Impact of a Multi-factor Digital Intervention on the Reading and Affect Skills of Children with Reading Difficulties

by

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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Master of Arts

In

Psychology

Carleton University

Ottawa, Ontario

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Abstract

Learning to read is a basic human right. However, not all children learn to read successfully. Thus, early diagnosis and targeted interventions are crucial for the 5 to 10% of children who have reading difficulties despite receiving adequate instruction. The focus of this thesis was to test whether participation in a 13-week computerized game-based reading intervention, Neuralign©, resulted in improvements in reading skills and affect for children in Grades 2 to 8 with reading difficulties or other challenges. Children were randomly assigned to be in the Neuralign© or waitlist group. Analyses of reading outcomes and reading affect after the intervention were conducted using multiple regression, controlling for pretest performance and cognitive skills. Results showed no evidence that Neuralign© influenced children’s post-test scores on reading or affect skills. The current study adds to the literature about computer-based reading interventions by testing Neuralign© and provided useful direction for development of the intervention.
Acknowledgments

I would like to take this opportunity to thank those without whom this project would not have been possible. First, I would like to thank my supervisor, Dr. Jo-Anne LeFevre, and my principal investigator, Dr. Heather Douglas, for their consistent support throughout the completion of this project. Their patience, insight, attention to detail, and support enabled me to step out of my comfort zone and accomplish more than what I expected. I feel truly grateful and honoured for having the opportunity of being a mentee under Dr. LeFevre and Dr. Douglas. I am positive that the skills they have taught me will benefit me in my career in the future. Thank you.

Second, I would like to extend my heartfelt gratitude to my committee members, Dr. Monique Sénéchal and Dr. Michael Rodgers, who provided me with constructive advice regarding my thesis which enabled me to dive deeper into my thesis topic and improve on it.

Further, I would like to thank my colleagues who supported during data collection and article discussions namely, Taeko Bourque, Lara Russo, Camryn Webb, Mikayla Perrier, Haily Rioux, Tru Gamble, and Isa Godoy. Of course, I would like to extend a special thank you to parents, teachers, and children who agreed to be a part of this study.

Finally, I would like to thank my family and friends for their consistent support and my high school teacher Ms. Manu Tandon for instilling a love for psychology in me.
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Introduction

From birth, children are exposed to spoken language through their interactions with other people and their everyday activities. Learning spoken language does not require direct instruction because it develops naturally (Rayner et al., 2016). In contrast, reading is not a naturally occurring skill because it must be built through instruction and practice over many years (Castles et al., 2018; Rayner et al., 2016). Despite receiving adequate instruction, 5 to 10% of children struggle to acquire age-appropriate reading skills (Ontario Human Rights Commission, 2022). These children may experience long-term negative consequences, including increased risk for school dropout, attempted suicide, incarceration, anxiety, depression, and low-self-concept (McArthur & Castles, 2017). Thus, early diagnosis and targeted interventions are crucial for these children who are struggling to read (Ontario Human Rights Commission, 2022).

Most children who are reading below grade level have a range of difficulties. Therefore, interventions for improving children’ reading outcomes in upper elementary grades typically involve a multicomponent approach that includes decoding, fluency, vocabulary, and comprehension (Vaughn et al., 2022). Moreover, after reviewing technology-based intervention research from 2010 to 2020, Alqahtani (2020) concluded that effective traditional reading instruction can be enhanced through technology. The goal of this thesis was to evaluate the efficacy of a multi-factor digital intervention, Neuralign©, for enhancing the reading skills of children with reading difficulties. In this introduction, I first review how children learn to read and the components of reading skills. This review is structured according to the consensus in the science of reading, which is the accumulated knowledge about reading, reading development, and practices for reading instruction determined by scientific methods of investigation (Petscher et al., 2020). Next, I provide an overview of reading difficulties and describe the features of intervention programs that can alleviate these difficulties. Finally, I discuss the Neuralign© program and describe the intervention study.

How do Children Learn to Read?

The goal of learning to read is accessing the meaning of text. Skilled readers direct their cognitive resources at meaning-making goals of reading which allows them to recognize words in isolation quickly, accurately, and effortlessly (Metsala & David, 2022).
The Simple View of Reading

According to the Simple View of Reading (see Figure 1), reading comprehension is mostly dependent on the product of two cognitive capacities: word identification (decoding) and language (listening) comprehension. Hence, neither decoding nor language comprehension alone is sufficient for reading comprehension (Gough & Tunmer, 1986). For example, a child who decodes written text without comprehension is not reading. Similarly, regardless of a child’s language comprehension level, they will not be a successful reader without being able to decode.

In a longitudinal study, Hjetland et al. (2019) found that almost all of the variability (99.7%) in reading comprehension skills for children at age 7 could be explained by language comprehension and decoding. Because decoding is necessary for comprehension, according to the Simple View of Reading, decoding is the key bottleneck in learning to read. The Simple View of Reading is an evidence-based, overarching perspective that provides an effective framework for conceptualizing reading development over time (Petscher et al., 2020). Further, it highlights components that are essential to provide instructional support for reading. Therefore, I chose to frame my research according to the Simple View of Reading.

Figure 1. The Simple View of Reading

Developing Alphabetic Decoding Skills

To decode, children must learn to map the phonology (sound) to the orthography (letters) to retrieve word meanings (Gough & Tunmer, 1986; Rayner et al., 2016). In alphabetic systems like English, phonemes are represented by individual letters or groups of letters called graphemes (e.g., b → /b/, ph → /f/). Because alphabetic languages vary in how closely orthography connects to phonology, the language in which children learn to read influences the difficulty of that learning (Aro, 2013; Castles et al., 2018). For example, English has numerous inconsistent relations between sounds and letter patterns and so decoding is complex (e.g., consider the pronunciations of cough, tough, and through).

Age four to seven years is a critical window of opportunity for teaching children foundational word reading skills and oral language skills in preschool and primary school are
closely correlated with later reading comprehension (Castles et al., 2018, Ontario Human Rights Commission, 2022). However, decoding alone is insufficient for skilled word reading. For example, reading even simple sentences requires that readers engage in complex mental operations such as identifying individual words, activating the meaning of those words appropriate for context, making casual connections and inferences, and integrating background knowledge by engaging executive skills like working memory (Perfetti & Stafura, 2014). Therefore, learning phonology-orthography mappings is a necessary critical starting point to reading acquisition (Castles et al., 2018) but insufficient for becoming a skilled reader.

**Developing Fluent Word Recognition**

Lexical quality is defined as the degree to which a stored mental representation of a word specifies its form and meaning in a way that is both precise and flexible (Perfetti, 2007). Importantly, frequently occurring words are high in lexical quality and recognized and processed automatically with little effort. Reading fluency elements comprise the accuracy, prosody (rhythm), and speed of oral text reading (Hudson et al., 2005, Metsala & David, 2022). When children learn to decode automatically, they will read fluently because words can be directly and effortlessly retrieved from the orthographic lexicon (i.e., the mental dictionary; Verhoeven & Perfetti, 2022). Through repeated exposure, children develop an efficient word-recognition mechanism that supports reading for meaning (Castles et al., 2018). Therefore, fluent reading comes from practice and feedback.

Late elementary school (i.e., Grade 4 and 5) is a critical developmental stage for reading because children are expected to have mastered early reading skills and they are expected to engage in reading activities that are more demanding than those completed in earlier grades (e.g., reading lengthy prose and identifying themes across texts; Meece & Miller, 1999). Morphology is acquiring links between spelling and meaning. Skilled reading requires knowledge of how morphology underpins the mapping between spelling and meaning (e.g., magic, magical, and magician or darkness comprises constituents {dark} + {ness}; Castles et al., 2018). Hence, if a reader does not develop automaticity, decoding will be a laborious task and cognitive capacities such as attention and working memory will be less available to draw meaning from text (Charalambous, 2022). The next section highlights essential components for successful reading development of children (i.e., both average and struggling readers) as outlined by evidence-based findings in the science of reading.
Components of Reading Skill

The literature on reading development is clear on the cognitive processes that support reading acquisition. Cognitive precursors of reading are skills that are functionally related to reading and whose developments starts prior to reading (Landerl et al., 2022). The following section divides essential skills required for reading acquisition into components in line with the Simple View of Reading (Gough & Tunmer, 1986). Phonological processes, naming speed, fluency, comprehension, and affective factors will be highlighted because the Neuralign© intervention aims to improve these skills in struggling readers.

**Phonological Processes**

Phonological processes encompass language-related sound perception (i.e., phonics, phonological awareness, and phonological working memory).

**Phonological awareness.** Phonological awareness is the ability to perceive and manipulate the sounds of spoken words (Konza, 2011; Melby-Lervåg et al., 2012). Accumulated evidence shows that phonological awareness is a fundamental predictor of reading and writing development (Melby-Lervåg et al., 2012; Pasqualotto & Venuti, 2020) and earlier training of phonological awareness can improve children’s reading outcomes (Melby-Lervåg et al., 2012; Suggate, 2016). English is an alphabetic language which means that letters in English represent the sounds of the language rather than the meaning and therefore, readers must develop the ability to map written symbols onto oral language representations (Duff et al., 2012). Consistent with Ehri et al. (2001), phonological awareness interventions are defined as those that increase children’s awareness of sounds at the word level (e.g., dig, dug, dog; Suggate, 2016).

**Phonemic awareness.** Phonological awareness is a broader concept than phonemic awareness because it involves auditory and oral manipulation of sounds in words whereas phonemic awareness is limited to the ability to understand the relationship between letters that represent the sounds in spoken words (Milankov et al., 2021). Phonemic awareness is defined as the ability to perceive the separate phonemes that make up words (Konza, 2011). Phonemic awareness interventions target awareness of the sounds (i.e., phonemes) composing words (e.g., cat /k/a/t/). Notably, effective interventions for children with dyslexia are phonologically based, involving training in phoneme awareness and letter knowledge combined with structured reading practice (McArthur et al., 2012).
**Phonics.** Phonics refers to the relation between the smallest units of sound called phonemes and the smallest units of writing called graphemes. Therefore, phonics interventions involve print and are focused on helping children link associations between phonemes and orthography (Suggate, 2016). In a meta-analysis of 38 experiments, Ehri et al. (2001) found that systematic phonics instruction had an overall statistically significant moderate effect ($d = 0.41$) on reading. Further, effects were larger when instruction began early ($d = 0.55$) than after first grade ($d = 0.27$), suggesting that phonics instruction is important during children’s initial stages of learning. In a review, Shanahan (2021) concluded that phonics instruction should be central to whole class instruction because it helps both average and struggling readers acquire foundational reading acquisition skills. Overall, systematic phonics instruction encourages children’s insight into the alphabetic principle by combining phonological awareness training with teaching grapheme-phoneme correspondence which is the basis for reading larger units such as words or syllables.

To develop skilled reading, children must explicitly learn how sounds in words work (i.e., phonemic awareness) and then, how those sounds connect to the letters in print (i.e., phonics). In sum, intervention approaches that involve training phonological awareness and letter-sound relationships are an effective intervention method for majority of the children with reading difficulties (Duff et al., 2012; Torgesen, 2005). However, although phonological processes are key predictors of reading, not all reading difficulties are caused by phonological processing problems because reading involves more than just decoding.

**Phonological Working Memory.** Executive functions like working memory, cognitive flexibility, and inhibitory control play a role in reading (Miyake & Friedman, 2012). Working memory is the capacity for retaining a limited amount of information in an accessible form allowing it to be used or manipulated to carry out cognitive tasks (Baddeley, 2003). A meta-analysis by Peng et al., (2018) found that working memory indirectly supports reading comprehension when controlling for decoding and vocabulary abilities. Working memory is important for reading at all levels, from decoding to reading comprehension (Christopher et al., 2012; Seigneuric & Ehrlich, 2005). Overall, working memory underpins important academic functions including reading.

Researchers have shown that working memory is impaired in some children with dyslexia (Peng et al., 2018). For example, some children with dyslexia have poor verbal or phonological
working memory (Alloway et al., 2017), and/or poor visual-spatial working memory, and have difficulty binding visual and phonological information (Litt & Nation, 2014; Toffalini et al., 2018). Alt et al. (2022) highlighted the need for researchers to focus on both phonological aspects of working memory and central executive function in children with dyslexia. In previous studies, researchers have suggested that working memory training may be beneficial for improving reading abilities in dyslexic individuals. However, training working memory and reading simultaneously results in better transfer to reading than training working memory alone (Pasqualotto & Venuti, 2020; Peijnenborgh et al., 2016). Overall, some interventions have focussed on working memory skills because of its central role to reading but the research about reading interventions that train working memory are insufficient. Therefore, research is required on whether training executive functions like working memory alongside other core reading skills will support improved reading.

Rapid Autonomized Naming (RAN). Naming speed, measured with RAN tasks, is the ability to name visual information quickly and effortlessly. RAN is assumed to be strongly related to reading fluency (Kirby, 2010; Landerl et al., 2022). RAN indicates the speed with which readers can accesses the verbal units represented by sequences of visual symbols and is typically measured by asking people to name sequentially presented digits, letters, or quantities. For example, letter and digit RAN tasks are closely associated with reading because they require the fluent naming of graphic symbols required for reading (Landerl et al., 2022). A meta-analysis of 137 studies by Araujo et al. (2015) indicated moderate relation between RAN and reading performance ($r = .43$). In sum, RAN constitutes a separate precursor of reading development (Parrila et al., 2004) and is a universal and unidirectional precursor of reading with only minor differences between orthographies (Landerl et al., 2022).

Fluency. Fluency is a critical factor necessary for reading comprehension (Cunningham & Stanovich, 1997; National Reading Panel, 2000). Fast and accurate word reading facilitates reading comprehension because it makes space for a reader’s cognitive resources (e.g., working memory) to focus on meaning (Perfetti, 1980). Hence, fluency interventions target this ability to read with speed and fluency (Therrin, 2004) and generally include repeated reading, tutoring, or peer-reading activities (Fuchs & Fuchs, 2005).

Repeated reading, that is, successively reading the same text, results in improved reading fluency (Stevens et al., 2017), in turn, building readers’ lexical knowledge of the exact spelling
of the word and freeing cognitive resources for comprehension (Castles et al., 2018). Further, meta-analyses show that non-repetitive reading (i.e., successively reading different texts) is a feasible alternative to repeated reading interventions for improving reading fluency (Zimmermann et al., 2021). In a meta-analysis by Morgan et al. (2012), interventions that provided vocabulary definitions, listening passage preview, goal setting, performance feedback, repeated practice, and peer tutoring showed promise for increasing children’ reading fluency. However, more research is needed to understand how to best combine decoding and fluency for interventions targeting children with reading difficulties.

**Comprehension**

Turning to interventions with less focus on phoneme and text level decoding, reading comprehension interventions provide specific procedures that guide children to become aware of how well they are understanding meaning (comprehending) as they attempt to read (National Reading Panel, 2000; Suggate, 2016). Typical activities in reading comprehension interventions, involve reflection, prior knowledge, question generation, pictorial cues, identifying themes, inferential thinking, summarization, and story structure (Suggate 2010, Shanahan, 2021) and these features are shown to relate positively to intervention outcomes (National Reading Panel, 2000).

**Affective Factors Related to Reading Acquisition**

Increasing attention has been given to socio-emotional dimensions such as motivation and emotions associated with reading outcomes because these dimensions are important in children’ literacy development (Barber & Klauda, 2020; Jalongo & Hirsh, 2010; Toste et al., 2020). Overall, affective factors (i.e., motivation, self-efficacy, reading anxiety, reading self-concept) are correlates of reading (Guthrie et al., 1999; Macdonald et al., 2021; Pollack et al., 2021; Ramirez et al., 2019) that are important to consider for children’ struggling to read because they account for variability in reading beyond cognitive factors (Ramirez et al., 2019).

**Reading Anxiety.** Anxiety is reported as one of the most experienced emotions in academic settings (Pekrun et al., 2002). Reading anxiety, specifically, is defined as an acute fear or apprehension linked to situations that require reading (Ramirez et al., 2019). Reading anxiety is rooted in repeated negative emotional, cognitive, and physiological reactions related to reading (Jalongo & Hirsh, 2010; Piccolo et al., 2017) including perceived or actual critical reaction from others about one’s reading skills that may result in a reduction of reading motivation and
involvement (Jalongo & Hirsh, 2010). For children with reading anxiety, reading comprehension can be an intimidating process (Barber et al., 2022). Macdonald et al. (2021) found a small but statistically significant unique contribution of reading anxiety (2.3%) to reading comprehension. McArthur et al. (2022) found that children with reading difficulties do not have mental health problems prior to learning to read (Kempe et al., 2011), suggesting that such problems are a consequence of difficulty with learning to read.

Evidence for the association between poor reading and emotional problems such as anxiety fail to provide causal explanations for these associations because these conclusions are not supported by intervention studies (McArthur, 2022). McArthur (2022) proposed the Poor reading and anxiety (PRAX) causal model which hypothesizes that a circular chain of events, once trigged by poor reading, creates a cycle of negative casual influences that may impair children’s abilities to pay attention to reading instruction. In turn, the lack of attention to instruction slows their reading development. In sum, the PRAX model hypothesizes that poor reading may be linked to anxiety via reading self-concept and peer relations, whereas anxiety may be linked to poor reading via inattention. However, more training studies are required to compare the effects of training reading difficulties on anxiety-related issues and training anxiety-related problems on reading problems (McArthur, 2022).

In terms of remediation, interventions for children that teach them to attribute reading difficulties to factors under their control such as amount of effort and task difficulty may help struggling readers reduce reading anxiety, in turn, improving their academic achievement (Haimovitz & Dweck, 2017). Further, reading anxiety may be alleviated if the focus of intervention is placed on fostering a sense of pleasure about reading by structuring reading activities for success while incrementally increasing the level of challenge (Jalongo & Hirsh, 2010). Results from intervention studies suggest that combined reading and anxiety interventions may attenuate difficulties for children with poor reading (Francis et al., 2021; McArthur, 2022; Vaughn et al., 2022). Overall, more investigations into interventions targeting children’s reading skills and negative affect about reading are required because as students grow older, reading becomes an important skill across academic domains (Ramirez et al., 2019).

**Reading Self-Concept.** Reading self-concept is the overall perception of oneself as a reader (Conradi et al., 2014). The type of reading instruction children receive may influence the association between reading and self-concept. For example, Francis et al. (2021) found that
children who learned to read through word-level instruction had a higher reading self-concept compared to children using text-based approaches. Negative feedback from teachers, peers, and parents can lead children to form a negative self-concept (Boyes et al., 2016). McArthur et al., (2016) found that children who have reading and attentional problems were more likely than children without reading and attentional problems to report problems with poor reading self-concept. Importantly, children who show impairments in multiple areas (e.g., both auditory and attentional difficulties) are at more risk for low self-concept than children with single impairments (McArthur et al., 2016). Reading self-concept, particularly, is modulated by age and has been observed to decline after the first three years of instruction (Chapman & Tunmer, 1997).

**Summary.** Children who have difficulty learning to read have higher levels of anxiety and lower self-concept than average readers (Mugnaini et al., 2009; Snowling et al., 2007; Taylor et al., 2010). Negative socioemotional factors may be stronger predictors of children’ reading than positive factors compared to positive socioemotional factors such as self-efficacy and interest in reading, but the former have received limited attention (Chapman & Tunmer, 1995; Guthrie et al., 2013; Ramirez et al., 2019; Snowling et al., 2007; Taylor et al., 2010). Overall, there is growing but limited literature on negative socioemotional factors such as reading anxiety (Ramirez et al., 2019). Therefore, more research is needed to determine the effectiveness of reading interventions that target affective factors to support reading improvement for struggling readers.

**What are Reading Difficulties?**

Varying terms have been used to describe children that display low-level reading skills. Often, dyslexia and reading disability are used for more severe cases whereas terms like poor readers, reading problems, or reading struggles are used to describe less severe levels of low reading achievement (Quinn & Org, 2018). In this paper, I use the term reading difficulties to refer to the challenges experienced by a heterogeneous group of children (McArthur & Castles, 2017). I will also use the term dyslexia when the research that I am discussing used that term. 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).

**What is Dyslexia?**

Dyslexia is clinically defined as a reading disorder in which people have difficulties with
the phonological components of language that are required for decoding and spelling (American Psychiatric Association, 2013). These difficulties are unrelated to other cognitive abilities and the provision of effective classroom instruction. Dyslexia is assumed to be neurodevelopmental because it has an early onset, is heritable, and has life-long consequences (e.g., adversely impacts individual’s performance in academics; American Psychiatric Association, 2013; Snowling et al., 2020).

Although dyslexia is often assumed to be a disorder that is distinct from poor reading skills, the assessment criteria for a dyslexia diagnosis are based on scores derived from arbitrary criteria and thus, children falling below the cut-off are not qualitatively different from children above the cut-off (Peters & Ansari, 2019). Dyslexia co-occurs with other learning difficulties more often than expected by chance. Specifically, approximately 40% of children with dyslexia have one or more other disorders that affect their learning skills such as ADHD, anxiety, depression, dyscalculia, or language disorders (Moll et al., 2020; Peters & Ansari, 2019).

Addressing the nature and extent of children’s reading and other cognitive (e.g., attentional and working memory) difficulties is more critical than diagnosing children with dyslexia because these difficulties have emotional and academic consequences (Galuschka et al., 2014). People with reading and spelling difficulties typically show slow decoding skills, but they may also have weak cognitive skills such as difficulties with working memory, processing speed, visual attention (e.g., seeing print properly, tracking and focusing), and auditory processing (Alt et al., 2022; Galuschka et al., 2014; Lawton & Shelley-Tremblay, 2017; Rayner et al., 2001; Sala & Gobet, 2020; Snowling et al., 2020). In summary, not every student who struggles to read has dyslexia (Shanahan, 2021) but all struggling readers require intervention.

**Visual and Temporal Processing: Alternative Explanations for Reading Difficulties**

Phonological processing is a reliable and robust predictor of children’ future reading skills (Mann & Liberman, 1984; Wagner et al., 1997). However, phonological deficits do not fully account for the variance in reading and not all poor readers display phonological deficits (Lawton, 2016). The magnocellular hypothesis posits that dyslexia is characterized by poor temporal processing (i.e., impaired visual and auditory sequencing). Temporal processing occurs in the transient /magnocellular systems found throughout the brain (e.g., in the visual system, auditory system, cerebellum, hippocampus, and brainstem; Stein, 2019). The magnocellular theory posits that dyslexia stems from difficulties with the processing of auditory and visual
sequencing of the sounds in a word and visual sequencing of letters (Stein & Walsh, 1997). Successful sequencing depends on accurate timing of auditory and visual sensory inputs. The auditory transient system or the auditory magnocellular system mediates accurate sequencing of sounds in a word (Stein, 2019). Impaired development of magnocellular cells in dyslexics may cause commonly observed difficulties while reading such as impaired fixation stability, lack of smooth pursuit, poor serial search, and inaccurate saccades from word to word (Stein, 2018).

**Magnocellular and Parvocellular Cells.** The magnocellular cells and parvocellular cells work together to process information coming into the visual field. 10% of the ganglion cells in the retina are defined as magnocellular and the other 90% are parvocellular (Stein, 2019). These magnocellular cells are 50 times the size of the parvocellular cells and respond more rapidly to light transients (i.e., when light is turned on or off in their receptive field) than parvocellular cells (Kolb et al., 1992). Therefore, magnocellular cells are specialized for rapid temporal processing and play an essential role in detecting light changes, visual motion, for visual control of attention and eye movements (Stein, 2019). Lovegrove et al. (1980) and Hansen et al. (2001) found that parvocellular functioning among dyslexics was similar to that of readers in the control group, whereas magnocellular function was significantly impaired in dyslexics.

**Dorsal and Ventral Pathway.** Meta-analysis of 36 brain imaging studies shows that the neural basis for reading in alphabetic systems involves two pathways to compute meaning from text (Castles et al., 2018; Taylor et al., 2013). The first pathway is the dorsal or magnocellular pathway which underpins phonologically mediated reading (Taylor et al., 2013) and allows visual form discrimination (Lawton & Shelley-Tremblay, 2017). The second pathway is the ventral or parvocellular pathway which underpins direct access to meaning from print (Taylor et al., 2013) and allows for location and motion processing (Lawton & Shelley-Tremblay, 2017). Visual timing deficits from sluggish magnocellular neurons in the dorsal stream may be involved in reading deficits (Stein & Walsh, 1997). Problems with visual motion processing have been implicated as a factor in reduced functionality of attention networks in dyslexics, in turn, they may be involved in slower reading speed and poor comprehension in dyslexics (Lawton, 2016). Lawton and Shelley-Tremblay (2017) found some support for training of visual movement discrimination in remediating reading problems. Lawton (2011) found that there may be a link between reading speed performance and training on motion direction-discrimination which was
designed to maximally activate and improve the timing sensitivity of magnocellular neurons and dorsal stream function in both average and dyslexic readers.

**Summary:** There is disagreement about the role of visual processing in reading disorders. Vellutino et al. (2004) proposed that visual processing difficulties are not a cause of reading problems but a consequence. They also claimed that magnocellular systems are not related to reading difficulties that correlate between poor reading and the magnocellular systems but that these systems may be a biological marker of dyslexia. Further, Shovman & Ahissar (2006) concluded that the word reading difficulties in dyslexics is not caused because of visual processing deficit and thus, visual processing difficulties are not relevant for remediation programs because they are not a bottleneck in learning to read. Therefore, intervention studies for children with reading difficulties targeting the dorsal stream may be useful to clearly determine whether there is a causal link from dorsal stream functioning to reading skill (Kevan & Pammer, 2009) or whether sluggish dorsal stream functioning is a consequence of poor reading. However, remediation of reading difficulties will still need to primarily target phonological and lexical processing because these skills are proximal causes of reading performance (Shanahan, 2021).

**Reading Interventions**

Research into reading difficulties over the past three decades has led to the development of numerous reading intervention programs that target various skills (e.g., auditory, phonological, visual, or motor impairments; Charalambous, 2022). Some programs focus on a single skill, whereas others train multiple skills simultaneously (e.g., training executive functions and phonological processes; Alqahtani, 2020). Common interventions target phonemic awareness, reading fluency, working memory, and visual-attentional skills (Galuschka et al., 2014; Toffalini et al., 2021). Shanahan (2021) reviewed technology-based intervention research from 2010 to 2020 and concluded that teaching of phonemic awareness, phonics, text-reading fluency, reading comprehension strategies, and written language features, such as vocabulary or text structure, all support reading acquisition. He also concluded that learning gains from instruction including these components appears to be reasonably robust across learner types (i.e., average and struggling readers) and instructional settings. In sum, interventions training these skills may be beneficial for all children’ reading acquisition including those with reading difficulties.
Multi-Tiered Systems of Support for Instruction

The Institute of Education practice guide (Gersten et al., 2009) provides an overview of a system of instruction called Multi-Tiered Systems of Support (MTSS) that includes three levels of instructional support for elementary school children. **Tier 1** involves high-quality, whole-class, evidenced-based classroom instruction that should benefit most children. Most children will learn to read if they have adequate Tier 1 instruction and sufficient practice. However, 5% to 20% of children may continue to struggle after receiving Tier 1 instruction, in turn, requiring Tier 2 and/or Tier 3 instruction (Ontario Human Rights Commission, 2022). **Tier 2** support involves supplemental small-group additional instruction for those children who do not make adequate progress with whole-class instruction (Gersten et al., 2009). For children with reading difficulties, Tier 2 evidence-based interventions must explicitly target the foundational skills of sound-letter knowledge, phonemic awareness, decoding skills, word-reading accuracy, and fluency (Gersten et al., 2009, Goldfeld et al., 2022, Ontario Human Rights Commission, 2022).

**Tier 3** interventions are for children who continue to struggle despite Tier 2 interventions. Tier 3 interventions provide children with one-to-one support, scaffolded practice, and enough review to ensure mastery of reading skills (Ontario Human Rights Commission, 2022). Tier 3 interventions are built on instructional approaches offered by lower levels of the tier (i.e., Tier 1 and Tier 2) but have greater intensity, duration, and frequency (Fuchs & Fuchs, 2006).

In sum, MTSS is a preventive model for efficiently reducing the incidence of reading difficulties. The number of children requiring intensive Tier 3 support can dramatically be reduced following science-based effective Tier 1 classroom instruction, and further reduced following Tier 2 intervention (Lovett et al., 2017). Overall, regardless of the intervention tier, children must learn fundamental skills (i.e., letter-sound mappings) and then build on this knowledge to achieve fluency (Park & Mackey, 2022).

**Interventions Addressing Multiple Skills**

According to the multiple-deficit model of reading (Pennington, 2006), dyslexia can result from several risk factors, such as weaknesses in phonological awareness, rapid automatic naming, working memory, and/or verbal reasoning because a phonological deficit does not account for all the observed performance variability in individuals with dyslexia. Therefore, a multiple-deficit approach may provide a better model for studies (Boada et al., 2012). Addressing several skills simultaneously has been found to be an effective way to improve
reading (Fälth et al., 2013; Wolff, 2011), especially for older readers with reading difficulties. For example, Suggate (2010) found that phonics interventions appear to be advantageous only until Grade 1; subsequently, mixed comprehension interventions become more beneficial, at least through Grade 7. Thus, interventions for older children (beyond Grade 1) who have a history of reading difficulties must address multiple skills simultaneously to improve children’s reading skills. Therefore, in line with the assumptions of the multiple-deficit model for reading difficulties (Pennington, 2006) interventions addressing these core skills simultaneously may be beneficial for children with reading difficulties.

**Online Interventions**

Technological tools have the potential to efficiently support learning performance in children with reading difficulties because technology includes multiple activities that address different skills at the same time (Alqahtani, 2020; Jamshidifarsani et al., 2019). Research to provide support through technological tools is growing (Chauhan, 2017). However, the quality (i.e., how the instruction is delivered) of computer-based instruction varies widely by design and implementation of programs (Görgen et al., 2020). For example, ABRACADABRA (A Balanced Reading Approach for Children Always Designed to Achieve Best Results for All; shortened to ABRA) is a computer-based intervention including activities targeting primary school children’s literacy skills including phonics, phonemic awareness, fluency, and reading comprehension (Piquette et al., 2014). In a meta-analysis of 17 studies, Abrami et al. (2020) found an overall positive effect of the ABRA intervention with a significant weighted average of $g = 0.78$ for phonemic awareness. Therefore, integrating these skills with technology may be a promising avenue for children with reading difficulties (Alqahtani, 2020) because Tier 2 and 3 interventions may be the most efficient and accessible if they can be provided online for struggling readers.

**Game-Based Interventions**

Digital games designed for learning are known as ‘serious games’ and they aim to pair game features (e.g., rules, sensory stimuli, control, and challenge) with instructional content to motivate learning (Garris et al., 2002; Ronimus et al., 2019). So far, there is inconsistent evidence about the efficacy of serious games as learning tools. Research is required to determine the effectiveness of serious games for children who have learning difficulties (Ke & Abras, 2013).
Compared to offline reading games, online reading games provide training for more skills and deliver higher quality instruction for core reading skills such as grapheme-phoneme relations and phonological awareness (Wood et al., 2015). To make fluency and comprehension training more appealing for children with reading difficulties, innovative game elements such as challenges, rewards, and visible cues showing progress that are combined with learning content of reading approaches may be beneficial (Jamshidifarsani et al., 2019). Furthermore, integrating features such as adaptivity to student performance, immediate feedback, and reinforcement into the training may allow children to learn independently (Görgen et al., 2020). These features may be easier to implement in online (i.e., games that require internet access) than in offline games (i.e., games that require downloaded versions or CDs).

**Neuralign© Reading Intervention**

The following section describes the Neuralign© intervention. Neuralign© is an interactive structured, cumulative, and multisensory online intervention requiring a high level of independent effort by the student. Neuralign© can be considered a serious online game. The intervention was developed by Ingrid Poupart in Canada in 2018. Although originally designed for children with dyslexia, Neuralign© aims to improve reading for all struggling readers because it targets multiple skills that are impaired in children with reading difficulties including cognitive, phonological, visual, and attentional skills. The components of the Neuralign© intervention align with the multi-deficit theory of reading difficulties (Pennington, 2006) because the intervention simultaneously addresses multiple skills that are deficit in children with reading difficulties. Neuralign© is not intended solely for children who have a clinical diagnosis of dyslexia or a reading disability but is also assumed to support neurodiverse children who are below their age-appropriate reading level.

The components of the Neuralign© intervention are shown in Figure 2. The three components are a cognitive therapy (i.e., intensive computerized training), fluency practice, and reading exercises to improve comprehension. Neuralign© is for individuals above the age of five with reading difficulties. The full program consists of 13 weeks of targeted cognitive training and reading instruction. The first three weeks involve Cognitive Therapy and the last 10 weeks are Reading Practice which includes fluency practice exercises, reading comprehension exercises, and cognitive memory games. Children complete activities targeting cognitive skills,
phonological skills, and visual skills with the overall goal of improving all aspects of their reading skills (i.e., decoding, fluency, and comprehension).

**Figure 2. Neuralign© Intervention**

![Neuralign© Intervention Diagram](image)

**Initial Placement Assessment and Levels of Neuralign ©**

Before the intervention, an initial placement assessment is done to determine the difficulty level for each student (i.e., Junior, P1, P2, P3, P4) based on their current reading skill level. The first three questions are sample items after which children answer as many questions as they can out of the 43 multiple-choice questions within ten minutes. There are three to four answer options for each question (see Figure 3).

**Figure 3. Initial Assessment Placement in Neuralign©**

![Initial Assessment in Neuralign©](image)

Neuralign© is structured around a series of games. The games are named after countries, because every game has a background relevant to the name of the country. For example, Australia has an ocean theme symbolizing the Great Barrier Reef. Children in the Junior and P1 levels of Australia have both pictures and words as stimuli, but from the P2 level on the number of times the stimuli appears decreases making the level more challenging for the student. In contrast, the cognitive memory games (i.e., Pathfinder, Memory cards, Silly Machine, and
Colour Hopper) do not have varying levels. The initial assessment is intended to ensure that the difficulty level of the intervention is challenging enough to keep the student engaged, but not too difficult that the student is overwhelmed by the requirements of the intervention. The whole intervention is implemented online which allows monitoring of progress. A detailed explanation of the various games and the skills that they target is shown in Appendix A. Briefly, each game targets either a core reading skill (e.g., decoding and reading fluency), a cognitive skill (e.g., working memory) or comprehension building strategies (See Table 1).

**Table 1. Core Skills Targeted by the three Components of Neuralign©**

<table>
<thead>
<tr>
<th>Neuralign© Component</th>
<th>Cognitive Therapy</th>
<th>Fluency Practice</th>
<th>Reading Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Decoding</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working Memory</td>
<td>√</td>
<td></td>
<td>√</td>
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<tr>
<td>Phonological Processing</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Skills</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comprehension</td>
<td>√</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

*Note.* For a detailed breakdown of which skill is targeted by each game refer to Appendix A, B and C.

**Cognitive Therapy**

The Cognitive Therapy component of Neuralign© targets auditory and visual pathways, working memory, and executive function, as well as decoding and word reading. It is completed over three weeks in 15 one-hour sessions. Each session incrementally increases in difficulty by manipulating the content and graphics of the games. Moving graphics constantly change in direction, shape, density, velocity, and translucence, allowing the computer screen to display a range of visual sensory input against a stationary background. The fluency practice and reading comprehension exercises were designed to allow children to consolidate the skills targeted in the Cognitive Therapy component.
**Reading Practice**

The reading practice component of Neuralign© is divided into two parts, fluency practice and reading comprehension exercises. It is designed to require approximately 10 weeks to complete.

**Fluency Practice.** Fluency practice comprises short one-minute assessments of the children’s day-to-day reading during the intervention. Fluency practice begins after nine sessions (out of the 15) of the Cognitive Therapy component are complete and lasts for 10 weeks. Each day, children are required to read a story shown on the computer screen for one minute (shown by a timer on the screen). They click on the last word they have read when the timer chimes to indicate their progress each day. There are five sessions of fluency practice per week. Children read the same story for five sessions and every sixth session a new story is presented.

**Reading Comprehension.** These activities include 20-minute long reading practice exercises that target children’s reading comprehension skills. The reading exercises begin only after the entire Cognitive Therapy component of the program is complete. The reading comprehension exercise requires children to read a story and answer questions (see Appendix C, Figure 20). The reading exercises take 15 to 30 minutes per day over 10 weeks. Children read at their own pace and compete with their own scores from previous sessions. After all questions were answered in a session, children review the correct answers.

**Memory Exercises.** Children also play cognitive memory games before and after each reading comprehension exercise. The purpose of these games is to keep children motivated by providing instructional content in a game format.

**What are the Main Components of Neuralign© that May Support Reading Improvement?**

The core elements of reading include decoding, reading fluency, reading comprehension, and vocabulary; reading is also supported by various general cognitive processes such as visual processing, verbal working memory, and executive functions. Neuralign© provides children with practice in many skills that support reading development. For the purposes of this thesis, decoding, fluency, visual processing, auditory and visual processing of words and sounds, comprehension, and affective factors (i.e., reading self-concept and reading anxiety), are highlighted.
Decoding

Decoding is supported by Neuralign© in all cognitive therapy games (e.g., Egypt, Australia, and Holland; see Appendix A for more details). For example, in Egypt, the target word or sentence to be decoded must be held in working memory, in turn, training reading and working memory simultaneously which has shown to result in better transfer than training working memory alone (Pasqualotto & Venuti, 2020; Peijnenborgh et al., 2016). Then, the student must pick letters or words retrieved from rows of letters scrolling across the screen below. For example, ‘the ball hit the wall’ needs to be decoded amongst other moving words. In Australia, Neuralign© trains older students that were placed in levels beyond P2 to discriminate homophones by providing visual and auditory cues. Holland is a game based on phoneme manipulation tasks that are similar in concept to ‘Pig Latin’, where the onset of the word is separated from the rime and moved to the end of the word and the suffix is then added. For example, in Pig Latin /town/ becomes /onwta/. Some research has shown that Pig Latin is associated with strong phonological awareness because manipulating words requires high cognitive effort and targets the ability to manipulate sounds at the word level (Hester & Hodson, 2004).

Fluency

The Fluency Practice component of Neuralign© targets fluency by engaging children in repeated reading (for more details see Appendix B). Neuralign© provides performance feedback in the form of points and stars displayed on the screen after children complete the repeated reading practice. Past research indicates that repeated reading improves children’ reading fluency (Morgan et al., 2012). Children read the same story for a week within five sessions. Then, during the first session of the next week a new story is presented. Students can complete more than five sessions of fluency practice per week if they prefer. This repeated reading targets reader’s lexical knowledge of the exact spelling of the word (Castles et al., 2018; Stevens et al., 2017).

Visual Processing

Neuralign© was also designed to support the development of the dorsal or magnocellular pathway responsible for phonologically mediated reading and visual form discrimination to support the development of reading skills. This aspect of the program is based on the idea that dyslexic children have poor coordination between two pathways (i.e., dorsal-magnocellular and ventral-parvocellular) that send signals through the visual system (Castles et al., 2018; Taylor et
al., 2013). According to the magnocellular theory (Stein, 2019), for these networks to strengthen, the processing of auditory and visual input needs to be fluent enough so these sources of information work together to allow accurate and fast processing of phonological and orthographic functions. The Neuralign© intervention was intended to address impaired brain pathways in struggling readers by building decoding, fluency, and auditory processing skills. The visual effects are intended to target magnocellular processing in the dorsal stream by adaptively reducing the contrast needed for figure/ground discrimination of sinewave gratings moving left or right against a stationary background. This manipulation may be similar in rationale to the that used in a study conducted by Lawton (2011) which showed that by training children on motion direction-discrimination which improves dorsal stream function, children’s reading skills also improved.

**Combined Auditory and Visual Processing of Words and Sounds**

In games like Canada, Scotland, and China, children read letters, words, and sentences that are presented with corresponding aural cues (see Appendix A for more details). Auditory processing is targeted via elongated sound parcels composed of phonemes. For example, before the written word is presented, the children hear a word broken down into its components sounds such as c/a/t for cat. Words are acoustically modified with a ‘stretch’ to enable the struggling reader to hear the individual sounds that comprise the word. Letter-sound association games reinforce the association between grapheme and phonemes. For example, in Australia, letter sounds that are close in sound (e.g., /f/, /v/, and /th/) and those sounds that children with reading difficulties tend to confuse (e.g., /b/ instead of /d/) are presented in rhyming sets to help children practice and distinguish between these sounds.

In each game containing aural cues, after the aural cue of the word or sentence is presented, the visual cues of the moving stripes and the target word appeared in the moving background which potentially trains motion direction-discrimination. For example, in China the visual cue (e.g., letters of the word) are presented along a stationary background with moving stripes only after the target word is presented aurally. This intentional delayed timing between the aural and visual cue may allow more time for children to catch up with the word that needs to be decoded by targeting neural timing in the dorsal stream. Lawton (2011) found that there is a link between reading skills and training children on motion direction-discrimination by improving dorsal stream function.
Comprehension

In the reading comprehension component of Neuralign© children engaged in reading activities involving summarization, application of prior knowledge, highlighting key ideas, and inferential thinking by answering content-related questions. These strategies are shown to be beneficial instructional strategies for struggling readers (Suggate, 2010, Shanahan, 2021) and these features are shown to relate positively to intervention outcomes (National Reading Panel, 2000).

Affective Factors

Self-Concept. Neuralign© is also designed to improve children’s motivation to read and their self-concept regarding reading. It is presented as a game with timers and review exercises to keep the children engaged in learning. The intervention motivates children to persist at activities that they may otherwise find repetitive because it integrates novelty by placing tedious tasks in a game format (e.g., cartoon characters like panda, games with motion graphics, and embedded text). Furthermore, motivation is supported by the reward system incorporated into the game that provides positive feedback through bonus points and graphs to monitor progress. For example, children get points for each correct answer, and they get additional bonus points for every correct answer under five seconds. These elements may support game-based learning (Admiraal et al., 2011). Further, Neuralign© minimizes negative feedback, focusing on providing children with positive feedback by ensuring their points consistently increase as the progress through the intervention. Research shows that negative feedback from the children’s environment can lead to forming a negative self-concept (Boyes et al., 2016).

Reading Anxiety. Similarly, the bonus point system may alleviate reading anxiety by placing the focus of the intervention on fostering pleasure in reading by structuring reading activities for success while incrementally increasing the level of challenge (Jalongo & Hirsh, 2010).

Summary. Overall, the design of Neuralign© involves activities targeting specific student needs and provides consistent instructional support in skills outlined by the Simple View of Reading. Notably, the Neuralign© program also includes memory games during the reading exercises phase (e.g., Pathfinder) to provide a break from the reading exercises. These memory games are intended to keep children engaged but may also provide some training of visual working memory.
Current Study

The data I used in the current study was collected as part of a larger project, funded by MITACS, which focussed on the efficacy of the Neuralign© intervention on the reading skills of struggling readers. The company which created and promotes the Neuralign© intervention (originally called LSWorks, but now referred to as Neuralign©; https://lsworks.org/home) contributed money that was matched by MITACS to provide funding for interns to conduct research to evaluate whether the program is beneficial for children with reading difficulties and/or dyslexia. The project was led by Dr. Jo-Anne LeFevre at Carleton University. Funding was provided for a postdoctoral scholar (Dr. Heather Douglas) and two graduate student interns (myself and Taeko Bourque). Several undergraduate students were also involved in the project as part of the requirements for their honours thesis work. Testing of the students was done by myself, Dr. Douglas, and the undergraduates.

In this thesis, I compared the reading and affect skills of an intervention group to those of a waitlist control group using hierarchical regression models. I used regression, rather than pre-to post-test ANOVA designs because I wanted to control for covariates known to be related to reading. Studies have shown that children with reading difficulties can benefit from targeting numerous skills that support reading (Fälth et al., 2013; Ring & Black, 2018). On this assumption, the goal of the present study was to evaluate the efficacy of a multi-factor digital reading intervention, Neuralign©, on the reading skills of struggling readers. Thus, the results of this study extended current knowledge about technology-based treatment for children with reading difficulties by evaluating a novel reading intervention.

Hypothesis 1

I predicted that the Neuralign© intervention would explain a statistically significant amount of variance in the reading skills of children with reading difficulties and/ dyslexia after controlling for pretest cognitive and reading skills. The reading skills that were expected to improve included phonological processing skills (sound blending and segmentation), decoding (letter-word identification and pseudo-word reading), spelling, reading fluency, and passage comprehension.
Hypothesis 2

I predicted that the intervention would explain a statistically significant amount of variance in the affective skills (i.e., reading anxiety and reading self-concept), of children with reading difficulties and/ dyslexia after controlling for pretest affective and cognitive skills.

Method

Recruitment

All procedures including recruitment, testing, and obtaining parental consent and child assent were approved by Carleton University’s Research Ethics Board (CUREB-B). Children between grades 2 to 8 with reading difficulties were recruited from one learning centre and two private schools in Ottawa (i.e., Sites 1, 2, and 3). For the learning centre (Site 1), emails inviting parents to participate in the study were sent and advertisements about the study were posted on social media. In the two schools (Sites 2 and 3), all the children were invited to participate via emails sent by the school’s administration. Parents who expressed interest provided consent and completed an online background survey which took approximately 10 minutes.

Sample

At pretest, 58 children participated (33 boys, 23 girls, and two children who chose not to indicate their gender). At post-test, 50 children were tested again (27 boys, 21 girls, and two children who chose not to indicate their gender). Ages at pre-test ranged from 6.91 to 13.80 years ($M_{age} = 10.49$ years). Overall, forty-seven out of fifty parents filled out the survey. Most children (93.6%) spoke English as their first language, 4.3% spoke French, and one each spoke Russian and Hebrew (2.1%). Most parents had a university degree indicating that the sample contains children from a high socio-economic background. For the highest level of education, 8.5% ($n = 4$) had a doctoral degree, 12.8% ($n = 6$) had a master’s degree, 42.5% ($n = 20$) had a bachelor’s degree, 23.4% ($n = 11$) had a college diploma, 10.6% ($n = 5$) had some college or university level education but, with a degree/diploma, and 2.1% ($n = 1$) were high school graduates.

Overall, 57.4% ($n = 27$) of parents reported that their children had completed a psychoeducational assessment. The most common psychoeducational diagnoses were ADHD (38.2%), dyslexia and/ 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 42.6% of 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 (82.1%; \( n = 38 \)) had a formal diagnosis or suspected diagnosis contributing to difficulties in learning, and these difficulties were heterogenous; 17.9% \( (n = 9) \) of the children had no formal or suspected diagnoses. Overall, there were 31 children in the waitlist control group and 27 children in the Neuralign© intervention group. Eight children dropped out of the study before post-test at Time 2 (i.e., two in the waitlist group, five in the intervention group and one student who dropped out before pretesting).

**Site 1**

Site 1 is a learning centre located in the suburbs of Ottawa, Ontario. This centre provides one-on-one and small group tutoring services, school consultation, and psychoeducational assessments. Overall, 22 children were tested at Site 1 during pre-test. Out of those, four children did not complete the study. One had an intellectual disability that prevented them from completing baseline testing. Two children from the intervention condition dropped out of the study because the Neuralign© intervention did not suit their learning needs (i.e., the intervention was too easy for one and too difficult for the other). The final student that dropped out from Site 1 did not respond to requests for scheduling the post-test. One student completed two of the testing tasks online because of medical reasons but completed the other tasks in person.

**Site 2**

Site 2 is a small, urban private school for children with learning difficulties in Ottawa, Ontario. Site 2 provides individualized classes for children in elementary and high school. The size of each classroom varied ranging from 2 to 8 children. Overall, 24 children were tested at Site 2 during pre-test. Out of those, one child dropped out of the study prior to completing the intervention or post-test session because they moved to a different school.

**Site 3**

Site 3 is a small, rural private school for children with learning challenges in Cornwall, Ontario. The classroom size ranged from 2 to 7 children. Overall, 12 children were tested at site three during pre-test. Of these, three children dropped out of the program during post-test. One student who was assigned to the control group dropped out of the study because they changed school locations. Two children who were a part of the intervention condition dropped out of the
study because the program was too demanding on their cognitive resources, and the user interface of the intervention caused frustration.

Procedure

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 by continuous testing. After baseline testing was complete, children at the learning centre were matched by grade and then, randomly assigned to either the intervention group or the waitlist control group. At the schools, assignment to intervention versus waitlist was done by randomly assigning classrooms to intervention or waitlist control conditions. Random assignment of individuals to treatment and control groups is considered the gold standard for intervention designs (Sella et al., 1970).

Pre-test and Post-test Testing procedures

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 any 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 US version).

The following accommodations for examinees with learning and or/reading difficulties were necessary. Examinees with weaknesses in specific abilities were offered more reinforcement (e.g., specific praise and positive comments) during the testing process than those
that learned easily (Mather & Wendling, 2014). However, to maintain consistency, experimenters did not (a) read the reading tests to children because the reading test would have become a measure of oral comprehension or (b) increase the time limit for timed tasks if the child was taking too long to respond.

**Time 1, Pre-test.** Baseline testing sessions lasted for 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.

**Time 2, Post-test.** 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 group questions relating to the intervention. Parents received a $10 gift card as a compensation for completing the survey.

**Apparatus**

The materials children used to complete the intervention consisted of varying devices such as computers, laptops, or tablets, and a stable connection to the internet so that children can access the program online. iPads to display relevant stimuli and response booklet materials were used by the experimenter, who sat diagonally 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.

**Intervention Group**

Children in the intervention group were tested three times (see Figure 4a). First, each student participated in one baseline session (T1) 2 to 3 weeks prior to beginning the intervention program. Then, the Neuralign© intervention was supervised by the program co-ordinator at Site 1 and by the classroom teachers at Sites 2 and 3 who were all given resources (e.g., guides and login information) explaining how to administer the Neuralign© intervention. Once children completed the 13-week intervention, post-testing was done (T2). A delayed post-test occurred thirteen weeks after the post-test (T3).
Children in the waitlist control group were also tested at three time points (see Figure 4b). Like the intervention group, each student participated in one baseline session (T1). However, when children in the intervention group took part in the 13-week intervention, children in the waitlist control continued tutoring or their regular classroom activities. After completing the intervention, the waitlist control group was tested at a second-time point (T2). Then, they completed the Neuralign© intervention following the same procedure as the intervention group. Importantly, testing was done at an additional third-testing point (T3), and this immediately followed the intervention after it was completed for the waitlist group to help measure the change in reading skills directly after the intervention. In this thesis, I focussed on the data from pretest (T1) to post-test (T2).

Measures

The complete list of measures is shown in Table 2. 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. All testing from T1 to T3 was completed by June of 2023.
Table 2. Measures in the Proposed Study

<table>
<thead>
<tr>
<th>Measures</th>
<th>Pretest (T1)</th>
<th>Post-test (T2)</th>
<th>Post-test/ Delayed Post-test T3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Cognitive Measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working Memory (Digit Forward and Backward)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Spatial Span</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Matrix reasoning</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid Automatized Naming²</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Affective Measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading affect (Reading anxiety and self-concept)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Math anxiety</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Reading Skills</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory Processing (Segmentation, Sound Blending)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Decoding (Word Attack, Letter-word Identification)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sentence Reading Fluency</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Spelling</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Passage Comprehension</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Math Skills</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math Facts Fluency</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Applied Problems¹</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number Line Estimation</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Note. Measures under reading skills and math skills are all subtests of Woodcock-Johnson IV Tests of Oral Language and Woodcock-Johnson IV Tests of Achievement (Mather & Wendling, 2014). ¹Applied problems was replaced by Number Line estimation during post-test and delayed post-test because of time constraints. ²Digits, letters, quantities.

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 5). 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 ($\alpha = .89$) was based on the sub scores of trials 1, 2 and 3.
**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 ($\alpha = .92$).

**Rapid Automatized Naming (RAN).** This task required children to name stimuli aloud as quickly and accurately as possible (see Figure 6). Children completed three versions: Letters, Digits, 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 ($\alpha = .88$).
Figure 6. Rapid Automatized Naming Stimuli (Form A - Numbers, Quantities, and Digits)

<table>
<thead>
<tr>
<th>Form A</th>
<th>Form A</th>
<th>Form A</th>
</tr>
</thead>
<tbody>
<tr>
<td>A M C A A M</td>
<td>2 1 3 1 2 2</td>
<td>1 3 2 3 2 1</td>
</tr>
<tr>
<td>C M C A M M</td>
<td>1 3 2 3 2 1</td>
<td></td>
</tr>
<tr>
<td>M M A C A C</td>
<td>1 1 3 2 2 3</td>
<td></td>
</tr>
<tr>
<td>A C M C A M</td>
<td>3 2 1 1 2 3</td>
<td></td>
</tr>
</tbody>
</table>

**Picture Vocabulary.** This sub-test from Woodcock-Johnson IV Tests of Oral Language (Mather et al., 2014) briefly measured children’s 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 Affect.** Children’s reading affect was measured with two tasks: reading anxiety and reading self-concept.

**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 7). Test reliability was calculated using all 16 items was \( \alpha = .88 \). The items were recoded such that a low score reflected high anxiety allowing reading affect variables to be scaled in the same direction.
Table 3. Reading Anxiety Questionnaire

<table>
<thead>
<tr>
<th>Children’s Reading Anxiety Questionnaire (CRAQ; Ramirez et al., 2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
<tr>
<td>2. How do you feel when you are about to take a big test in your reading class?</td>
</tr>
<tr>
<td>3. How do you feel when you try to read a word you’ve never seen before?</td>
</tr>
<tr>
<td>4. How do you feel when you have to sit down and start your reading homework?</td>
</tr>
<tr>
<td>5. How would you feel if you were asked to read these words? Bug sheep bath.</td>
</tr>
<tr>
<td>6. How would you feel if you were asked to read this sentence? Dan’s bus was coming.</td>
</tr>
<tr>
<td>7. How do you feel when seeing all the words in a storybook?</td>
</tr>
<tr>
<td>8. How do you feel when you are reading in class and don’t understand something?</td>
</tr>
<tr>
<td>9. How would you feel if you were asked to spell the word &quot;cooked&quot;?</td>
</tr>
<tr>
<td>10. How do you feel when your teacher asks you to read out loud during class?</td>
</tr>
</tbody>
</table>

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 8). 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 $\alpha = .88$. 
Table 5. Math Anxiety

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>How would you feel when you are in the arithmetic lesson and your teacher says you will learn something new?</td>
</tr>
<tr>
<td>2</td>
<td>Look at the clock. How would you feel if you were asked what time it will be in 20 minutes?</td>
</tr>
<tr>
<td>3</td>
<td>How would you feel if you had to sit down and start your math homework?</td>
</tr>
<tr>
<td>4</td>
<td>How do you feel when your teacher explains how to solve arithmetic problems?</td>
</tr>
<tr>
<td>5</td>
<td>How do you feel when you take a big test in the arithmetic lesson?</td>
</tr>
<tr>
<td>6</td>
<td>How do you feel when you take your arithmetic book and see all the numbers in it?</td>
</tr>
<tr>
<td>7</td>
<td>How do you feel when you are in the arithmetic lesson, and you don’t understand something?</td>
</tr>
<tr>
<td>8</td>
<td>How do you feel when the teacher asks you to solve a calculation exercise on the blackboard?</td>
</tr>
<tr>
<td>9</td>
<td>How would you feel when you have to solve 34-17?</td>
</tr>
</tbody>
</table>

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

Figure 8. 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’s 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).

**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.

**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).

**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).

**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 9). 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 (α = .93).

**Figure 9.** Number Line Estimation App

![Number Line Estimation App](image)

**Analyses**

Data from the two time-points: pretest (T1) and post-test (T2) and all three sites were analyzed using hierarchical regression models. I chose this design because the focus of my analysis was to see if the Neuralign© intervention condition explained a statistically significant amount of variance in children’s scores on reading and affect measures (i.e., dependent variable) after controlling for pretest scores and cognitive skills. Analyses were conducted using SPSS version 27.
Results

Affective and Attitudinal Measures

Child Neuralign© Feedback survey

During the post-test, children in the Neuralign© intervention group completed a feedback survey containing questions about their experiences and opinions of the Neuralign© intervention. In the survey, children were asked to give a star rating for each of the games they played ranging from one star to five stars (see Appendix G for list of questions asked). Out of the 18 responses received, most children gave higher ratings to games targeting working memory skills such as Mosaics, Colour hopper, and Memory cards whereas games that targeted decoding such as Sunny Scotland, Egypt, and China were rated lower by children (see Figure 10 and Appendix H). One possible explanation for students rating working memory games higher than games targeting decoding could be that children prefer games that do not involve reading because they are already struggling with reading.

Figure 10. Students’ ratings of the Neuralign© 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) like very much. The number of responses varied depending which games the student had played (n = 13 to 18).

Feedback about the intervention that was gathered through open-ended questions and anecdotal evidence suggested that children had a mixed response to the intervention. For example, some children claimed, “I am learning more about reading”, whereas others commented that the intervention was “Too easy, repetitive, and boring”. When asked whether they enjoyed the intervention overall, two students said ‘No’ whereas the other 14 selected either
‘Sort of’ or ‘Yes’. Similarly, when asked whether they felt that their reading improved after using the program, nine students reported either ‘Yes’ or ‘Sort of’, whereas five students selected ‘No’. Of course, enjoyment is not necessarily the most important feature of an intervention. If students are not engaged, however, it may reduce their motivation to continue learning.

**Child Affect Survey**

All children, including those in the waitlist group completed a survey about their academic anxiety and reading self-concept (i.e., reading anxiety, math anxiety, and reading self-concept). In the sample, mean reading anxiety was between “A little nervous (2)” to “Somewhat nervous (3)”, \(M = 2.24, SD = 1.04\). Unexpectedly, reading self-concept was towards the positive end of the scale with the mean between “Neutral” or “Somewhat agree” \(M = 3.21, SD = 0.84\). Finally, children’s average level of math anxiety was between “A little nervous” and “Somewhat nervous” \(M = 2.44, SD = 0.94\). Overall, the sample of students in the current study had low levels of reading anxiety, low math anxiety, and high reading self-concept.

**Parent Feedback Survey**

Parental feedback \((N = 15)\) about the Neuralign© intervention was also gathered (see Figure 11). For some questions, parents were asked to rate their agreement on a Likert-type scale. The majority of the parents’ responses fell within the positive (‘strongly agree or somewhat agree’) or neutral (‘neither agree nor disagree’) categories. For example, 67% of the parents felt that the videogame format of the program kept their child engaged. Around half (53%) of the parents felt that their child benefitted from the intervention, and 40% of parents reported that their child felt more positive about reading after completing the intervention. Finally, when asked whether they would recommend the Neuralign© program to other parents and children 53% of parents agreed that they would whereas 47% chose a neutral response (i.e., neither agree nor disagree). There were some very positive comments about the children’s experience surrounding Neuralign©, “the intervention helped build a better reading foundation” and “she has become a lot more fluent in her reading”. In contrast, other parents felt: “our child is still struggling with reading” or “kids would benefit from more structured one-on-one time”. Thus, similar to student responses, parents’ responses to the intervention were mixed.
Figure 11. *Parent's Feedback about Neuralign© Intervention*

**Descriptive Statistics**

Children were in grades 2 to 8 (see Table 6). Most children completed all tasks: Missing data at Time 1 included one child for letter-word identification and two children for the spatial span task. Missing data at Time 2 (post-test) included one child for letter-word identification and two children for the spatial span task. Descriptive statistics for each variable are summarized in Table 7.

**Table 6. Number of Children in Each Grade at Pretest (T1) and at Post-test (T2)**

<table>
<thead>
<tr>
<th>Grade</th>
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*Note. Site 1 (n = 22), Site 2 (n = 24), Site 3 (n = 12).*
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Note. During Time 1 (pre-test) number line task replaced (n = 25) applied problems (n = 32) because of time constraints. ¹RAN stands for rapid automatized naming. ²Reverse coded so a lower score is more positive. Internal reliability was calculated using Cronbach’s alpha for each measure. This table shows the grade equivalent scores for Woodcock-Johnson IV reading and math measures. For descriptive statistics with raw scores refer to Appendix F.
Preliminary analyses were conducted to ensure that the assumptions of normality, linearity and homoscedasticity were not violated. Given the small sample size, verifying the distribution of the variables was important for choosing an appropriate statistical method.

Outliers were defined as scores falling $\pm 3 \text{ SD}$. At pretest, there was one outlier for each of matrix reasoning, segmentation, letter-word identification, math anxiety, reading anxiety and reading self-concept measures. Further, there were three outliers for digit backward, two outliers for sound blending and five for passage comprehension. At post-test there was one outlier for sound blending, passage comprehension, math facts fluency, and four outliers for digit forward and digit backward measures.

Shapiro-Wilks test of normality showed that the distribution of spelling, word attack, sentence reading fluency, reading anxiety differed significantly from normality for pre-test scores. Similarly, for post-test scores Shapiro-Wilks tests showed reading anxiety, spelling, sound blending, sentence reading fluency, differed significantly from normality.

**Comparisons Between Groups at Pretest**

There were no group differences at baseline for the measures used in the analyses. The comparison of pre-test performance showed that there were no significant differences between the scores of children in the intervention versus waitlist conditions ($p > .05$) (see Appendix D).

**Correlations**

Correlations between predictor variables for pre-test and post-test measures are shown in Table 8 (also see Appendix E, Table 22 for correlations among pre-test variables). As expected, the cognitive measures (i.e., digit forward, digit backward, matrix reasoning and picture vocabulary) were correlated with reading measures. Out of these cognitive measures, verbal working memory showed the highest correlation with reading and affect measures. Also, as expected, all the reading measures at pre-test were correlated with each other at post-test (Table 8; grey cells). Notably, pre-test measures of decoding, spelling and passage comprehension were strongly correlated with their respective post-test measures. These high correlations might make it harder to detect differences across conditions because pre-test to post-test correlation coefficients are positively related to the variability in test scores. Therefore, high correlations indicate that the sample variability is also high (i.e., the sample is heterogenous). Further, reading affect variables (i.e., reading anxiety and reading self-concept) were highly correlated with each other and showed a similar pattern of correlations with other reading and cognitive
variables. Overall, high correlations between pre-test reading and affect measures with their respective post-test measures suggests that all students change to same extent and so, there is not much change to predict. There was no change in the pattern between variables in the correlation analyses when outliers were excluded from analysis, so no data were discarded.
Table 8. Correlations Among Measures used in Regression Models (N = 50)

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Note. For all standardized tests, grade equivalent scores were used. Grey cells are correlations for the same tests at T1 and T2. † p ≤ .10, * p ≤ .05, ** p < .01, *** p < .001.
Data Reduction

For reading measures, raw scores were transformed into grade equivalent scores because these convey meaningful information about children’s level of development. Grade equivalent scores represent the child’s performance in relation to the grade level of the norming sample in which the median score is the same as the child’s raw score (Mather et al., 2014; Mather & Wendling, 2014). This conversion is done by using children’s raw scores and converting them by referring to the Woodcock-Johnson IV scoring table for each form (i.e., either A, B or C) for the respective tasks (e.g., for segmentation, if the number of correct responses was 20, the grade estimate for that student was 1.4 or fourth month of the first grade). For the Woodcock-Johnson IV, the grade norms range from kindergarten to grade 12. In this sample, 54 out of 58 students were more than half a grade level below their expected reading level on all reading assessments and four students were close to or above their grade reading level.

Composite scores were created by averaging z-scores for affect or grade equivalent scores for reading measures (as appropriate) that were highly correlated and assumed to capture the same latent variables. These composite scores included verbal working memory (i.e., digit forward and digit backward, $r_{T1} = .66, p < .001$), phonological processing (i.e., segmentation and sound-blending, $r_{T1} = .56, p < .001$), decoding (i.e., letter-word identification and pseudoword reading, $r_{T1} = .86, p < .001$), and reading affect (i.e., reading anxiety and reading self-concept $r_{T1} = .56, p < .001$).

Experiment Wise Error Rate

An adjusted error rate ($p = .0083$) was calculated by dividing the standard p-value ($p = .05$) by the number of regression analyses that were run (i.e., six). This adjusted p value was used
to evaluate whether the intervention predicted post-test scores. As described below, none of the measures showed significant effects of the intervention using this critical value of $p$.

**Research Question 1: Did the Neuralign© Intervention Influence Reading Skills?**

Hierarchical regression models were used to determine whether the Neuralign© intervention improved phonological processing, decoding, reading fluency, spelling, and passage comprehension for children in the intervention versus waitlist control group. Because Woodcock-Johnson IV grade equivalent scores were used in the analyses, grade was already accounted for in the reading scores. In the first block (Model 1), pre-test scores and the cognitive control variables were included for the reading measures (i.e., verbal working memory, matrix reasoning, and picture vocabulary measures). For each regression, these three cognitive measures were used as control variables because, consistent with the literature on reading acquisition, they are common predictors of reading performance and were expected to be related to performance on the reading tasks. This assumption was verified by the pattern of correlations (see Table 8). In the second block (Model 2), intervention condition was added as a predictor.

**Phonological Processing**

The regression analysis of phonological processing at Time 2 is shown in Table 9. In Model 1, as expected, phonological processing scores at pre-test explained unique variance in phonological processing scores at post-test. Of the cognitive control measures, only verbal working memory accounted for unique variance. In Model 2, when intervention condition was added as a predictor, phonological processing scores at pre-test and verbal working memory were the only variables that accounted for unique variance in children’s post-test phonological processing score. In summary, post-test phonological processing was not related to the intervention.
Table 9. Analysis of Phonological Processing at Post-test (Time 2)

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</tr>
<tr>
<td>Matrix Reasoning T1</td>
<td>0.02</td>
<td>0.02</td>
<td>0.12</td>
<td>0.90</td>
<td>0.37</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.04</td>
<td>0.04</td>
<td>0.16</td>
<td>1.19</td>
<td>0.24</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>0.16</td>
<td>0.21</td>
<td>0.10</td>
<td>0.79</td>
<td>0.43</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Note. Phonological processing is the composite of Segmentation and Sound Blending. Squared semi-partial correlations indicate unique $R^2$ within that specific model tested. † $p \leq .10$, * $p < .05$; ** $p < .01$; *** $p < .001$. In Model 1, $R^2 = 41.3\%$, $F (4, 45) = 7.90$, $p < .001$; in Model 2, $R^2 = 42.1\%$, $F (5, 44) = 6.41$, $p < .001$; $\Delta R^2 = 0.8\%$.

Decoding

The regression analysis of decoding at Time 2 is shown in Table 10. As anticipated, Model 1 shows that decoding scores at pre-test explained unique variance in decoding scores at post-test. When the cognitive control measures were entered into Model 1, none of them (i.e., verbal working memory, matrix reasoning and picture vocabulary) accounted for unique variance in children’s post-test decoding scores. In Model 2, when intervention condition was added as a predictor, decoding scores at pre-test was the only variable that accounted for unique variance in children’s sentence reading fluency scores at post-test. These results indicate the intervention did not improve children’s decoding skills. Notably, the high correlation between decoding scores at T1 and T2 might make it harder to detect differences across conditions because they indicate that the variability in decoding skills for the current sample of children is high.
Table 10. Analysis of Decoding at Post-test (Time 2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>t</th>
<th>p</th>
<th>Unique R²</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Decoding</td>
<td>0.88</td>
<td>0.06</td>
<td>0.92</td>
<td>15.22</td>
<td>&lt;.001</td>
<td>0.85</td>
<td>.90</td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.08</td>
<td>0.12</td>
<td>0.04</td>
<td>0.69</td>
<td>0.49</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Matrix reasoning T1</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>1.04</td>
<td>0.30</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>-0.07</td>
<td>0.07</td>
<td>-0.05</td>
<td>-1.01</td>
<td>0.32</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.90</td>
</tr>
<tr>
<td>T1 Decoding</td>
<td>0.88</td>
<td>0.06</td>
<td>0.92</td>
<td>14.98</td>
<td>&lt;.001</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.09</td>
<td>0.12</td>
<td>0.05</td>
<td>0.75</td>
<td>0.46</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Matrix Reasoning T1</td>
<td>0.05</td>
<td>0.04</td>
<td>0.06</td>
<td>1.10</td>
<td>0.28</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>-0.07</td>
<td>0.07</td>
<td>-0.06</td>
<td>-1.07</td>
<td>0.29</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>-0.15</td>
<td>0.39</td>
<td>-0.02</td>
<td>-0.39</td>
<td>0.70</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Note. Decoding is the composite of letter-word identification and pseudoword reading. Squared semi-partial correlations indicate unique R² within that specific model tested. † p ≤ .10, * p < .05; ** p < .01; *** p < .001. In Model 1, R² = 90.4%, F (4, 45) = 105.54, p < .001; in Model 2, R² = 90.4%, F (5, 44) = 82.87, p < .001; ΔR² = 0%.

Sentence Reading Fluency

Model 1 shows that sentence reading fluency scores at pre-test explained unique variance sentence reading fluency scores at post-test (see Table 11). None of the cognitive control measures except picture vocabulary accounted for unique variance in children’s sentence reading fluency post-test scores. In Model 2, when intervention condition was added as a predictor, sentence reading fluency at pre-test and picture vocabulary were the only variables that accounted for unique variance in children’s sentence reading fluency scores at post-test. These results indicate that the Neuralign© intervention did not affect children’s sentence reading fluency. The negative coefficient of the Condition variable (B = - .15) indicates that waitlist control group improved more than the Neuralign© intervention group on sentence reading fluency.
### Table 11. Analysis of Sentence Reading Fluency at Post-test (Time 2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>t</th>
<th>p</th>
<th>Unique $R^2$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.62</td>
</tr>
<tr>
<td>T1 Fluency</td>
<td>0.50</td>
<td>0.11</td>
<td>0.49</td>
<td>4.40</td>
<td>***</td>
<td>&lt;.001</td>
<td>0.31</td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.22</td>
<td>0.18</td>
<td>0.14</td>
<td>1.27</td>
<td>.21</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Matrix reasoning T1</td>
<td>0.03</td>
<td>0.07</td>
<td>0.04</td>
<td>0.39</td>
<td></td>
<td>0.70</td>
<td>0.00</td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.34</td>
<td>0.11</td>
<td>0.34</td>
<td>3.13</td>
<td>**</td>
<td>0.00</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.64</td>
</tr>
<tr>
<td>T1 Fluency</td>
<td>0.52</td>
<td>0.11</td>
<td>0.51</td>
<td>4.64</td>
<td>***</td>
<td>&lt;.001</td>
<td>0.34</td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.26</td>
<td>0.17</td>
<td>0.16</td>
<td>1.47</td>
<td></td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>Matrix Reasoning T1</td>
<td>0.05</td>
<td>0.07</td>
<td>0.08</td>
<td>0.75</td>
<td></td>
<td>0.46</td>
<td>0.01</td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.30</td>
<td>0.11</td>
<td>0.30</td>
<td>2.72</td>
<td>**</td>
<td>0.01</td>
<td>0.15</td>
</tr>
<tr>
<td>Condition</td>
<td>-1.01</td>
<td>0.64</td>
<td>-0.16</td>
<td>-1.59</td>
<td></td>
<td>0.12</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Note. Squared semi-partial correlations indicate unique $R^2$ within that specific model tested. † $p \leq .10$, * $p < .05$; ** $p < .01$; *** $p < .001$. In Model 1, $R^2 = 61.6\%$, $F (4, 43) = 17.25$, $p < .001$; in Model 2, $R^2 = 63.8\%$, $F (5, 42) = 14.79$, $p < .001$; $\Delta R^2 = 0.02\%$.

### Spelling

In the hierarchical regression for spelling, Model 1 shows that spelling scores at pre-test explained unique variance in spelling scores at post-test (see Table 12). Of the cognitive measures, only verbal working memory accounted for unique variance explained in children’s post-test spelling scores. In Model 2, intervention condition did not account for unique variance in children’s spelling scores at post-test. The negative coefficient of the Condition variable ($B = - .62$) indicates that waitlist control group improved more than the Neuralign© intervention group on spelling. However, this effect was not significant according to the adjusted p value of .0083. These results indicate that children’s post-test scores on spelling are not influenced by the intervention.
Table 12. Analysis of Spelling at Post-test (Time 2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>t</th>
<th>p</th>
<th>Unique R²</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Spelling</td>
<td>0.83</td>
<td>0.04</td>
<td>0.90</td>
<td>21.4***</td>
<td>&lt;.001</td>
<td>0.90</td>
<td>.94</td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.17</td>
<td>0.08</td>
<td>0.09</td>
<td>2.11**</td>
<td>0.04</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Matrix reasoning T1</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>1.00</td>
<td>0.32</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.03</td>
<td>0.05</td>
<td>0.03</td>
<td>0.71</td>
<td>0.48</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Spelling</td>
<td>0.84</td>
<td>0.04</td>
<td>0.90</td>
<td>22.6***</td>
<td>&lt;.001</td>
<td>0.92</td>
<td>.94</td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.19</td>
<td>0.08</td>
<td>0.11</td>
<td>2.51**</td>
<td>0.02</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Matrix Reasoning T1</td>
<td>0.05</td>
<td>0.03</td>
<td>0.06</td>
<td>1.63</td>
<td>0.11</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.01</td>
<td>0.05</td>
<td>0.01</td>
<td>0.14</td>
<td>0.89</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>-0.62</td>
<td>0.26</td>
<td>-0.08</td>
<td>-2.38**</td>
<td>0.02</td>
<td>0.12</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Squared semi-partial correlations indicate unique R² within that specific model tested. † p ≤ .10, * p < .05; ** p < .01; *** p < .001. In Model 1, R² = 94.6%, F (4, 45) = 197.55, p <.001; in Model 2, R² = 94.7%, F (5, 44) = 175.53, p <.001; ΔR² = 0.60%.*

Passage Comprehension

As expected, passage comprehension scores at pre-test explained unique variance in passage comprehension scores at post-test (Model 1, see Table 13). None of the cognitive control measures accounted for unique variance in children’s post-test passage comprehension scores.

Similarly, in Model 2, when intervention condition was added as a predictor, passage comprehension at pre-test was the only variable that accounted for unique variance in children’s post-test passage comprehension. These results indicate that the intervention did not influence children’s passage comprehension skills.
Table 13. Analysis of Passage Comprehension at Post-test (Time 2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE</th>
<th>β</th>
<th>t</th>
<th>p</th>
<th>Unique R²</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.79</td>
</tr>
<tr>
<td>T1 Passage Comprehension</td>
<td>0.85</td>
<td>0.12</td>
<td>0.71</td>
<td>7.03</td>
<td>&lt;.001</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.16</td>
<td>0.11</td>
<td>0.13</td>
<td>1.45</td>
<td>0.15</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Matrix reasoning T1</td>
<td>0.05</td>
<td>0.04</td>
<td>0.09</td>
<td>1.15</td>
<td>0.26</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.06</td>
<td>0.08</td>
<td>0.08</td>
<td>0.86</td>
<td>0.39</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.79</td>
</tr>
<tr>
<td>T1 Passage Comprehension</td>
<td>0.84</td>
<td>0.13</td>
<td>0.7</td>
<td>6.66</td>
<td>&lt;.001</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Working Memory T1</td>
<td>0.17</td>
<td>0.12</td>
<td>0.13</td>
<td>1.45</td>
<td>0.15</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Matrix Reasoning T1</td>
<td>0.05</td>
<td>0.05</td>
<td>0.10</td>
<td>1.16</td>
<td>0.25</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Picture Vocabulary T1</td>
<td>0.06</td>
<td>0.08</td>
<td>0.07</td>
<td>0.82</td>
<td>0.41</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>-0.10</td>
<td>0.41</td>
<td>-0.02</td>
<td>-0.25</td>
<td>0.80</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Note. Squared semi-partial correlations indicate unique R² within that specific model tested. † p ≤ .10, * p < .05; ** p < .01; *** p < .001. In Model 1, R² = 78.7%, F (4, 45) = 41.59, p < .001; in Model 2, R² = 78.7%, F (5, 44) = 32.59, p < .001; ΔR² = 0%.

Research Question 2: Did the Neuralign© Intervention Influence Reading Affect?

Reading Affect

A hierarchical regression was conducted with two blocks of variables to predict children’s change in reading affect scores (i.e., reading self-concept and reading anxiety) at post-test (see Table 14). Model 1 comprised the control variables (i.e., children’s pre-test scores on reading affect measures and grade). For affect variables, grade was controlled for because these are raw z-scores. As anticipated, children’s pre-test reading affect scores explained unique variance in post-test scores. Affect scores were not related to grade. In Model 2, intervention condition did not account for any unique variance in children’s reading affect post-test scores. In sum, the intervention did not influence children’s reading affect.
Table 14. Analysis of Reading Affect at Post-test (Time 2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>t</th>
<th>p</th>
<th>Unique $R^2$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.72</td>
</tr>
<tr>
<td>T1 Reading Affect</td>
<td>0.85</td>
<td>0.08</td>
<td>0.84</td>
<td>10.82</td>
<td><strong>&lt;.001</strong></td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>-0.04</td>
<td>0.04</td>
<td>-0.08</td>
<td>-1.02</td>
<td>0.31</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.72</td>
</tr>
<tr>
<td>T1 Reading Affect</td>
<td>0.85</td>
<td>0.04</td>
<td>0.84</td>
<td>10.81</td>
<td><strong>&lt;.001</strong></td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>-0.04</td>
<td>0.04</td>
<td>-0.09</td>
<td>-1.10</td>
<td>0.28</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>0.13</td>
<td>0.14</td>
<td>0.07</td>
<td>0.92</td>
<td>0.36</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

Note. Squared semi-partial correlations indicate unique $R^2$ within that specific model tested. † $p$ ≤ .10, * $p$ < .05; ** $p$ < .01; *** $p$ < .001. In Model 1, $R^2$ = 71.7%, $F (2, 47) = 59.46, p < .001$; in Model 2, $R^2$ = 72.2%, $F (3, 46) = 39.78, p < .001; $\Delta R^2 = 0.50%$.

Summary

For Hypothesis 1, the regression models show that changes in children’s performance was not affected by Condition and thus, the Neuralign© intervention did not support children’s reading skills at post-test after accounting for cognitive skills. Similarly, for Hypothesis 2, children’s affect scores at Time 2 (i.e., reading self-concept and reading anxiety) were not related to the intervention. In sum, neither of my hypotheses were supported.

Discussion

The purpose of the present research was to determine whether participating in the Neuralign© intervention supports improvement in reading skills and reading affect for students with reading difficulties. People who have reading difficulties avoid reading and therefore, they have less experience with printed materials and gain less from learning opportunities in school than their peers. These differences in experience may lead to maladjustment, dropping out of school or falling behind their grade level (Rosas et al., 2017). An inability to comprehend text causes difficulties in day-to-day activities from a young age and as adults, may influence issues such as completing school homework to passing driver’s licence exams (Hasselbring & Goin, 2004). Overall, it is very important to intervene early and develop evidence-based interventions.
for the 5 to 10% of children who struggle to acquire age-appropriate reading skills (Ontario Human Rights Commission, 2022).

Yuzaidy et al. (2018) reviewed current intervention methods for children with dyslexia. They found that there are numerous types of interventions targeting different skills for students with reading difficulties and dyslexia (e.g., multisensory methods, phonological intervention, and cognitive training method). However, fewer interventions combine cognitive functions (e.g., attention and working memory) and essential reading skills. Similarly, the authors of two reviews of technology-based reading interventions concluded that interventions that are successful in supporting reading acquisition for both struggling and average readers focus on core reading skills like phonemic awareness, phonics, text-reading fluency, vocabulary, and reading comprehension strategies (Alqahtani, 2020; Shanahan, 2021). These authors also concluded that Tier 2 and 3 interventions may be more efficient and accessible if they are provided online for struggling readers. Using technology to support learning of these essential skills may be a promising strategy for students with reading difficulties because technology allows for multiple activities that address different skills simultaneously (Alqahtani, 2020; Jamshidifarsani et al., 2019). For example, ABRACADABRA (i.e., A Balanced Reading Approach for Children Always Designed to Achieve Best Results for All) is an online game-based computer intervention that showed an overall positive effect on participants’ reading skills, particularly on phonemic awareness ($g = 0.78$). It included multiple components such as phonics, phonemic awareness, fluency, and reading comprehension (Abrami et al., 2020; Piquette et al., 2014). Thus, the Neuralign© intervention is promising because it combines executive function and reading skills practice, is available online, can be used by students at home or at school, and involves core reading skills.
Consistent with the multiple-deficit model for reading difficulties (Pennington, 2006), interventions addressing core skills simultaneously may be beneficial for students with reading difficulties. Although there is considerable research on the effects of existing reading interventions (Yuzaikey et al. 2018), more research is required to evaluate the impact of multi-factor interventions that target more than one foundational skill in struggling readers. Therefore, in the current study, we examined the effect of the Neuralign© intervention on the reading skills and affective factors of children with reading difficulties.

**Research Question 1: Did the Neuralign© Intervention Influence Reading Skills?**

Contrary to my hypothesis, children’s reading scores at post-test for phonological processing, decoding, sentence reading fluency, spelling, and passage comprehension did not differ in the intervention and the waitlist condition, and thus, there was no evidence that the intervention influenced children’s reading skills.

The Neuralign© intervention is focussed on foundational reading skills, especially, decoding. Accordingly, any effect of the intervention seems most likely for those skills and was the focus of the present analysis. However, the program also is intended to train the visual magnocellular systems during the first three weeks of the intervention. For example, out of 20 hours of the Neuralign© intervention children spend approximately 15 hours (i.e., Cognitive therapy component) playing games that simultaneously train their visual system and target foundational reading skills (e.g., decoding and phonological processing). The visual effects are intended to target magnocellular pathways that are assumed to be causally related to students’ reading deficits. The Neuralign© games in the Cognitive Therapy component (e.g., Switzerland and Egypt) are intended to decrease visual timing deficits in the dorsal stream by manipulating the patterns and speed in the moving foreground against a stationary background (e.g., Lawton,
2016). However, because the intervention did not affect children’s reading skills, and because I did not assess visual processing directly, I am unable to determine if these games influenced visual processing in the magnocellular pathway. Moreover, the literature on children with dyslexia provides limited support for the magnocellular hypothesis. Some researchers suggest that magnocellular dysfunction is a consequence, rather than a cause, of poor reading (Vellutino et al., 2004), because children have not been able to strengthen these networks through reading experiences.

Relevant Question 2: Did the Neuralign© Intervention Influence Reading Affect?

Although Neuralign© is not directly designed to influence children’s reading affect, improving children’s reading skills could, in turn, support children’s reading affect. Investigating children’s negative affect surrounding reading is important to consider, particularly, for children struggling to read because it can explain variability in their reading skills (Ramirez et al., 2019). Regression analysis was used to determine whether the intervention condition had an influence on children’s affect, specifically reading anxiety and reading self-concept. Contrary to my hypothesis, the intervention did not influence children’s affect; scores at post-test were not different across conditions after controlling for pre-test affect, children’s grade level, and cognitive measures (see also McArthur, 2022).

There is no consensus on the role of affective factors during reading development so, it can be useful to assess poor readers for factors like anxiety and self-concept (McArthur & Castles, 2017). The Active View of Reading (AVR) expands upon models like the Simple View of Reading by considering bridging processes (e.g., reading fluency, vocabulary knowledge, and morphological awareness) and active self-regulation which includes affective factors such as motivation, engagement, executive function skills, and strategy use (Burns et al., 2023). In the
current study, reading affect showed moderate correlations with reading skill on certain post-test measures particularly, phonological processing \( (r = 0.36) \), decoding \( (r = 0.45) \), spelling \( (r = 0.37) \), and passage comprehension \( (r = 0.41) \). Further, the pattern of correlations between reading affect factors and reading outcomes during pre-test and post-test remained similar (i.e., within a moderate range; see Table 8). Therefore, affective factors are related to children’s reading skills but not to changes in their performance at post-test. Overall, the current study adds to the existing literature about the role of affective components for struggling readers by examining the relationship between reading affect (i.e., reading anxiety and reading self-concept) and reading skills.

**Implications for Future Research and Limitations**

**Sample Size**

Despite our best efforts, this research had several limitations. First, the number of students recruited and who completed the study \( (n = 50) \) may have resulted in low power to detect small effects. The research team contacted all private schools and several tutoring programs in an attempt to recruit a larger sample. However, only three organizations agreed to participate. The time commitment required in the study is presumably a significant factor in whether the research seems valuable to parents, coaches, and teachers. Therefore, future studies should consider replicating this intervention study with a larger sample of students to gauge a more precise estimate of the intervention effects and ensure that participants are able to commit throughout the required duration of the intervention.

**Sample Heterogeneity**

Second, a potential complication was that the sample that was recruited for the study was not homogenous. Children had varying diagnoses and multiple learning issues. They were
recruited from a broad range of grade levels (i.e., grades 2 to 8). Replicating this intervention study with students that are from similar grade levels and are all diagnosed with reading difficulties may be beneficial to determine whether Neuralign© has potential benefits for students with reading difficulties. To do so, a different recruitment strategy is necessary.

**External Factors**

Third, baseline and post-test testing procedures were conducted in three different sites and so, differences in the environment where testing took place could have influenced the results of the study through factors out of the researcher’s control. For example, differences in teacher’s instructions surrounding the intervention at each site. Further, there were differences between the noise levels at each location such that in Site 1, students had quiet, individual rooms and procedures proceeded uninterrupted but, in Site 2 there was on-going student traffic because of limited space.

**Study Design**

The design of the study, in particular the choice of reading outcome measures, may have limited our ability to detect change in students’ reading skills. The reading outcome measures were all standardized tests from Woodcock-Johnson IV and thus may not be sensitive to change that occurs in children’s reading skills over the short duration of the intervention (i.e., 13 weeks). Therefore, future research should include alternative measures that may be more sensitive to changes in students’ change in skills. Ideally, such measures could be built into the intervention itself, to simplify data collection and provide more evidence for how the intervention may influence students’ learning process while using the program.
**Implementation Issues**

Fourth, implementation issues including technical difficulties, content-related issues, factors impacting fidelity, and socio-economic status may have influenced the results of the current study.

**Technical Difficulties.** Participants experienced a range of technical difficulties that may have influenced the fidelity of the intervention. For some participants, the audio or video in the game would not load on the user interface of the computer. For others, student scores were not recorded accurately (i.e., the points earned by students were not reflective of actual student performance on the Neuralign© games). Moreover, because the bonus point scoring system that was built into the program was not reflective of students’ improvement it was difficult for teachers to interpret students’ progress in the intervention. Further, the teachers who monitored the intervention found it challenging to navigate the program. For example, teachers experienced software-related challenges while adding new students to the program and while allowing students to view their individual progress through each session as they completed the components of the intervention. Teachers could only view the progress of one student at a time instead of the entire class. The program developers should consider making the program more user-friendly to manage these technical difficulties. In particular, it would be useful if teachers can see the progress of the whole class. Finally, the built-in scoring systems of the Neuralign© program should be separated so that teachers can view trends like actual progress of students versus inflated progress. These technical difficulties with the design of the intervention may have compromised the results of the study.

**Content.** Some students reported that the level at which the program placed them at the start of the intervention did not match their reading skill level which led to frustration and a lack
of engagement with the intervention. Further, the program was not adaptable to students’ reading skills, so some children reported that they found the experience too easy while others found it too difficult. Within the games there were some content-related issues too. For example, the words presented during the games were repetitive and limited. Finally, teachers also reported frustration with certain games (e.g., Scotland) because there were spelling mistakes in the correct answers for the questions and some students constructed swear words by putting together letters provided in the answer options. Therefore, program developers should consider modifying the intervention with a careful and increased selection of letters, words, and questions to maximize student engagement with the intervention. Effective instruction should be guided by a student’s level of development or upper threshold of instruction and so, learning is optimal within an appropriate difficulty level (i.e., zone of proximal development; Shabani et al., 2010). Therefore, for future studies, to improve content-related issues it may be beneficial to integrate features such as adaptivity and immediate feedback into the online intervention training as that may allow students to learn independently (Görgen et al., 2020). These content-related difficulties with the design of the intervention may have compromised children’s level of engagement with the intervention.

Fidelity. The fidelity of the study was compromised because of various challenges in timing and scheduling. For example, some students were unable to complete the entire intervention before post-testing. In future studies, it would be beneficial to clearly outline the timeline for each of the three components of the intervention and how to navigate those components (e.g., logging in and looking at progress graphs). Another challenge to fidelity was that some students were receiving additional tutoring support outside of their school curriculum which could have interfered with the results of the current intervention. Specifically, students at
Site 1 (the learning centre) attended tutoring sessions once or twice a week. In the parent survey, out of 29 responses, 31% \((n = 18)\) of parents reported that their child was getting additional learning support outside of school curriculum (either at home or in school), whereas 1.7% \((n = 1)\) were not sure. A further 17.2% \((n = 10)\) reported that their child was receiving some of form of additional support outside of school such as occupational, behavioural, vision, or speech therapy. Hence, future studies should try to determine the impact of the Neuralign© intervention on reading while considering any additional support received by students.

**Socio-economic Status (SES).** Finally, the sample of the current study was not representative of a range of socio-economic backgrounds. Two specific indices supported this conclusion. First, most parents were highly educated. Parental education level is a highly correlated indicator of socio-economic status (SES; Erola et al., 2016), and family SES plays an important role in children’s reading ability. For example, parents who are not well educated may be unable to provide tutoring for their children’s academic achievement (Chen et al., 2018). Second, all the sites from which students were recruited were private institutions, either tutoring programs or private schools. Only students whose parents could afford to pay the fees would have participated in this study. It was not possible to recruit from public schools because it would be difficult to identify and select students with reading difficulties without the support of the schools. When the study was planned, no partnerships existed between the Neuralign© company and any public schools in Ontario. Therefore, the conclusions from this study do not generalize to students whose families have low or mid-level socio-economic status. Future studies examining the efficacy of Neuralign© in public school settings or with students’ from less privileged backgrounds are necessary to fully understand the impact of the intervention. That
said, the intervention is not currently designed to be used in a school setting, and so significant changes would be needed to improve the implementation.

**Conclusion**

In the current study, I tested whether participation in a computerized reading intervention, Neuralign©, resulted in improvements in reading skills and affect (i.e., reading anxiety and reading self-concept) for students with reading difficulties or other challenges. Overall, I did not find evidence that the Neuralign© intervention affected children’s post-test scores on the reading or affect. There are few randomized controlled trials of computer-based reading interventions (Messer & Nash, 2018). Therefore, the current study examining the efficacy of Neuralign© may add to the literature relating on computer-based reading interventions and provided some useful direction for development of the intervention using evidence-based strategies. Fundamental aspects of the program are consistent with the literature on reading acquisition. For example, placing emphasis on core reading skills such as phonics, phonological processing, decoding, and fluency are all beneficial for children’s reading development. Neuralign© places some emphasis on reading fluency through repeated reading exercises (i.e., five minutes per week for ten weeks) which is supported by research (Morgan et al. 2012), but increasing the duration of this component of the program may ensure that the fluency component of the intervention is implemented as intended so that gains are consolidated over time. However, other aspects of the program are not well supported by research. For example, the intervention places a heavy emphasis on children’s visual skills, with the intent of supporting improvements in activation of the magnocellular systems, and consequently improving children’s reading skills. There is no consensus in the literature, however, whether such activities are helpful for improving reading. Overall, I conclude that more research is required to better understand how Neuralign© can
target core reading skills. With further testing and improvements, such as incorporating evidence-based intervention strategies like immediate feedback, reflection, prior knowledge, question generation, pictorial cues, identifying themes, inferential thinking, summarization, and story structure (Suggate 2010, Shanahan, 2021), the Neuralign© intervention may prove to be a useful tool for students who need intensive support to learn to read.
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Neuralign© is structured around a series of games. The games are named after countries because every game has a background relevant to the name of the country. For example, Egypt contains letters with a hieroglyphic theme. Each game is designed to develop children’s reading, attentional, or other language skills in one or more specific areas (see Table 20).

Table 15. *Skills targeted by Cognitive Therapy games in the Neuralign© Intervention*
**Switzerland and Morocco Games.** Switzerland (see Figure 12) is a puzzle game. Children see two honeycomb patterns on their screens. One pattern contains bees and the other is empty. To play the game, children dragged the bees from their original location to the opposite empty honeycomb and then, back to the original honeycomb while ensuring that the pattern is replicated correctly. Similarly, Morocco (see Figure 12) is a puzzle game which required children to drag coloured hexagons from their original location over to the opposite side’s mosaic while replicating the pattern of the colours correctly. Once colours are transferred from their original location over to the empty corresponding hexagon then, back to the original hexagon, the exercise is complete. The computer does not move onto the next game until children accurately replicated the patterns. These two games were designed to target tracking and attention skills. The movement of the bees and colours from right to left and left to right help children practice their saccadic eye movements and tracking. There are more hexagons appearing in front of the bees in later levels than lower levels. Theses visual effects of the rotating hexagon foreground on the interface aim to address magnocellular pathways by targeting neural timing of magnocellular cells in the dorsal stream by focussing on central and peripheral vision simultaneously.

**Figure 12. Switzerland (Bees) and Morocco (Mosaics) Gameplay**
**Egypt Game.** In this game (see Figure 13), pre-recorded sentences are presented orally, and the child is required to search for the correct words to build the sentence out of the lines of moving words displayed on the screen. The lines of words slide across the screen from left to right and right to left. Once, the child has identified the correct word they are required to drag the word onto the corresponding line to complete the sentence correctly. This game targets decoding, tracking, and visual attention skills. Children practice decoding whole words while building because the student must search for the correct word in the complex visual display.

**Figure 13. Egypt Gameplay**

**Canada Game (Pinball).** In this game, children listened to the auditory cue of the target word and then dragged the pinball with the matching word indicated by the cue on to the corresponding bumper correctly (see Figure 14). The audio stimuli that children hear are built to stretch-out and enunciate the first letter in the word. Auditory and visual cues in this game aim to target phonological processing skills such as sound-blending and visual skills.
Sunny and Rainy Scotland. This game (see Figure 15) targets phonological processing skills (i.e., sound blending), decoding (i.e., letter-word identification), spelling and attention skills. Children listened to auditory cues that break down the target word with an emphasis on the first letter of the word. After the auditory cue of the word is presented (e.g., /b/ /au/ /el/), a cloud containing the target word appears (e.g., ball). This intentional delayed timing allows more time for children to catch up with the word that needs to be decoded. Moving lines with letters appear on the screen downwards. The goal is for the child to accurately spell the target word by searching for the correct letters and dragging the ‘raining’ letters into the black cloud located at the top of the screen (e.g., ‘ant’).
**Figure 15.** Sunny and Rainy Scotland Game

**Australia.** This game (see Figure 16) builds homophone knowledge and vocabulary by targeting working memory and the automaticity of decoding skills through auditory and visual cues. For lower levels, children listened to a target word and for higher levels children listened to a sentence containing the target word (e.g., the bear left a scratch on the tree). After the auditory cue of the word or sentence was presented two homophone answer options appeared (e.g., bear and bare). This intentional delayed timing allows more time for children to catch up with the word that needs to be decoded. Children picked the word that is appropriate to the meaning of the target cue and placed it in the blue box. Once the correct word is entered the process will repeat itself for the next word.
China Game. In this game (see Figure 17), children listened to the target word with an emphasis on the first letter and a long stretched-out pronunciation of the entire word (e.g., m/a/n for man). This game targets auditory processing. The elongation of the whole word allows children to process each individual component of the word and then, to formulate the target word. After the target word is presented aurally, four words appear on the screen, one of which is the correct target word (e.g., man, nan, fan, and pan). Children clicked on the correct option out of the four and then, dragged the answer into the rectangular response box. The process was repeated with a new target word once the correct word is dragged into the response box.
**Holland Game.** This game (see Figure 18) targets working memory, coding, decoding, and comprehension. At the first level of the game, a target word appears on the bottom of the screen. Children were required to find the pig Latin word floating on the balloons displayed on the screen (e.g., ‘the’ for target word ‘heta’) and then, move it onto the response line displayed above. At higher levels, children were required to decode the pig Latin word. For example, if a pig Latin word such as ‘oatba’ is presented then, they need to drop the ‘a’ from the end of the word and move the ‘b’ to the front of the word, producing the correct word ‘boat.’ Initial levels started with two words and then, higher levels increased in difficulty by presenting sentences with less time. Answers were presented several times at the beginning.
Figure 18. Holland Game
Appendix B. Fluency Practice (Weeks 2 - 12 of Intervention)

After 9 sessions of the cognitive therapy component of the program children engaged in fluency practice (see Figure 19 and Table 1). A story was shown in the screen. Children clicked the start button when they were ready to read the story. Then, they read the story for one minute and clicked on the last word they read when the one-minute timer was done. Their score was the number of words read per minute. Children read the same story for five days and click on the last word they have read to indicate their progress each day. Every sixth day a new story is presented.

Figure 19. Fluency Practice
Birthday Surprise

Almost every day for as long I can remember, I have asked my mom and dad if we can get a puppy. Every time I asked them, they've said "Maybe sometime in the future, but not right now."

On the morning of my 10th birthday, my mom said, "Come on, Caroline, get in the car. We have a birthday surprise for you."

I was so excited to see my surprise, I jumped in the car right away. Mom and Dad drove for about 15 minutes until we arrived at the pet store near my house. I was really hoping that we were getting a puppy, but I didn't want to get my hopes up just yet.

We walked in the front doors, Mom and Dad led me past the fish, then the hamsters, then the lizards, all the way to the back of the store. Behind glass walls, I could see five little puppies running around and
Appendix C. Reading Exercises (Weeks 3 - 13 of Intervention)

The reading exercises were available to children only after they had completed the entire Cognitive Therapy component of the program, that is, from Week 3 to Week 13. This portion of the intervention involved two different types of activities, namely reading comprehension and practice reading (see Table 20 for list of skills targeted). Children completed the reading comprehension and practice reading exercises on alternate days. For example, on Day 1, 3 and 5 a student completed reading stories with comprehension exercises and on Day 2 and 4 the same student completed practice reading stories aloud. Children can view their scores on a graph after they have completed the reading exercises (See Figure 20).

Figure 20. Individual Student Progress

Reading Comprehension

During the reading comprehension exercise, children were presented with stories tailored
to their reading level that they read at their own pace. Then, children answered multiple choice questions with three answer options about the story they read. Children were required to indicate one response for each multiple-choice question before the intervention allowed them to proceed to the next activity. Their performance was saved so that once all questions were answered children had the option to review the correct answers for additional feedback (see Figure 21).

**Figure 21. Reading Comprehension Exercises**

![Reading Comprehension Exercises](image)

**Reading Exercises**

The goal of the reading exercises (see Figure 22) was to build on the reading skills the children picked up on during earlier parts of this intervention. This exercise required the children to click on the timer on the computer screen and read the story for 10 minutes out loud. If children finished before 10 minutes, they could click on the next button to proceed to the next activity.
Figure 22. Reading Exercises

Cognitive Memory Games

Two cognitive memory games are played before and after each reading exercise. The purpose of these games is to keep children motivated to read by providing instruction in game format.

The Pathfinder game (see Figure 23) showed a trail of arrows that children clicked on to indicate the correct number of arrows required by the character to get to the end of the trail displayed on the computer screen. The main purpose of these games is to reward children by acting as positive reinforcement for reading.
For the **Memory Cards** game (see Figure 24), children clicked on cards until they found the correct matching pairs for each character. For initial levels, children are required to match two cards at a time. For higher levels, children are required to find three matching cards.
For the **Silly Machine** game, children saw a machine displayed on their screen that eats letters and spits out jumbled words (see Figure 25). Above the machine there were four clouds with only one of them containing the target word. Children were required to find the correct word that the jumbled letters represent and match it to one of the four clouds displayed on the screen. The aim of Silly Machine is to allow children to prevent them from using guessing strategies, instead encouraging them evaluate individual letters in each word.
The Colour Hopper game targets children’s working memory because it required children to remember the sequence of colours that light up in the correct order. These strings of colours activate with a sound. The strings begin with 1 and can go up to a series of 15 depending on the children’s performance (See Figure 26).
In the **Wordbuilder Holland** game, a core word was presented and then, children were asked to find as many words as possible that they could using the core word. For example, if the core word was ‘some’ then children can construct words like ‘somebody’ and ‘awesome’. This game aims to target children’ spelling skills (See Figure 27).
Figure 27. Cognitive Memory Games – Wordbuilder Holland
### Table 16. Skills practiced during Reading Exercise Activities in Neuralign© Intervention

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<thead>
<tr>
<th>Target Skill</th>
<th>Reading Exercise Activities</th>
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<td>Reading Speed</td>
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<tr>
<td>Comprehension</td>
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<tr>
<td>Working Memory</td>
<td>√</td>
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<tr>
<td>Decoding</td>
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### Appendix D. Independent Samples T-Test (Comparison Between groups at Pre-test)

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<td>0.06</td>
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**Note.** *p <= .05.* There were no significant differences for t-test for equality of means on any of the tests which indicates that the mean on T1 measures is not significantly different for those in the intervention vs waitlist control group. Therefore, there were no group differences at baseline for the measures of interest that were used in the analyses.
### Appendix E. Correlations among Pre-test (Time 1) Measures

Table 17. Correlations among Pre-test (Time 1) Measures (N = 58)

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*Note.* †p ≤ .10, *p ≤ .05, **p < .01, ***p < .001.
### Table 18. Descriptive Statistics at Pre-test and Post-test (Raw Scores)

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<th>Measures</th>
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<th>Time 2 (n = 50)</th>
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Note: During Time 1 (pre-test) number line task replaced (n = 25) applied problems (n = 32) because of time constraints. RAN stands for rapid automatized naming. Internal reliability was calculated using Cronbach’s alpha for each measure.
Appendix G. Survey Questions

Table 19. *Neuralign® Star Game Rating Survey*

Children were shown pictures of each game for questions 1 to 15 to remind them of the context:

1. Rate Mosaics
2. Rate Bees
3. Rate Pinball
4. Rate Egypt
5. Rate Sunny Scotland
6. Rate Rainy Scotland
7. Rate Australia
8. Rate China
9. Rate Holland
10. Rate Word Finder
11. Rate Path Finder
12. Rate Memory Cards
13. Rate Silly Machine
14. Rate Colour Hopper
15. Rate Wordbuilder Holland
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:* The five-point star scale categories for questions 1 to 15 were ‘don’t like very much’, ‘don’t like’, ‘neither like nor dislike’, ‘like’, and ‘like very much’. Questions 16 to 23 were open-ended.
Appendix H. Student Ratings for Neuralign© Games

Figure 28. Mean Student Star Ratings for Neuralign© 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) like very much. The number of responses varied depending which games the student had played ($n = 13$ to $18$). The error bar are based on values from the standard error of the mean.