3 for the intervention-first group, suggesting that the improvement was delayed. Students in the wait-listed group also showed some improvement for Time 2 to Time 3. Overall, however, reading (and spelling) skills were quite low for these students.

In summary, although there was some evidence that the intervention helped students' reading skills, the amount of improvement was less than expected. The realities of implementing a year-long intervention study, and issues with fidelity of implementation, limited the power of the study. Nevertheless, these findings are promising and support the conclusion that the Neuralign© program can support reading achievement for students with severe reading and other learning difficulties. They also suggest that the intervention may need to be continued, to support further growth, because for most of the measures there was a levelling off after the intervention was finished. Case studies of individual students who improved highlighted the range of variability across this diverse group of learners.

Appendices

Appendix A. Description of Measures Used in the Study

Cognitive Skills

Working Memory

Children's verbal working memory was measured with two tasks: digit forward span and digit backward span. Visual-spatial working memory was measured with the spatial span task.

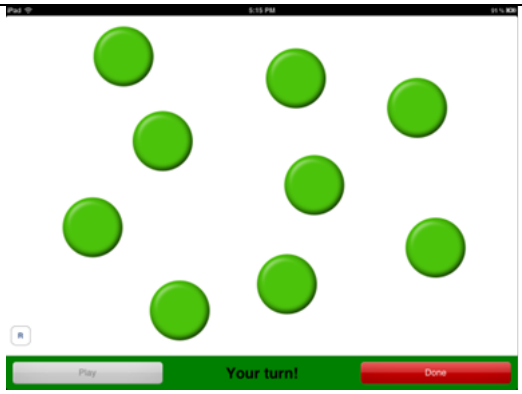
Digit Span Forward. In this task, prerecorded lists of numbers were presented auditorily at a rate of one per second. Children were asked to respond by repeating the numbers in the same order in which they were said (e.g., if 3-5-7 is recited, then the correct response is 3-5-7). There was one practice trial and two trials for each span length starting at 2 to a maximum of 9. Testing was discontinued when both trials for a given span were repeated incorrectly. Scores were based on the total number of correct trials recalled (i.e., 1 if correct and 0 if incorrect; maximum of 16). Test reliability ($\alpha = .79$) was based on two items which were the sum scores of the first and second trials of the spans.

Digit Span Backward. This measure of verbal working memory is part of the WISC-5 test battery (Wechsler, 2014). Like digit forward, children listened to prerecorded lists of numbers presented at a rate of one per second. However, in this task, children were required to repeat those lists of numbers in reverse order (e.g., if 2-7-9 is recited then, the correct response is 9-7-2). There was one practice trial and two trials for each span length starting at 2 to a maximum of 9. Testing was discontinued when both trials for a given span were repeated incorrectly. Scoring was based on the total number of correct trials recalled (i.e., maximum of 16). Test reliability is ($\alpha = .82$) based on two items which was the sum scores of the first and second trials of the spans.

Spatial Span. The PathSpan app (Hume & Hume, 2014) measured visual-spatial working memory. In each trial, a group of green circles lit up one by one in a random pattern (see Figure 12). Span length of these patterns started with two circles and increased to longer lengths depending on children's performance. For each trial, children were asked to touch the dots in the same order as the pattern that lit up on the app. After the experimenter demonstrated the practice trial, children were given three more trials of sequences of two locations without any feedback. If at least one of those sequences are correctly replicated, then the task proceeded to the next incremental span length (i.e., three trials with sequences of three locations). When errors were made on all three sequences for each length, the task is terminated by the App. Score was the total number of sequences completed correctly. This task has been used extensively to index visual-spatial processes in children (Astle et al., 2013; LeFevre et al., 2010; Xu & LeFevre, 2016). The score of the spatial span task is the total number of sequences completed correctly. Task reliability (α = .89) was based on the sub scores of trials 1, 2 and 3.

Figure 12. *Spatial Span Task*

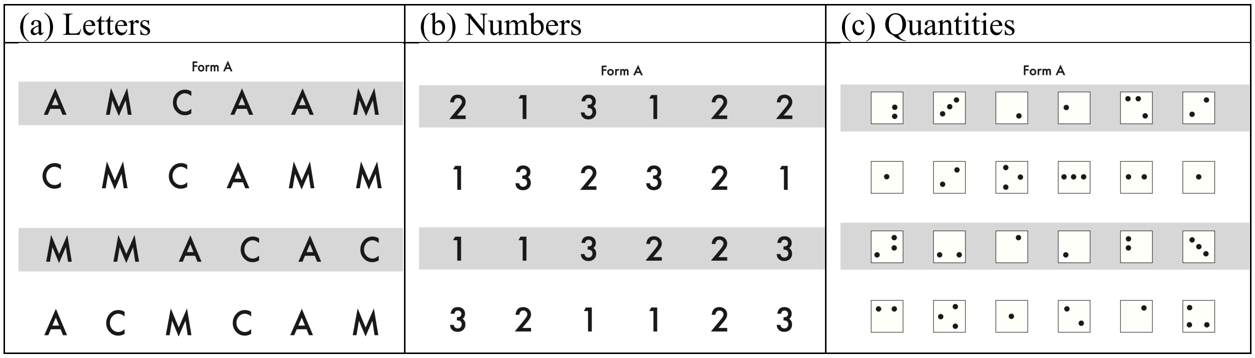
(a) Screen Shot from the Path Span App



Matrix Reasoning
The Matrix reasoning subtest is a part of the Weschler Intelligence Scale for Children-Fifth Edition (WISC-5; Wechsler, 2014). The test measures fluid reasoning. Fluid reasoning describes a child's skill at grasping non-verbal concepts (i.e., shapes, designs, visuospatial patterns) such that s/he can identify missing or incorrect aspects of those concepts and complete or correct them. In this task, the child looked at an array of pictures that form a pattern but had one part of the pattern missing. They were required to identify the missing part by selecting one of the five response options to form the complete pattern. Overall, there were 32 items and two sample questions. Testing was discontinued after three consecutive errors. Scoring was based on the total number of correct responses. The task reliability for matrix reasoning is (α = .92).

Rapid Automatized Naming (RAN)
This task required children to name stimuli aloud as quickly and accurately as possible (see Figure 13). Children completed three versions: Letters, Numbers, and Quantities**.** Practice trials included one row of letters, numbers, or groups of dots that children were required to read aloud before beginning the task. Each version consisted of one page with three rows of eight letters, numbers, or groups of dots ordered randomly. For the RAN-Quantity task, children were asked to name sets of 1, 2, or 3 dots. For the RAN-number task, children named the numbers 1, 2 or 3. For the RAN-Letter task, children named the letters C, M or A. The experimenter recorded naming time in seconds (i.e., how long it took to read all 24 items) and accuracy (i.e., the number of errors committed) for scoring purposes. Scoring was the number of correctly named items per second (24-naming errors/naming time in seconds). Test reliability based on item efficiency for the three tasks was (α = .88).

Figure 13. *Rapid Automatized Naming Stimuli (Form A – Letters, Numbers, Quantities)*



Picture Vocabulary

This sub-test from Woodcock-Johnson IV Tests of Oral Language (Mather et al., 2014) briefly measured children' word (lexical) knowledge and oral language development. The first two items required that children point to a picture of an object. The remaining 52 items required children to say the name of the picture. Thus, this test measured expressive vocabulary at the single word level. Items became increasingly difficult, and testing was discontinued when after 6 consecutive incorrect responses because ceiling was established. This task has a median reliability of .78 in the 5 to 19 age range (Mather et al., 2014). Overall, there were 54 items and two sample items.

Affective Measures

Reading and Math Affect

Children's reading affect was measured with two tasks: reading anxiety and reading self-concept. Children's math affect was measured using a questionnaire for math anxiety.

Reading Anxiety. Children completed the Children's Reading Anxiety Questionnaire (CRAQ; Ramirez et al., 2016). The CRAQ was developed by adjusting the 16 items of the Children's Math Anxiety Questionnaire (CMAQ; Ramirez et al., 2016) to pertain to a reading context. This 15-item questionnaire asked children to indicate how nervous they would feel in reading related situations, including specific reading related tasks, and reading situations in the classroom (see Table 3, e.g., how do you feel when you have to look something up in a dictionary?). All questions were read aloud by the experimenter. Children were required to select one of the five smiley faces that are displayed on an emotional gradient from 'not nervous at all' to 'very very nervous' on an iPad (See Figure 14). Test reliability was calculated using all 16 items was α = .88. The items were recoded such that a low score reflected high anxiety allowing reading affect variables to be scaled in the same direction.

Figure 14. *Children's Reading Anxiety Questionnaire Scale*

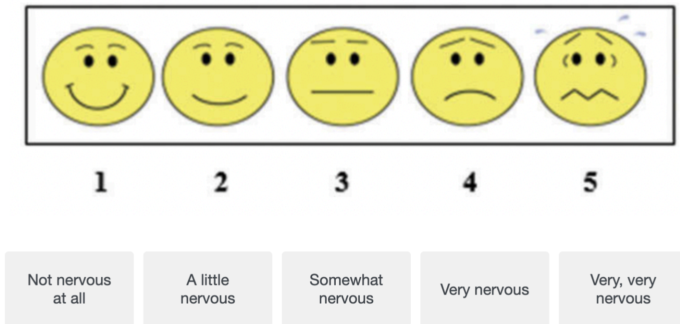


Table 3. *Reading Anxiety Questionnaire*

Children's Reading Anxiety Questionnaire (CRAQ; Ramirez et al., 2016)
1. How would you feel if you were asked to read these words? You don't have to read them, just tell me how you would feel. Raft trumpet cradle.
2. How do you feel when you are about to take a big test in your reading class?
3. How do you feel when you try to read a word you've never seen before?
4. How do you feel when you have to sit down and start your reading homework?
5. How would you feel if you were asked to read these words? Bug sheep bath.
6. How would you feel if you were asked to read this sentence? Dan's bus was coming.
7. How do you feel when seeing all the words in a storybook?
8. How do you feel when you are reading in class and don't understand something?
9. How would you feel if you were asked to spell the word **"cooked"**?
10. How do you feel when your teacher asks you to read out loud during class?

Note. The five-point Likert scale categories were 'not nervous at all', 'a little nervous', 'somewhat nervous', 'very nervous', and 'very, very nervous.

Reading Self-Concept. This survey is an adapted version of the Motivation to Read Profile – Revised (MRP-R; Malloy et al., 2013). The original MRP-R (Malloy et al., 2013) contained 20 items with two subscales that measured reading self-concept and reading value. To measure children's reading self-concept, the 10 items from reading self-concept subscale were used with modifications. Modifications included converting the four-point scale response options of the original scale into a Likert-type scale (e.g., my friends think I am ___ *a very good reader, a good reader, an OK reader, a poor reader* was changed to my friends think I am a good reader with a Likert-type scale ranging from strongly disagree to strongly agree; see Table 4).

Table 4. *Reading Self-Concept*

Adapted Motivation to Read Profile – Revised (Malloy et al., 2013)
1. My friends think I am a good reader.
2. When I come to a word I don't know, I can figure it out.
3. I read better than my friends.
4. When I am reading by myself, I understand everything I read.
5. I am a poor reader.*
6. I worry about what other kids think about my reading. *
7. When my teacher asks me a question about what I have read I always think of an answer.*
8. Reading is hard for me.*
9. When I am in a group talking about books I have read, I love to talk about my ideas.
10. When I read out loud, I am a good reader.

Note. The five-point Likert scale categories were 1=strongly disagree, 2=somewhat disagree', 3= neutral, 4=somewhat agree, 5=strongly agree. Items with * were reverse scored and thus a high reading self-concept score indicates the student feels good about their reading.

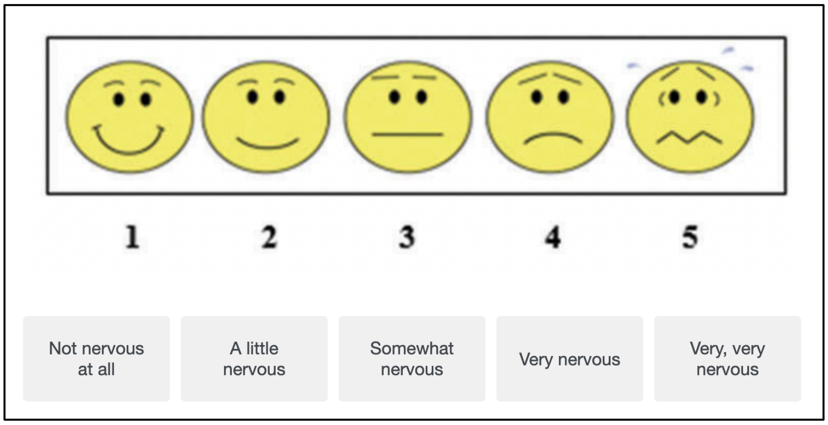
Math Anxiety. Children completed 9 items from the revised Children's Math Anxiety Questionnaire – CMAQ (Ramirez et al., 2016). In this questionnaire, children indicated how nervous they would feel in a math-related situation (see Table 5; e.g., How would you feel when you have to solve 34 – 17?). Children were required to select one of the five smiley faces that were displayed on an emotional gradient from 'not nervous at all' to 'very very nervous' on an iPad (see Figure 15). Due to an administration error, the reading anxiety scale was presented first in the Time 2 testing. Test reliability calculated using all 9 items was α = .88.

Table 5. *Math Anxiety*

Children's Math Anxiety Questionnaire – CMAQ (Ramirez et al., 2016)
1. How would you feel when you are in the arithmetic lesson and your teacher says you will learn something new?
2. Look at the clock. How would you feel if you were asked what time it will be in 20 minutes?
3. How would you feel if you had to sit down and start your math homework?
4. How do you feel when your teacher explains how to solve arithmetic problems?
5. How do you feel when you take a big test in the arithmetic lesson?
6. How do you feel when you take your arithmetic book and see all the numbers in it?
7. How do you feel when you are in the arithmetic lesson, and you don't understand something?
8. How do you feel when the teacher asks you to solve a calculation exercise on the blackboard?
9. How would you feel when you have to solve 34-17?

Note. The five-point Likert scale categories were 'not nervous at all', 'a little nervous', 'somewhat nervous', 'very nervous', and 'very, very nervous.

Figure 15. *Children's Math Anxiety Questionnaire Scale – CMAQ (Ramirez et al., 2016).*



Reading and Writing Skills

Subtests of the Woodcock-Johnson IV Achievement (Mather & Wendling, 2014) and Woodcock-Johnson IV Tests of Oral Language (Mather et al., 2014) were used to measure reading and writing skills that are essential to reading acquisition. The starting item was determined by the students' grade level. For many subtests, a basal and ceiling criterion was established to limit the number of testing items administered while allowing us to have an accurate estimate of the children' score if all items were administered. Basal levels for each student were established by recording the first six consecutive correct responses. For most subtests, testing was discontinued after the student made six consecutive incorrect answers. Timed tasks (i.e., sentence reading fluency and math facts fluency) were discontinued after three minutes. For most subtests, all items below the basal level were scored as 1 and students received 1 point for every correct response higher than the basal. For sentence reading fluency and math facts fluency, every correct response was scored as 1 and every incorrect response was scored as 0. Scores were the total number of correct responses.

Phonological Processing

Phonological processing measured a student's ability to understand and use the sounds within words and was measured using two subtests of the Woodcock-Johnson IV Tests of Oral Language (Mather et al., 2014) — *sound blending* and *segmentation*.

Sound Blending. This sub-test required children to synthesize sound (phonemes) to say a word. Two sample items of segmented words were administered orally to ensure the student understood the task (e.g., if you heard *da/ddy* then, the correct answer is *daddy*). Then, children listened to a series of phonemes presented through audio stimuli on an iPad and were required to blend the sounds to form a word (e.g., the student would hear f/i/sh in the audio and synthesize the word 'fish'). There were 33 items in this task. This test has a median reliability of .88 in the 5 to 19 age group (Mather et al., 2014).

Segmentation. Segmentation involved children breaking down a word into its syllables and phonemes (e.g., breaking down the word *forget* into its constituent syllables *for-get*). There were 37 items in this task. The initial 10 items required children to look at pictures of words to break them down into its components (e.g., looking at the pictures of a pan, a cake, and pancakes to figure out the correct word pancake). The next 10 items required children to break down a word into syllables after the experimenter had read the whole word orally (e.g., *recall* → re-call). The remaining items required children to break down a word into phonemes (e.g., blow → b/l/o). There were six sample items total. Two sample items were administered before each section to ensure the student understood the task. This test has a median reliability of .93 in the 5 to 19 age group (Mather et al., 2014).

Decoding

Word Attack. This sub-test of the Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014) measured student's ability to apply phonic and structural analysis skills to the pronunciation of unfamiliar words. Two sample items were administered before item 6 to ensure the student understood how to segment the word. The initial six items required children to look at pictures and point out the correct picture that begins with certain letters (e.g., the experimenter asked to point to the picture that begins with /k/ for cat). Remaining 26 items required students to read nonwords out loud (e.g., vack, jop, zent). This test has a median reliability of .93 in the 5 to 19 age group (Mather et al., 2014).

Letter-Word Identification. This sub-test from the Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014) measured a child's letter and word identification skills. Initial items required the children to point to correct individual letters on the stimuli page with printed bolded letters and images (e.g., I want you to point to *S*). Proceeding items involved showing children images of letters in different fonts and asking them to name letters out loud. As items increased in difficulty children were presented with rows of words. Most items required children to read words aloud of increasing difficulty in isolation. The words were presented in list form rather than in the context of a sentence (e.g., *at, and, no, man, she, cup, fish)*. The student was not required to understand the meaning of the items. This task has a median reliability of .92 in the 5 to 19 age range (Mather & Wendling, 2014). There were 78 items and no sample items.

Fluency

Sentence Reading Fluency. This sub-test from the Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014) measures the rate at which students read simple sentences. Within a three-minute time limit, children were asked to silently read a series of simple sentences and indicate if they are true, or false by circling 'Y' for yes or 'N' in the Response Booklet. The difficulty of these sentences increased with each item (e.g., from "An apple is blue", to more difficult sentences like "Drivers never get tickets when they go over the speed limit"). Overall, there were 110 items. Sentence reading fluency has a test-retest reliability of .97 in the 7 to 11 age group (Mather & Wendling, 2014).

Spelling

This sub-test of the Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014) measured children's ability to write orally presented words correctly. Items included (a) measured prewriting skills such as drawing lines and tracing letters; (b) required children to produce upper and lowercase letters; and (c) measured the child's ability to spell words correctly. Initial items involve showing or asking children to draw simple lines or copy letters (e.g., draw a line like I did and stay on the road). Most items required children to spell dictated words of increasing difficulty. There were 60 items total and no sample items. This sub-test has a median reliability of .91 in the 5 to 19 age group (Mather & Wendling, 2014).

Comprehension

Passage Comprehension. This sub-test of the Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014) measures student's understanding of written text. Specifically, it measures children's ability to use syntactic and semantic cues to identify a missing word (reading-writing ability). The initial 10 items measured symbolic learning which is the ability to match the printed word of an object with the actual picture of the object (e.g., matching the word 'cat' to a picture of a cat). The following 42 items required children to match a short phrase to the appropriate picture when given three answer options. Most items required the student to respond with an appropriate missing keyword in the blank space of the presented sentence or passage (e.g., a bird has two ____). Passages and sentences were presented in an order to measure children's speed of solving simple addition, subtraction, multiplication, and division facts. Items were presented with increasing difficulty (i.e., initial items involved solving addition and subtraction facts and later items involved solving multiplication and division facts). This test measures both quantitative knowledge and cognitive processing speed. Within a three-minute time limit, children were required to provide the answer to a series of simple math facts (e.g., 2 + 4). This task has a test-retest reliability of .95 in the 7 to 11 age range (Mather & Wendling, 2014).

Mathematical Skills

Applied Problems. This sub-test from the Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014) measured a student's ability to analyze and solve math problems. Initial 19 items required an application of simple number concepts. Subsequent 37 items required children to listen to the problem, identify the mathematical procedure that must be followed, and perform the appropriate calculations (e.g., If the probability of rain tomorrow is 2/5, then what is the probability of no rain?). Items increased in difficulty and included extraneous information allowing children to decide between appropriate mathematical operations and which numbers should be included in the response. There were 56 items total. This task has a median reliability of .91 in the 5 to 19 age range (Mather & Wendling, 2014).

Number Line Estimation. In the Estimation Line App (Hume, 2014), children estimated the position of a target number on a 0-1000 number line shown on an iPad (See Figure 16). It was designed to test children's estimation skills by having them position a target number on a number line. The app is based on an experimental method used to study numerical estimation in children and saves results to CSV files for later analysis. Before beginning the task, children had three practice trials (the first trial was demonstrated by the experimenter) where children were required to tap a green target on the number line for calibration. Then, children pressed the go button to start. Subsequently, in each trial, the target digit was displayed above the number line. The child was required to tap the location on the number line where they think the target number belongs. A red vertical mark was displayed to show their estimate. During the practice trials, children were asked to place the numbers 100, 400, 900 on the number line. There are a total of 24 experimental trials. Scoring was based on the percent absolute error (PAE) between the placement of each number compared to the actual location of that number. The time limit for each trial was 30 seconds. Task reliability is based on PAE for all 24 trials ($\alpha = .93$).

Figure 16. *Number Line Estimation App*

(a) Calibration trial	(b) Example Number Trial
	

Appendix B. Survey Questions

Table 6. *Neuralign© Star Game Rating Survey*

Open Ended Questions:
16. Did you enjoy doing the Neuralign© program? 17. What did you like the best about the program? 18. What did you like the least about the program? 19. Did you like that it was on a computer? 20. What part of the sessions did you like the most? Why? 21. How can we make the program better? 22. Do you think your reading improved after using the program? 23. Is there anything else you would like to tell us about the program?

Note. Children were shown pictures of each game of the 15 games and asked to rate them on the five-point star scale 1 = 'don't like very much', 2 = 'don't like', 3 = 'neither like nor dislike', 4 = 'like', and 5 = 'like very much.'

Table 7. *Neuralign© Post Intervention Parent Survey*

Please tell us about your experiences with the ReadLS/Neuralign© intervention:

1. Please rate your agreement with the following statements:
   (a) My child benefitted from the ReadLS/Neuralign© program.
   (b) I would recommend the ReadLS/Neuralign© program to other parents and children.
   (c) The video game format kept my child engaged during the program.
   (d) My child feels more positive about reading now
2. What parts of the ReadLS/Neuralign© program did you find beneficial to your child? Select all that apply:
   (a) The Cognitive Games (first three weeks)
   (b) Reading Fluency/Speed Reading
   (c) Reading comprehension games
   (d) Not sure
3. Overall, did the ReadLS/Neuralign© program have an impact on your child's attitudes towards reading? (Yes, Maybe, No)
4. Please describe how the ReadLS/Neuralign© program impacted your child's attitude toward reading.
5. Overall, did the ReadLS/Neuralign© program have an impact on your child's reading skills? (Yes, Maybe, No)
6. Please explain how the ReadLS/Neuralign© program impacted your child's reading skills.
7. Please add any additional comments you would like to share about the reading program.
8. Did your child receive extra reading support at school this year? (Yes, No)
9. Did your child use a specific reading program (e.g., Empower)? (Yes, No,
10. Did your child receive extra reading support outside school? (Yes. Please specify, not sure, No)
11. How often did your child receive the support? (Daily, 2-3 times/week, 1/week, Other)
12. How long were the sessions? (30 minutes, 1 hour, 1.5 hours, Other)
13. Did your child receive extra reading support outside of school? (Yes, No)
14. Was a specific program being used (e.g., Empower)? (Yes. Please specify, not sure. No)
15. Did your child get other kinds of support at school (Yes. Please describe, not sure, No).
16. Did your child get other kinds of support outside of school? (Yes. Please describe, not sure, No).

17. Please indicate any changes you have seen in your child's reading and attention since we first tested your child:
    (a) Reading words they have never seen before
    (b) Reading aloud
    (c) Spelling
    (d) Sound out words
    (e) Understanding what they are reading.
    (f) Attentional Skills
    (g) Time spent focussing on task
    (h) Enjoyment while reading
    (i) Time spent reading for pleasure
18. Please rate your child's skills compared to other children in their class.
    (a) Reading skills
    (b) Writing skills
    (c) Math Skills
    (d) Attentional Skills
19. Please rate your level of agreement with the following statements:
    (a) My child has anxiety about math.
    (b) My child has anxiety about reading.
    (c) My child has anxiety about writing.
    (d) My child is an anxious person.
20. Please tell us about your child's feelings about math and literacy.
    (a) My child finds math enjoyable.
    (b) My child finds reading enjoyable.
    (c) My child avoids situations involving math.
    (d) My child avoids situations involving reading.
21. On average, how many minutes per day does your child spend on homework in the following subjects? (English Reading, French Reading, Spelling, Writing, Math, Science).
22. On average, how many minutes per day do you help your child with homework in the following areas? (Reading, Spelling, Writing, Math, Science).
23. Please rate how anxious you feel when helping your child with homework? (Homework in general, arithmetic homework, fraction homework, math problem-solving homework, spelling homework, reading homework, writing homework).
24. In a typical week, how many times do you or other members of your household listen to your child read aloud? (At bedtime, other times).
25. Please tell us about your child's reading skills
    (a) My child is a good reader.

(b) My child reads quickly and easily.
(c) My child is a good speller.
(d) My child finds it hard to read new words.
(e) My child finds it difficult to read aloud.

26. Please rate how true these statements are about your child:
    (a) Has difficulty concentrating.
    (b) Needs supervision.
    (c) Avoids mental effort.
    (d) Makes carless mistakes.
    (e) Has arithmetic problems.
    (f) Has sloppy handwriting
    (g) Fails to finish.
    (h) Is forgetful

Note. Questions 4 and 6 are open-ended.

References

Alt, M., Fox, A., Levy, R., Hogan, T. P., Cowan, N., & Gray, S. (2022). Phonological working memory and central executive function differ in children with typical development and dyslexia. *Dyslexia*, *28*(1), 20–39. https://doi.org/10.1002/dys.1699

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders*. American Psychiatric Association. https://doi.org/10.1176/appi.books.9780890425596

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest*, *19*(1), 5–51. https://doi.org/10.1177/1529100618772271

Douglas, H., Lefevre, J., & Bourque, T. (2022). *Client Survey: Parents Share their Children' s Experiences of the Neuralign Intervention student's overall experience* (Issue November).

Galuschka, K., Ise, E., Krick, K., & Schulte-Körne, G. (2014). Effectiveness of treatment approaches for children and adolescents with reading disabilities: A meta-analysis of randomized controlled trials. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0089900

Hasselbring, T. S., & Goin, L. I. (2004). Literacy instruction for older struggling readers: What is the role of technology? *Reading and Writing Quarterly*, *20*(2), 123–144. https://doi.org/10.1080/10573560490262073

Hulme, C., & Snowling, M. J. (2013). Learning to Read: What We Know and What We Need to Understand Better. *Child Development Perspectives*, *7*(1), 1–5. https://doi.org/10.1111/cdep.12005

Hume, S., & Hume, T. (2014). *Number Line Estimation app.*

Malloy, J. A., Marinak, B. A., Gambrell, L. B., & Mazzoni, S. A. (2013). *ASSESSING MOTIVATION TO READ: The Motivation to Read Profile–Revised*. *67*(4), 273–282. https://doi.org/10.1002/TRTR,1215

Mather, N., & Wendling, B. J. (2014). *Tests of Achievement Examiner's Manual Standard & Extended Batteries*. www.riversideinsights.com

Mather, N., Wendling, B. J., & Iv, W.-J. ®. (2014). *Tests of Oral Language Examiner's Manual*. www.wj-iv.com

McArthur, G. M., & Hogben, J. H. (2012). Poor Auditory Task Scores in Children With Specific Reading and Language Difficulties: Some Poor Scores Are More Equal Than Others. *Scientific Studies of Reading*, *16*(1), 63–89. https://doi.org/10.1080/10888438.2010.542526

Moats, L. (2007). Whole-Language High Jinks: How to Tell When "Scientifically-Based Reading Instruction" Isn't. In *Thomas B. Fordham Institute*. Thomas B. Fordham Institute.

Moll, K., Snowling, M. J., & Hulme, C. (2020). Introduction to the Special Issue "Comorbidities between Reading Disorders and Other Developmental Disorders." *Scientific Studies of Reading*, *24*(1), 1–6. https://doi.org/10.1080/10888438.2019.1702045

Ontario Human Rights Commission. (2022). *Executive Summary Right to Read: Public inquiry into human rights issues affecting students with reading disabilities man Rights Commission*. www.ohrc.on.ca

Pasqualotto, A., & Venuti, P. (2020). A Multifactorial Model of Dyslexia: Evidence from Executive Functions and Phonological-based Treatments. *Learning Disabilities Research & Practice*, *35*(3), 150–164. https://doi.org/10.1111/ldrp.12228

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. *Cognition*, *101*(2), 385–413. https://doi.org/10.1016/j.cognition.2006.04.008

Peters, L., & Ansari, D. (2019a). Are specific learning disorders truly specific, and are they disorders? *Trends in Neuroscience and Education*, *17*. https://doi.org/10.1016/j.tine.2019.100115

Peters, L., & Ansari, D. (2019b). Are specific learning disorders truly specific, and are they disorders? *Trends in Neuroscience and Education*, *17*(July). https://doi.org/10.1016/j.tine.2019.100115

Quinn, J. M., & Org, J. (2018). Differential identification of females and males with reading difficulties: A meta-analysis. *Read Writ*, *31*, 1039–1061. https://doi.org/10.1007/s11145

Ramirez, G., Chang, H., Maloney, E. A., Levine, S. C., & Beilock, S. L. (2016). On the relationship between math anxiety and math achievement in early elementary school: The role of problem solving strategies. *Journal of Experimental Child Psychology*, *141*, 83–100. https://doi.org/10.1016/j.jecp.2015.07.014

Rayner, K., Foorman, B. R., Perfetti, C. A., Pesetsky, D., & Seidenberg, M. S. (2001). How psychological science informs the teaching of reading. *Psychological Science in the Public Interest*, *2*(2), 31–74. https://doi.org/10.1111/1529-1006.00004

Sala, G., & Gobet, F. (2020). Working memory training in typically developing children: A multilevel meta-analysis. *Psychonomic Bulletin and Review*, *27*(3), 423–434. https://doi.org/10.3758/s13423-019-01681-y

Sella, F., Raz, G., & Kadosh, R. C. (1970). *When randomisation is not good enough: Matching groups in intervention studies*. https://doi.org/10.3758/s13423-021-01970-5/Published

Snowling, M. J., Hulme, C., & Nation, K. (2020). Defining and understanding dyslexia: past, present and future. *Oxford Review of Education*, *46*(4), 501–513. https://doi.org/10.1037/dev0000265

Spencer, M., Wagner, R. K., Schatschneider, C., Quinn, J. M., Lopez, D., & Petscher, Y. (2014). Incorporating RTI in a hybrid model of reading disability. *Learning Disability Quarterly*, *37*(3), 161–171. https://doi.org/10.1177/0731948714530967

Wechsler, D. (2014). WISC-V: Technical and Interpretive manual. *NCS Pearson, Incorporated*

Yuzaidey, M., Din, N. C., Ahmad, M., Ibrahim, N., Razak, R. A., & Harun, D. (2018). Interventions for children with dyslexia: A review on current intervention methods. *Medical Journal of Malaysia*, *73*(5), 311–320.