DEPARTMENT OF PSYCHOLOGY

COMPUTER-BASED REMEDIATION FOR READING DIFFICULTIES IN A CONSISTENT ORTHOGRAPHY: COMPARING THE EFFECTS OF TWO THEORY-DRIVEN PROGRAMS

DOCTOR OF PHILOSOPHY DISSERTATION

KTISTI CHRISTIANA

2015

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KTISTI CHRISTIANA

A Dissertation

Submitted to the University of Cyprus

in Partial Fulfillment of the Requirements

for the Degree of Doctor of Philosophy

April 2015

VALIDATION PAGE

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Doctoral Thesis Title: Computer-based remediation for reading difficulties in a consistent orthography: Comparing the effects of two theory-driven programs.

"The present Doctoral Dissertation was submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the Department of Psychology and was approved on the 29 April 2015 by the members of the Examination Committee."

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The present doctoral dissertation was submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy of the University of Cyprus. It is a product of original work of my own, unless otherwise mentioned through references, notes, or any other statements.

Christiana Ktisti

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ΠΕΡΙΛΗΨΗ

Η πρώιμη παρέμβαση των δυσκολιών ανάγνωσης είναι επιθυμητή τόσο από τους γονείς όσο και από τους εκπαιδευτικούς. Παρά την πρόοδο στην επιστήμη της παρέμβασης των αναγνωστικών δυσκολιών, εξακολουθεί να υπάρχει ένα μικρό ποσοστό μαθητών που, αν και έχει δεχτεί παρεμβάσεις, αδυνατεί να σημειώσει την αναμενόμενη πρόοδο όσον αφορά στις αναγνωστικές δεξιότητες. Παρά το γεγονός ότι οι φτωχοί αναγνώστες αποκωδικοποιούν επαρκώς, εμφανίζουν δυσκολίες στην αναγνωστική ευχέρεια, ιδιαίτερα σε γλώσσες με διάφανο ορθογραφικό σύστημα, όπως η ελληνική, που χαρακτηρίζεται από ορθογραφική συνέπεια και κανονικότητα (Padeliadu, Sideridis, & Rothou, 2014). Σκοπός της παρούσας έρευνας είναι να συγκρίνει δύο παρεμβατικά προγράμματα, ένα γραφο-φωνημικό, το Graphogame (Lyytinen, Erskine, Kujala, Ojanen, & Richardson, 2009), με ένα γνωστικό, το PREP (Papadopoulos, Das, Parrila, & Kirby, 2003), ως προς την αποτελεσματικότητά τους για την ενδυνάμωση της αναγνωστικής επίδοσης στην πρώιμη σχολική ηλικία.

Για τους σκοπούς της έρευνας, έγινε η προσαρμογή στην ελληνική γλώσσα και η πιλοτική εφαρμογή του Graphogame ως ένα διαδικτυακό πρόγραμμα παρέμβασης, καθώς επίσης ο σχεδιασμός και η ανάπτυξη της ηλεκτρονικής εφαρμογής του προγράμματος PREP. Συγκεκριμένα, το Graphogame αναπτύχθηκε αρχικά στη φιλανδική γλώσσα για παιδιά με μαθησιακές δυσκολίες ή με ρίσκο για εμφάνιση δυσλεξίας και επικεντρώνεται στην ανάπτυξη των δεξιοτήτων ανάγνωσης, δίνοντας έμφαση στην εξάσκηση των δεξιοτήτων φωνολογικής επεξεργασίας. Το PREP αναπτύχθηκε ως ένα γνωστικό πρόγραμμα και στηρίζεται στη θεωρία PASS (Planning, Attention, Simultaneous and Successive processing) (Das, Naglieri, & Kirby, 1994). Επικεντρώνεται στην βελτίωση των δεξιοτήτων επεξεργασίας πληροφοριών, δηλαδή της διαδοχικής-σειριακής και ταυτόχρονης-παράλληλης επεξεργασίας, οι οποίες υποστηρίζουν το έργο της ανάγνωσης.

Στην έρευνα συμμετείχαν 56 ελληνόφωνα παιδιά με αναγνωστικές δυσκολίες, ηλικίας 6-7 ετών, τα οποία έλαβαν για 4 εβδομάδες φωνολογική ή γνωστική παρέμβαση ή συνδυασμό των δύο. Χωρίστηκαν σε 4 ομάδες (n=14 σε κάθε ομάδα) με τη μέθοδο της τυχαίας κατανομής. Επίσης, στην έρευνα συμμετείχε και μία ομάδα ελέγχου (n=17), χωρίς δυσκολίες ανάγνωσης. Οι πειραματικές ομάδες εξετάστηκαν σε διάφορες δεξιότητες πριν, κατά τη διάρκεια, στο πέρας της παρέμβασης και ένα χρόνο μετά και οι επιδόσεις τους συγκρίθηκαν με αυτές της ομάδας ελέγχου. Παράλληλα,

εφαρμόστηκε μικρογενετική ανάλυση, για να εξεταστεί πώς συντελείται η μάθηση σε κάθε συμμετέχοντα και να διερευνηθούν τα αναπτυξιακά στάδια των αναγνωστών κατά τη διάρκεια της παρέμβασης, με την ανάλυση των ηλεκτρονικών τους πρωτοκόλλων.

Οι αναλύσεις διακύμανσης έδειξαν ότι όλες οι ομάδες βελτιώθηκαν σημαντικά σε φωνολογικές, γνωστικές, αναγνωστικές, ορθογραφικές δεξιότητες και σε δεξιότητες γρήγορης ονομασίας ερεθισμάτων, με το πέρασμα του χρόνου. Η ανάπτυξη σε αυτές τις ικανότητες ήταν συγκρίσιμη με την ανάπτυξη που παρατηρήθηκε στην ομάδα ελέγχου, μετά τον έλεγχο της αρχικής τους βαθμολογίας (T1), και ήταν πιο ταχεία από αυτή που αναμενόταν. Δε βρέθηκαν στατιστικά σημαντικές διαφορές ανάμεσα στις πειραματικές ομάδες παρόλο που οι ομάδες έδειξαν κάποιες ξεκάθαρες τάσεις από την παρέμβαση. Τα αποτελέσματα συμφωνούν με τα ευρήματα προηγούμενων ερευνών που αποδεικνύουν ότι τόσο η εντατική γνωστική παρέμβαση (Papadopoulos et al., 2003), όσο και η εντατική γραφο-φωνημική παρέμβαση (Lyytinen & Richardson, 2013) είναι αποτελεσματικές για την πρώιμη αντιμετώπιση των αναγνωστικών δυσκολιών. Το νέο και ενδιαφέρον εύρημα είναι ότι η βελτίωση στις αναγνωστικές δεξιότητες παρατηρείται επίσης, όταν συνδυάζονται τα δύο είδη παρεμβάσεων. Η συζήτηση επικεντρώνεται στην ανάγκη για δημιουργία παρεμβατικών προγραμμάτων που θα έχουν θεωρητικό και ερευνητικό υπόβαθρο, εάν θέλουμε να επιτύχουμε ισχυρές επιδράσεις στο χώρο του αλφαβητισμού (Kearns & Fuchs, 2013).

ABSTRACT

Early remediation of reading difficulties is desired by both parents and teachers. Despite advances in the science of reading intervention, there still exists a small percentage of students who fail to make the expected progress in reading-related skills, notwithstanding attempts at intervention. Even if these struggling readers learn to decode adequately, fluency remains a problem for many, particularly in transparent orthographies, such as Greek, that is characterized by orthographic consistency and regularity (Padeliadu, Sideridis, & Rothou, 2014). This study aimed to compare a grapho-phonemic remediation program, the Graphogame (Lyytinen, Erskine, Kujala, Ojanen, & Richardson, 2009), with a cognitive program, the PREP: PASS Reading Enhancement Program (Papadopoulos, Das, Parrila, & Kirby, 2003), for the enhancement of reading performance in early school years. For the purposes of the study, Graphogame was adapted and piloted in Greek as a web-based intervention, and an electronic version of the PREP program was designed and developed.

Specifically, Graphogame has been originally developed in the Finnish language for children with learning disabilities and risk for dyslexia and it focuses on learning the connections between spoken and written language. The PREP program, in turn, has been developed as a cognitive remedial program based on the PASS (Planning, Attention, Simultaneous and Successive processing) model of cognitive functioning (Das, Naglieri, & Kirby, 1994a) aiming at improving selected aspects of children's information-processing skills and increasing their word reading and decoding abilities.

A group of 56 Greek-speaking children with RD, aged 6-7, were assigned to 4-week intervention focusing on cognitive (PREP) or phone-code (Graphogame, GG) training or the two combined (PREP-to-GG or GG-to-PREP). Children were divided into four experimental groups following a randomized control trial design. Also, a chronological age control group (n=17) participated in the study. Experimental and control groups were compared on multiple skills, before, during, and after treatment as well as at a follow-up a year later. A microgenetic design was also implemented to examine the learning progress dynamics and the developmental stages of the readers during intervention, by analyzing participants' computer protocols.

Analyses of covariance revealed that all experimental groups showed sizable improvements in phonological, naming, cognitive, reading, and orthographic processing skills over time. The development in these abilities was comparable to the development seen in the CA-C group, after controlling for their initial score, which was far faster than what would be expected over participants' school careers. No significant differences of the type of treatment were found, although experimental groups showed some clear trends towards intervention. The results are consistent with the findings of previous studies demonstrating that both an intensive cognitive intervention (Papadopoulos et al., 2003) as well as an intensive grapho-phonemic intervention (Lyytinen & Richardson, 2013) hold promise for improving students' word reading performance early on. The new and interesting finding is that this improvement is also observed when the two types of interventions are delivered in combination. Discussion focuses on the need for devising remedial schemes that will be both theoretically driven and cost-effective, if we wish to determine strong effects on literacy (Kearns & Fuchs, 2013).

To my family

ACKNOWLEDGMENTS

I would like to express my special appreciation and thanks to my supervisor, Professor Dr. Timothy C. Papadopoulos, for being a tremendous mentor for me. I am thankful for encouraging my research and for his aspiring guidance, invaluably constructive criticism and friendly advice during the whole process. His advice on both research as well as on my career has been priceless.

I express my warm thanks to my committee members, Dr. Fofi Constantinidou, Dr. Timotheos C. Papadopoulos, Dr. George Spanoudis, Dr. Ulla Richardson, and Dr. Susana Padeliadu, for serving as my committee members. I also want to thank them for letting my defense be an enjoyable moment, and for their brilliant comments and suggestions.

I would especially like to thank the Agora Center from the University of Jyväskylä and the Graphogame team led by Professors Dr. Heikki Lyytinen and Dr. Ulla Richardson for consent to include Graphogame as a part of my Thesis and for their help and guidance during Graphogame adaptation.

I would like to pay my appreciation to Dr. Christoforos Christoforou and Maria Loizou, for their valuable help and support throughout the course of this Thesis. Special thanks to the research assistants and special education teachers who helped with the administration of the assessment tests and intervention programs.

Words cannot express how grateful I am to my family, to whom this dissertation is dedicated to, for all of the sacrifices they have made on my behalf. My family has been a constant source of love, concern, support and strength all these years. They supported me in writing and incented me to strive towards my goal.

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CHAPTER 1

INTRODUCTION: LITERATURE REVIEW

Despite a number of successful early remediation programs, a percentage of students continue to experience difficulties in reading-related skills, notwithstanding attempts at intervention. Even if these struggling readers learn to decode adequately, fluency remains a problem for many, particularly in languages with a transparent orthography, such as Greek. This study aims to use a randomized experimental design to test the efficacy of a grapho-phonemic versus a cognitive intervention program on word reading fluency and accuracy, spelling, and reading-comprehension outcomes in a group of readers with reading difficulties identified as early as in Grade 1. The section that follows on literature review (a) defines specific reading disability and dyslexia, (b) summarizes the most recent findings on early correlates of reading development, (c) examines the concurrent and longitudinal predictors of word decoding and reading fluency in children learning to read in languages varying in orthographic consistency and (d) outlines the rationale and principles for designing and implementing two theory-driven first-grade reading interventions that aim to improve the necessary cognitive and linguistic skills for successful reading to young poor readers. These reviews are followed by the methodology and the specific aims and hypotheses of the present study.

Specific Reading Disability

It is widely accepted that one in five children has trouble learning to read and spell in spite of having normal intelligence, adequate instruction, no emotional disturbances, no neurological or sensory deficits (Vellutino, Fletcher, Snowling, & Scanlon, 2004). The question of why some children experience such difficulties has been the focus of a great deal of research over the past four decades. Such children have extreme difficulties with accurate and/or fluent word identification, poor spelling and phonological decoding, that is in acquiring basic reading subskills (Lyon, Shaywitz, & Shaywitz, 2003). These difficulties tend to be accompanied by specific deficits in cognitive abilities related to reading and other literacy skills. This symptom pattern is often called “dyslexia” or “specific reading disability” (Vellutino et al., 2004).

Dyslexia is considered by many as a specific learning disability whose prevalence rates range from 5% to 10%, depending on the primary language spoken in a population and the criteria used to identify the disorder (Anthony & Francis, 2005). Dyslexia initially manifests itself by difficulty in manipulating the sounds of speech and the rapid naming of stimuli and later by problems in learning to read and erratic spelling (Grigorenko, 2001; Papadopoulos, Georgiou, & Kendeou, 2009a; Wolf & Bowers, 1999). These difficulties may result from a deficit in the phonological component of language (Lyon et al., 2003) or from a deficit in rapid naming performance (Georgiou, Parrila, & Kirby, 2006). Difficulties in learning to read could also result from specific deficiencies in reading-related cognitive abilities, such as working memory deficits (Baddeley, 1999; Papadopoulos, Charalambous, Kanari, Loizou, 2004; Swanson, Cooney, & McNamara, 2004). Das, Mok, and Mishra, (1993) demonstrated that the phonological mechanisms in working memory are closely related to reading and reading disability. Information processing deficits also provide a broader theoretical approach to the explanation of reading difficulties. Specifically, successive and simultaneous processing seems to be more strongly related to poor reading and dyslexia (Papadopoulos, Georgiou, & Douklias, 2009b). The current experiment is concerned with the study and remediation of all these skills in a group of young readers in Grade 1.

Cognitive and Linguistic Correlates of Early Reading Development

Learning to read is a considerable educational milestone in our literate society. Children who read early and proficiently experience more print exposure and consequent growth in several knowledge domains (Cunningham & Stanovich, 1997). Therefore, it is important to understand the processes involved in early reading acquisition. A diverse body of research indicates that reading acquisition requires various critical component skills, such as phonological processing abilities, rapid naming speed, speech rate, and efficient working memory (Das, Mishra, & Kirby, 1994b; Nikolopoulos, Goulandris, Hulme, Snowling, 2006), which, themselves, depend on normal development of reading-related linguistic (e.g., phonological skills) and non-linguistic cognitive abilities (e.g., information processing) (Anthony et. al., 2002).

Reading is a complicated process that depends on the development of decoding and comprehension, each of which depends on different underlying skills and abilities

(McNamara & Kendeou, 2011). The relation between these two sets of skills is expressed in various models and most succinctly within the Simple View of Reading (Gough & Tunmer, 1986; Kirby & Savage, 2008). However, word decoding has been the main focus in theoretical approaches to literacy skill development for many years because of its critical role in early reading acquisition (e.g., Adams, 1990; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Rayner & Pollatsek, 1989). More recently, research also focuses on the importance of reading comprehension on the initial stages of reading acquisition (Kendeou, Papadopoulos, & Spanoudis, 2012; Kendeou, van den Broek, White, & Lynch, 2009; Lonigan, Burgess, & Anthony, 2000), examining comprehension as a core competency along with decoding for the early reading process. As a result, there are two forms of reading disorders: difficulties with decoding and difficulties with comprehension (Cain, 2010; Hulme & Snowling, 2009; Papadopoulos, Kendeou, & Shiakalli, 2014). These different reading disorders have different causes and require different treatments (Snowling & Hulme, 2012). The present thesis focuses on the former disorder.

When a beginning reader has to read a previously unseen word, he or she is faced with at least five tasks that must be undertaken in order to recognize the word. First, the letters of the word have to be recognized and differentiated from their visually confusing neighbors (e.g., b-d, g-q-p, m-n, E-F, V-Y). Second, the sounds of the letters or letter combinations must be retrieved and differentiated from their phonetically confusing neighbors (/g/-/k/, /b/-/p/, /t/-/d/, /s/-/z/). Third, all phonemes must be stored in working memory in the same order as they are presented in the word. Fourth, the group of phonemes in working memory has to be blended together to form a phonological representation of the word. Fifth, this phonological representation of the word must be used to gain access to the lexicon (Papadopoulos, 2002).

A beginning reader will require the use of both *proximal* and *distal* cognitive processes, and also the necessary knowledge base, to accomplish these five tasks and achieve word reading. The necessary knowledge base consists of two components: a) knowledge of letters/letter combinations and the sounds they make, and b) underlying cognitive processes that are important to the understanding of mental functioning (e.g., as a proper state of arousal that provides the opportunity for learning, and coding and planning that interact to perform various acts and facilitate acquisition of knowledge). The *proximal cognitive processes* are the mostly linguistic skills that are directly related to all the aforementioned tasks (Das, Parrila, & Papadopoulos, 2000). The most frequently recognized proximal processes in word reading are phonological processes, namely the cognitive processes that deal with the sound structure of the spoken language, and orthographic processes, defined as the ability to represent the unique array of letters that defines a printed word (Vellutino, Scanlon, & Tanzman, 1998). The *distal cognitive processes*, such as planning, attention, simultaneous processing and successive processing, are more general and modality unspecific underlying cognitive processes. These processes enable the development and employment of proximal processes. The influence that distal cognitive processes have on reading is not necessarily direct but can be mediated by proximal processes (Papadopoulos, 2002). For example, the effects of successive processing on word reading are primarily mediated by phonological processing, and the effects of simultaneous processing on reading are mediated by visual and orthographic processing skills (Papadopoulos, Ktisti, Chistoforou, & Loizou, 2015).

Although research on reading has been dominated by the study of the English language (Share, 2008), there is a general consensus that skills such as the preceding act as predictors of reading skill across different language systems (Ziegler et al., 2010). By implication, deficits in these component reading skills lead to the diagnosis of reading difficulties as a specific learning disorder, as described in the DSM-5 (APA, 2013). Consequently, an understanding of these component reading skills is essential to ensure that children's reading difficulties are identified early, and that timely interventions are put in place. A short description of the proximal and distal cognitive processes to reading follows next.

Proximal Cognitive Processes to Reading

Alphabet knowledge and letter identification

Linguistic and visual coding processes facilitate the establishment of firm associations among the spoken and written components of printed words in ways that help the child acquire a sight word vocabulary. Sight word learning depends on children's understanding of print concepts and conventions, such as that written words represent words in spoken language, that words are consisted of letters, that they are processed from left to right in alphabetic languages (Vellutino et al., 2004). Vital to this learning process is children's ability to understand and use functionally the alphabetic principle, that is to understand that letters and combinations of letters are the symbols used to represent the speech sounds of a language based on systematic and predictable relationships between written letters, symbols, and spoken words. Alphabetic principle is essential for acquiring proficiency in phonological decoding (Suggate, 2010). Phonological decoding (i.e. the process of transforming the letters of a word into the speech sounds of a language) and word recognition depend on children's phonological awareness (i.e. awareness of sounds in words), phonemic awareness (i.e. awareness of phonemes in words; Papadopoulos, Spanoudis, & Kendeou, 2009), alphabetic knowledge (Schneider, Roth, & Ennemoser, 2000), and vocabulary (Snow, Burns, & Griffin, 1998).

Alphabet knowledge refers to children's ability to understand both the letter-name and letter-sound (Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998), and predicts reading achievement in non-transparent orthographies (Caravolas, Hulme, & Snowling, 2001). Letter-name knowledge at kindergarten has been found to be a strong predictor of learning to read (Caravolas et al., 2001; Naslund & Schneider, 1996). Similarly, letter-sound knowledge, that is the ability to comprehend that letters stand for phonemes in print and to map the letters to their associated sounds, is widely acknowledged as necessary for acquiring the alphabetic principle (Byrne, 1998). Studies with English-speaking children have demonstrated that kindergarten children know the names of the letters better than their sounds and that letter-name knowledge seems to enhance children's letter sound learning (Evans, Bell, Shaw, Moretti, & Page, 2006; Foulin, 2005; McBride-Chang, 1999). However, in transparent orthographies kindergarten children achieve higher scores on letter-sound knowledge than on letter-name knowledge (Levin, Shatil-Carmon, & Asif-Rave, 2006; Manolitsis, Georgiou, Stephenson, & Parrila, 2009; Tafa & Manolitsis, 2008). Manolitsis and Tafa (2009) reported that letter knowledge seemed to correlate satisfactorily with phonological awareness skills. Specifically, the authors found that phonological awareness directly predicted children's letter knowledge by the end of kindergarten. Phonological awareness in combination with letter-sound knowledge seems to be an effective strategy for helping young children grasp the alphabetic principle (Bus & van IJzendoorn, 1999; Schneider et al., 2000). For the purpose of this study we investigated whether young readers varying in reading ability in Greek encountered difficulties in letter identification and in understanding the alphabetic principle. We also examined whether grapho-phonemic or cognitive training for reading disabilities can help to ameliorate such skills.

Phonological Awareness

There is a great body of research showing that acquisition of facility in alphabetic mapping depends, partly, on the acquisition of phonological awareness (Caravolas, Vólin, & Hulme, 2005; Parrila, Kirby, & McQuarrie, 2004). Phonological awareness refers to conceptual understanding and explicit awareness that spoken words are comprised of individual speech sounds (phonemes) and combinations of speech sounds (syllables, onset-rime units). Such knowledge is critical for learning that letters carry sound values and for learning to map alphabetic symbols to sounds.

Phonological awareness is measured at the syllabic and phonemic level, by tasks that require children to identify, isolate, or blend the individual phonemes or syllables in words. These tasks vary in difficulty and the level of phonological awareness assessed. In English, at the beginning level, phonological awareness is frequently assessed by tasks that involve rhyme, alliteration detection, and sound categorization. These tasks, together with tasks that include syllable manipulation in words (i.e. syllable completion and syllable segmentation) are too easy for Grade 1 students in transparent orthographies. More difficult measures of phonological awareness involve manipulation of phonemes. More complex tasks create variability in readers in transparent orthographies. Such measures include phoneme deletion, phoneme counting, phoneme blending, phoneme reversal, and spoonerisms (Anthony & Lonigan, 2004; Papadopoulos, Kendeou, & Spanoudis, 2012).

Some researchers suggest that phonological awareness contributes directly to alphabetic literacy achievement (e.g., Tunmer, Herriman, & Nesdale, 1988) and that alphabetic literacy stimulates phonological awareness (Mann & Wimmer, 2002). Some others propose that phonological awareness is a by-product of alphabetic literacy learning (Castles & Coltheart, 2004; Morais, 2003). Other researchers suggest that phonological awareness precedes reading (Lundberg, Frost, & Petersen, 1988; Muter, Hulme, Snowling, & Stevenson, 2004). There are also findings that support the view that fine-grained awareness of the sound structure of words typically develops in parallel with reading instruction (Lonigan et al., 2000; Ziegler & Goswami, 2005). In English, prior to reading instruction, children frequently develop awareness of rhyme and alliteration, but phoneme awareness can only be developed as a consequence of reading (Muter et al., 2004). In contrast, in Greek language, children demonstrate syllabic skills during kindergarten, while phonemic sensitivity develops gradually from kindergarten to Grade 1. Phoneme sensitivity in Greek begins to develop at 5-years old, before the beginning of formal instruction (Papadopoulos et al., 2009c, 2012), as opposed to what earlier research has supported for languages with transparent orthographies (e.g., Aidinis & Nunes, 2001; de Jong & van den Leij, 1999).

The association between phonological awareness and reading development is well established in children learning to read in English (e.g., Bowey, 2005) as well as in Greek (e.g., Manolitsis & Tafa, 2009; Nikolopoulos et al., 2006; Papadopoulos et al., 2012; Rothou, Padeliadu, & Sideridis, 2013) and in cross-linguistic comparisons (Georgiou et al., 2008). Several studies conducted with English-speaking children have shown that phonological awareness measured prior to or at the beginning of reading instruction predicts successfully reading acquisition in later years (Kirby, Parrila, & Pfeiffer, 2003; Manis, Doi, & Bhadha, 2000; Parrila et al., 2004). For example, Parrila et al. (2004) found that phonological awareness, measured in Grade 1, was the strongest predictor of reading performance in Grade 3. They also reported that phonological awareness, measured in kindergarten and Grade 1, accounted for unique variance in all reading measures. Likewise, Kirby et al. (2003) demonstrated that phonological awareness measured in kindergarten was a strong predictor of reading performance in Grade 1 and Grade 2.

In addition to serving as a predictor variable of reading performance, phonological awareness difficulties co-exist in children with reading disabilities (Blachman, 2000; Snowling, 2003). For example, Juel (1988) examined the reading development of 54 children from Grade 1 to Grade 4, and found that poor readers at the end of Grade 4 entered Grade 1 with phonological awareness deficits. Ramus, Pidgeon, and Frith (2003) also demonstrated that children with dyslexia exhibit deficits in phonological awareness, in comparison to their normally developing peers. Similarly, Swan and Goswami (1997) assessed the performance of 15 dyslexic children, 15 reading age-matched controls and 15 chronologically age-matched controls on various literacy skills, and they reported that dyslexic children were significantly poorer than any of the other two groups on phonological awareness tasks.

Deficits in phonological awareness have also been reported in studies with consistent orthographies, such as Czech (e.g., Caravolas et al., 2005), Dutch (e.g., de Jong, 2003), Hebrew (e.g., Share, 2003), Greek (e.g., Papadopoulos et al., 2004; Porpodas, 1999), Finnish (e.g., Puolakanaho, Poikkeus, Ahonen, Tolvaven, & Lyytinen, 2004), Spanish (e.g., Jiménez, 2012), Italian (e.g., Brizzolara, Chilosi, Cipriani, Filippo, & Gasperini, 2006), and Arabic (e.g., Abu-Rabia, Share, & Mansour, 2003). A transparent orthography is based on consistent one-to-one mappings between graphemes and phonemes, while a non-transparent orthography contains orthographic inconsistencies and complexities, such as multi-letter graphemes, context dependent rules, irregularities, and morphological effects (Seymour, Aro, & Erskine, 2003). The studies mentioned above have shown that phonological awareness predicts variations in reading skill in regular orthographies. Nevertheless, there are studies that have challenged the importance of phonological deficits in children with reading difficulties learning to read in consistent orthographies (e.g., de Jong & Van der Leij, 2003; Wimmer, 1993). These researchers have argued that the effect of consistent spelling-sound correspondences in consistent orthographies is sufficiently powerful to secure children's phonological ability, at least after the first few years of schooling or until the age of 9 (see also Kirby et al., 2003; Papadopoulos et al., 2009a; and Torppa et al., 2013 for a similar discussion).

Ziegler and Goswami (2005) demonstrated that phonological awareness tasks may be easier for struggling readers in transparent orthographies, since there is little pronunciation ambiguity and children receive consistent feedback from the effect of consistent spelling-sound correspondences (Share, 1995). Seymour et al. (2003) suggest that the consistent feedback together with systematic phonics instruction facilitates the development of phonological awareness. In contrast, English is regarded as a deep orthography containing many inconsistencies and complexities, and therefore, the development of phonological awareness is much more complex. Normally achieving readers in consistent orthographies, such as Greek, develop phonological awareness more rapidly compared to readers in English. Greek is a transparent orthography in which the mapping between letters and sounds is relatively direct and unambiguous (Protopapas & Vlahou, 2009). This may explain why struggling readers in transparent orthographies manage to overcome their phonological awareness deficits by Grade 2 and gradually find means to compensate for poor reading performance (Papadopoulos et al., 2009a).

Although research findings clearly demonstrate the presence of pronounced deficits in phonological awareness among English and Greek children identified as exhibiting reading difficulties, by itself the phonological-core deficit does not account for all that is known about the development of reading disabilities (Papadopoulos et al., 2009b). Other verbal abilities were also found to be strong predictors of reading outcomes, not only from kindergarten children but also from younger ages (de Jong & Olson, 2004). While the importance of phonological awareness in reading acquisition is generally acknowledged, researchers have begun to look into alternative explanations concerning other possible causes of individual differences in reading. A prominent alternative explanation maintains that individual differences in reading performance are caused by a deficit in rapid naming speed (Wolf & Bowers, 1999).

Rapid Automatized Naming

Rapid automatized naming (RAN) has been shown to be a significant predictor of both concurrent and future reading development in alphabetic (e.g., Cardoso-Martins & Pennington, 2004; Georgiou, Papadopoulos, Fella, & Parrila, 2012; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002) and non-alphabetic writing systems (e.g., Chan, Ho, Tsang, Lee, & Chung, 2003; Ho & Lai, 1999). RAN or speed of lexical access is the ability to name visually presented and highly familiar symbols, such as letters, digits, colors and objects, as fast as possible (Wagner & Torgesen, 1987). It has been shown to be a strong predictor of reading ability in both transparent (e.g., de Jong & van der Leij, 2003; Wimmer, Mayringer, & Landerl, 2000) and non-transparent orthographies (e.g., Georgiou, Parrila, & Papadopoulos, 2008; Savage & Frederickson, 2005; Wolf, Bally, & Morris, 1986). The faster the child is in naming visually presented symbols the better his/her reading performance is expected to be, at least in the case of reading fluency (Georgiou, Parrila, & Kirby, 2006). A plausible explanation for the strong naming speed – reading relationship is that the same brain systems that are involved in mapping between visual and phonological codes for stimulus naming also underlie the mapping process between printed words and their pronunciations

(Georgiou, Parrila, Cui, & Papadopoulos, 2013; for a thorough review on naming speed – reading relationship see also Kirby, Georgiou, Martinussen, & Parrila, 2010).

Rapid naming performance distinguishes average from poor readers during childhood (Badian, Duffy, Als, & McAnulty, 1991; Cornwall, 1992; Wolf et al., 1986). Furthermore, rapid naming has survived as an important predictor of reading even after statistically controlling for IQ (Cornwall, 1992), reading experience and articulation rate (Parrila et al., 2004), speed of processing (Bowey, McGuigan, & Ruschena, 2005), letter knowledge (Kirby et al., 2003), and, most importantly, phonological awareness (Kirby et al., 2003; Manis et al., 2000). Alphanumeric RAN tasks (Digit and Letter Naming) are stronger predictors of reading performance than non-alphanumeric RAN tasks (Color and Object Naming) in both transparent (Papadopoulos et al., 2009a) and non-transparent orthographies (Compton, 2003; Georgiou et al., 2006). Specifically, RAN-Digits and RAN-Letters are significant predictors of reading fluency and likely exert their influence early on in reading development, i.e. in Grades 1 and 2 (Compton, 2003; Georgiou et al., 2006; Meyer, Wood, Hart, & Felton, 1998).

Converging evidence suggests that a deficit in rapid naming performance is a characteristic of reading difficulty from the early stages of reading (Wolf & Bowers, 1999) to adulthood (Birch & Chase, 2004; Korhonen, 1995). A number of studies have demonstrated that individuals with reading difficulties are slower in performing naming tasks in both inconsistent (e.g., Cornwall, 1992; Kirby et al., 2003; Lovett, Steinbach, & Frijters, 2000) and consistent orthographies (e.g., Papadopoulos et al., 2009a; Torppa, Georgiou, Salmi, Eklund, & Lyytinen, 2012) as well as cross-linguistic comparisons (Georgiou et al., 2008), with the effects of naming speed deficits on reading increasing with grade level. Korhonen (1995) included in his study English-speaking dyslexic children from age 9 to 18 and found that the group of dyslexic children was significantly slower in rapid naming in comparison to the matched control group. Likewise, Badian et al. (1991) showed that dyslexic children and good readers differed in rapid naming. Group strengths and weaknesses were evident already in kindergarten and maintained until Grade 4. The kindergarten tasks that most successfully predicted reading differences at Grade 4 were letter sound and rapid naming. However, there are also studies that demonstrated that in English-speaking children, the contribution of naming speed appears to be time-limited and dependent on the type of naming tasks used (Letter and Digit Naming vs. Color and Object Naming), in contrast to phonological awareness which appears to remain strong through elementary school (Compton, 2003; Georgiou et al., 2006).

With regard to the findings from consistent orthographies, several studies have suggested that naming speed plays a more important role than phonological awareness in predicting reading development from Grade 2 onward (i.e. Papadopoulos et al., 2009a). For example, de Jong and van der Leij (1999) showed that when phonological awareness, verbal short-term memory, and naming speed were measured in kindergarten in Dutch, only naming speed was an important predictor of Grade 1 and Grade 2 reading achievement. From Grade 1 onward, naming speed had an independent influence on further reading development. Similarly, Wimmer et al. (2000) found that German-speaking Austrian children, classified as experiencing difficulties with naming speed when they entered school, continued to have naming speed deficits at the end of Grade 3. In addition, these children had deficits in reading speed, i.e. in reading fluency, in comparison to children with no naming speed deficit. In the same study, children with a phonological deficit exhibited a reliable reading rate deficit for text only and showed no rate deficit at all for non-word reading. They also showed high phonological coding accuracy and high scores on phoneme segmentation tasks at the end of Grade 3. Deficit groups showed close to ceiling accuracy for text, word reading, and even non-word reading.

Also, Georgiou et al. (2008) examining the cognitive and linguistic predictors of early reading in typical Greek and English Grade 1 and 2 readers found that RAN-Digits and RAN-Colors were stronger predictors of word decoding and reading fluency in Grade 1 in Greek than in English. In English, the most significant predictors of word decoding are phonological awareness and orthographic processing.

In turn, Papadopoulos et al. (2009a) have reported the presence of pronounced deficits in both phonological ability and naming speed in Greek children with reading difficulties. However, the authors suggest that, even before formal reading instruction begins, problems in languages with consistent orthographies are manifested as difficulties in naming speed and not as deficits in phonological ability. Specifically, they suggest that in kindergarten, the deficits appear to be specified in the process of naming speed. A year later in Grade 1, naming speed is not as important as phonological awareness in the process of reading, most likely because formal reading instruction is under way. However, in Grade 2, naming speed is strongly associated with impairments in reading fluency and reading comprehension. The regular structure of the Greek language is responsible for the most persistent nature of naming deficits compared to the nature of phonological deficits in children with reading difficulties in early years.

Taken together, this section talks about naming speed and its relation to reading fluency and accuracy, and how it differs from phonological awareness in English and Greek. These results suggest that although both naming speed and phonological awareness are significant predictors of early reading in both languages, they seem to account for different amounts of variance at different points of development. For example, phonological awareness is important in the first couple of years in Greek, when reading is formally taught, and its effects fade out by Grade 2, when naming speed becomes more important (Rothou & Padeliadu, 2014; Wimmer et al., 2000). As a result, due to the regular structure of the Greek language, naming speed deficits are more persistent than phonological deficits among children experiencing reading difficulties in early years, as opposed to what the English literature supports where both phonological awareness and naming speed are equally important. Based on these findings, it is of great importance to test these relationships longitudinally to get a clear picture of the significance and the role of these deficits over time. To date, the majority of the research on reading has accumulated little evidence from longitudinal studies (Vukovic & Siegel, 2006). The present study examined the contribution of phonological skills and rapid naming speed to the definition of poor reading in Greek in Grade 1 and 2. The study also examined whether grapho-phonemic or cognitive remediation for reading difficulties could lead to significant group effects in naming speed and phonological awareness.

Distal Cognitive Processes to Reading

Working Memory

Several researchers have acknowledged that rapid naming speed and phonological awareness alone, as proximal processes to reading, cannot explain all that is known about reading acquisition and reading difficulties (Das, 1995; Share &

Stanovich, 1995). Therefore, the question is whether other fundamental, albeit distal, cognitive processes underlie phonological processing and add to the explanatory power of a model predicting reading development (Papadopoulos, 2002).

Among the various etiological cognitive predictors of reading difficulties that have been proffered over the last 30 years, memory deficits have been the most researched (Alloway, Gathercole, Adams & Willis, 2005; Friedman & Miyake, 2004; Swanson, 2015; Swanson et al., 2004). Learning to read involves memory systems and allied processes. Working memory is defined as the capacity to store information for a short period of time and manipulate or process it (Baddeley & Hitch, 1974; Gathercole, 2007). The ability to retain phonological information in working memory is an aspect of language processing that is assumed to be related to reading performance (Porpodas, 1999).

Similarly, verbal working memory (VWM) deficits, in particular, have frequently been identified as markers of reading disabilities (Papadopoulos et al., 2004; Siegel & Ryan, 1989; Spanoudis, Papadopoulos, & Spyrou, 2014). For some, these difficulties are considered as manifestations of the underlying cognitive deficits in phonology and language skills as opposed to specific problems with VWM (Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Snowling, 2003; Wagner et al., 1997). For others, they are attributed to deficits at the level of information processing, considering particularly the significance of memory span to reading and comprehension as a function of cognitive processing speed (Bisanz, Das, Varnhagen, & Henderson, 1992; Das, Mensink, & Mishra, 1990; Das, et al., 1993; Papadopoulos, 2001). On the basis of a comprehensive review of the literature, Savage, Lavers, and Pillay (2007) suggested that, in making sense of the relationship between phonological processing and WM, one needs to consider the type and demand of the task involved as well as the developmental level of children and the element of WM involved (see Anthony & Francis, 2005; Papadopoulos et al., 2012 for a similar discussion).

Das et al. (1994b) demonstrated, using tasks requiring the serial recall of words or nonsense sentences, that the phonological mechanisms in working memory are closely related to reading and reading disability. Swanson and colleagues also found that working memory plays a significant role in word reading and reading comprehension (Swanson, 2000; Swanson & Howell, 2001). Several other studies have also demonstrated that in comparison with typically developing readers, children with reading difficulties perform poorly on tasks requiring the ordered recall of spoken sentences of letters and words (Brady, 1986; Liberman, Shankweiler, & Liberman, 1989). Deficits in working memory have been associated with difficulties in the production of pronunciations for nonsense words and in word reading accuracy measures, being indicative of a deficit in the phonological system, that is responsible for the temporary storage of verbal information (Gathercole & Baddeley, 1993; Hansen & Bowey, 1994). To date, several studies are available for children with reading difficulties learning to read in Greek (e.g., Anastasiou & Protopapas, 2015; Papadopoulos, 2002; Papadopoulos et al., 2004; Papadopoulos et al., 2009b) emphasizing the important role that working memory plays in reading in early years.

To examine the contribution of working memory to reading, researchers use various tests depending on the theoretical approach applied. The most widely used tests are the sentence and counting span tests (Jarrold & Towse, 2006; Savage et al., 2007). These tests require simultaneous storage (e.g., participants have to remember from a couple to several words) and processing of information (e.g., participants have to repeat the words or digits heard in the same sequence). In the present study, both verbal (e.g., Sentence Questions) and non-verbal memory tasks (e.g., Figure Memory) were used to investigate the performance of young Greek poor readers in working memory tasks. Memory functions and, thus, memory deficits are at the heart of cognitive information processing theories, such as the PASS theory of intelligence (Das et al., 1994a; see below). Next, we present a brief account of the cognitive basis of word reading and reading difficulties in the context of the PASS theory.

Successive and Simultaneous processing, Attention and Planning

While working memory plays a significant role in reading difficulties, its influence may be too broadly interpreted (Papadopoulos, 2002). For example, not all children with reading disabilities have working memory deficits (Torgesen, Kistner, & Morgan, 1987). Also, working memory problems may be specific to tasks that require phonological coding (Share, 1995). Furthermore, how reading acquisition is specifically connected to the development of working memory is not fully understood or explained (Papadopoulos, 2002). It seems, therefore, that the search for relevant cognitive processes should include working memory and go beyond the traditional working memory paradigm.

There are also other more general and perhaps modality nonspecific underlying cognitive processes that enable the development and successful employment of proximal processes, and thus, of reading (Das et al., 2000). Das et al. (2000) have suggested that two types of cognitive processes are necessary: a) those, such as successive and simultaneous processing that contribute to the development of phonological processing and decoding of print; and b) those, such as planning and attention, which allow the successful deployment of phonological and other skills. For the scope of the present study, we utilize a rather influential model of information processing, namely the PASS (planning, attention, simultaneous, and successive) model of cognitive functioning, that includes both kinds of processes. The PASS theory of intelligence (Das et al., 1994a) is based largely on the neuropsychological work of Luria (1973, 1980). The maintenance of attention, the processing and storing of information, and the management and direction of mental activity comprise the activities of the operational units that work together to produce cognitive functioning (Das et al., 1994a). Specifically, the PASS theory of intelligence proposes that cognition is organized in three systems – namely, the planning, the attention and arousal, and the processing systems – and four processes – namely, Planning, Attention, Simultaneous and Successive processing (e.g., Naglieri & Das, 2005). Information processing deficits provide a broader theoretical approach to the explanation of reading difficulties.

In terms of the PASS theory, it is sufficient to say that of these four component skills, successive and simultaneous processing seem to be more strongly related to poor reading and dyslexia. On the one hand, successive processing refers to coding information in discrete, serial order in which the detection of one portion of the information is dependent on its temporal position relative to other material. It is used in skills such as word decoding and spelling where maintaining the exact sequence or succession of letters in the word is crucial for completion (Das, 2002; Naglieri, 2001; Papadopoulos, 2001, 2002). Thus, successive processing predicts reading through the effects of phonological processing, as it includes the perception of stimuli in sequence and the linear execution of sounds (Das et al., 1994a; Papadopoulos, 2001). Successive processing is frequently assessed by tasks that involve storage and articulation, such as word series, sentence repetition and question, and naming speed. All tasks involve both processing and storage.

On the other hand, simultaneous processing is a strong correlate of word reading and passage comprehension, as it directly taps the perception of logical-grammatical relations. Simultaneous processing involves the arrangement of incoming information into a holistic pattern that can be surveyed in its entirety. For example, recognition of whole words by sight involves this kind of processing, as does comprehension of the meaning of a sentence or a paragraph (Das et al., 2000; Kendeou et al., 2012; Kendeou, Papadopoulos, & Spanoudis, 2015). Simultaneous processing is necessary in performing tasks tapping orthographic knowledge (Wang, Georgiou, & Das, 2012) and visual-spatial reasoning abilities, such as matrix reasoning (e.g., Raven's Progressive Matrices; see Raven, 2000) and the block design test (from WISC-III; Wechsler, 1991).

Apart from successive and simultaneous processing, attention and planning are also important for reading. Attention is a hierarchical function that influences the individual's simultaneous and successive processes as well as planning. It refers to the ability to demonstrate focused, selective, and sustained activity over time while handling incoming stimuli, and is located in the brain stem and lower cortex (see Petersen & Posner, 2012, for a comprehensive review). Focused attention refers to the type of cognitive functioning in which concentration on a specific object or activity is observed. This type of processing can be automatic or effortless, governed by the attention/arousal system or cortical tone in maintaining alertness (Kirby & Williams, 1991), or conscious and effortful in maintaining optimal vigilance and performance during tasks (Quay, 1988). Selective attention refers to the ability to focus on the relevant aspects of stimuli while screening out the irrelevant ones. Sustained attention, in turn, refers to the ability to maintain the mental focus of attention over an extended period of time on a specific issue, object, or task (Posner & Boies, 1971). Das et al. (1994a) found that attentional skills, such as the ability for shifting and resistance to destruction are significant for reading.

Planning involves executive functions responsible for regulating and programming behavior, selecting and constructing strategies, and monitoring performance, and is closely aligned with the definition of frontal lobe functioning (Alvarez & Emory, 2006). The planning system, therefore, involves solution planning and monitoring and plan execution. Poor readers seem to have weak performance, compared to their chronologically matched peers, on measures of planning (Kirby, Booth, & Das, 1996) and attention (Das et al., 1990).

These functional units are all related while at the same time they maintain independence by having distinct functions. In addition, all processes are influenced by the knowledge base and thus, the integration of knowledge is important for effective processing to be accomplished (Das et al., 1994a).

Das, Georgiou, and Janzen (2008a) tested parts of this model with 70 First-Nations Canadian children attending grades 3 and 4, and reported that phonological processing and naming speed mediated the effects of successive processing on word reading. Joseph, McCrachan, and Naglieri (2003), in a sample of 62 primary grade children referred for reading problems, showed that both successive and simultaneous processing accounted for 33% of the variance in phonological processing, which, in turn, accounted for 23% of the variance in letter-word identification performance. In addition, the authors demonstrated that PASS variables accounted for a small but significant amount of variance in Letter-Word Identification and Word Attack even after the effects of phonological awareness and RAN were controlled. Furthermore, it has been shown that tasks from the Cognitive Assessment System (CAS; Naglieri & Das, 1997) used to assess successive processing, and tasks used to assess simultaneous processing, correlate strongly with word decoding (Papadopoulos, 2001), orthographic processing (Papadopoulos & Georgiou, 2010), and reading comprehension (e.g., Kendeou et al., 2012).

With regard to reading disability, poor readers have been found to experience difficulty primarily in the successive processing tasks, such as remembering random word sequences or word series, sentence repetition, and speech rate (Das, et al., 1994b; Das et al., 1993; Kirby et al., 1996; Papadopoulos et al., 2003). They also have been found to have inferior performance compared to their chronologically matched peers on measures of planning and simultaneous tasks accounting for significant independent variance in reading performance and, particularly, reading comprehension (Das et al., 1990; Kirby et al., 1996; Kirby & Das, 1977).

The role of these cognitive correlates to reading has been also examined in Greek with groups varying in reading ability and age across the elementary school (e.g., Kendeou et al., 2012; Papadopoulos, 2001; Papadopoulos et al., 2004; Papadopoulos & Georgiou, 2010; Papadopoulos & Kendeou, 2010). Similarly, Constantinidou and Evripidou (2012) have found executive functioning and processing deficits as well as persistent verbal and nonverbal working memory deficits in older elementary school children with reading difficulties. Results provide converging evidence for the influence of these processes on learning to read in Greek (for a review of relevant studies in Greek, see Papadopoulos, 2013). For this reason, a number of tasks tapping these processes were included in the present study.

A closer examination of these deficits does affirm the pattern that phonologically driven tasks, such as the successive tasks, are more strongly related to word decoding, whereas planning and simultaneous tasks are more strongly linked to comprehension. If that is the case, then by linking phonological coding and articulation to successive processing we can account for the association between short-term memory span and reading.

Summing up

Difficulties in learning to read may relate to a number of different deficits in reading-related cognitive and linguistic abilities in one or more of the aforementioned processing systems, ranging from alphabet knowledge and working memory to naming speed and information processing.

All the above skills have been found to distinguish, to different degrees, poor from typical developing readers and, thus, are considered essential in the assessment and treatment of reading disability in early years. On the contrary, orthographic, semantic, and syntactic skills carry greater weight than phonological and cognitive skills in later years. These skills are usually a consequence of longstanding reading disorder or a comorbid oral language disorder (Bishop, 1997; Papadopoulos et al., 2009b). Given the specific focus of the present study on early reading intervention, these latter skills were not assessed. Rather, the emphasis was placed on the specific relationships between the various cognitive and linguistic predictors of early reading development and their independent and additive contribution to the prediction and treatment of reading difficulties.

Early Reading Development in Different Languages

Most of the research concerning reading development as well as the nature and the origin of developmental dyslexia comes from studies that have been conducted in English. Nonetheless, there are fundamental differences between orthographies and a complete science of reading must consider all these differences (Share, 2008). The findings of such studies need to be reconciled with the fact that different orthographies have different rules for mapping letters onto sounds (Patel, Snowling, & de Jong, 2004; Ziegler & Goswami, 2005). English orthography has an exceptional nature in comparison with other alphabetic orthographies. In the developmental literature, researchers have characterized English orthography as “dramatic” (Frith, Wimmer, & Landerl, 1998; Hutzler, Ziegler, Perry, Wimmer, & Zorzi, 2004), “extreme” (Seymour, 2005), “profound” (Ellis & Hooper, 2001), and “particularly unnatural” (Snowling & Hulme, 2005).

In the current study, the emphasis is placed on the Greek orthography that is characterized by orthographic consistency and regularity (Padeliadu et al., 2014; Protopapas & Vlahou, 2009). It is based on consistent one-to-one mappings between graphemes and phonemes and its phonology contains a simple syllabic structure. We believe that the observable cross-linguistic differences between Greek and English (see for example, Georgiou et al., 2008) have implications for the role of phonological and cognitive training on children’s reading development, at least with regard to the strength of the relationship between type of deficits (phonological, naming, cognitive), type of remediation (phonological vs. cognitive), and hence reading in languages varying in orthographic consistency. Therefore, the present study was undertaken to examine this relationship in a large cohort of typically developing and poor Grade 1 readers in Greek.

Ziegler, Perry, Jacobs, and Braun (2001) propose that an important aspect that differs across orthographies is how consistently letters map onto sounds. In terms of grapheme-to-phoneme mappings, English has probably the most complex (i.e., irregular) orthography (Share, 2008). In a relatively inconsistent orthography, such as English, the mappings between letters and sounds are often equivocal: some letters or letter clusters can be pronounced in more than one way, and some sounds can be spelled in more than one way. On the contrary, in relatively consistent orthographies, such as Greek, the mappings between orthography and phonology are highly consistent. Greek orthography allows complete sequential alignment between graphemes and phonemes, therefore permitting full analyses at both letter and grapheme levels (Protopapas & Vlahou, 2009).

Reading acquisition is more rapid in orthographies in which letter-sound relationships are highly consistent (Ziegler & Goswami, 2005). Children who are learning to read in more orthographically consistent orthographies, such as Greek, rely heavily on grapheme–phoneme decoding strategies, as the relationship between graphemes and phonemes is straightforward (Georgiou et al., 2008). In contrast, children learning to read in orthographically inconsistent orthographies, such as English, cannot rely on smaller grain sizes because inconsistency is much higher for smaller grapheme units than for larger units. Therefore, children develop flexible unit size recoding strategies (Ziegler & Goswami, 2005).

The above differences between languages varying in orthographic consistency influence also the way reading skills are measured. For instance, developmental reading research in the English language has been based on measures of accuracy rather than speed or fluency (Share, 2008). Reading accuracy is the process of deriving an accurate or at least approximate pronunciation of a word. It is a pressing concern for readers who encounter unfamiliar letter strings and words. For English readers, many of these items will be irregular (Foorman, Francis, Davidson, Harm, & Griffin, 2004). As a result word and nonword reading are usually quite inaccurate. This means that children with reading difficulties tend to be both slow and inaccurate readers. However, reading accuracy, is largely a trivial issue for the majority of the world's (alphabetic) orthographies in which performance levels approach ceiling by the end of Grade 1 (Seymour et al., 2003). When accuracy is close to ceiling, speed and fluency become the discriminating measures of developmental and individual differences (de Jong & van der Leij, 2003; Leppanen, Niemi, Aunola, & Nurmi, 2006; Lyytinen, Aro, & Holopainen, 2004; Papadopoulos et al., 2009a).

Indeed, in consistent orthographies, the main difficulty for poor readers is not decoding accuracy but reading speed (Cossu, 1999; Lyytinen et al., 2004; Porpodas, 2006; Wimmer, 1993; Wimmer et al., 2000; Zoccolotti et al., 2005). Converging evidence for the importance of reading fluency in transparent orthographies comes from different languages. For example, Wimmer et al. (2000) found that dyslexic learners in

Germany showed close to ceiling accuracy for text and word reading, and even non-word reading accuracy was around 90%. Similarly, Cossu (1999) reported that reading performance in Italian reached 97.8% in a large normative sample in Grade 1, increasing by Grade 3 to 99.6%. In contrast, mean reading speed decreased from 3.5 s per word in Grade 1 to 2.1 s by Grade 3. Moreover, in German (Wimmer, 1993), Dutch (Yap & van der Leij, 1993), Norwegian (Lundberg & Hoien, 1990), Italian (Zoccolotti et al., 2005), Greek (Papadopoulos et al., 2009a; Porpodas, 2006), Finnish (Lyytinen et al., 2004, Torppa et al., 2013), Hungarian (Csepe, 2006), and Hebrew (Breznitz, 1997), even children with reading difficulties attain high level of reading accuracy but remain slow readers. As a result, in consistent orthographies, standard reading measures focus on fluency (i.e., reading rate) (e.g., *Dutch* One-Minute-Test: Brus & Voeten, 1979; *Swedish* Wordchains Test: Jacobson, 1993; *German* word reading list and nonsense word reading list: Wimmer, 1993; *Greek* One-Minute Word Identification and One-Minute Word Attack: Georgiou, Protopapas, Papapadopoulos, Skaloumbakas, & Parrila, 2010; Papadopoulos et al., 2009a; Porpodas, 1999). To that end, Share (2008) supports that the single most significant and universal fact about skilled word reading is the remarkable speed and apparent effortlessness of word identification.

This is also true for Greek. Porpodas (1999) proposed that reading in Greek can be developed effortlessly even by young readers who experience difficulties in literacy acquisition. Porpodas has particularly demonstrated that children with reading difficulties achieve a very high accuracy rate (almost 98% for real-word reading and 92% for pseudo-word reading), regardless of the difficulty of the words. In fact, in consistent orthographies, the effect of consistent spelling-sound correspondences is adequately powerful to secure children's phonological recoding skills after a few months of reading experience, in spite of their levels of phonological awareness (Caravolas, 2006; Papadopoulos, 2001; Porpodas, 1999). Papadopoulos (2001) and Papadopoulos et al. (2009a) concluded that the cognitive processing of managing the decoding of almost any letter array successfully deteriorates when a time frame is set and the child is required to read as many words as possible within it. The authors also concluded that the contribution of naming speed to the definition of poor reading in Greek is different at different points of development. These results are in line with those obtained from other studies with young Greek readers (Georgiou et al., 2008; Nikolopoulos et al., 2006; Papadopoulos et al., 2009a) and from studies on other regular orthographies (Patel et al., 2004; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Korne, 2003).

Research to date in languages with a transparent orthography has reached conclusive evidence regarding the nature of children's reading difficulties. The present study tested longitudinally group differences on both accuracy and fluency in an orthographically consistent language. Specifically, our aim was to examine the effects of a grapho-phonemic and a cognitive intervention program for reading difficulties on both reading accuracy and reading fluency and particularly, to examine whether the effects are similar across reading conditions.

The Case for Early Reading Intervention

The failure to reach functional levels of reading skills can lead to cumulative deficits in reading and in other areas of academic and cognitive functioning (Parrila, Das, Kendrick, Papadopoulos, & Kirby, 1999). In the area of reading difficulties there are no empirically validated answers to the question of what intervention(s) work best for which children in what setting(s) for what duration and for what reason (Papadopoulos & Kendeou, 2010). Factors such as the type and severity of learning difficulties, the cognitive characteristics of the learner and the interaction between cognitive attributes and features of remediation may be important in predicting the effectiveness of remedial programs (Kearns & Fuchs, 2013). Reading difficulties that are diagnosed after the age of eight resist to intervention, and thus, the educational systems ought to get more deeply involved in the area of early reading identification and intervention (Foorman, Francis, Beeler, Winikates, & Fletcher, 1997).

With the controversy still surrounding the type of intervention most useful for reading problems (Tunmer, Chapman, & Prochnow, 2003), this study tested the efficacy of a grapho-phonemic (Graphogame) versus a cognitive (PREP) intervention program on word reading fluency, spelling, and reading comprehension outcomes of a group of readers with reading difficulties identified as early as in Grade 1 in a consistent orthography. As it has been previously demonstrated, phonological and cognitive processes are strongly associated with reading difficulties in both transparent and non-transparent orthographies. These remedial programs aim to develop children's letter knowledge, and reading ability in terms of both accuracy and fluency. The fundamental difference between these two approaches is that in the Graphogame program, phonological and reading skills are taught directly and concurrently through phonological training (Lyytinen et al., 2009; Saine, Lerkkanen, Ahonen, Tolvanen, & Lyytinen, 2011), while in the PREP program, enabling processes, apart from phonological processes, can be developed even before word-identification skills are introduced (Papadopoulos et al., 2004).

Several training studies have demonstrated that specific training in phonological awareness can have a positive impact on success in early reading (Schneider, Ennemoser, Roth, & Kuspert, 1999; Torgesen et al., 1997; Troia, 1999). There is evidence that early reading programs which emphasize on the relations among the phonological structure of spoken words and the alphabet can help close the gap between struggling readers and typically developing readers (Blachman, 2000; Ehri et al., 2001). It has been demonstrated that promising effective reading intervention programs combine direct training in phonological awareness with letter-sound training (Hatcher, Hulme & Snowling, 2004; Hulme, Snowling, Caravolas, & Carroll, 2005; Schneider et al., 2000).

An important question is whether direct training in phonological awareness is equally suited to all children, or whether it is more effective for children with initially higher levels of phonological awareness. Unfortunately, it is difficult to determine from existing data whether phonological awareness training is a useful intervention for children with lower levels of reading ability (Schneider et al., 2000; Torgesen & Davis, 1996) or for children with underlying cognitive deficits. Further, it has been reported that not all remedial reading practices are sufficient in supporting children at risk for or with reading disabilities (Hatcher et al., 2004; Torgesen, 2005). The present reading intervention study was designed to contribute to understanding of the intervention conditions that need to be in place to ameliorate children’s reading problems with emphasis on letter knowledge and phonological processing skills.

Remediation is typically given to small groups (Carlson & Das, 1997) or on an intensive one-to-one basis (Elbaum, Vaughn, Hughes, & Moody, 2000) depending either on student’s ability level, intervention type or grade (Suggate, 2010). Torgesen (2005) has emphasized that an individualized approach can be more effective in training at-risk children for reading difficulties than a mini-group approach. Computer-assisted reading intervention has been recently explored as an individual-oriented, intensive and viable method of training reading skills on an individual and intensive basis (McCormick, 1999; Torgesen, 2002) and it has been acknowledged to be a more powerful instrument in training literacy skills of children with reading difficulties than paper-and-pencil remedial reading intervention methods (Jiménez et al., 2007; Lynch, Fawcett, & Nicolson, 2000), particularly in Grade 1 (e.g., Abrami, Savage, Wade, Hipps, & Lopez, 2008; Chambers et al. 2008; Savage, Abrami, Hipps, & Deault, 2009). Their advantage over traditional reading remediation programs lies on the instantaneously adjustable learning environment that promotes an active and individual-oriented reading support. In addition, computer-aided interventions provide direct visual and audio feedback to both correct and incorrect responses, which is of great importance in the development and enhancement of reading related strategies from the child's part (Saine et al., 2011). The next section examines the properties, remedial objectives, and efficacy of a program focusing on grapho-phonemic training (Graphogame; Lyytinen et al., 2009) and a cognitive intervention program (PREP: PASS Reading Enhancement Program). Both programs were delivered as computer-based applications.

Graphogame intervention

One of the reading remediation programs that was used in the present study is the Graphogame computer assisted intervention (Lyytinen et al., 2009). The theoretical underpinnings of Graphogame can be tracked back to the phonological deficit hypothesis (Snowling, 2001), which places mainly emphasis on an impairment of phonological representations or phonological coding as one of the main explanations for reading difficulties. Graphogame aims to improve the reading skills of children with reading disabilities with specific emphasis on the training of phonemic awareness skills and letter knowledge (Lyytinen, Ronimus, Alanko, Poikkeus, & Taanila, 2007). Graphogame has been originally developed within the Jyvaskyla Longitudinal Dyslexia Study (see e.g., Lyytinen, Erskine, Tolvanen, Torppa, Poikkeus, & Lyytinen, 2006) in Finnish, a language with a consistent orthography (Seymour et al., 2003), for children with learning disabilities or at-risk for dyslexia. For the purposes of the present study, the software of Graphogame was adapted and piloted in Greek as a web-based intervention.

The program provides practice in letter-sound relations, phonemic awareness, decoding skills, accuracy, and fluency and is delivered over the internet (Saine et al., 2011). It focuses on the core issue of reading, learning the connections between spoken and written language (Lyytinen et al., 2009), by providing an intensive adaptive learning environment with individualized repetition. It progresses from letter-sound relations to the stage of phonological recoding and decoding, covering the basic areas needed for fluent and accurate reading (Saine et al., 2011). In the Graphogame application, the acquisition of alphabetic knowledge and facility with letter-sound relationships are essential to beginning reading (Lyytinen et al., 2007). Intervention data are recorded on a server, and online recordings enable researchers to monitor the responses of each individual. Usually, Graphogame is delivered over a period of 4 weeks in daily 30-minute sessions, on an individual basis.

Finnish language is similar to Greek in terms of syllabic structure and orthographic consistency. Specifically, they both have simple syllabic structure characterized by a predominance of open CV syllables with few initial or final consonant clusters. They also have shallow orthographies, which are based on consistent one-to-one mappings between graphemes and phonemes (Seymour et al., 2003). As mentioned earlier, Seymour et al. (2003) demonstrated that word reading skills are easier to acquire in the context of a language with a simple syllabic structure and a consistent system of grapheme-phoneme correspondences than in a language with a complex syllabic structure and an inconsistent system of grapheme-phoneme correspondences, such as English. Children in transparent orthographies can read accurately relatively early with adequate teaching (Aro & Wimmer, 2003; Lyytinen, Aro, Holopainen, Leiwo, Lyytinen, & Tovlanen, 2006). However, intensive and individual training is necessary for children being either at-risk for or exhibiting reading difficulties, to become adequate readers in the Finnish or Greek language context.

Early results are very promising regarding the effects of Graphogame on the reading skills of young readers with or without reading disabilities, in both Finnish (Lyytinen et al., 2007; Saine et al. 2011) and English (Kyle, Kujala, Richardson, Lyytinen, & Goswami, 2013). This conclusion has implications for the teaching of reading in general and for remedial purposes (Lyytinen et al., 2009). Saine et al. (2011) included in their study beginning readers who were at-risk for developing reading difficulties due to their low pre-reading skills. Saine et al. reported that at-risk students who received Graphogame intervention in combination with a teacher-based intervention gained significantly more in reading-related skills, such as letter-knowledge, as well as in word decoding, reading fluency, and spelling in Grade 1, than students who solely received individual reading intervention. Children in the Graphogame group continued to progress similarly in the follow-ups (Grade 2 and 3), catching-up to their counterparts in reading accuracy, fluency and spelling.

Further, Alanko and Nevalainen (2004) found that first-grade non-readers who played Graphogame for one to three hours clearly outperformed, in reading skills, the non-readers who only received the normal support offered by the school. Moreover, Taanila's (2004) study included 6 to 7-year-old kindergarteners who where non-readers. These children were divided into two matched groups. One group started by playing the Graphogame and the other group played first a control game with math content. After one or two weeks, the two groups switched games. Both groups were exposed to both games for the same amount of time. Taanila found that during the "Graphogame" playing period, children's performance on syllabic and phonemic blending tasks was significantly improved. In contrast, their improvement in blending performance was relatively lower and more variable during the control game period. These findings favor the Graphogame intervention. However, none of the studies reviewed here has examined the efficacy of the Graphogame against another competitive early reading intervention program. Nor did they contrast the development of training groups receiving different remedial reading interventions. Moreover, follow-ups were largely absent, apart from one study (Saine et al., 2011), and effect sizes were presented in only a few studies. Further, none of the above studies has examined the participants learning progress that occurs within the learning situation, as well as the variation in individual gains and differences. Another limitation that should be taken into consideration is that the participants recruited in the above studies came from average socio-economic backgrounds. Many interventions are for children from less advantaged backgrounds and those findings may do not apply to them. Finally, the sample size in the intervention groups was quite small and further replication is necessary before the program can be adopted in practice.

The present study is expected, therefore, to significantly contribute to the existing literature in several ways. It is the first study that examined the efficacy of Graphogame against another competitive early reading intervention program for the enhancement of reading fluency in a transparent orthography. It also investigated whether web-based applications can produce significant effect sizes for change in literacy (including both word reading and reading comprehension skills) in Grade 1 when following a randomized control intervention design. Moreover, the present study included both a short- (immediate post-test upon completion of the interventions) and a follow-up component (a year after the completion of the programs) to test the long-term effects of the programs by examining the transfer of the potential positive remediation effects to the word-decoding and reading comprehension performance for the experimental groups. A microgenetic design was also implemented to examine the learning progress dynamics and the developmental stages of the readers during intervention. It was of great importance to test how a child’s cognitive and linguistic profiles may play a central role in establishing beneficial effects of an intervention or procedure.

PASS Reading Enhancement Program (PREP)

Although specific training in phonological skills has been accompanied by significant gains in fluent word recognition, similar gains have been also achieved by other more cognitively oriented programs. Carlson and Das (1997) and Papadopoulos et al. (2003) have suggested that reading attainment does not lie only in skills that are considered proximal to reading, but also in more distal cognitive processes which, in turn, have to be included in reading intervention programs to maximize treatment effects. Simply put, by itself, the phonological-core deficit does not account for all that is known about the development of reading difficulties (Olson, Wise, Johnson, & Ring, 1997). Therefore, diverse theories have been proposed to give an explanation for the cognitive aspects of reading disabilities (Papadopoulos & Kendeou, 2010).

Cognitively focused remediation starts from the premise that each child has an enormous potential for learning, only some of which is usually exploited in the regular classroom instruction (Das & Abbott, 1995). Thus, cognitively focused remediation aims to help the individual to compensate for the experienced difficulties and to correct the observed weaknesses on the basis of existing strengths (Holmes, Gathercole, & Dunning, 2009). Cognitive remediation, therefore, goes beyond those surface difficulties that are easily observed in academic tasks. A recent review of the research on cognitively focused instruction suggests that instruction designed for children with a particular cognitive deficit promotes greater academic improvement than academically focused instruction alone (Kearns & Fuchs, 2013).

For the purposes of the present study, the PASS Reading Enhancement Program (PREP) was also implemented for the enhancement of reading performance. PREP was developed as a cognitive remedial program based on the PASS (Planning, Attention, Simultaneous, and Successive) model of cognitive functioning, and it focuses on training both proximal and distal processes. It was designed to improve selected aspects of children's information-processing skills and increase their word reading and decoding abilities (Papadopoulos et al., 2003). PREP is an alternative to direct training of strategies for remediating reading skills and is based on the assumption that transfer of principles can be facilitated through inductive rather than deductive inference (Carlson & Das, 1997). Accordingly, the remedial training is structured in a way that allows inductive inference to occur spontaneously with internalization of principles and strategies rather than through deductive rule learning (Campione & Brown, 1987; Das, Mishra, & Pool, 1995; Vygotsky, 1962). Remedial training of this kind is more likely to ensure transfer of learned principles and produce strategies for novel situations with higher rates of success (Das et al., 1995). To meet the multiple objectives of the study, a computerized version of the PREP program was designed and piloted in Greek following up the original work by Papadopoulos et al. (2004). The intervention program was delivered on a CD-ROM, allowing data keeping and processing locally.

PREP was originally designed to be used with students in Grades 3 or 4 (Das et al., 1995). Parrila, Das, Kendrick, Papadopoulos, & Kirby (2000) and Papadopoulos et al. (2003) expanded on that work by developing and implementing a version suitable for Grade 1 readers. Each task includes a global training component and a curriculum-related bridging component. The global components require the application of simultaneous or successive strategies and include structured non-reading tasks. These tasks also facilitate transfer by providing the opportunity for children to internalize strategies in their own way (Das et al., 1995). The bridging tasks also include simultaneous and successive processing, which are practiced with reading-related materials (letters, parts of word and words). Each task is designed to facilitate the development of strategies such as rehearsal, categorization, monitoring of performance, prediction, revision of prediction, sounding and sound blending; and children develop their ability to use these strategies through experience with the tasks (Papadopoulos et al., 2003). In the present study, *eight* of the ten tasks of the PREP version for Grade 1 students were selected and adapted in e-format.

Reviews on the efficacy of PREP can be found in several recent papers (e.g., Das, Hayward, Georgiou, Janzen, & Boora, 2008b; Kearns & Fuchs, 2013; Mahapatra, Das, Stack-Cutler, & Parrila, 2010; Papadopoulos, 2013; Papadopoulos et al., 2003). Generally, PREP has produced positive results in terms of cognitive performance and reading ability, in both non-transparent (e.g., Carlson & Das, 1997; Das et al., 1995; Papadopoulos et al., 2003; Parrila et al., 2000) and transparent orthographies (e.g., Papadopoulos et al., 2004; Papadopoulos & Kendeou, 2010); with children at-risk for reading difficulties in Kindergarten (e.g., Papadopoulos et al., 2004), poor readers in Grades 1 and 2 (e.g., Papadopoulos et al., 2003; Parrila et al., 2000), Grades 3 and 4 (e.g., Das et al., 1995; Das et al., 2008b) or Grades 5 and 6 (Boden & Kirby, 1995); with First-Nations children in Canada (e.g., Das et al., 2008b; Hayward, Das, & Janzen, 2007) or poor readers learning English as a second language (Mahapatra et al., 2010); in small groups (Carlson, 1996; Carlson & Das, 1997; Papadopoulos et al., 2003) or on an intensive one-to-one basis (Papadopoulos et al., 2004; Papadopoulos & Kendeou, 2010); in comparison with other experimental groups receiving different treatment programs, such as phonics-based (e.g., Das et al., 2008b), meaning-based (Papadopoulos et al., 2003) or neuropsychological-based programs (Papadopoulos & Kendeou, 2010); and with designs including a follow-up component allowing examination of the long-term efficacy of PREP (Papadopoulos et al., 2003, 2004; Papadopoulos & Kendeou, 2010).

Particularly, Das et al. (1995) used PREP with a group of 51 Grade 3 and 4 students with reading disabilities. Participants were divided into two groups, PREP remediation and a no-intervention control group, while the control group participated in regular classroom activities. The PREP group received 15 sessions of training, over a period of 2 ½ months. The results showed that the PREP group gained significantly more on Word Identification and Word Attack. Similarly, Carlson and Das (1997) used a small-group version of the PREP with underachieving Grade 4 students. The experimental group received 15 hours training with PREP over an eight week period. The control group received no additional training. The results revealed considerable improvement following training in PREP. A second study by the same researchers replicated these results with a larger sample of Grade 4 students. The results were also replicated by other studies completed in the same school district with children from Grades 3, 4, 5 and 6, and with both bilingual (Spanish-English) and monolingual (English) students (Carlson, 1996).

Boden and Kirby (1995) also reported on the effectiveness of a modified PREP for poor readers from Grades 5 and 6. Children were randomly assigned to either a control or an experimental group. The control group received regular classroom instruction and the experimental group received PREP, in groups of four, for 14 hours. The results indicated that the PREP group performed significantly better than the control group on the Word Identification and Word Attack tests. Further, Parrila et al. (1999) compared PREP with a competing program. Specifically, they divided 58 Grade 1 children with reading disabilities into two remediation groups, PREP remediation and Meaning-Based Reading intervention. The Meaning-Based intervention emphasized on the philosophy of the whole-language approach to teaching reading. Both groups received remediation for approximately six hours. The results revealed that the PREP group gained more than the Meaning-Based group in terms of simple decoding skills.

More recently, Papadopoulos et al. (2003) expanded on the Parrila’s et al. (1999) study by including a follow-up component to examine the long-term efficacy of both remedial programs. The results showed that the positive effects of the PREP intervention were still evident up to ten months later. Thus, remediation had long-lasting effects, a finding that has not been frequently reported in reading remediation literature (Bus & Ijzendoorn, 1999). Moreover, Papadopoulos et al. (2004) divided 30 Greek-speaking children aged 5.1 attending Kindergarten in Cyprus into two groups, PREP remediation and no-intervention control group. The experimental group included children at-risk for developing reading difficulties who received a four-week intervention, while the control group, who exhibited no risk for confronting difficulties with reading, followed the regular kindergarten program. Results showed that the experimental group performed equally well with the control group on measures of phonological and cognitive processing skills. Also, the PREP program appeared to be successful in improving phonological skills in children whose cognitive profile matched the emphasis on successive information integration. A follow-up component demonstrated positive long-term effects of the PREP remediation on reading. Particularly, both groups kept improving similarly a year after remediation, as revealed by their reading and spelling scores. Children in the PREP group exhibited the same performance with the control group even with regard to their ability to decode pseudowords and name pictures and letters (see Kearns & Fuchs, 2013, for a review on PREP studies).

Finally, Papadopoulos and Kendeou (2010) compared PREP with a neuropsychological program with strong phonological, naming speed, and meaning components (*DEST-RT: DEST Remedial Tool*) for the remediation of reading difficulties. Greek-speaking Grade 1 children were divided into four groups: two experimental groups experiencing reading difficulties who received either PREP or DEST-RT remedial programs, a reading-age matched group also experiencing reading difficulties that received no-treatment, and a control group exhibiting no reading difficulties who was matched to the experimental groups on chronological age. Results indicated that PREP group improved significantly compared to the control and DEST-RT groups in successive processing, and also outperformed the DEST-RT group on an orthographic processing task. Further, both PREP and DEST-RT performed better than the other two groups in phonological sensitivity, RAN alphanumeric (digit and letter naming), word reading (both real and pseudoword), and passage comprehension. Aptitude-treatment interaction analyses showed that different initial cognitive and linguistic characteristics were associated with a more favorable outcome in PREP than in DEST-RT program.

However, the findings from the above studies (e.g., Papadopoulos et al., 2004; Papadopoulos & Kendeou, 2010) need to be replicated in Greek, by including a larger sample of children in the experimental groups. What is also important is to compare the effects of the PREP program to those of another competitive remedial program, such as a phonologically-based early intervention, on reading in a language with a transparent orthography. Further, most of the studies have shown short-term benefits of the PREP program, and only a few studies have indicated that these benefits are long-lasting (e.g., Papadopoulos et al., 2003, 2004). The present study sheds light into the appropriate remediation of reading difficulties in languages with transparent orthographies. It is noteworthy that this study included a microgenetic design, which advanced our understanding of how PREP remediation tasks work, what cognitive processes are used and why some children gain more from treatment than others. To date, no other study has examined how microgenetic (see next) development occurs within individual cases across training sessions.

This study contributes to the existing literature in testing the application of PREP as an interactive web-based literacy program designed for early elementary school-aged students. Also, by testing the long-term effects of the treatment programs on participants' reading performance in Grade 2, the present study allowed to have a clearer picture with regard to which intervention works best for which children in what settings for what duration and for what reason. This study represents additions to the research literature that draw on longitudinal data covering predictors of literacy skills, development of reading acquisition, and computer-assisted remedial reading intervention.

In sum, a remediation aims to help children to compensate for the difficulties that they encounter and to treat their problems. Thus, a remediation ought to go beyond the surface difficulties that are easily observed in real academic tasks. Any structured remedial approach has to consider the underlying cognitive and linguistic reasons of the reading difficulties experienced by the child and aim to modify any unused potentials. Naturally, designing a remedial program requires careful consideration of the type of tasks and situations in which the skills will be applied, so the use of cognitive strategies that a child may be lacking can be enhanced (Papadopoulos & Kendeou, 2010). The selection, adaptation, and use of the two theory-driven programs in the present study were driven by these requirements.

Microgenetic studies of reading remediation

An equally important issue in designing and delivering a remediation relates to the collection of data on how the anticipated improvement is produced in the participant-treatment interaction, an analysis that is known as microgenetic analysis (Siegler, 2006). Traditionally, the efficacy of reading remediation programs has been determined by comparing participants' performance to controls in measures of cognitive, linguistic, reading, and orthographic processing skills at pre-, mid-, and post-intervention assessments. However, computerized implementation of the remedial programs go a step further and record micro-genetic data during intervention; i.e., log details about the specific actions individuals perform during each task of the intervention. Such information could enable researchers to gain valuable insights in understanding the learning progress dynamics of the readers during intervention, as well as an individual's (or group's) gain variation on different elements of the intervention. These insights, in turn, could help tailor reading intervention programs, such as PREP and Graphogame, to the progress dynamics of each individual (Christoforou, Ktisti, & Papadopoulos, 2014).

A microgenetic analysis of the learning situation and the participant's responses during each Graphogame or PREP session was necessary, as it was aimed to establish a causal link between the theory of cognitive functions underpinning PREP and Graphogame and the changes in learning that occur during training. Therefore, children's accuracy and speed were observed, day by day, during remediation with the data being retrieved from their computerized protocols. Stevenson (1983) proposed that children are active organisms who devise strategies to reach their goals. The only way to discover how children learn is to study them closely while they are learning. Within-child variability, choice and change tend to be related to subsequent learning, and microgenetic studies reveal how these operate in the context of children's learning (Siegler, 2006; 2007).

In short, the study of the process of learning advances our understanding about children's cognitive development (Siegler, 2006). It is also generally accepted that information processing approaches recognize that children's learning is crucial for understanding how development occurs (Siegler, 2005). In spite of this theoretical importance of the study of the learning process, there have been only a handful of studies that have examined the learning process in academic outcome measures, focusing primarily on math development and none that we know of in the area of reading development. To the best of our knowledge, no other study to date has examined cognitive change in the area of reading remediation using microgenetic methods and computer applications. This means that the processes through which children acquire the skills and knowledge while working on specific reading tasks has received little attention. For this reason, the present study also explored microgenetically how learning is discovered from the child's part during remediation, by observing learning actually taking place within a subject over time.

CHAPTER 2

RESEARCH DESIGN AND METHODOLOGY

Purpose of the study

The purpose of the present study was to compare a grapho-phonemic remediation program, the Graphogame, with a cognitive intervention program, the PREP (PASS Reading Enhancement Program) for the enhancement of reading performance in early school years. The intervention programs were delivered over the internet or on a CD-ROM using different platforms that allowed data keeping and processing via remote servers and locally, respectively. Specifically, the study aimed to:

a) examine the efficacy of Graphogame against another competitive early reading intervention program, the PREP, on word reading fluency, spelling, and reading comprehension outcomes of a group of poor readers identified as early as in Grade 1 in a transparent orthography;
b) test the application of PREP as an interactive web-based literacy program designed for early elementary school-aged students;
c) investigate whether web-based applications can produce significant effect sizes for change in literacy (including both word reading and reading comprehension skills) in Grade 1 when following a randomized control intervention design;
d) test the long-term effects of both programs by examining the transfer of the potential positive remediation effects to the word-decoding, spelling, and reading comprehension performance for the experimental groups;
e) explore the processes that occur within the learning situation and the participants' responses during intervention through microgenetic analysis of the participants' computer protocols.

Providing specific answers to these questions would allow having a clearer picture with regard to which intervention works best for which children in what settings for what duration and for what reason.

Research Hypotheses

On the basis of previous research focusing on the remediation of reading difficulties and the orthographic transparency of the Greek language, it was hypothesized that:

a) The participants in the control group (typically developing readers) would exhibit higher performance in the majority (if not all) of reading, orthographic, phonological and cognitive measures compared to the participants in the experimental groups during remediation; however, differences would be minimized following up remediation and at follow-up.
b) The experimental groups who received interchangeably both PREP training and Graphogame training (i.e., combined treatment groups) would show the fastest reading development among the experimental groups, following up remediation.
c) The Graphogame group would be improved significantly more in phonological processing, compared to the group that received cognitive training, from the second assessment and beyond.
d) The combined treatment and PREP groups would be improved significantly more on distal cognitive processes, namely, successive and simultaneous processing, compared to the group that received Graphogame training, following up remediation.
e) The combined treatment and PREP groups would not differ significantly from each other with respect to the improvement in cognitive processing, and
f) Combined treatments would not differ significantly on any direct comparisons.

Furthermore, it was hypothesized that:

g) Microgenetic analysis would help understand in detail the processes and strategies that occur within the learning situation,
h) The use of interactive web-based and computer aided reading remediation designed carefully for early elementary school-aged children would have significant beneficial effects on the literacy skills of early readers or students who may be at risk of school failure in Cyprus, and
i) The implementation of Graphogame in Greek would serve as a basis for adapting a variety of measures and remedial tools between languages with a transparent orthography (such as Finnish and Greek).

Participants

The children participating in the study were first graders recruited from general and special education classes. All participants attended public primary schools in the districts of Nicosia, Limassol and Larnaca. Recruitment was conducted in compliance with international and national laws concerning personal and participants' data, according to good scientific practices and research ethics. Permission for participation of children was requested from parents, school principals, and Grade 1 teachers of those school districts and elementary schools involved in the project prior to the execution of the project.

Sampling started right after the end of the first school semester (i.e., on February) with a selection of Grade 1 students who were identified by their teachers as having reading difficulties. Research has revealed that judgments made by teachers about their students' reading levels are generally confirmed by the subsequent reading scores of these children (see e.g., Fox & Routh, 1984). This recruitment was followed by formal diagnosis on reading (word identification and word attack; see next section) and verbal and non-verbal ability tasks. We tested the nominated children with reading fluency and general cognitive ability tests to ensure that they met the inclusionary criteria for reading difficulties as described in the Diagnostic and Statistical Manual of Mental Disorder (DSM-IV, 1994). Those children scoring below at least 1 SD deviation below the age group mean on the two reading fluency tasks (word reading fluency, nonword reading fluency) and within average range on both verbal and non-verbal ability tasks (similarities, vocabulary, and color matrices) were included in the group of children with reading disabilities. From those children identified with reading difficulties, four matched groups were formed each comprised of 14 participants following a random group assignment. A randomized control trial is supposed to provide the best evidence for the effectiveness of an intervention (Harrington, Cartwright-Hatton, & Stein, 2002; Torgerson & Torgerson, 2001).

In addition, a chronological age control group (n=17) with no difficulties participated in the study. The control group was consisted of those randomly selected cases from the general population whose reading as well as verbal and non-verbal ability performance was within the normal range.

In all instances, children were excluded from the sample if they were: (a) students whose problems are mainly emotional in nature; (b) students with sensory handicaps (visual or hearing deficits); (c) students with developmental disabilities (e.g., mild mental retardation) or (d) students who spoke Greek as a second language. Also, children who scored lower than 1 SD below the age mean on the vocabulary subtest were excluded from the sample, thus controlling for the effects of potential comorbid language deficits.

Table 1 shows the group scores on nonverbal and verbal ability measures (raw scores are presented) along with the mean and range of ages, gender distributions, and parental education level for all four groups in Grade 1.

Table 1

Data on the Demographic and Ability Variables for the CA–Control, PREP, GG, PREP+GG, and GG+PREP groups in Grade 1

	Groups				
Variables	CA – Control (n = 17)	PREP (n = 14)	GG (n = 14)	PREP+GG (n = 14)	GG+PREP (n = 14)
Age					
Mean (SD)	6.83 (0.46)	6.95 (0.45)	7.16 (0.56)	6.80 (0.47)	6.82 (0.46)
Range	1.25	1.09	0.91	1.09	
Gender					
Females	12 [70.6%]	6 [42.9%]	5 [35.7%]	9 [64.3%]	10 [71.4%]
Males	5 [29.4%]	8 [57.1%]	9 [64.3%]	5 [35.7%]	4 [28.6%]
Parental Education Level					
Less than HS	4 [23.6%]	4 [28.6%]	4 [28.6%]	3 [21.4%]	4 [28.6%]
HS Graduate	5 [29.4%]	4 [28.6%]	3 [21.4%]	5 [35.7%]	2 [14.3%]
Some College	5 [29.4%]	3 [21.4%]	4 [28.6%]	5 [35.7%]	6 [42.8%]
College Graduate	3 [17.6%]	3 [21.4%]	3 [21.4%]	1 [7.2%]	2 [14.3%]
Non-Verbal Ability					
CAS Matrices	7.53 (2.15)	7.86 (1.29)	8.50 (2.07)	7.64 (1.60)	7.71 (1.78)
Verbal Ability					
Similarities	6.82 (1.94)	6.93 (1.31)	6.43 (1.55)	6.79 (2.22)	7.21 (0.70)
Vocabulary	9.18 (2.13)	10.64 (1.60)	10.14 (1.79)	10.36 (2.06)	9.93 (2.76)

Note: Values in parentheses are *SDs*; values in brackets are percentages; the reported ability scores are raw scores.

Procedure

The five groups of children (four remedial groups and one control group) were compared, on a number of cognitive, linguistic, reading and orthographic processing measures, prior, at mid-point and after a four-week intervention in Grade 1. A follow-up assessment was also conducted a year later in Grade 2. Testing involved, therefore, four phases, namely, pre-test, mid- and post-remediation, and follow-up. All groups were matched on the basis of age, gender, parental education levels, non-verbal and verbal ability. Experimenters were trained undergraduate and graduate research assistants enrolled in a series of courses specializing in assessment and diagnosis of learning difficulties, and they were recruited and guided for providing assessment to children attending Grade 1.

Importantly, the vast majority of the cognitive, linguistic, reading, and orthographic tests which were used in the present study have undergone extensive development or adaptation, and validation in Greek, yielding high internal consistency. All the tests are well-known and robust in content and concurrent validity (Naglieri & Otero, 2011; Papadopoulos et al., 2009a). They have also been found to correlate strongly with reading development and school achievement (for a review see Papadopoulos et al., 2009a). In addition, the inclusion of all these tests offered (a) the unique advantage of a comprehensive cognitive and linguistic assessment of poor readers, and (b) the possibility to determine the magnitude of treatment effects on proximal (e.g., phonological) and distal (e.g., planning) underlying processes of reading, apart from reading skills per se. With the exception of the verbal and non-verbal ability tests which were administered only at pre- and follow-up assessments, all the other tests were administered to participants at pre-test, post-test, and follow-up assessments. Due to time constraints, only those tests that are considered stronger indicators of reading development were administered at mid-point assessment (i.e., phonological: rhyming, initial syllable oddity, phoneme elision; RAN: pictures, digits and letters; successive and simultaneous processing: visual-spatial relations, word series) along with reading and orthographic processing tests.

Remediation phase commenced immediately after the screening phase that led to group assignment. Remediation was conducted in two different consecutive phases using a multiple treatment design in which two groups received alternating treatments

(T1 to T2 vs. T2 to T1) and two groups received the same treatment (T1 vs. T2) throughout the same period. The control group received no remediation and followed the regular curriculum-based program offered at school. Remediation consisted of 20 thirty-minute sessions. It started in April and was administered individually over a four-week period during school hours by certified special education teachers and trained graduate psychology students. It was expected that when children completed Grade 1, a clear picture with regard to the short-term benefits of remediation would be on hand. Similarly, the long-term effects of the treatment programs on the cognitive and reading performance of the participants were examined after the completion of the follow-up assessment in Grade 2. A microgenetic design was also implemented to examine the participants learning progress in both programs.

Assessment Tools

Phonological Sensitivity

Participants' phonological skills were assessed using six tasks that differed in linguistic complexity with words that were familiar to the participants. Three of these tasks measure phonological ability at the syllabic level: Rhyme Oddity, Syllable Completion and Initial Syllable Oddity tasks. The remaining three tasks tap phonological ability at the phonemic level: Sound Isolation, Phoneme Elision and Phoneme Blending. This set of phonological tasks has undergone extensive development and validation (Papadopoulos et al., 2009c, 2012).

Rhyme Oddity. This task was adapted to Greek by Papadopoulos (2001) based on the work of Bradley and Bryant (1985). The child was required to listen to three words presented orally and to identify the one that ends with a different rhyme compared to the other two (e.g, *μπάλα/άλογο/γάλα; bala/alogo/gala/; ball/horse/milk).*

Syllable Completion. In this task, the participants were asked to say aloud the second part of a bisyllabic word, following the experimenter who pronounced the first syllable (see also Loizou & Stuart, 2003; Stuart, 1986). All words contained open syllables as target syllables, ending with a vowel, of CV (e.g., /μύ-τη/; /mi-ti/; nose), CCV (e.g., /κά-δρο/; /ka-dro/; frame) or CCCV (e.g., /δε-ντρο/; /de-dro/; tree) structure.

A set of pictures, each illustrating the matching familiar object, was used following the administration procedure of this task in its original version.

Initial Syllable Oddity. In this task, participants were asked to pay attention to initial syllables and select the member of each three-item set that begin with a different syllable than the other two. This task was also adapted from Bradley and Bryant (1985). There were three different groups of items: items that began with CV (e.g., *μαμά/μέρα/μένω; /mama/mera/meno/*; mom, day, stay), CCV (e.g., *κρατώ/κρεμώ/κρασί; /krato/kremo/krasi/*; hold, hang, wine), and CCCV (e.g., *στρατός/στρέμμα/στράτα; /stratos/stremma/strata/*; army, plot, street). With the exception of only two item sets, which were used to introduce the participants to the task, the odd-word out was contrasted to the other two on the basis of the syllable's vowel.

Sound Isolation**.** This task was a Greek adaptation (Papadopoulos, 2001) of the work of Wagner, Torgesen, Laughon, Simmons, and Rashotte (1993) where they compared alternative models of young readers' phonological processing abilities. In this test, children were asked to repeat the first, last, or middle sound in a word (e.g., *which is the middle sound in the word /θέα/; /thea/;* view). Testing items consisted of three- and four- phoneme, one- and two-syllable words.

Phoneme Elision**.** This task was also an adaptation of the work by Wagner et al. (1993). In this task, children were asked to repeat a word after deleting an identified phoneme. The targeted phonemes were either vowels or consonants and their position varies across items. After deleting the target phoneme, the remaining phonemes formed a word (e.g., *say the word /τώρα/; /tora/;* now, *after deleting the sound* /t/ → */ώρα/; /ora/;* time).

Blending. This task was designed to assess phoneme-blending skills. Audio prompts presented the sounds of two- to six-sound words separately, and the child was asked to orally blend them into a word. The child's response was recorded as correct when s/he reproduced all the sounds in the final word. Word complexity was progressively more difficult. The first four words consisted of two- to four-phoneme segments that were of CV or CVC structure (e.g., */φως/; /fos/;* light). The more difficult items contained more complex phoneme segments such as CCV (e.g., */στόμα/; /stoma/;* mouth).

Rapid Automatized Naming

This set of tasks was originally developed by Papadopoulos et al. (2004). All four measures were made up of two tasks (one relatively easy and one more difficult) also made up of 20 testing items (5 different stimuli, each repeated four times). The items in each task were presented on a single page, with four lines of 5 items per page. Order of items changed from one line to the other. As in the case of the phonological tasks, testing preparation included a short sample. In all instances, the participant's score was the ratio between the number of items named correctly divided by the time taken, for each pair of tasks.

RAN Colors. Five basic and relatively more frequent colors, namely, *red, green, yellow, blue,* and *white* were included in the first task. The second task was comprised of less frequent and secondary colors such as *pink, light blue, brown, orange,* and *purple*. The participants had to say the name of the colors for an answer to be recorded as correct.

***RAN Pictures*.** This measure was modeled after Wimmer et al. (2000). The words of the first task started with the same single-consonant cluster (καπέλο*/καρέκλα/κεράσι/καρότο/κλειδί; /kapelo/karekla/kerasi/karoto/klidi/*; hat, chair, cherry, carrot, key), whereas the words of the second task started with different consonant clusters (*φράουλα/πλυντήριο/σκύλος/σταυρός/μπανάνα;/fraoula/plintirio/ skilos/stavros/banana/*; strawberry, washer, dog, cross, banana).

***RAN Digits*.** The digits from 1 to 5 were included in the first task. The second task was comprised of the digits 6 to 9 and 0 (zero). The participants had to say the name of the digit for an answer to be recorded as correct.

***RAN Letters*.** The letters of the first task were only vowels (*α, η, ε, ο, υ*), and the letters of the second task were only consonants which share similar characteristics and are usually confused from poor readers in Greek (*π, τ, σ, δ, θ*). The participants had to either say the name of the letter or the sound that it makes, for an answer to be recorded as correct.

Reading

Word Reading

Two standardized measures were used to assess participants' word reading ability, namely, a real word and a pseudoword reading task (Papadopoulos et al., 2009c). In both tasks, the instruction to the participants was to read the entire list of words. Both accuracy score, that is the number of words read correctly, and reading speed (fluency) score, that is the total number of words read correctly within 60 seconds, were recorded for each participant. Both scores were used for at least two reasons: (a) It has been already shown in previous studies in Greek (Papadopoulos, 2001; Porpodas, 1999) that children with reading difficulties achieve a very high accuracy rate (almost 98% for real-word reading and 92% for pseudoword reading), despite the difficulty of the words. This means that in reading a regular writing system like Greek, even beginning readers with reading difficulties manage to decode almost any letter array successfully. However, this cognitive processing deteriorates when a time frame is set and the child is required to read as many words as possible within it. (b) Research to date in orthographically consistent languages has not reached agreement about whether children's difficulties are solely observed in reading speed (e.g., Wimmer et al., 2000) or in decoding accuracy as well (Escribano, 2007). By examining group differences in both accuracy and fluency measures we were able to answer the essential question about the nature of the deficits observed in a language with a transparent orthography. Both the real word and the nonword lists were preceded by a practice list to familiarize children with the list-reading procedure and with nonwords, respectively.

Word Identification. This test consisted of 80 words forming a 2 x 2 x 2 factorial design in terms of frequency (high/low), orthographic regularity (regular/exception), and length (bisyllable/trisyllable). Half of the words were sampled from the first-grade language books and the other half were taken from second-grade language books, following Porpodas (1999) and used initially by Papadopoulos (2001). The stimulus words are mainly nouns with a few adjectives and verbs.

Word Attack. This task consisted of 45 pronounceable nonwords that were derived from real words after changing two or three letters (either by substituting them or using them backwards). The task started with bisyllabic words and ended with five-syllabic words.

Reading Comprehension

Three tasks were administered to the participants to assess reading comprehension skills. Maze, WRMT-R and Passage Comprehension (multiple choice) were administered in both Grades 1 and 2. The first two tasks have been developed and standardized in Greek (Papadopoulos, Spanoudis, & Kendeou, 2008a). The latter has been developed for the purpose of the present study, modeled after Padeliadu & Antoniou (2008; see Test-A).

Woodcock-Johnson Passage Comprehension: This test was an adaptation of WRMT-R (Woodcock Reading Mastery Test-Revised; Woodcock, 1987). Participants were required to read a short passage (usually two to three lines long) and identify a keyword (represented by a blank line) missing from the passage. To successfully complete the item, a participant generally had to understand not only the sentence containing the missing word but also the remaining sentence(s). Before starting the test, the examiner instructed the child to read each passage silently and then orally provide a suitable word for the blank space. A sample item was administered in order to ensure that the participant understood what was expected. The version used in this study contained 68 items. The participant's total score was the number of correctly filled blanks. The task was discontinued after four consecutive mistakes.

CBM-Maze. The Maze Test of Curriculum Based Measurement (CBM) (Deno, 1985; Espin & Foegen, 1996) is a test of reading comprehension developed for students with reading and learning disabilities (Kendeou & Papadopoulos, 2012; Kendeou et al., 2012; Papadopoulos et al., 2014). The test required students to read three passages that included incomplete sentences. Participants were asked to choose the correct word among three options (one correct and two incorrect) to appropriately complete the sentence as they read the text. These passages were similar to texts that the individuals were exposed to in their own reading or in school, with the exception that they had these multiple-choice test sentences embedded within them. Students had one minute to read as much of each passage as possible and, while reading, circle the appropriate word to accurately complete the target sentences. This same pattern was repeated for all passages. Students were guided through two practice sentences and then continued with the remainder of the test. The total time for test administration ranged from 5 to 10 minutes. Students' score consisted of the average number of correct words chosen minus the number of incorrect words chosen.

Passage Comprehension (multiple choice). This test was an adaptation of Test-A reading test (Padeliadu & Antoniou, 2008). In this test, participants were required to read silently or aloud two passages (nine to ten lines long) and answer six multiple-choice questions following each passage. Participants were asked to choose the correct answer among four options (one correct and three incorrect). These passages were similar to texts that the individuals were exposed to in their own reading or in school. Students' score consisted of the average number of correct answers minus the number of incorrect answers chosen.

Orthographic Processing Measures

Three tasks were administered to the participants to assess their orthographic processing ability, namely, Orthographic Choice, Word Chains, and Two-Minute Spelling. All tests were administered in both Grade 1 and 2. These tasks have been also standardized in Greek by Papadopoulos et al. (2008a).

Orthographic Choice. This task was adapted from the work of Olson and colleagues (e.g., Olson, Forsberg, Wise, & Rack, 1994; Olson, Wise, Conners, Rack, & Fulker, 1989) and was initially used by Papadopoulos et al. (2009a). It consisted of 20 items that were constructed in a way that phonological transcription alone did not reliably result in identifying the one orthographically correct word among the three words included in each item (e.g., */αρέσει/αρέσι/αρέσοι; /aresi/; like*). Participants had to use their knowledge of the orthographic patterns for the given words in order to identify the one that was both phonologically and orthographically correct. The resulting score was the number of orthographically correct spellings identified by the child.

Word Chains. In this test, the children were asked to scan words presented as a continuous line of print without interword spaces (e.g., *boygomeet*). The children were given 1 minute and were asked to identify the words in each row by drawing a line to indicate where the spaces should be (e.g., *boy/go/meet*). This test included a total of 15 rows of words of increasing length. The first two rows consisted of two words put together, whereas the last three items consisted of five words put together. Students were guided through 3 practice word chains and then continued with the remainder of the test. The individual's score on this task was the number of correctly placed slashes.

***Two-Minute Spelling*.** This is a typical spelling test, which assesses children's orthographic knowledge, and comes from the Dyslexia Screening Test-Junior (Fawcett & Nicolson, 2005), also standardized in Greek (Papadopoulos et al., 2009a). Participants were asked to write on a page within two minutes as many words as possible from a list of words dictated by the experimenter. The total number of words that were orthographically reproduced was used as the final score for each participant.

Cognitive Processing Measures

Eight measures (two simultaneous processing, three successive processing, one attention, and two planning) taken from the Das-Naglieri Cognitive Assessment System (DN-CAS; Das & Naglieri, 1997; Greek standardization by Papadopoulos, Georgiou, Kendeou, & Spanoudis, 2008b) were used to assess participants' cognitive processing skills. The two simultaneous processing tasks were Simultaneous Verbal and Figure Memory, the three successive processing tasks were Sentence Questions, Word Series, and Speech Rate, the two planning tasks were Planned Search and Matching Numbers and the attention task was Expressive Attention (Stroop Test).

Simultaneous processing tasks

Verbal-Spatial Relations. This 29-item task involved evaluation of logico-grammatical relationships by the participants, who were asked to point to one of the six pictures that corresponded with a verbal statement, such as "the ball in a basket on a table (*η μπάλα μέσα στο καλάθι, πάνω στο τραπέζι).*" The time limit for each item was 45 seconds and the task was discontinued after four consecutive errors. The task was scored for the number of correct responses.

Figure Memory. This task consisted of 20 geometric designs, such as a triangle or a square, that were presented to the participant one at a time for a period of five seconds each. Following the presentation of a particular target design the participant was given a more complex design in which the target design was embedded. The participant then was asked to outline the original target. The task was discontinued after four consecutive failures. The participant's score was the total number of items correctly reproduced.

Successive processing tasks

Sentence Questions. This task required the participant to answer questions about nonsensical sentences in which the content words have been replaced by colour words (e.g., "The yellow greened the blue"; *το κίτρινο πρασίνισε το μπλε*). Thus, the participant could use syntactic cues but no semantic cues to remember the sentences or to answer the questions. The participant's score was the number of correctly answered questions. The task was discontinued after four consecutive failures.

Word Series. In this task, the participants were required to repeat aloud, after the instructor, two to eight familiar and phonetically dissimilar words (e.g., *papi-doro-mama, παπί-δώρο-μαμά*). The task consisted of twenty-seven word series and the participants' score was the number of correct repetitions. The series increased progressively in length and difficulty.

Speech Rate. In this task, the participants were required to say aloud three familiar and phonetically dissimilar words (e.g., *mera-topi-ena*, *μέρα-τόπι-ένα*) as fast as possible for 10 times. The task consisted of eight three-word series and the participants' Speech Rate score was the combined time taken to complete all eight items.

Planning tasks

Planned search (or visual search). This task required the participants to develop an efficient approach to find a particular stimulus on a page. The participants were typically introduced to point to a picture, number, or a letter located in a field around the target in a stimulus box. Items have been composed of one or two searches per page. Items were timed from the point the page was exposed to the moment the second target was found. The participants' score was the amount of time taken to complete all the items.

Matching Numbers. This task involved two pages which both contained numbers. Each page contained eight rows, with six visually similar presented numbers in each row. The participants were required to find and circle the same numbers in each row, as fast as possible. The first page contained one-digit and two-digit numbers, while the second page consisted of two-digit and three-digit numbers. The participants' score was the number of correctly identified pairs of numbers on each page.

Attention task

Expressive Attention (Stroop test). This task was based on the Stroop task that was first composed by Stroop (1935) and had been widely used as a measure of interference (Das et al., 1994a; Papadopoulos, Das, Kodero, & Solomon, 2002). The version used in this study involved three conditions each containing 40 images of several animals in varying order, and arranged in seven rows. In the first condition, all animals had the same size. The participants were required to say the actual size of the animals in the real world, either big or small. In the second condition, the size of the animals was responding to reality; the smaller animals had smaller images, while the bigger ones had bigger images. In the third condition, the pictures varied in size. For example, some big animals had small images and vice versa. The participants were instructed to say the actual size of the animals, rather than name the animals, as fast as possible. In each condition the participant's score was the time taken to complete each page and the number of correct responses.

WISC and CAS

Verbal ability. Groups' verbal ability was assessed using the Similarities and Vocabulary subscales from the Wechsler Intelligence Scale for Children (WISC-III-R; Wechsler, 1992; *Greek adaptation*: Georgas, Paraskevopoulos, Bezevegis, & Giannitsas, 1997) and the PPVT-R test (Dunn & Dunn, 1981). The PPVT-R had been adapted in Greek by Spanoudis and Papadopoulos (2010).

Nonverbal ability. Nonverbal ability was assessed using the Color Matrices from the Das-Naglieri Cognitive Assessment System (Naglieri & Das, 1997; *Greek adaptation*: Papadopoulos et al., 2008b).

Reading Remedial Interventions

PASS Reading Enhancement Program (PREP)

PREP was developed as a remedial program based on the PASS (planning, attention, simultaneous processing and successive processing) model of cognitive functioning (Das et al., 1994a). Two out of the four components of the PASS model, simultaneous and successive processing, are the most highly related to reading skills, with simultaneous processing more strongly related to comprehension and successive processing more strongly related to word decoding (Das et al., 1994a). These predictions derive from the need for simultaneous processing in the relating of meaningful units and their integration into higher level units, and from the involvement of successive processing in the sequential analysis and blending of phonemes and syllables (Kirby et al., 1996).

The PREP remediation program aims to improve the information processing strategies that underlie reading, while at the same time tries to teach inductively word reading skills, such as phoneme segmentation or blending. PREP is founded on the premise that the transfer of principles is best facilitated through inductive, rather than deductive, inference (Carlson and Das, 1997). The program is accordingly structured so that tacitly acquired strategies are likely to be used in appropriate ways.

In the present study, *eight* of the ten tasks of the PREP version for Grade 1 students (Papadopoulos et al., 2003) were adapted in e-format (the tasks are described in Appendix). Each of the tasks involves both a global training component and a curriculum-related bridging component. The global components, which require the application of simultaneous or successive strategies, include structured non-reading tasks. These tasks also facilitate transfer by providing the opportunity for children to internalize strategies in their own way (Das et al. 1995). The bridging tasks involve the same cognitive demands as their matched global components, that is, simultaneous and successive processing, that are now practiced with reading related materials (letters, parts of word and words).

To ensure that strategy acquisition occurs in small steps, the global tasks begin with content that is familiar and non-threatening (Das et al., 1994a). Complexity is introduced gradually. Through specific discussions of strategies used during each remediation session, children are encouraged to apply their strategies to academic tasks such as word decoding. Each task is designed to facilitate the development of strategies such as rehearsal, categorization, monitoring of performance, prediction, revision of prediction, sounding, and sound blending. Children develop their ability to use these strategies through experience with the tasks. It is important to emphasize, however, that rather than being explicitly taught these strategies by the instructor, children are encouraged to become aware of their use of strategies through verbalization. Growth in the ability to use strategies and awareness of appropriate opportunities for their use is expected to develop over the course of remediation.

What is also important is that the global and bridging components are further divided into three levels of difficulty. In the present study, only the first two levels of difficulty for each task were administered. In addition, a system of prompts is an integral part of each global and bridging component. The series of prompts creates a scaffolding network that supports and guides the child to ensure that tasks are completed with a minimal amount of assistance and a maximal amount of success. For the purposes of the present study, a record of these prompts was used as a monitoring system for the instructor to determine when the material was too difficult for a child or when a child was able to successfully progress to a more difficult level. Also, a criterion of 80 percent correct responses was required before a child could proceed to the next level of difficulty. If the criterion was not met, an alternate set of tasks, at the same difficulty level, was used to provide the additional training required.

The reasons for employing PREP as one of the remedial programs in the current project were the following: (a) PREP does not focus particularly on phonological training but it was designed to improve selected aspects of children's information-processing skills, namely successive and simultaneous processing, and increase their word reading and decoding abilities (Hayward et al., 2007; Papadopoulos et al., 2003); (b) PREP is an alternative to direct training of strategies for remediating reading skills and is based on the assumption that transfer of principles can be facilitated through inductive rather than deductive inference (Carlson & Das, 1997); and (c) PREP has already shown robust results in improving the reading performance of young poor readers in Greek (Papadopoulos et al., 2004).

Graphogame

Graphogame is a child-friendly computer game that helps children to learn the basic letters and their sounds. It is based on the assumption that the most predictive index of later reading difficulties that is most practical to implement is poor letter-sound knowledge. By playing the game, children learn the most typical letter-sound relations in a synthetic-type phonics approach. Graphogame progresses from letter-sound relations to the stage of phonological recoding and decoding, covering the basic areas needed for fluent and accurate reading. The graphics used in the main game of Graphogame include falling balls which contain an orthographic stimulus. Simultaneously an auditory stimulus is given through the loudspeakers. The child is asked to select the ball that matches the auditory stimulus, among the 2-9 falling balls presented on the screen. Mixed in with these reactive types of trials are the more active tasks which are described in Appendix.

Through a series of levels, gradually, the child is able to construct letters into syllables, small words and then larger words, aiming at acquisition of the alphabetic principles. The game incorporates a dynamic element in that it also adapts to the child's own level of ability and sets further levels according to this ability. If the child does well, the number of items that fall down from the screen increases in number and speed. Children who make progress are assigned new, more difficult tasks. If the child is struggling, the number of options and their speed decreases. This prevents frustration in the context of learning while, at the same time, enjoyable positive feedback sustains the child's interest in playing for sufficient time for learning to be established. As a reward, the child collects a series of animals which are used to populate their own animal park (Saine et al., 2011).

In Graphogame, letters and words appear at an accelerating rate on the screen and children improve automatized naming and visual recognition (Lyytinen et al., 2007). What is also important is that the child is not assisted during game playing. This is because of the adaptive nature of the game in that, if the child is helped, then the game will automatically move to a harder level beyond the child's capabilities and any future playing would always be too difficult.

The reasons for employing Graphogame, as the second remedial tool, were also rather straightforward: (a) Finnish is a language with a transparent orthography such as

Greek, with evidence-based similarities on grapheme-phoneme mappings between the two orthographies (Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012). In transparent orthographies in which the mapping of graphemes onto phonemes is relatively unambiguous, phonological recoding operates at a smaller grain size (e.g., phoneme) and the development of phonological skills follows a rather similar progression represented by a single ability (Papadopoulos et al., 2009c; Vloedgraven & Verhoeven, 2007). It is expected, therefore, that not only the implementation of Graphogame in Greek will be successful in enhancing phonological processing and (word) reading skills in Greek, but also that the use of Graphogame will serve as a basis for adapting a variety of measures and remedial tools from one language to the other for children with learning disabilities and risk for dyslexia (b) Graphogame has already shown robust results in improving reading performance by focusing on the core issue of learning the connections between spoken and written language (Lyytinen et al., 2009). Because Graphogame provides practice by drilling and motivates towards faster performance, it also supports fluency.

CHAPTER 3

RESULTS

The aim of the study was to analyze the effects of *PREP: PASS Reading Enhancement Program* and *Graphogame*, on word reading fluency, spelling, and reading-comprehension outcomes across mid-remediation, post-remediation, and follow-up assessments. Particularly, a series of between subjects analyses of covariance (ANCOVA) was performed to determine the effects of the four training combinations (i.e., GG, PREP, GG+PREP, PREP+GG) on mid-intervention (T2), post-intervention (T3) and follow-up (T4) performance. Pre-intervention performance (T1) was used as a covariate in order to remove the effects of pre-test performance and thus, reduce the within-group error variance.

Two different ANCOVA analyses were carried out, some with three time points and some with two time points (post-intervention and follow-up) based on the scores that were available. Particularly, a series of 5 (group) x 3 (time) between subjects analysis of covariance was conducted for naming pictures, digits and letters, visual-spatial relations, word series, rhyming, initial syllable oddity, phoneme elision, word chains, two-minute spelling, word reading fluency, phonemic decoding fluency, word reading accuracy, phonemic decoding accuracy and CBM-maze. A series of 5 (group) x 2 (time) was conducted for naming colours, sentence questions, speech rate, figure memory, expressive attention, matching numbers, planned search, onset-rime, blending, orthographic choice, and passage comprehension (WJPC). Also, a mixed-model repeated measures analysis of variance with time as a within-subjects factor (time x 2) and group as between-subjects factor (group x 5) was conducted for passage comprehension (multiple choice test).

In all analyses, the results on the evaluation of the normality assumptions of sampling distributions, linearity, and homogeneity of covariance were satisfactory. Following the study’s hypotheses, between-group planned contrasts were also conducted to determine where the differences between groups lay and which group performed better on the dependent measures during remediation, right after remediation and at follow-up. In all instances, Bonferroni adjustment was applied. The results for Time 2 (whenever available) through Time 4 are presented next.

Tables 2 to 28 present the unadjusted and adjusted intervention means for mid-intervention (whenever available), post-intervention, and follow-up performance with pre-intervention scores as a covariate.

Linguistic skills

Phonological Awareness

Supraphonemic Sensitivity

Rhyme: Results revealed that after adjustment for pre-intervention performance (Time 1), no significant differences of the type of treatment were found, $F(4, 67) = .44$, $p > .05$, $\eta^2 = .03$, nor was there a significant interaction between group and time (p >.05). However, statistically significant changes in Rhyme were revealed over time, $F(1,67) = 15.95$, $p < .001$, $\eta^2 = .19$. Subsequent analyses revealed significant differences from mid- to post-intervention, $F(1,67) = 5.11$, $p < .05$, $\eta^2 = .07$, from post-intervention to follow-up, $F(1,67) = 10.46$, $p < .01$, $\eta^2 = .14$, and from mid-intervention to follow-up, $F(1,67) = 35.66$, $p < .001$, $\eta^2 = .35$. In other words, children participating in this study were improved on detecting rhymes, irrespective of the group they belonged to.

Initial Syllable Oddity: Results revealed that no significant differences of the type of treatment were found, $F(4, 67) = .54$, $p > .05$, $\eta^2 = .03$, nor was there a significant interaction between group and time (p >.05). However, statistically significant changes in Initial Syllable Oddity were revealed over time, $F(1,67) = 20.34$, $p < .001$, $\eta^2 = .23$. Specifically, subsequent analyses revealed significant differences from mid- to post-intervention, $F(1,67) = 9.53$, $p < .05$, $\eta^2 = .13$, from post-intervention to follow-up, $F(1,67) = 12.98$, $p = .001$, $\eta^2 = .16$, and from mid-intervention to follow-up, $F(1,67) = 38.52$, $p < .001$, $\eta^2 = .37$. These results indicate that all experimental groups developed phonological skills enabling them to manipulate syllables in words.

Table 2
Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Rhyme

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	7.53	4.09	5.91	0.81	8.24	3.93	6.84	0.84	10.06	3.17	8.95	0.65
PREP	14	6.07	4.16	6.34	0.82	7.21	3.91	7.44	0.85	8.21	2.36	8.40	0.65
GG	14	5.50	2.79	5.85	0.82	6.43	2.93	6.73	0.85	8.14	2.32	8.38	0.66
PREP+GG	14	6.29	3.56	6.98	0.83	7.36	3.79	7.96	0.86	8.93	2.56	9.41	0.66
GG+PREP	14	5.21	2.61	5.87	0.83	6.71	2.61	7.28	0.86	8.21	2.99	8.66	0.66

Table 3
Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Initial Syllable Oddity

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	6.18	2.86	4.68	0.74	7.06	2.77	5.99	0.72	7.94	2.77	6.99	0.57
PREP	14	5.07	4.18	5.61	0.73	6.07	3.20	6.46	0.71	6.71	2.37	7.06	0.56
GG	14	3.93	2.70	4.56	0.73	4.36	2.59	4.81	0.71	6.43	1.99	6.83	0.56
PREP+GG	14	4.14	2.45	4.16	0.72	5.36	2.10	5.37	0.70	6.57	2.06	6.58	0.55
GG+PREP	14	3.21	2.56	3.85	0.73	5.71	3.07	6.17	0.71	7.00	1.61	7.40	0.56

Syllable Completion: No significant differences of the type of treatment were found, $F(4, 67) = 1.84$, $p > .05$, $\eta^2 = .10$, nor was there a significant interaction between group and time (p >.05). Also, there were no statistically significant changes in Syllable Completion over time (p >.05). Results show that experimental groups reached ceiling early on, as this supraphonemic sensitivity task is a relatively easy task for young children learning to read in Greek (Papadopoulos et al., 2012).

Table 4

Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Syllable Completion

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	13.94	0.90	13.83	0.26	14.18	0.88	14.11	0.20
PREP	14	13.21	1.37	13.17	0.29	13.71	0.83	13.69	0.22
GG	14	13.36	1.08	13.43	0.29	13.71	0.61	13.76	0.22
PREP+GG	14	12.86	1.10	12.93	0.28	13.64	0.93	13.69	0.22
GG+PREP	14	12.93	1.07	12.96	0.29	13.57	0.85	13.59	0.22

Phonemic Sensitivity

Blending: Results revealed no significant differences of the type of treatment, $F(4, 67) = .31$, $p > .05$, $\eta^2 = .02$. Likewise, the interaction between group and time was not significant (p >.05). However, statistically significant changes in Blending were revealed over time from post-intervention to follow-up, $F(1,67) = 9.17$, $p < .01$, $\eta^2 = .12$, indicating that remediation continued to exert significant effects on blending skills for all treatment groups up to Grade 2.

Table 5

Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Blending

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	7.18	3.97	5.81	0.79	7.76	3.29	6.87	0.59
PREP	14	6.43	3.67	6.76	0.81	7.21	2.49	7.43	0.61
GG	14	5.29	3.15	5.76	0.82	6.93	1.98	7.24	0.61
PREP+GG	14	5.64	3.73	5.73	0.81	7.43	2.50	7.49	0.60
GG+PREP	14	5.07	2.43	5.83	0.83	6.36	1.82	6.86	0.62

Sound Isolation: Similarly, no significant differences of the type of treatment were found, $F(4, 67) = 0.60$, $p > .05$, $\eta^2 = .03$, nor was there a significant interaction between group and time (p >.05). However, statistically significant changes were also revealed in this task over time, $F(1,67) = 55.27$, $p < .001$, $\eta^2 = .45$. In particular, subsequent analyses revealed significant differences from mid- to post-intervention, $F(1,67) = 44.19$, $p < .001$, $\eta^2 = .40$, from post-intervention to follow-up, $F(1,67) = 19.44$, $p < .001$, $\eta^2 = .23$, and from mid-intervention to follow-up, $F(1,67) = 96.10$, $p < .001$, $\eta^2 = .59$, indicating that children participating in the study continued to show improvements in manipulating sounds in words up to Grade 2, irrespective of group.

Phoneme Elision: Results indicated that no significant differences of the type of treatment were found, $F(4, 67) = .88$, $p > .05$, $\eta^2 = .05$. No significant interaction between group and time was detected either (p >.05). However, once again statistically significant changes in Phoneme Elision were revealed over time, $F(1,67) = 105.36$, $p < .001$, $\eta^2 = .61$, from mid- to post-intervention, $F(1,67) = 56.39$, $p < .001$, $\eta^2 = .46$, from post-intervention to follow-up, $F(1,67) = 65.79$, $p < .001$, $\eta^2 = .50$, and from mid-intervention to follow-up, $F(1,67) = 169.05$, $p < .001$, $\eta^2 = .72$. These results demonstrate that all treatment groups were improved in manipulating phonemes even a year after remediation.

Table 6

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Sound Isolation

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	11.82	2.63	9.36	0.91	12.71	2.26	11.24	0.86	13.24	1.52	12.83	0.54
PREP	14	7.07	5.03	7.53	0.91	10.14	3.18	10.42	0.86	11.50	1.61	11.58	0.54
GG	14	8.00	2.69	8.51	0.91	10.93	3.81	11.23	0.86	12.14	2.25	12.23	0.54
PREP+GG	14	7.43	4.70	8.39	0.92	9.79	4.04	10.36	0.87	11.57	2.38	11.73	0.55
GG+PREP	14	7.14	5.70	8.20	0.92	10.21	4.32	10.84	0.87	12.14	2.41	12.32	0.55

Table 7

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Phoneme Elision

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	*6.82*	3.47	5.11	0.88	*7.88*	3.59	6.53	0.81	*11.24*	2.66	10.42	0.82
PREP	14	*5.21*	4.96	5.23	0.88	*8.93*	4.43	8.94	0.81	*9.29*	3.97	9.29	0.83
GG	14	2.86	3.16	3.72	0.90	*5.50*	2.35	6.18	0.82	*8.36*	1.86	8.77	0.84
PREP+GG	14	2.14	3.39	3.00	0.90	*6.21*	2.26	6.90	0.82	*8.43*	3.06	8.84	0.84
GG+PREP	14	3.93	3.69	4.28	0.89	*6.64*	3.52	6.92	0.81	*9.64*	3.99	9.81	0.83

To sum up, the results from the phonological skills show that all four experimental groups continued to improve in manipulating sounds at both syllabic and phonemic level up to Grade 2 and that the different treatment conditions provided equivalent benefits.

Cognitive skills

Simultaneous Processing

Visual-Spatial Relations: Results showed that no significant differences of the type of treatment were found, $F(4, 67) = .81$, $p > .05$, $\eta^2 = .05$, nor was there a significant interaction between group and time ($p > .05$). However, statistically significant changes in Visual-Spatial Relations were revealed over time, $F(1,67) = 4.58$, $p < .05$, $\eta^2 = .06$. Subsequent analyses showed significant differences from post-intervention to follow-up, $F(1,67) = 4.48$, $p < .05$, $\eta^2 = .06$, and from mid-intervention to follow-up, $F(1,67) = 8.34$, $p < .01$, $\eta^2 = .11$. These results indicate that children participating in this study were improved on combining discrete and unconnected stimuli into a whole to assist information processing.

Table 8

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Visual-Spatial Relations

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	11.88	2.15	11.57	0.41	13.47	2.74	13.14	0.49	13.47	1.70	13.29	0.38
PREP	14	11.79	1.89	11.74	0.45	12.29	2.09	12.24	0.53	12.50	1.74	12.48	0.42
GG	14	10.50	1.51	11.04	0.46	11.57	1.83	12.14	0.55	12.14	1.29	12.46	0.43
PREP+GG	14	11.79	2.15	11.80	0.45	12.29	2.33	12.30	0.53	13.29	2.05	13.30	0.42
GG+PREP	14	11.14	1.70	11.01	0.45	12.86	1.79	12.72	0.53	13.57	1.28	13.50	0.42

Figure Memory: Similar results were observed for Figure Memory with no significant differences of the type of treatment, $F(4, 67) = 1.69$, $p > .05$, $\eta^2 = .09$, and no significant interaction between group and time ($p > .05$). However, statistically significant changes were revealed over time, from post-intervention to follow-up, $F(1,67) = 14.17$, $p < .001$, $\eta^2 = .18$, indicating that all treatment groups developed non-verbal memory skills enabling them to arrange information into a holistic pattern.

Table 9
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Figure Memory

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	5.82	2.83	5.37	0.53	6.65	2.76	6.47	0.47
PREP	14	6.07	2.64	5.95	0.58	6.79	1.48	6.74	0.52
GG	14	5.43	2.59	6.03	0.59	6.29	1.54	6.53	0.52
PREP+GG	14	5.79	3.09	5.67	0.58	6.64	2.27	6.59	0.52
GG+PREP	14	5.57	2.82	5.76	0.58	6.64	1.74	6.72	0.52

Successive Processing

Word Series: Results showed that no significant differences of the type of treatment were found, $F(4, 67) = 1.42$, $p > .05$, $\eta^2 = .08$, nor was there a significant interaction between group and time ($p > .05$). However, once again statistically significant changes were observed over time, $F(1,67) = 7.44$ $p < .01$, $\eta^2 = .10$. Subsequent analyses revealed significant differences from post-intervention to follow-up, $F(1,67) = 4.02$, $p = .05$, $\eta^2 = .06$, and from mid-intervention to follow-up, $F(1,67) = 14.20$, $p < .001$, $\eta^2 = .18$, suggesting that all treatment groups were gradually able to retain and reproduce successfully a series of discrete stimuli on a temporary basis in their original order, as did the control group.

Table 10

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Word Series

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	7.88	2.91	6.88	0.33	8.24	2.88	7.45	0.47	9.00	2.29	8.30	0.37
PREP	14	6.50	1.91	6.46	0.34	7.07	2.09	7.04	0.49	8.07	1.86	8.05	0.39
GG	14	6.00	1.92	6.13	0.34	6.00	1.66	6.10	0.49	7.36	1.22	7.45	0.39
PREP+GG	14	5.93	1.21	6.46	0.34	6.57	2.41	6.99	0.50	7.29	2.05	7.66	0.39
GG+PREP	14	5.57	0.64	6.16	0.35	6.43	1.02	6.89	0.50	7.14	0.95	7.56	0.40

Sentence Questions: No significant differences of the type of treatment were found, $F(4, 67) = .13$, $p > .05$, $\eta^2 = .01$, nor was there a significant interaction between group and time ($p > .05$). However, once again, statistically significant changes were revealed over time, from post-intervention to follow-up, $F(1,67) = 32.91$, $p < .001$, $\eta^2 = .33$, indicative of the continuous improvement showed by all treatment and the control groups in verbal short-term memory.

Table 11
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Sentence Questions

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	5.82	2.83	5.37	0.53	6.65	2.76	6.47	0.47
PREP	14	6.07	2.64	5.95	0.58	6.79	1.48	6.74	0.52
GG	14	5.43	2.59	6.03	0.59	6.29	1.54	6.53	0.52
PREP+GG	14	5.79	3.09	5.67	0.58	6.64	2.27	6.59	0.52
GG+PREP	14	5.57	2.82	5.76	0.58	6.64	1.74	6.72	0.52

Speech Rate: Results revealed that there was a significant interaction between group and time, $F(1, 67) = 13.51$, $p < .001$, $\eta^2 = .17$, as well as statistically significant changes in Speech Rate over time, from post-intervention to follow-up, $F(1,67) = 4.63$, $p < .05$, $\eta^2 = .07$, suggesting that all children continued to show speeded phonological processing skills. No significant differences of the type of treatment were found, $F(4, 67) = .46$, $p > .05$, $\eta^2 = .03$.

Table 12
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Speech Rate

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	146.29	39.35	159.00	5.23	136.65	27.08	145.57	4.72
PREP	14	168.07	38.77	168.85	5.63	148.21	25.27	148.76	5.09
GG	14	168.93	44.23	169.33	5.63	143.29	30.24	143.57	5.09
PREP+GG	14	173.93	22.03	163.23	5.70	147.50	24.60	139.99	5.16
GG+PREP	14	172.71	29.16	166.81	5.65	150.93	31.35	146.78	5.11

Attention and Planning Tasks

Expressive Attention: Although attention is not a typical predictor or reading performance, it was examined whether intensive remedial instruction via computer applications had any effects on attentive behaviour. No significant differences of the type of treatment were found, $F(4, 67) = .52$, $p > .05$, $\eta^2 = .03$, nor was there a significant interaction between group and time ($p > .05$). Also, there were no statistically significant changes in Expressive Attention over time ($p > .05$).

Table 13

Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Expressive Attention

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	0.74	0.17	0.73	0.03	0.85	0.13	0.83	0.03
PREP	14	0.74	0.17	0.74	0.04	0.78	0.20	0.77	0.04
GG	14	0.76	0.15	0.80	0.04	0.79	0.14	0.83	0.04
PREP+GG	14	0.73	0.17	0.73	0.04	0.82	0.17	0.82	0.04
GG+PREP	14	0.74	0.12	0.74	0.04	0.83	0.16	0.82	0.04

Matching Numbers: This task was used as an indicator for planning skills. Results showed no significant differences of the type of treatment, $F(4, 67) = .54$, $p > .05$, $\eta^2 = .03$, interaction or time ($p > .05$), a result that was relatively expected given the weak relationship that this factor usually shows with word reading in early years (see Kendeou et al., 2015, for relevant discussion).

Table 14
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Matching Numbers

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	0.07	0.02	0.07	0.00	0.09	0.03	0.09	0.01
PREP	14	0.07	0.02	0.07	0.01	0.08	0.01	0.08	0.01
GG	14	0.06	0.03	0.07	0.01	0.08	0.03	0.09	0.01
PREP+GG	14	0.07	0.01	0.07	0.01	0.09	0.02	1.00	0.01
GG+PREP	14	0.07	0.02	0.07	0.01	0.09	0.03	0.09	0.01

Planned Search: Similar results were also obtained in the second planning task, as no significant differences of the type of treatment, $F(4, 67) = .41$, $p > .05$, $\eta^2 = .02$, interaction or time ($p > .05$) were observed.

Table 15
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Planned Search

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	183.29	52.81	181.93	10.98	152.65	31.62	151.95	9.69
PREP	14	177.86	64.32	179.06	12.09	133.21	24.66	133.83	10.67
GG	14	183.93	40.13	176.79	12.18	171.71	50.59	168.06	10.75
PREP+GG	14	174.36	51.40	179.75	12.14	144.86	33.33	147.61	10.72
GG+PREP	14	165.50	47.94	167.71	12.10	157.64	60.36	158.77	10.68

To sum up, the results from the cognitive skills show that all four groups continued to improve in successive and simultaneous processing up to Grade 2 irrespective of the treatment condition.

Rapid Automatized Naming

RAN Colors: Analysis indicated that after adjustment for pre-intervention performance (Time 1), no significant differences of the type of treatment were found, $F(4, 67) = .43$, $p > .05$, $\eta^2 = .03$, nor was there a significant interaction between group and time ($p > .05$). Also, there were no statistically significant changes in RAN Colors over time ($p > .05$), as participants approached ceiling quite early.

Table 16

Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for RAN Colors

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	0.65	0.22	0.60	0.03	0.73	0.25	0.68	0.05
PREP	14	0.61	0.21	0.60	0.04	0.69	0.23	0.68	0.06
GG	14	0.58	0.15	0.57	0.04	0.67	0.22	0.66	0.06
PREP+GG	14	0.56	0.21	0.60	0.04	0.70	0.34	0.74	0.06
GG+PREP	14	0.53	0.23	0.57	0.04	0.73	0.33	0.77	0.06

RAN Pictures: Similar results were also obtained in the second non-alphanumeric RAN task, as no significant differences of the type of treatment, $F(4, 67) = 1.62$, $p > .05$, $\eta^2 = .09$, time ($p > .05$) or their interaction were observed.

RAN Digits: Results showed a significant main effect of time, $F(1, 67) = 6.83$, $p = .01$, $\eta^2 = .09$ and group, $F(4, 67) = 2.93$, $p = .03$, $\eta^2 = 0.15$, suggesting that all groups developed across time but also that groups differed from one another. However, unexpectedly, the interaction between time and group was not significant ($p > .05$). Subsequent analyses revealed significant differences from post-intervention to follow-up, $F(1,67) = 5.19$, $p < .05$, $\eta^2 = .07$, and from mid-intervention to follow-up, $F(1,67) = 10.75$, $p < .01$, $\eta^2 = .14$. In other words, children participating in the study were improved on naming speed irrespective of the group they belonged to.

Table 17

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for RAN Pictures

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	0.73	0.17	0.50	0.11	0.76	0.28	0.81	0.18	0.77	0.18	1.22	0.21
PREP	14	0.56	0.18	0.50	0.19	0.64	0.16	0.65	0.19	0.65	0.14	0.96	0.22
GG	14	0.59	0.13	0.44	0.11	0.65	0.13	0.78	0.19	0.65	0.10	0.87	0.22
PREP+GG	14	0.58	0.19	0.37	0.11	0.59	0.17	0.84	0.19	0.62	0.21	1.10	0.23
GG+PREP	14	0.54	0.20	0.61	0.11	0.61	0.17	0.83	0.19	0.66	0.22	1.15	0.23

Table 18

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for RAN Digits

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	1.18	0.33	1.06	0.06	1.18	0.26	1.08	0.06	1.63	0.32	1.52	0.09
PREP	14	1.15	0.40	1.04	0.07	1.16	0.43	1.06	0.07	1.48	0.47	1.37	0.09
GG	14	0.94	0.28	0.97	0.07	1.07	0.25	1.09	0.07	1.35	0.28	1.38	0.09
PREP+GG	14	1.03	0.40	1.11	0.07	1.10	0.36	1.17	0.07	1.40	0.43	1.48	0.09
GG+PREP	14	1.09	0.42	1.24	0.07	1.15	0.41	1.28	0.07	1.52	0.60	1.66	0.09

RAN Letters: No significant differences of the type of treatment were found, $F(4, 67) = 0.36$, $p > .05$, $\eta^2 = .02$, nor was there a significant interaction between group and time ($p > .05$). However, statistically significant changes in RAN Letters were revealed over time, $F(1,67) = 12.63$, $p < .001$, $\eta^2 = .16$. Subsequent analyses revealed significant differences from post-intervention to follow-up, $F(1,67) = 10.45$, $p < .01$, $\eta^2 = .14$, and from mid-intervention to follow-up, $F(1,67) = 18.97$, $p < .001$, $\eta^2 = .22$.

Overall, the results obtained from the RAN tasks show that all four experimental groups continued to improve up to Grade 2 in alphanumeric tasks (i.e., RAN Digits and RAN Letters) as opposed to the nonalphanumeric ones (i.e., RAN Pictures and RAN Colors). The different treatment conditions provided equivalent benefits.

Table 19

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for RAN Letters

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	1.06	0.30	0.96	0.05	1.09	0.32	0.99	0.06	0.95	0.43	0.95	0.09
PREP	14	0.98	0.31	0.87	0.05	1.07	0.38	0.96	0.07	1.03	0.36	1.03	0.10
GG	14	0.80	0.21	0.85	0.05	1.01	0.35	1.06	0.07	0.82	0.31	0.82	0.10
PREP+GG	14	0.86	0.24	0.91	0.05	0.98	0.30	1.03	0.07	0.80	0.38	0.80	0.10
GG+PREP	14	0.84	0.42	0.95	0.05	0.94	0.41	1.06	0.07	0.83	0.34	0.83	0.10

Word Reading Fluency and Accuracy Performance

***Word reading fluency*:** Results showed that after adjustment for pre-intervention performance (Time 1) on word reading fluency, no significant differences of the type of treatment were found, $F(4, 67) = .44$, $p > .05$, $\eta^2 = .03$, nor was there a significant interaction between group and time ($p > .05$). However, statistically significant changes in word reading fluency were revealed over time, $F(1,67) = 35.94$, $p < .001$, $\eta^2 = .35$. Subsequent analyses revealed significant differences from mid- to post-intervention, $F(1,67) = 27.15$, $p < .001$, $\eta^2 = .29$, from post-intervention to follow-up, $F(1,67) = 21.32$, $p < .001$, $\eta^2 = .24$, and from mid-intervention to follow-up, $F(1,67) = 53.03$, $p < .001$, $\eta^2 = .44$. In other words, children participating in this study were learning to read irrespective of the group they belonged to.

***Phonemic Decoding Fluency*:** Similar results were observed for phonemic decoding fluency. Particularly, no significant differences among the groups were found, $F(4, 67) = 1.39$, $p > .05$, $\eta^2 = .08$, nor was there a significant interaction between group and time ($p > .05$). However, statistically significant changes in phonemic decoding fluency were found over time, $F(1,67) = 46.08$, $p < .001$, $\eta^2 = .41$. Subsequent analyses showed significant differences between mid- and post-intervention scores, $F(1,67) = 27.14$, $p < .001$, $\eta^2 = .29$, between post-intervention and follow-up scores, $F(1,67) = 51.92$, $p < .001$, $\eta^2 = .44$, and between mid-intervention and follow-up scores, $F(1,67) = 66.60$, $p < .001$, $\eta^2 = .50$. These results indicate that all treatment groups developed decoding skills enabling them to reliably identify words that are unfamiliar to them in print.

Table 20
Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Word Reading Fluency

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	18.71	5.50	14.44	0.86	19.82	5.95	16.53	0.95	30.35	6.59	25.13	1.65
PREP	14	13.93	3.12	13.94	0.82	15.36	3.00	15.36	0.91	27.71	9.57	27.73	1.58
GG	14	11.50	5.36	13.47	0.85	15.71	3.17	17.24	0.94	26.29	7.29	28.70	1.63
PREP+GG	14	12.36	4.22	14.27	0.84	16.00	3.53	17.48	0.94	26.21	5.91	28.56	1.62
GG+PREP	14	12.64	5.33	13.92	0.83	15.76	5.37	16.78	0.92	26.57	7.54	28.14	1.60

Table 21
Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Phonemic Decoding Fluency

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	14.41	4.09	10.38	0.87	17.29	4.52	13.62	1.04	19.00	4.99	16.09	1.23
PREP	14	10.57	2.74	11.05	0.83	13.00	3.19	13.43	0.98	18.14	5.55	18.49	1.16
GG	14	9.14	5.45	10.15	0.83	10.57	6.03	11.49	0.99	16.71	4.12	17.44	1.17
PREP+GG	14	9.64	4.40	11.98	0.87	13.57	3.94	15.70	1.03	17.43	3.55	19.12	1.21
GG+PREP	14	9.86	5.45	10.93	0.83	12.86	5.50	13.84	0.99	17.43	5.96	18.20	1.17

Word reading accuracy**:** Similar findings to fluency were revealed for reading accuracy. Analysis indicated that no significant differences of the type of treatment were found, $F(4, 67) = .68$, $p > .05$, $\eta^2 = .04$, nor was there a significant interaction between group and time ($p > .05$). However, once again statistically significant changes were revealed over time, $F(1,67) = 65.66$, $p < .001$, $\eta^2 = .50$. Subsequent analyses revealed significant differences from mid- to post-intervention scores, $F(1,67) = 41.45$, $p < .001$, $\eta^2 = .38$, from post-intervention to follow-up scores, $F(1,67) = 27.51$, $p < .001$, $\eta^2 = .29$, and from mid-intervention to follow-up scores, $F(1,67) = 116.61$, $p < .001$, $\eta^2 = .64$.

Phonemic Decoding Accuracy**:** Results showed that after adjustment for pre-intervention performance (Time 1) on phonemic decoding accuracy, no significant differences among the groups were found, $F(4, 67) = .46$, $p > .05$, $\eta^2 = .76$, nor was there a significant interaction between group and time ($p > .05$). However, statistically significant changes in phonemic decoding accuracy were found over time, $F(1,67) = 60.20$, $p < .001$, $\eta^2 = .47$. Subsequent analyses showed significant differences between mid- and post-intervention scores, $F(1,67) = 30.90$, $p < .001$, $\eta^2 = .32$, between post-intervention and follow-up scores, $F(1,67) = 35.86$, $p < .001$, $\eta^2 = .35$, and between mid-intervention and follow-up scores, $F(1,67) = 102.59$, p < .001, $\eta^2 = .61$.

Overall, the results pertaining to word reading skills support the efficacy of the remedial reading interventions used in the present study which have been designed to improve word reading fluency among young poor readers.

Table 22

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Word Reading Accuracy

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	48.12	18.72	25.63	3.90	53.76	16.72	38.80	5.33	64.29	16.36	53.36	5.06
PREP	14	30.00	14.50	31.86	3.17	44.29	20.21	45.52	4.33	52.79	17.72	53.69	4.11
GG	14	24.43	17.07	32.18	3.29	41.64	17.52	46.80	4.49	53.07	14.98	56.84	4.27
PREP+GG	14	23.93	14.52	34.66	3.40	41.93	11.87	49.07	4.65	57.00	15.17	62.22	4.41
GG+PREP	14	24.86	18.73	31.82	3.26	44.07	22.07	48.71	4.46	55.86	17.24	59.24	4.23

Table 23

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Phonemic Decoding Accuracy

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	23.29	10.05	15.76	1.78	27.49	9.77	20.96	2.30	30.59	6.39	27.25	2.17
PREP	14	16.57	5.17	17.16	1.53	23.43	9.17	23.94	1.97	27.79	9.24	28.05	1.86
GG	14	14.50	6.96	17.32	1.58	21.93	7.94	24.38	2.04	25.93	6.72	27.18	1.93
PREP+GG	14	15.07	6.01	18.37	1.60	22.71	5.93	25.57	2.07	27.50	6.21	28.96	1.95
GG+PREP	14	13.64	6.82	16.09	1.57	23.98	8.06	25.69	2.02	29.86	7.25	30.94	1.91

Reading Comprehension

Passage Comprehension (Multiple Choice): A series of 2 (time; Time 3 and Time 4) x 5 (groups) repeated measures analysis of variance was conducted for Passage Comprehension. Results revealed that the effects of group and their interaction with time were not significant but there was a significant effect of time from post-intervention to follow-up, F (1, 68) = 15.69, p <.001, η^2=0.19, suggesting that groups developed with time but also that groups did not differ from one another.

Woodcock-Johnson Passage Comprehension (WJPC): Results revealed that after adjustment for pre-intervention performance (Time 1), no significant differences of the type of treatment were found, $F(4, 67) = .34$, $p > .05$, $\eta^2 = .02$, nor was there a significant interaction between group and time (p >.05). However, statistically significant changes in WJPC were revealed again over time, from post-intervention to follow-up, $F(1,67) = 27.10$, $p < .001$, $\eta^2 = .29$.

Table 24
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for WJPC

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	21.12	7.42	17.61	1.35	24.06	5.54	22.24	1.14
PREP	14	19.43	4.69	20.26	1.40	22.36	2.98	22.79	1.18
GG	14	19.50	6.91	20.05	1.40	20.71	6.06	21.00	1.17
PREP+GG	14	19.07	8.28	19.96	1.40	22.14	5.64	22.61	1.18
GG+PREP	14	17.43	6.65	19.42	1.42	20.79	3.66	21.82	1.19

CBM-Maze: Similar findings were observed for CBM-Maze. Specifically, no significant differences of the type of treatment were found, $F(4, 67) = .32$, $p > .05$, $\eta^2 = .02$, nor was there a significant interaction between group and time (p >.05). However, statistically significant changes were revealed over time for CBM-Maze too, $F(1,67) = 18.76$, $p < .001$, $\eta^2 = .22$. Particularly, subsequent analyses revealed significant differences from mid- to post-intervention, $F(1,67) = 13.80$, $p < .001$, $\eta^2 = .17$, from post-intervention to follow-up, $F(1,67) = 8.82$, $p < .01$, $\eta^2 = .12$, and from mid-intervention to follow-up, $F(1,67) = 28.93$, $p < .001$, $\eta^2 = .30$.

Table 25

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for CBM-Maze

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	0.86	0.91	0.50	0.11	1.14	0.98	0.81	0.18	1.55	1.16	1.22	0.21
PREP	14	0.38	0.41	0.50	0.19	0.54	0.38	0.65	0.19	0.86	0.64	0.96	0.22
GG	14	0.57	0.76	0.44	0.11	0.91	0.67	0.78	0.19	0.99	0.83	0.87	0.22
PREP+GG	14	0.19	0.47	0.37	0.11	0.67	1.12	0.84	0.19	0.93	0.94	1.10	0.23
GG+PREP	14	0.33	0.41	0.61	0.11	0.57	0.74	0.83	0.19	0.91	0.97	1.15	0.23

Overall, the findings from reading comprehension tests indicate that all treatment groups improved their performance in reading comprehension up to Grade 2 irrespective of the treatment condition.

Orthographic Processing

Orthographic Choice: Orthographic processing was the last set of skills that were assessed. Results revealed that after adjustment for pre-intervention performance (Time 1), no significant differences of the type of treatment were found, $F(4, 67) = .19$, $p > .05$, $\eta^2 = .01$, nor was there a significant interaction between group and time ($p > .05$). However, consistent with previous analyses, statistically significant changes in Orthographic Choice were revealed over time from post-intervention to follow-up, $F(1,67) = 6.08$, $p < .05$, $\eta^2 = .08$, indicating that remediation continued to exert significant effects on phonetic spelling accuracy skills for all treatment groups in Grade 2.

Table 26
Unadjusted and adjusted intervention means for post-intervention and follow-up reading performance with pre-intervention scores as a covariate for Orthographic Choice

		Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	8.82	2.30	8.56	0.50	10.35	2.29	10.23	0.59
PREP	14	8.79	1.81	8.86	0.52	9.71	1.68	9.75	0.61
GG	14	8.29	2.13	8.38	0.52	9.64	2.34	9.69	0.61
PREP+GG	14	7.79	1.37	7.86	0.52	9.93	2.67	9.96	0.61
GG+PREP	14	8.21	1.97	8.29	0.52	10.43	2.17	10.46	0.61

***Two-Minute Spelling*:** Likewise, no significant differences of the type of treatment were found, $F(4, 67) = .95$, $p > .05$, $\eta^2 = .05$, nor was there a significant interaction between group and time ($p > .05$). However, statistically significant changes in this spelling task were revealed over time, $F(1,67) = 11.93$, $p < .001$, $\eta^2 = .15$. Subsequent analyses revealed significant differences from mid-intervention to follow-up scores, $F(1,67) = 15.04$, $p < .001$, $\eta^2 = .18$, and from post-intervention to follow-up scores, $F(1,67) = 13.18$, $p = .001$, $\eta^2 = .16$, indicating that remediation exerted significant effects on memory for specific spelling patterns for all treatment groups from mid-remediation onwards.

***Word Chains*:** Results revealed that no significant differences of the type of treatment were found, $F(4, 67) = .33$, $p > .05$, $\eta^2 = .02$, nor was there a significant interaction between group and time ($p > .05$). However, once again statistically significant changes in word chains were revealed over time, $F(1,67) = 8.74$, $p < .01$, $\eta^2 = .12$. Subsequent analyses revealed significant differences between mid- and post-intervention scores, $F(1,67) = 9.27$, $p < .01$, $\eta^2 = .12$, and from mid-intervention to follow-up scores, $F(1,67) = 14.10$, $p < .001$, $\eta^2 = .17$, indicating that all treatment groups benefited from remediation also with regard to their ability to quickly access visual-orthographic codes for specific words.

Overall, findings from the orthographic processing tests show that all treatment groups continued to improve their performance in orthographic processing up to Grade 2.

Table 27

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Two-Minute Spelling

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	1.29	0.99	1.16	0.18	1.47	1.07	1.23	0.23	2.29	1.83	2.06	0.31
PREP	14	0.71	0.61	0.79	0.19	1.14	0.77	1.28	0.25	1.71	0.83	1.85	0.33
GG	14	0.71	0.61	0.77	0.19	1.00	1.17	1.10	0.25	1.57	0.76	1.67	0.33
PREP+GG	14	0.64	0.63	0.66	0.19	0.79	0.58	0.81	0.24	1.43	0.51	1.45	0.33
GG+PREP	14	0.64	0.63	0.66	0.19	1.14	1.10	1.17	0.24	1.79	1.63	1.81	0.33

Table 28

Unadjusted and adjusted intervention means for mid-intervention, post-intervention, and follow-up reading performance with pre-intervention scores as a covariate for Word Chains

		Mid-intervention				Post-intervention				Follow-up			
		Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
Groups	N	Mean	SD	Mean	SE	Mean	SD	Mean	SE	Mean	SD	Mean	SE
CA-C	17	5.24	2.97	4.56	0.48	6.47	3.14	5.83	0.60	7.12	3.14	6.62	0.75
PREP	14	3.50	0.94	3.58	0.49	5.14	1.70	5.22	0.61	6.43	2.47	6.49	0.77
GG	14	3.71	1.68	4.01	0.49	5.29	1.86	5.57	0.61	5.71	3.71	5.93	0.78
PREP+GG	14	2.93	2.66	3.28	0.50	4.64	1.78	4.98	0.62	6.50	2.68	6.76	0.78
GG+PREP	14	3.71	1.27	3.80	0.49	5.71	2.79	5.79	0.61	6.36	2.24	6.42	0.77

Summing up

To sum up, analyses of covariance revealed that all groups showed sizable improvements in phonological, naming, cognitive, reading, and orthographic processing skills over time. The development in these abilities seen in all experimental groups was comparable to the development seen in the CA-C group, after controlling for their initial score, which was far faster than what would be expected over participants' school careers. Perhaps, this resulted in non-significant main group effects. However, a closer examination of group differences at post hoc level reveals some random exceptions which are discussed here for reasons of clarity of the trends relating to the benefits of the different treatments. Specifically, the CA-C group outperformed the PREP and PREP+GG groups on a phonemic sensitivity task (i.e., Phoneme Elision). Likewise, the CA-C group outperformed the GG group in reading comprehension and RAN Digits. In turn, GG group achieved higher scores at follow-up test than the CA-C group in phonemic decoding fluency.

No significant differences of the type of treatment were found. However, a closer look at the adjusted means reveals some trends in groups' performance, as a result of treatment. Specifically, children in the GG and GG+PREP groups showed greater improvement in a supraphonemic sensitivity (i.e., Initial Syllable Oddity) and a phonemic sensitivity (i.e., Phoneme Elision) task than those given cognitive treatment (PREP). On the other hand, children in the PREP group showed greater improvement in a planning task (i.e., Planned Search) than those given grapho-phonemic training or combined treatments. Also, groups receiving combined treatments yielded greater benefits than cognitive and grapho-phonemic groups in a simultaneous processing task (i.e., Visual Spatial Relations). Moreover, the GG group did not benefit as much as the other treatment groups in reading comprehension.

Microgenetic Data Analysis

Traditionally, the efficacy of the PREP and Graphogame intervention programs has been determined by comparing the performance of those receiving PREP or Graphogame to untreated children with reading difficulties (e.g., *PREP:* Das et al., 1995; *Graphogame:* Alanko and Nevalainen, 2004) or typically developing readers (e.g., *PREP:* Papadopoulos et al., 2004; *Graphogame:* Saine et al., 2011) on measures of cognitive, linguistic, reading, and orthographic processing skills at pre- and post-intervention assessments. However, computerized implementation of reading remedial interventions enables recording of microgenetic data during intervention; i.e., log details about the specific actions individuals perform during each task of the intervention. Such information could enable researchers to gain valuable insights in understanding the learning progress dynamics of the readers during intervention, as well as an individual's (or group's) gain variation on different elements of the intervention. These insights, in turn, could help tailor reading intervention programs, such as PREP or Graphogame, to the progress dynamics of each individual.

In the following section, a methodological framework is proposed for encoding and modeling microgenetic data, obtained during the administration of PREP and Graphogame intervention programs, either separately or in combination. First, a unified encoding scheme of the microgenetic data is formalized, and then four metrics are proposed to characterize the developmental stages of the readers during intervention and their learning progress dynamics. Moreover, potential applications of these metrics are outlined in the study of the reading remediation effects of both PREP and Graphogame.

Microgenetic Data Encoding Model

The level of detail and the format of microgenetic data vary greatly between tasks and across participants during the execution of PREP or Graphogame. For example, microgenetic data could be as detailed as logging specific key-presses and mouse movements, or logging time and accuracy on a second-by-second basis during the task. Moreover, the type of measurements recorded during different tasks of the intervention may differ. Furthermore, the variation in the difficulty level of each task and the navigation structure of PREP generate many missing values. This diversity in recorded data constitutes a challenge in developing a unified encoding scheme of microgenetic data for the purpose of understanding learning progress dynamics.

Motivated by the *Level-Rate* proposal first presented by Zigler (1969) as a cognitive-developmental approach for the study of individual differences in intelligence, this study proposes an encoding model that introduces the concepts of *Performance* and *Effort*. In particular, the model assumes that, whatever the underlying format of the raw microgenetic data may be, there exists a mapping from the raw data to a *Performance* score and an *Effort* score for each participant and each task (level) of PREP or Graphogame. Intuitively, *Performance* corresponds to a score of how well a participant executes a particular task and *Effort* corresponds to the energy (or resources) a participant allocates on the specific task. An example of a *Performance* score could be the number of correct (individual) answers during the execution of a task. Similarly, an example of an *Effort* score could be the total exposure time on the task (i.e. total time executing a task, as well as the number of attempts from the child's part to complete the task). It is left up to the researcher to define this mapping depending on the microgenetic data available in each task. However, there is great flexibility in how one defines each mapping which can vary from task to task or from level to level. The resulting *Performance-Effort* space captures information about the learning progress dynamics of each individual.

However, the absolute scores of *Performance* and *Effort* measures are not suitable for comparisons across groups, tasks, or levels of the intervention. First, the absolute scores vary widely between tasks due to differences in either the nature of the task or its difficulty level. Second, there are missing values on non-completed tasks. To achieve score comparability but also to compensate for the missing values in microgenetic data and to accommodate for the flexibility in the specification of the *Performance* and *Effort* metrics, the proposed method employs a rank score transformation. Specifically, for each task/level pair of the intervention, each participant is assigned a *Performance-rank* and an *Effort-rank* which corresponds to the relative ranking of that participant compared to the Performance and (respectively *Effort*) scores of all other participants under the same task/level pair. The resulting microgenetic data encoding model is then defined through the variables

$$P_n(t,v \mid \mathbf{N_P}) = \text{Performance-rank}(n,t,v \mid \mathbf{N_P}),$$

$$E_n\,(t,v \mid \mathbf{N_E}) = \text{Effort-rank}(n,v,l \mid \mathbf{N_E}),$$

where (t,v) corresponds to the task index, level index pair, $\boldsymbol{N_P}$ and $\boldsymbol{N_E}$ correspond to the set of raw performance and effort scores (respectively) of all participants and all task/level pairs. The notation X-rank $(n,t,v \mid \mathbf{N_P})$ specifies the rank of participant n, at task t and level v given the raw performance (or effort) scores of all participants.

Microgenetic Data Metrics Model

In this section, a model is proposed based on information theoretic measures, so as to model learning dynamics during the intervention programs given the microgenetic data encoding model as defined by the Performance-rank and Effort-rank variables presented in the preceding section.

First, the concept of the histogram profile (HP) is introduced. For a sub-group (G) of participants and a subset (TL) of task/level pairs we consider the histogram H over the rank values (either Performance-rank or Effort-rank) attained by participants in sub-group G, during a sub-set of task/level pairs (TL). Next, by applying a series of mathematical operations on histogram H (first a convolution, with a Gaussian kernel[1] (Shapiro & Stockman, 2001), and then normalization by dividing the result of the convolution with an appropriate constant), a smoothed estimate of the probability distribution over the rankings of the participants in subgroup G is obtained, while participants are performing tasks in TL. This probability distribution is termed as the histogram profile (HP) of the group and denote it as $HP\_{performance}$ if it is estimated using the *Performance-rank* values, and as HP_{Effort} if it is estimated using the *Effort-rank* values:

$$HP\_{performance} (r \mid G, TL, \text{Performance-rank})$$

$$HP\_{Effort} (r \mid G, TL, \text{Effort-rank})$$

It is noted that HP carries all available information about the overall achievement of the group during the tasks' execution. Had the participants in group G achieved the highest possible rankings during the task, their HP would be skewed toward the left of the distribution's domain (high ranks). On the other hand, had they achieved the lowest possible rankings, their HP would be skewed toward the right of the distribution's domain (lower ranks). Similarly, if the group had no particular achievement trend in the intervention, their HP would follow a uniform distribution. The HP for these three cases are denoted as $HP^{(opt)}$, $HP^{(worse)}$ and $HP^{(uniform)}$ respectively, and are expressed as analytic formulas (see also Christoforou et al., 2014). These three HPs are thus considered as benchmarked Histogram Profiles (bHP)

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[1] A Gaussian kernel is a function derived from the normal probability distribution, and is centered at zero. It is often used as a kernel in the convolution operation to smooth an input function (Shapiro & Stockman, 2001).

because they constitute measureable milestones reflecting achievement stages of a group. These bHPs are independent of the other groups in the sample, but they depend on participants' performance within a group. Figure 1 shows an illustration of the HP, $HP^{(opt)}$, and $HP^{(worse)}$ histogram profiles.

Starting from this promise, if a distance or similarity measure between the measured HP and the bHP could be defined, that measure would reflect the degree of which the group's achievement deviates or approaches a "favorable" or "unfavorable" benchmark. For example, the "closer" the HP of a group during a subset of task is to $HP^{(opt)}$ and the further away it is from $HP^{(worse)}$, the better would be the group's achievement level in the task. Moreover, the modulations of such similarity measures, across sub-groups and/or task level, provide information about the dynamics of the achievement level.

In the following section, four such measures (or metrics) are formulated based on a distance measure to quantify the learning stage of each individual and to model their learning progress dynamics during the intervention program. The first group of metrics are the instantaneous metrics. These metrics are the instantaneous Developmental Learning Stage (iDLS) for a group of participants and for an individual participant, and Learning Dynamic Trace (LDT) for a group of participants and for individual participants.

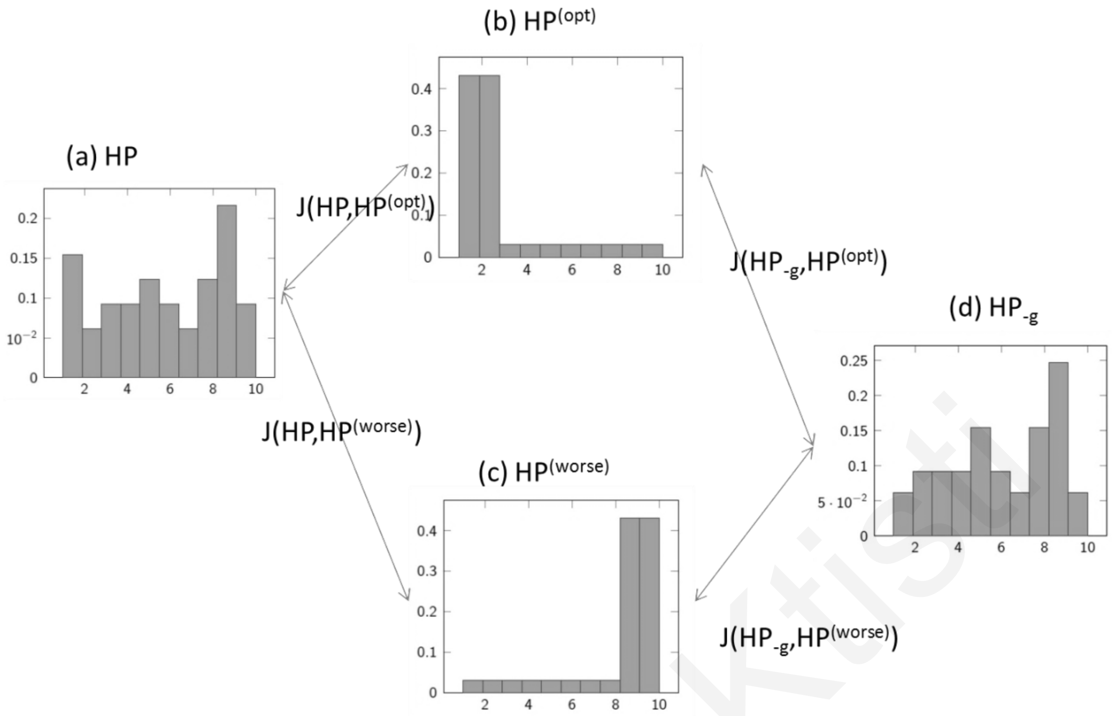

Figure 1: (a) The Histogram Profile (HP) for a group of participants; (b) The expected Histogram Profile had the group achieved the best possible performance $HP^{(opt)}$; (c) The expected Histogram Profile had the group showed the worst possible performance $HP^{(worse)}$; (d)The Histogram Profile (HP_{-g}) of the same group, where one participant (i.e., participant g) has been removed from the group. The function *J* (defined as the square root of the Jensen-Shannon Divergence) is a measure of the distance between the different Histogram Profiles. In the illustration above, the HP of the group [plot (a)] is further away from the group's worst possible performance $HP^{(worse)}$ and closer to the group's best possible performance $HP^{(opt)}$. This is reflected as a positive value of the instantaneous Developmental Learning Stage (iDLS) metric (which is the log-ratio of the two distances). Similarly, the Histogram Profile of the group when participant g is excluded from the group [plot (d)] is closer to the group's worst possible performance $HP^{(worse)}$, and further away from the group's best possible performance $HP^{(opt)}$. This is reflected as a positive value of the iDLS metric. The difference between the iDLS calculated on (HP) and the iDLS calculated on the (HP_{-g}) measures the degree participant g helped the group move toward its best possible performance. This difference is the IiDLS metric defined in the text.

Instantaneous Developmental Stage Metric for a Group

Typically, the PREP intervention program defines an ordering of the tasks and levels. For example, non-alphabetic tasks precede alphabetic tasks and each task has multiple levels ordered in increasing difficulty. Moreover, we are typically interested in the progress of a small sub-group of participants with common characteristics; for example, participants with similar scores in measures of cognitive, linguistic, reading, or orthographic processing skills obtained on pre-, mid-, or post-intervention assessments. Given such a sub-group of interest, $G_{i,}$, and a set of consecutive task/level pairs, TL_i, the metric of instantaneous developmental learning stage (iDLS) is defined in terms of either *Performance-ranking* or *Effort-ranking* as follows:

$$iDLS\big(HP(G_i, TL_i)\big) = \log\left(\frac{\sqrt{J\big(HP(G_i, TL_i), HP^{\{worse\}}(G_i, TL_i)\big)}}{\sqrt{J\big(HP(G_i, TL_i), HP^{\{opt\}}(G_i, TL_i)\big)}}\right)$$

where the $HP(G_i, TL_i)$ corresponds to the Histogram Profile of the group estimated based on participants' performance on tasks in TL_i. The function *J* is the Jensen-Shannon's Divergence[2] (Endres & Schindelin, 2003) between the two probability distributions. Intuitively, iDLS describes the degree to which the group performance is more similar to the best possible performance or to the worst possible performance. In the case in which the distance of HP to $HP^{(worse)}$ and the distance of HP to $HP^{(opt)}$ are the same, iDLS is equal to zero. In the case in which the distance of the observed HP to $HP^{(opt)}$ is greater than the distance of HP to $HP^{(worse)}$, iDLS will have a negative value. Similarly, if the opposite holds, the iDLS has a positive value, reflecting the proximity of the group to the best possible performance it could have achieved. The calculation of iDLS is illustrated in Figure 1.

Instantaneous Developmental Stage Metric for an Individual

It is of interest to know the degree of which each participant contributes to the iDLS during a subset of tasks; to this end, the individual's developmental learning stage (IiDLS) metric is proposed. In particular, for a specific participant g in the group

[2] Jensen-Shannon divergence is a popular method of measuring the similarity between two probability distributions. The square root of the Jensen-Shannon divergence is a distance function (Endres & Schindelin, 2003).

G_i and a set of consecutive task/level pairs TL_i, the contribution of participant g to the instantaneous Developmental Stage metric is defined as

$$IiDLS(g|\,.) = \ iDLS\big(HP(G_i, TL_i)\big) - \ iDLS(HP((G_i - g\backslash U)\ , TL_i)))$$

where $(G_i - g\backslash U)$ corresponds to the set of all participants in group G_i after information from participant g has been removed and replaced with a uniform distribution. Consequently, IiDLS can be thought of as a measure of the degree to which a participant's absence from the group would affect the group's iDLS. Similar to the iDLS metric, IiDLS can be defined either in terms of *Performance-rank* or *Effort-rank* measures. The calculations of both iDLS and IiDLS are also illustrated in Figure 2a, 2b, 2c, and 2d (see in a follow-up section).

Developmental Stage Dynamics for Group and Individuals

Both metrics (iDLS and IiDLS) proposed in the previous sections are static in the sense that they capture information about the group or individual's performance and effort for a fixed instance during the intervention. Often one is interested to model how the performance and effort of either a group of participants or an individual participant changes during the intervention. It is noted that the time instance during the intervention modeled by iDLS and IiDLS is specified through the selection of the task set TL. Given a sequence S={TL_1, TL_2,…, TL_M} of task/level pair set, the sequence of iDLS (and IiDLS) evaluated on S captures the variation of instantaneous learning dynamics during the course of intervention, and thus, constitutes a model of the learning dynamics.

Approaches for Using Developmental Stage Metrics

This section is concluded by outlining possible directions and approaches for using the proposed microgenetic data metric model in studies of the PREP and Graphogame intervention programs. At the most basic level, the metrics could be used in the study of performance and effort dynamics of each individual during the intervention. For example, IiLDS metrics could identify if a participant is gaining in the early stages of the intervention as opposed to the latter stages or throughout the program (see, for example, Figure 2b or 2d for an illustration). Likewise, metrics could project the groups' progress over the course of a given task (see, for example,

Figure 2a or 2c for an illustration). Going a step further, the proposed metric could be used to identify group differences in terms of the overall performance and effort, and correlate those to the cognitive, linguistic, reading, and orthographic processing skill measurements that are typically obtained at mid- and post-intervention. Finally, another interesting direction involves the use of the proposed metrics to define the attribution model of each task for each participant. For example, one could study the contribution of each task to the overall gain of a participant during the intervention. Such insights could suggest ways to further improve the type or difficulty level of the tasks which are administered during a reading remediation, in order to maximize impact on each participant.

Microgenetic Data Analysis Results

The proposed framework enables visualizing the progress of each individual and each group across different stages of the intervention in terms of Performance and Effort scores. To illustrate the utility of the proposed metrics (obtained from the microgenetic data) in understanding the learning stage dynamics under different intervention programs, a Correlation Trace Analysis and a Predictive Model Analysis were also performed.

Correlation Trace Analysis

The first step of analysis in the proposed model involved examining the correlation between the instantaneous performance and effort scores at each level of the intervention and reading performance scores post-intervention. This analysis is termed as Performance Dynamic Correlation Trace (PDcT) if it is estimated using the performance scores and Effort Dynamic Correlation Trace (EDcT) if it is estimated using the effort scores. The reading scores were obtained at post-intervention and correlation was calculated within each intervention group. To establish significance correlation levels a permutation test was performed and the null hypothesis of no-correlation was modeled. The resulting correlations provided information regarding the stage of intervention on which the group's performance predicted its final gain from the intervention and characterized the learning stage dynamics of different intervention groups (see Christoforou et al., 2014 for a detailed description about the calculation of the correlation trace analysis scores).

Predictive Model Analysis

An alternative approach to the analysis of micro-genetic data based on the proposed iPD and iED metrics is that of predicting the overall performance of an individual during intervention, based on the reading scores obtained pre- (T1), mid- (T2) and post- (T3) intervention. The metric presented below is defined in terms of either *Performance* or *Effort* dynamics (here the iPD is used as the baseline metric however the same formulas apply for the iED) as follows:

$$iPD(s, t) = \beta_1 R_s^{(pre)} + \beta_2 R_s^{(mid)} + \beta_3 R_s^{(post)} + \epsilon$$

where the $\{R_s^{pre}, R_s^{mid}, R_s^{post}\}_{s=1}^{S}$ corresponds to the set of absolute scores of each participant, in measures of word reading fluency and phonemic decoding fluency, obtained pre-, mid- and post- intervention. In particular, we considered the instantaneous performance dynamics of participants at any given task during the intervention as the dependent variables, and the reading fluency scores measured pre-, mid- and post- intervention as the independent variables. We estimated the model using a 10-fold cross validation procedure, where 9 blocks were used to obtain an estimate of iPD for every participant *n* and every task *t*.

Microgenetic Data Encoding Model focused on PREP Remediation

An important question for assessing the impact of reading remedial intervention programs involves qualifying and monitoring the progress of an individual (or a group) during intervention. Instantaneous performance dynamics scores (iPD) and instantaneous effort dynamics scores (iED) were used to visualize the progress of an individual and/or a group during different stages of the intervention. Figure 2a illustrates the average performance and effort modulations for the three intervention groups (PREP, GG+PREP, PREP+GG) during a simultaneous processing task, the Shape Design Task, of the PREP remedial program. This illustration is provided as a typical example of the four PREP tasks used in the present study, aiming to improve simultaneous processing skills. Results showed that those who received

Graphogame intervention followed by PREP intervention were likely to achieve high standards of performance although with the minimum effort, as opposed to those who received PREP followed by Graphogame who performed rather poorly again with the minimum effort. PREP group also performed poorly despite the continuous increasing effort. Figure 2b illustrates performance and effort modulations for three participants. Participants were randomly selected to illustrate the variation in performance (and effort) across task. Results indicated that participant 1 achieved high standards of performance, throughout the task, with maximum effort starting early on. Similarly, participant 3 achieved high performance as task progressed, whereas participant 2 performed rather poorly with the minimum effort.

Figure 2c shows an illustration of the average performance and effort modulations for the same groups during a successive processing task, the Connecting Letters Task, of the PREP remedial program. This illustration is also provided as a typical example of the four PREP tasks used in the present study, aiming to improve successive processing skills. Once again, results revealed that the most benefited group in relation to instantaneous Performance Dynamics was the GG+PREP group that seemed to achieve high performance but with less effort. The PREP+GG group seemed to attain an average performance, but it followed a slower pattern of progress with less effort. PREP group strived to perform the task, despite the maximum effort. Similarly, Figure 2d illustrates performance and effort modulations for three selected participants. Results showed that participant 1 performed rather poorly despite the continuous increasing effort, while participants 2 and 3 achieved high standards of performance starting early on. As task progressed, participant 3 maintained high performance but with less effort. Such visualizations are qualitative in nature but provide insights on the progress of each individual or group across intervention period, and help formulate hypotheses that can be tested using quantitative analysis.

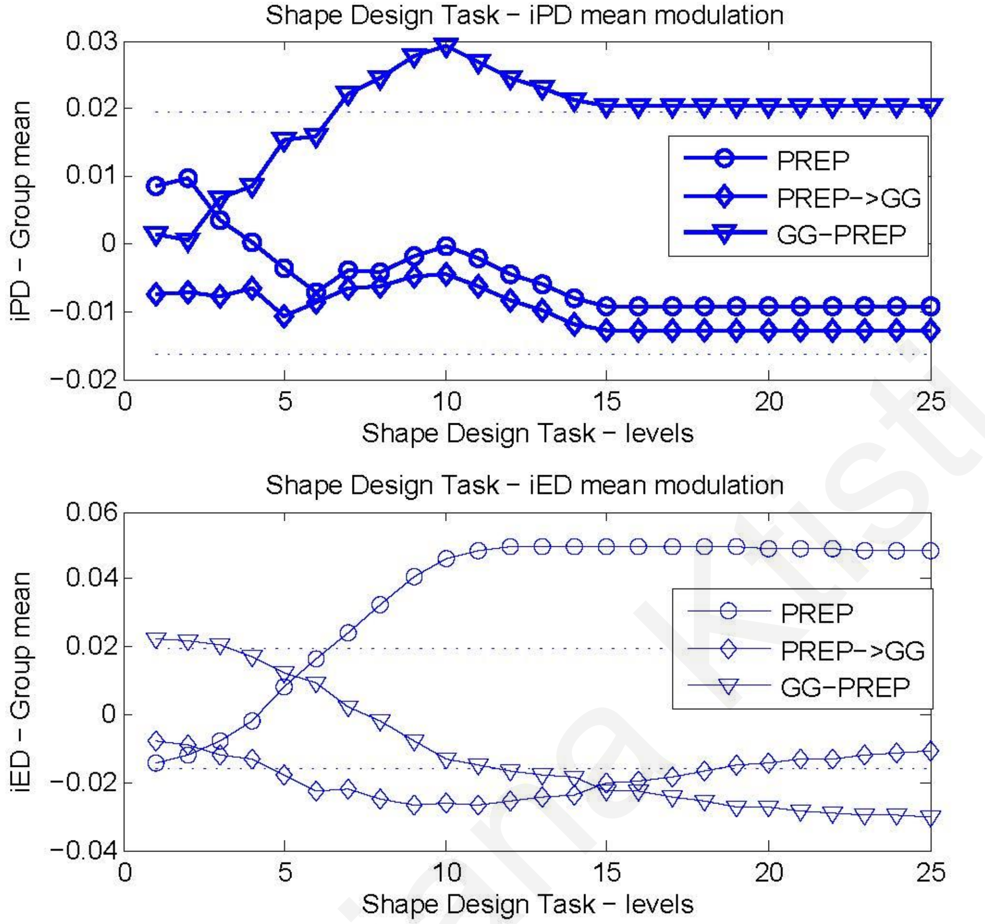

Figure 2a: The top plot shows the mean iPD for each group across the three intervention groups (i.e. the group received PREP remediation and those that received PREP followed by Graphogame [GG], and vice versa) during the Shape Design Task of the PREP remedial program. The bottom plot shows the iED of the same groups during the same task. The dotted line shows significance level at $p < .05$.

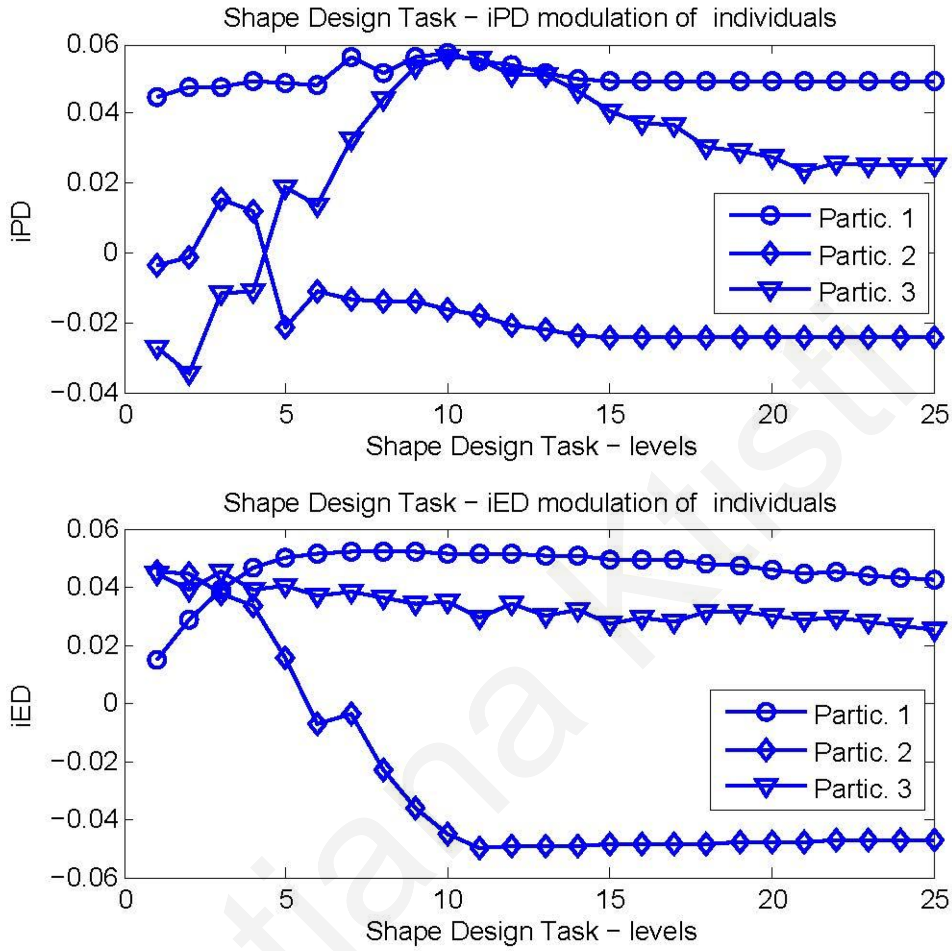

Figure 2b: The figure displays the instantaneous Performance Dynamics (iPD), in which the Individual's instantaneous Developmental Learning Stage (IiDLS) is calculated using the *Performance-ranking* metric, and the instantaneous Effort Dynamics (iED), in which the IiDLS is calculated using the *Effort-ranking* metric. The top plot shows the iPD of three participants during the Shape Design Task of the PREP remedial program. The bottom plot shows the iED of the same participants during the same task.

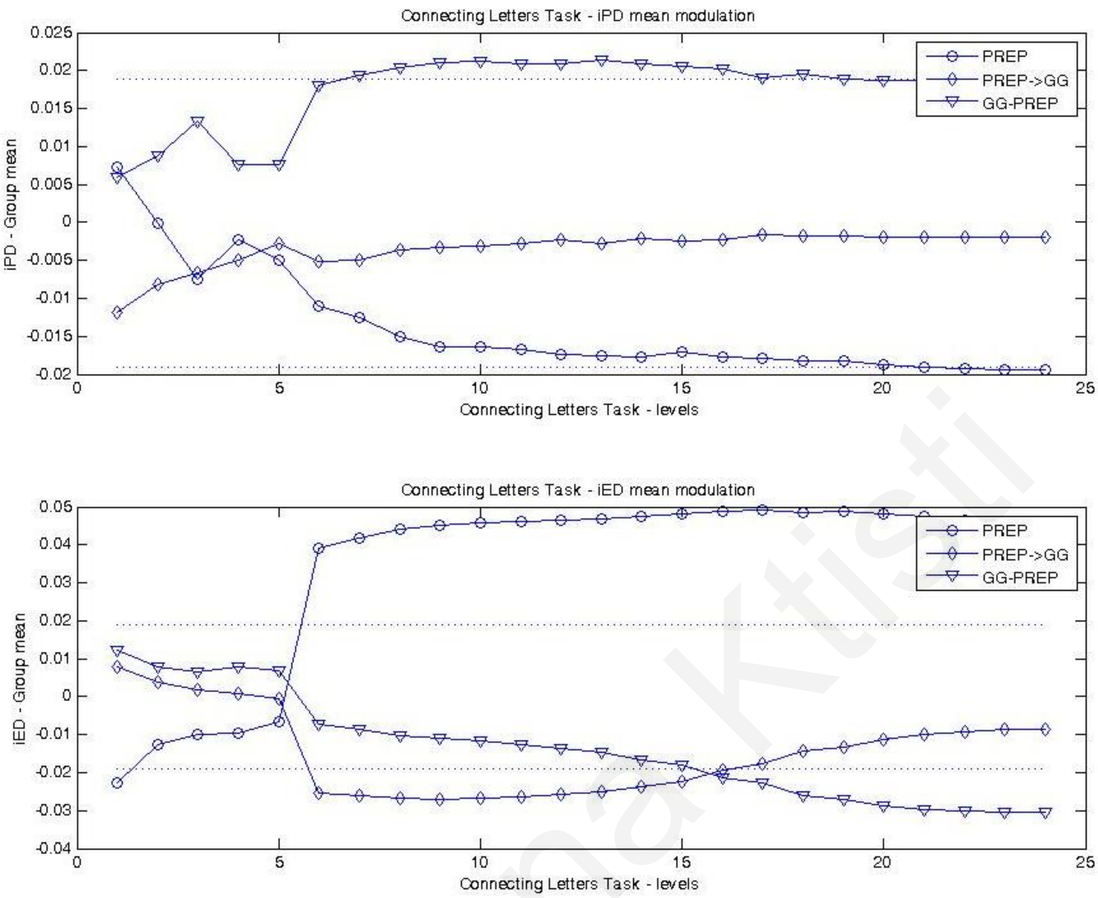

Figure 2c: Top plot shows the mean iPD for each group across the three intervention groups (i.e. the group received PREP remediation and those received PREP followed by Graphogame [GG], and vice versa) during the Connecting Letters Task of the PREP remedial program. Bottom plot shows the iED of the same groups during the same task. The dotted line shows significance level at $p < .05$.

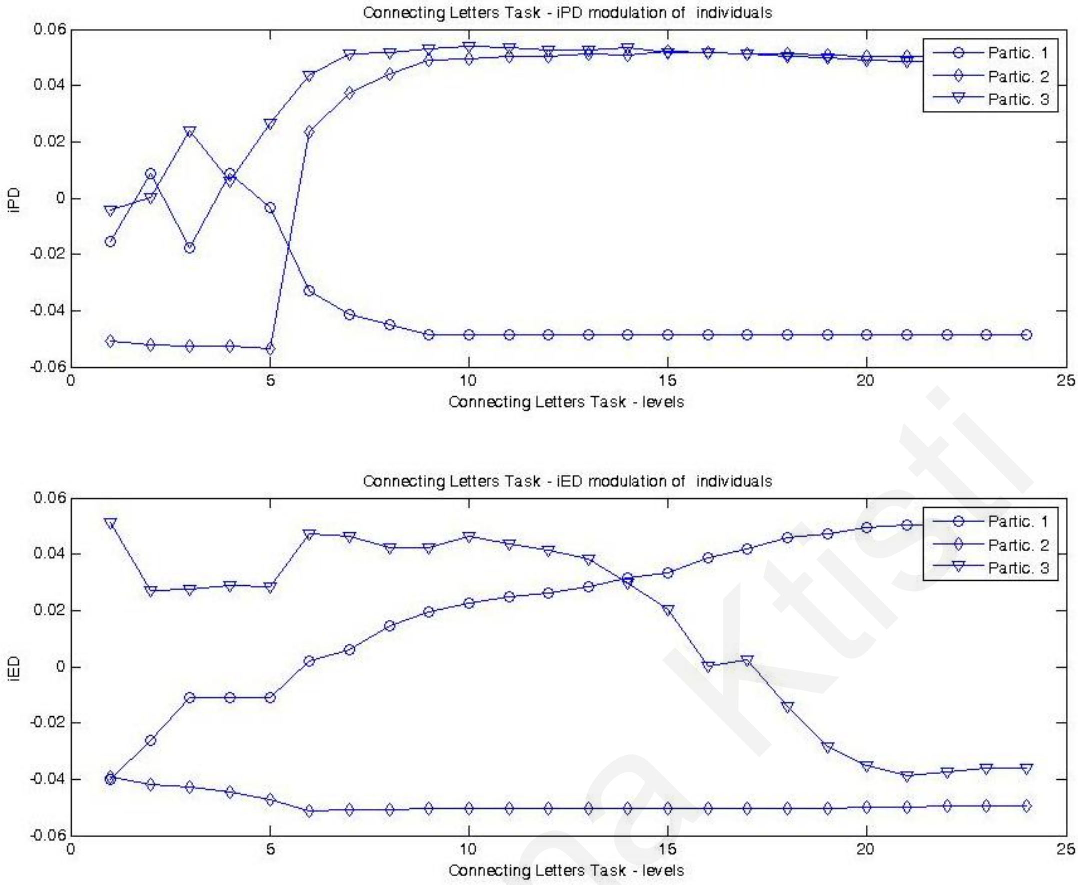

Figure 2d: It displays the instantaneous Performance Dynamics (iPD), in which the Individual's instantaneous Developmental Learning Stage (IiDLS) is calculated using the *Performance-ranking* metric, and the instantaneous Effort Dynamics (iED), in which the IiDLS is calculated using the *Effort-ranking* metric. Top plot shows the iPD of three participants during the Connecting Letters Task of the PREP remedial program. Bottom plot shows the iED of the same participants during the same task.

To understand the learning stage dynamics under different intervention programs, the correlation between the instantaneous performance and effort scores at each level of the intervention and reading performance scores at the post-intervention (Time 3) assessment was examined. In particular, the correlation values between the instantaneous performance dynamics scores during different stages of the PREP protocol and post-intervention actual reading scores were calculated, for the three intervention groups (PREP, PREP+GG, and GG+PREP), separately for the successive and simultaneous tasks. The results are displayed in Figure 3. The top row shows the correlation to Phonemic Decoding Fluency scores and the bottom row the correlation to Word Reading Fluency scores obtained by the participants at post intervention. The different PREP stages (X-axis) are defined as follows: 1 corresponds to early stage, non-alphabetic tasks; 2: late stage non-alphabetic tasks; 3: early stage alphabetic tasks; and 4: late stage alphabetic tasks. Tasks are grouped as early stage or late stage tasks, depending on the order in which they were delivered within each game (i.e., connecting letters, joining shapes etc.) and type (i.e. successive or simultaneous processing). Red bars show the correlation in participants in the PREP group, green bars show the correlation in participants in the GG+PREP group, and blue bars show the correlation in participants in the PREP+GG group. The dotted blue line shows the threshold for .05 significant levels. The correlation is defined based on the score values obtained within each intervention group throughout the program and indicates the degree to which the final group performance correlates with these values. Moreover, to establish significant correlation levels a permutation test was performed and the null hypothesis of no-correlation was modeled (i.e. by randomizing the labels assignment of the group and the performance level of each participant).

Results revealed that at the earliest stage of the intervention none of the groups showed significant correlation between their Phonemic Decoding Fluency and their corresponding instantaneous performance metric (top left figure) in the successive tasks. At stage 2, the PREP group crossed the ($p < .05$) significance line with the correlation to peak after the third task (i.e., window sequencing) of the intervention ($r = .42$). The PREP group also reached significance rather early in the simultaneous processing tasks (top right figure), after completing the first task (i.e., matrices) ($r = .60$), a performance that was maintained at the second half of the intervention. None of the other two groups showed significant correlation between their instantaneous performance metric and Phonemic Decoding Fluency, at any stage of the intervention.

The correlation patterns between the instantaneous performance and Word Reading Fluency showed a different picture, in that none of the groups showed significant correlation. These results suggest that, for certain groups, the proposed instantaneous performance metrics can carry information that predicts (to some degree) the impact of the intervention. Moreover, the predictive power of these metrics is modulated by the different stages of the intervention. Research is being continued to understand these modulations and their implications.

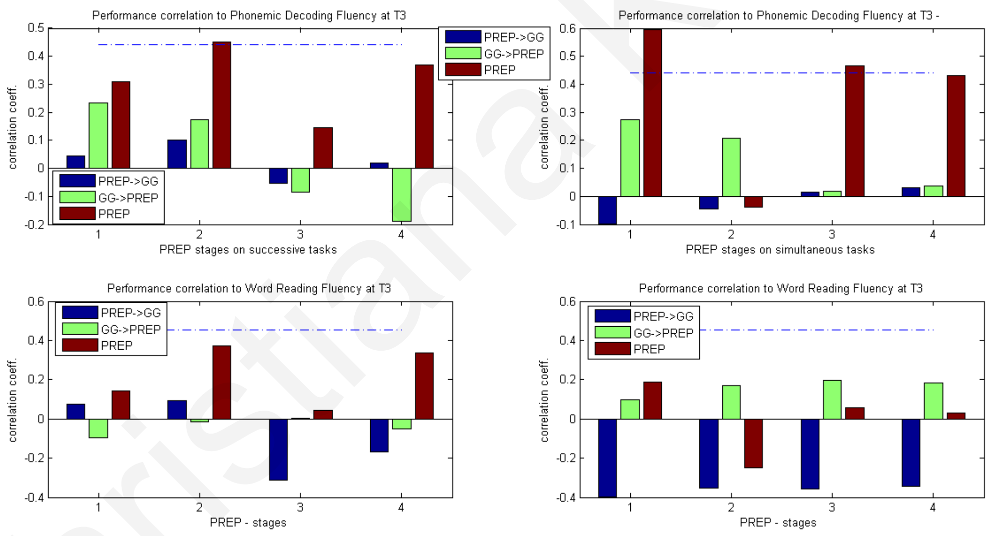

Figure 3: This figure shows the correlation values between the instantaneous Performance Dynamics (iPD) scores during different stages of the PREP intervention and post intervention reading scores. The top row shows the correlation to Phonemic Decoding Fluency scores while the bottom row the correlation to Word Reading Fluency scores obtained by participants at time T3 (post intervention). The different PREP stages (x-axis) are defined as follows: 1 corresponds to early stage, non-alphabetic tasks, 2: late stage non-alphabetic tasks, 3: early stage alphabetic task and 4: late stage alphabetic tasks. Tasks are grouped as early stage or late stage depending on the order that are delivered within each game (i.e., connecting letters, joining shapes etc.) and type (i.e. successive or simultaneous). Red bar shows the correlation of participants in the PREP group, green bars show the correlation in participants in the GG+PREP group, and blue bars show the correlation in participants in the PREP+GG group. The dotted blue line shows the threshold for .05 significance levels.

Microgenetic Data Encoding Model focused on Graphogame Remediation

Figure 4a illustrates the average performance and effort modulations for the two combined treatment groups (PREP+GG, GG+PREP) during the first 46 tasks of Graphogame remedial program. Results showed that those who received Graphogame intervention followed by PREP intervention were likely to achieve high standards of performance with the maximum effort from task 5 and beyond. In contrast, those who received PREP intervention followed by Graphogame seemed to perform rather poorly with the minimum effort. Figure 4b illustrates performance and effort modulations for two randomly selected participants. Results indicated that both individuals improved their performance during intervention and as task progressed they maintained high performance with maximum effort, although they followed a different pattern of development in terms of both performance and effort.

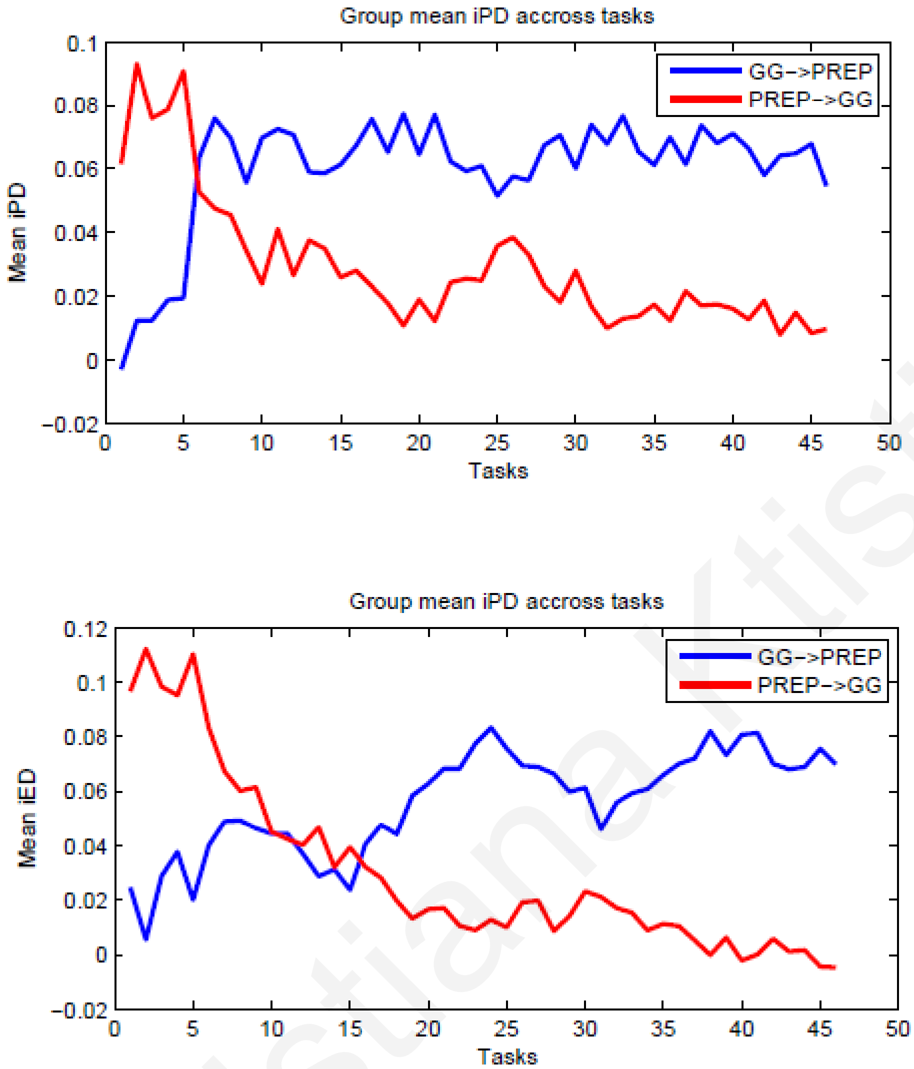

Figure 4a: Top plot shows the mean iPD for each group across the three intervention groups (i.e. the group received Graphogame remediation and those received PREP followed by Graphogame (GG), and vice versa) during the Graphogame remedial program.

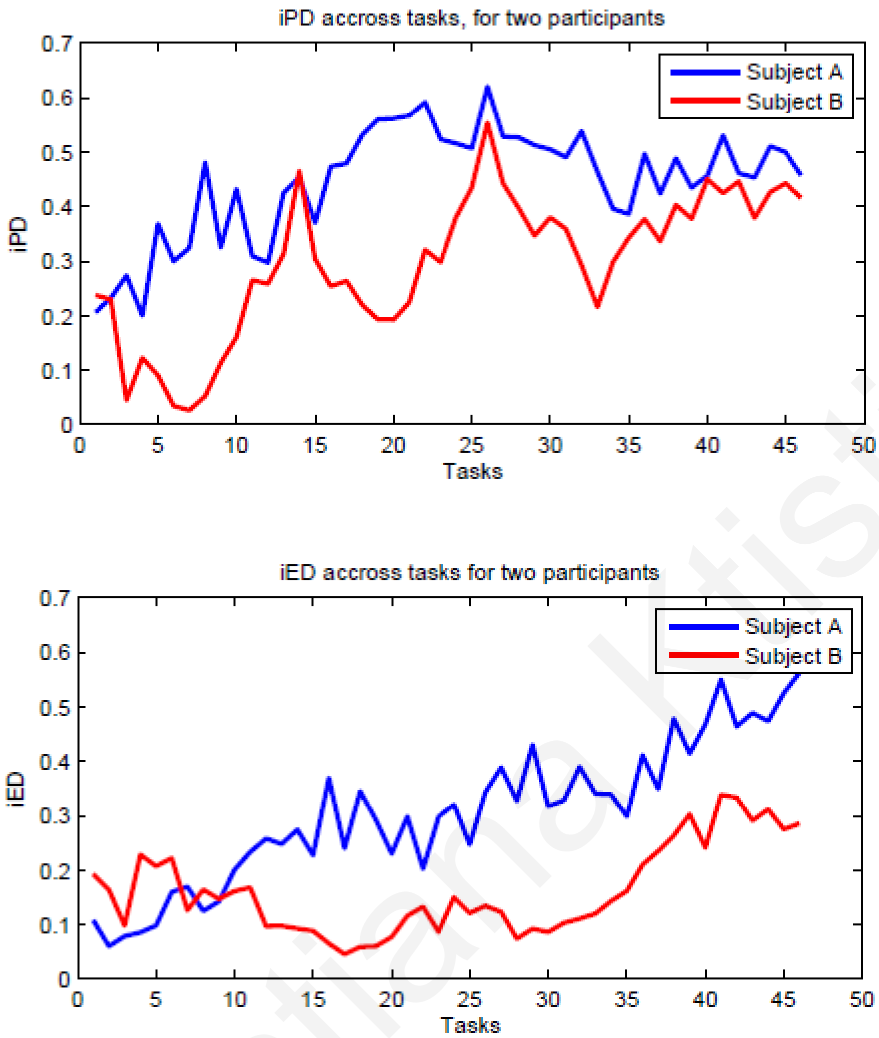

Figure 4b: It displays the instantaneous Performance Dynamics (iPD), in which the Individual's instantaneous Developmental Learning Stage (IiDLS) is calculated using the *Performance-ranking* metric, and the instantaneous Effort Dynamics (iED), in which the IiDLS is calculated using the *Effort-ranking* metric. Top plot shows the iPD of two participants during the Graphogame remedial program. Bottom plot shows the iED of the same participants.

Once again, the correlation between the instantaneous performance and effort scores at each level of the intervention and reading performance scores at post-intervention was examined (Time 3). Particularly, the correlation values between the instantaneous performance dynamics scores during different stages of the Graphogame intervention and post-intervention actual reading scores were calculated, for the three intervention groups (GG, PREP+GG, and GG+PREP). The results are displayed in Figure 5. The top row shows the correlation to Phonemic Decoding Fluency scores and the bottom row the correlation to Word Reading Fluency scores obtained by the participants at post intervention. Red lines show the correlation in participants in the Graphogame group, green lines show the correlation in participants in the GG+PREP group, and blue lines show the correlation in participants in the PREP+GG group. The dotted blue line shows the threshold for .05 significant levels. Once again, the correlation is defined based on the score values obtained within each intervention group throughout the program and indicates the degree to which the final group performance correlates with these values. To establish significant correlation levels, a permutation test was performed and the null hypothesis of no-correlation was modeled.

Results showed that at the early stages of the intervention (<16 tasks) none of the groups showed significant correlation between their Phonemic Decoding Fluency and their corresponding instantaneous performance metric (top left figure). Following the 16th task, the GG+PREP group crossed the ($p < .05$) significance line with the correlation to peak after the 24th task of the intervention (r=0.8). The Graphogame group's correlation followed a similar pattern, in that it increased following the 15th task, but it reached significance ($p < .05$) after the 30th task. The PREP+GG group showed no correlation between its instantaneous performance metric and its Phonemic Decoding Fluency, at any stage of the intervention.

The correlation patterns between the instantaneous performances and Word Reading Fluency showed a different picture (bottom left figure). At the early stages of the intervention (<16 tasks) none of the groups showed significant correlation between their Word Reading Fluency and their instantaneous performance metric. The GG+PREP group reached significant correlation following the 16th task and retained significance throughout the intervention thereafter. Neither of the other two groups showed significant correlation between their instantaneous performance dynamic and Word Reading Fluency, at any stage of the intervention.

The correlation traces to post-intervention reading scores provide unique insights in understanding the learning dynamics during the intervention and its impact to the overall effect of the intervention that traditional pre/post reading measures cannot provide.

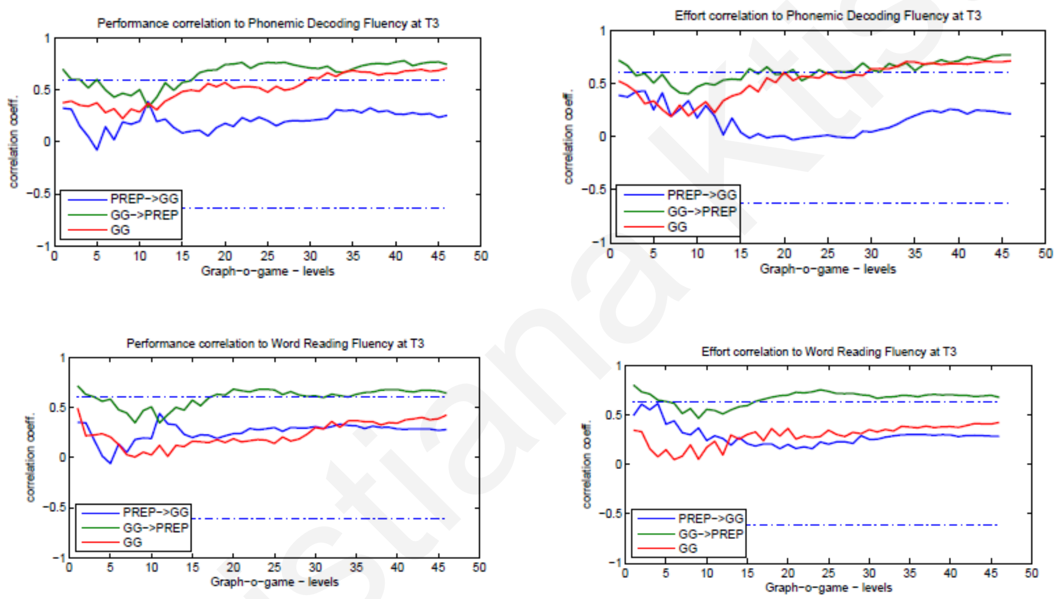

Figure 5: This figure shows the correlation values between the instantaneous Performance dynamics and Effort scores during different stages of the Graphogame intervention and post intervention reading scores. The top row shows the correlation to Phonemic Decoding Fluency scores while the bottom row the correlation to Word Reading Fluency scores obtain by participants at time T3 (post intervention). Red line shows the correlation of participants in the Grpahogame group, green line shows the correlation in participants in the GG+PREP group, and blue line shows the correlation in participants in the PREP+GG group. The dotted blue line shows the threshold for .05 significant levels.

To characterize the learning dynamics at each stage during Graphogame intervention and identify the factors that most likely contribute to performance during intervention a general linear model was implemented and we reported on the predictive power of each independent variable. In particular, the reading fluency scores (i.e., Phonemic Decoding Fluency and Word Reading Fluency) measured pre- (T1), mid- (T2) and post- (T3) intervention were considered as independent variables, and the instantaneous performance score at any given task during the intervention, as the dependent variable. A 10-fold cross-validation procedure was used to obtain the predicted performance at every task and goodness-of-fit of the model was reported using the r-squared, which is a measure of the variance in the predicted scores explained by the actual performance scores. Moreover, we reported on the predictive power of each independent variable. The results of this analysis are shown in Figure 6.

First, the predictive model based on the Phonemic Decoding Fluency and the instantaneous performance score was examined. Figure 6 (top figure) shows that the explained variance (measured in r^2) followed a cumulative pattern after the 15th task (r^2 = 0.2) while by the 45th task, the Phonemic Decoding Fluency predicted 45% of the variance (r^2 = 0.45) in instantaneous performance scores during the task. Moreover, the beta coefficients of the model showed that the factors T2 (mid-assessment) and T3 (post-assessment) carried almost all the predictive power of the model, while the initial Phonemic Decoding Fluency score (T1) had little to no predictive power. These results suggest that the instantaneous performance of participants was better described by the underlying reading performance of the participants measured post-intervention (i.e., T2 and T3) and that the initial learning state carried little information regarding participants' performance during intervention.

Subsequently, the predictive model based on the Word Reading Fluency and the instantaneous performance score was also examined. The r^2 values on Word Reading Fluency (bottom figure) showed a similar pattern with the model on Phonemic Decoding Fluency but at a slower rate of development. By the 45th task the Word Reading Fluency score explained 36% of the variance (r^2 = 0.36) in instantaneous performance scores during the task. However, the beta coefficients of the model for the three factors showed that T1 score carried all the predictive power (r^2 =0.92) while the scores at T2 and T3 had negative predictive power. Results suggest that the Graphogame intervention had no impact in modulating the underlying reading stage of participants in terms of Word Reading Fluency. In addition, performance at the end of the intervention was better explained by the existing word reading skills of the participants' prior remediation. The increase in explained variance across tasks can be explained by the increasing difficulty of the tasks and the tendency of participants to compensate for their difficulties. It is hypothesized that Word Reading Fluency affects performance during Graphogame intervention especially in more difficult tasks; however, the Graphogame intervention has no impact on the reading stage of participants in terms of Word Reading Fluency. Interestingly, both the Phonemic Decoding Fluency model and the Word Reading fluency model failed to predict the instantaneous performance between the first 5th and 10th tasks.

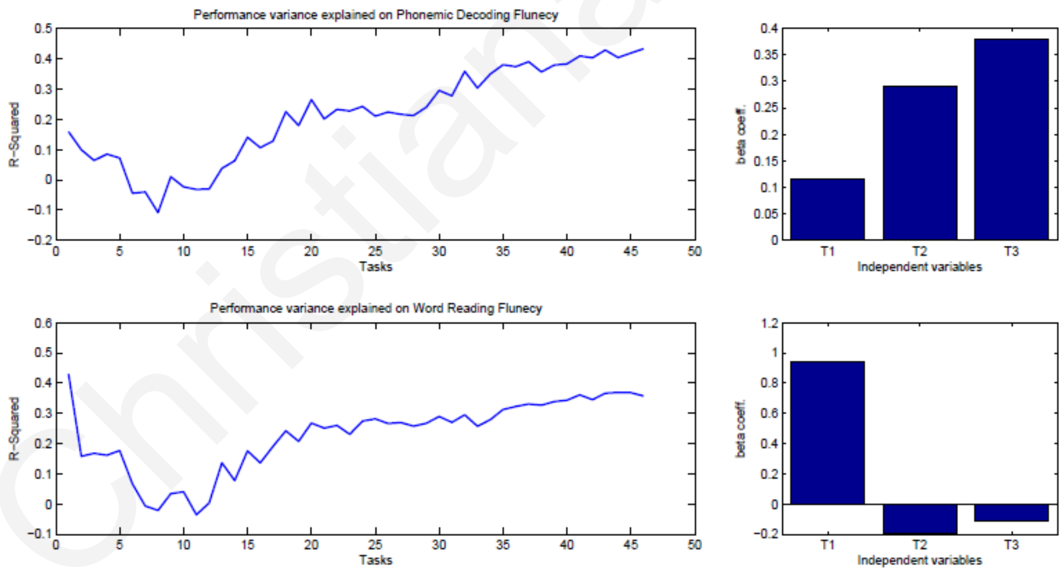

Figure 6: General linear model prediction analysis based on iPD

CHAPTER 4

FINDINGS, CONCLUSIONS, AND IMPLICATIONS

The present study compared the efficacy of PASS Reading Enhancement Program (PREP), a cognitive reading remediation program, to a remedial program with a more phone-code focus, the Graphogame, and their combined treatments, on children with reading difficulties learning to read in Greek, with the aim of examining the type of early intervention most useful for reading problems. Previous studies have demonstrated the efficacy of cognitive and phonological training for children with reading difficulties, but there is no study that has compared these two treatments or their combination (see Papadopoulos et al., 2015 for a thorough review). Also, although it has been widely reported that the regular teaching of reading provided in schools does not necessarily translate into improvements in literacy skills for struggling readers (e.g., Hatcher et al., 2004; Torgesen, 2005), studies comparing different intervention methods are scarce. Thus, the present study adds several significant findings to the existing literature, by comparing the performance of four groups (PREP, Graphogame, PREP+Graphogame, and Graphogame+PREP) on word reading fluency, spelling, and reading-comprehension outcomes at mid-remediation, post remediation and follow-up (a year after remediation).

Results suggest several conclusions about research and the development and practice of reading intervention. First, designing and implementing intervention schemes in reading research has never been an easy task and it is not going to become one, unless we understand what remediation actually requires. Our results show that successful remediation requires direct, intensive intervention with programs that build the necessary cognitive or linguistic skills to read proficiently. Specifically, our results are consistent with the findings of previous studies demonstrating that both an intensive cognitive intervention (Papadopoulos et al., 2003; Parrila et al., 2000) as well as an intensive grapho-phonemic intervention (Huemer, Landerl, Aro, & Lyytinen, 2008) hold promise for improving student word reading performance early on. The new and interesting finding is that this improvement is also observed when the two types of interventions are delivered in combination. Findings like these may be attributed in part to the theoretical underpinnings or the administration properties of the two programs and in part to the transparency of the Greek language or a combination of the two.

PREP aims at improving the distal cognitive processes that are responsible for the successful deployment of more proximal reading skills, such as phonological processing, and thus, reading (Papadopoulos et al., 2003). The results showed that all three groups who received PREP benefited considerably from training on phonological, naming, cognitive, reading and orthographic processing skills after remediation. This means that this was true even in the case where PREP followed Graphogame, a result that could be attributed to the properties of the Greek language and the nature of the Graphogame intervention (see next paragraph). Training success yielded significant long-term effects a year later, in Grade 2, a finding that has not been regularly reported in studies of reading remediation (Bus & Ijzendoorn, 1999; Troia, 1999; Papadopoulos et al., 2003).

Graphogame aims to train the reading skills of children with reading disabilities with specific emphasis on training phonological processing skills. It has been shown to be successful when it is delivered for both short (e.g., <20 days; Lyytinen & Richardson, 2013) as well as long (e.g., ≤30 days) periods of time (Kyle et al., 2013). Given also that in a transparent writing system, the letter-sound connections can be drilled efficiently and without complications (Lyytinen et al., 2009) and that reading accuracy and fluency are strongly predicted by phonological skills in Greek (Papadopoulos et al., 2009a), it does not come as a surprise that Graphogame alone or in combination with cognitive training may also lead to efficient word reading. The transparency of the Greek language allows young readers to use the phonological representations of any grain-size units (rhyme, syllable, or phoneme) that are available to them (Papadopoulos et al., 2012), enabling even children who show insufficient phonological processing at school entry to gradually tackle their difficulties with phonological processing and find means to compensate for poor reading performance (Papadopoulos et al., 2009a). Besides, experimental studies have demonstrated that training in phonological awareness effectively facilitates learning to read (e.g., Blachman et al., 2004; Lovett et al., 2000). Such findings emphasize the paramount importance of phonological awareness skills in reading development in a transparent orthography.

Treatment of Reading Deficits

A central hypothesis of the present study was that although participants in the control group (typically developing readers) would exhibit higher performance in the majority of reading, orthographic, phonological, and cognitive measures compared to the participants in the experimental groups before remediation, these differences would be gradually minimized, with gains for the experimental groups to be observed even at follow-up. Indeed, results indicated that experimental groups benefited from the type of treatment they received, showing already some notable improvements in some reading-related skills (e.g., supraphonemic sensitivity tasks, reading fluency and reading accuracy tasks) during remediation, and catching up to their counterparts at the end of the remediation in the majority of the tasks. In the following section, we discuss treatment effects on the reading-related skills that were assessed.

Linguistic Skills

The results from the phonological skills showed that all four experimental groups improved in manipulating sounds at both syllabic and phonemic level, and that this improvement was evident even a year later in Grade 2. Also, findings revealed that children in the experimental groups showed improvements in supraphonemic sensitivity tasks quite early, during remediation. In other words, benefits in phonological skills appeared after the first two weeks of the intervention. Thus, it can be concluded that phonological awareness training should start immediately at school entry.

Moreover, results indicated that the different treatment conditions provided equivalent benefits. Nevertheless, a closer look at the adjusted means revealed some interesting trends in groups' performance, as a result of treatment. For example, the participants receiving Graphogame remediation tended to show greater improvement in some of the phonological ability tasks (e,g., Initial Syllable Oddity and Phoneme Elision) compared to the group receiving PREP remediation. This tendency was also observed in the case where Graphogame preceded PREP, a finding that could be attributed to both the properties of the Greek language (Papadopoulos et al., 2012) and the nature of Graphogame (e.g., Lyytinen et al., 2009). This finding was also generally confirmed by the subsequent microgenetic analysis which indicated that children receiving Graphogame first benefited more from the remediation, compared to those who received PREP at the beginning (see following up section). Given the transparency of the Greek orthography (Protopapas & Vlachou, 2009) and the direct training on phonemic awareness provided in Graphogame, implemented by immediate exposure to letters and sound connections (Saine et al., 2011), it is rather reasonable to lead the reader to positive experience with reading at the onset of the training.

Cognitive Abilities

The results from the cognitive skills showed that all four groups improved their performance in successive and simultaneous processing and reached the level of their same age counterparts after remediation. Findings also revealed that, irrespective of the treatment condition, children continued to show improvements up to Grade 2. However, analysis of the adjusted means demonstrated that the participants receiving PREP remediation tended to show greater improvement in some of the cognitive processes underlying reading and spelling performance, such as simultaneous processing (proximal process) and planning (distal process) (see Das et al., 2000 and Kendeou et al., 2015 for a description). The relation between simultaneous processing and various aspects of reading has been confirmed in a number of studies in English (Das et al., 2008a; Das et al., 1994b; Kirby & Das, 1977; Kirby & Robinson, 1987), Greek (Papadopoulos, 2001) and Chinese (Wang et al., 2012). Furthermore, it has been reported that children with reading difficulties receiving PREP overcome their deficits as the relation between simultaneous processing and reading via orthographic processing is particularly important in the early stages of reading development (Das et al., 2000; Papadopoulos et al., 2003).

The positive effects of both PREP and Graphogame on a number of linguistic and cognitive abilities have important theoretical implications, as they suggest that the targeted abilities (i.e., phonological and information processing abilities) are not only the simple correlates of reading performance but may have a causal role in its development.

Reading Fluency and Accuracy

The results pertaining to word reading skills showed that all four experimental groups improved their performance in both reading fluency and reading accuracy and reached the level of their counterparts after remediation. Results also revealed that children continued to show improvements in both reading and spelling even a year after remediation, in Grade 2, and this was true for all four experimental groups. In other words, results support the efficacy of the remedial reading interventions used in the present study which have been designed to improve word reading fluency among young poor readers. These findings are consistent with those reported in previous reading remediation studies focusing on the enhancement of phonological coding (e.g., Elbro & Petersen, 2004) or cognitive skills (e.g., Papadopoulos et al., 2003) in which the gains in reading performance were evident in the follow-up tests. The gradual gains in reading during intervention and at follow-up testify to the fact that children with reading difficulties can reach the level of their chronological-age counterparts when interventions are theory-driven and evidence-based, focusing more on the abilities that training aims to improve and less on the techniques and their effects.

Reading Comprehension

The findings from reading comprehension tests indicate that all treatment groups made further gains in reading comprehension which were sustained at follow-up, as did control group. However, a closer look at the adjusted means indicated that phone-code focused training does not necessarily lead to direct improvements in reading comprehension, as it may occur in the case of the cognitive treatment or treatments' combinations. This tendency may be attributed to the properties of the Graphogame tasks included in this version of the game, as they primarily engaged the participants in learning the connections between spoken and written language (Lyytinen et al., 2009). In addition, the relevance of successive and simultaneous processing to reading comprehension, which is mostly evident through phonological and orthographic processing, respectively (Kendeou et al., 2015), may explain in part the reason why those participants receiving PREP remediation assured good reading comprehension at the end of remediation. At any rate, further studies are deemed necessary to replicate these results.

Overall, previous studies which have tested the effects of PREP and Graphogame separately have reached similar conclusions while focusing on the training of literacy skills in children with reading difficulties in non-transparent (e.g., Papadopoulos et al., 2003; Kyle et al., 2013) and transparent (e.g., Papadopoulos et al., 2004; Saine et al., 2011) orthographies. The new finding in the present study is that when the two types of interventions are delivered in combination, similar positive effects are also observed. Indeed, rather surprisingly, no significant differences of the type of treatment were found on any of the reading outcomes (in spite of some trends in groups' performance, as a result of treatment). This finding may suggest that when we move the object of remediation from the reading process itself to tasks that do not necessarily depend on reading per se, interventions may have an important advantage over other narrower forms of reading interventions, leading to notable improvements in reading performance.

Of course, the big question hanging over these results is why both treatments and their combinations were shown to be equally efficient in remediating reading fluency and accuracy problems. We believe that these patterns of results may be also due to the complementarity of the alternative treatments in a randomized control trial design or the lack of an untreated control group of children with reading difficulties or perhaps the small number of participants included in the treatment groups. We discuss these limitations next.

A randomized control trial design may be ill-suited to answer questions about the long-term effects of complementary or alternative treatments on reading difficulties. That our experimental groups did not differ from each other at either post-intervention (Time 3) or follow-up assessments (Time 4) indicates a difficulty in making causal inferences regarding the relationship between intervention(s) and outcome(s) when utilizing a randomized experimental design. In the case of the combined treatments, it is possible that some components of one program may augment components in the other, while others may be redundant, and still others may cancel out each other's effects. Therefore, comparing outcomes of these sorts of intervention may obscure systematic individual differences in response to specific treatments, whereas differentially effective treatments may be the result of systematic or predictable differences at the reader's level. Hence, as Das (2001) has pointed out, perhaps for reading research the question should be not which treatment works best, but more importantly which works best or better for whom, when, and why. In fact, earlier research which considered the individualization of a treatment to a unique combination of reader characteristics concluded that remedial benefits can be maximized when the cognitive and linguistic processes that may be lacking for learning to read are identified prior to intervention (Das, 2001; Papadopoulos & Kendeou, 2010).

The interesting question, therefore, concerns whether or not individuals who gained from remediation could be distinguished from those who did not, on the basis of their cognitive and linguistic profiles prior remediation. Our initial hypotheses might have not been confirmed, however, designs based on aptitude-treatment interaction have already provided answers regarding who might benefit from a remediation and why. Specifically, previous studies on aptitude-treatment interaction analysis based on the PREP intervention indicated that initially high scores in successive processing are associated with a more favorable outcome in PREP (Papadopoulos & Kendeou, 2010). Similarly, children who have high scores in phonological skills prior remediation are likely to have a more favorable outcome in Graphogame intervention (Saine, et al., 2011). Therefore, it is important for the science of reading intervention to understand better which aspect(s) of solid or combined remedial packages make a difference for whom, or how the various components (alone or in combination) actually work. This approach requires taking into consideration the possibility that the whole may exhibit properties that its separate parts do not possess. Therefore, we advocate for a more integrative analysis approach that studies both the whole and the parts of an intervention in relation to the performance shown and effort exerted by a participant on a specific task or a set of tasks.

The lack of randomly assigned untreated control group of children with reading difficulties, who would continue to receive regular class instruction, also limits the conclusions about how the groups would have performed with no intervention. The comparison of the remediated groups to an untreated control group would have allowed examining how receiving remediation affected the different treatment groups. We were not able to measure the difference with a standard no-treatment condition. Including an untreated group in intervention studies is desirable especially in studies that utilize a randomized control trial design. However, in the present study groups' selection has been a rather laborious task lasting for a longer period of time (i.e., an additional year) than what was initially anticipated. Thus, including an untreated group was practically prohibited for both methodological and ethical reasons, as it was difficult to have an untreated group waiting to receive remediation two years later than the onset of remediation, missing, thus, the critical window of opportunity to learn to read. Hence, further studies deemed necessary to confirm the present findings against an untreated group of poor readers. In such a case, groups' selection has to be completed before data collection begins, to compensate for this problem.

Another possible limitation is the small sizes of the intervention groups. Every possible attempt was made to find as many children as possible to participate in the present study. However, homogeneity of the treatment groups was considered very important for the design of the study, leading to a smaller number of children than the initial number we had planned to assign in the treatment groups. Nevertheless, the results are indicative of the beneficial effects of both programs and their combinations, given the within-group homogeneity. However, future studies should attempt to confirm some of the present findings with larger numbers of participants in the treatment groups.

Microgenetic Analysis

An equally important issue in designing and delivering remediation relates to the collection of data on how the anticipated improvement is produced in the participant-treatment interaction, which is known as microgenetic analysis (Siegler, 2006). It has been argued that microgenetic analysis of the learning situation and a participant's responses during an intervention is necessary, if we wish to establish a link between the theory of cognitive functions underpinning PREP or Graphogame and the changes in performance and effort that occur during training.

Microgenetic data showed differences between the experimental groups in terms of how each group's performance is modulated at different stages of the intervention, and in their predictive power regarding the final scores. Specifically, we examined the correlation between the instantaneous performance and effort scores at each level of the intervention and reading performance scores post-intervention. Correlation trace analysis can provide insights about the effect of the remedial program at different stages during intervention, which allows researchers to generate hypotheses on the optimal duration and/or combination of remediation. To exemplify this, we focused separately on the PREP and Graphogame interventions and examined which of the treatments, including the combined ones, improved the overall remediation effect.

In particular, analysis focused on the PREP program showed that only the PREP protocol that was delivered separately exhibited early in the intervention a significant correlation with the post-intervention phonemic decoding fluency performance, a correlation that was maintained throughout the intervention period. In addition, the correlation effect appeared after the first couple of simultaneous tasks and almost the first half of the successive tasks of the intervention. These results indicate that even from the first couple of tasks, the PREP group's performance predicts its final gain from the intervention in terms of phonemic decoding fluency. However, this was not the case for the combined treatment groups that showed no correlation between their instantaneous performance metric and their phonemic decoding fluency, at any stage of the intervention. This result indicates, at least in relation to PREP, that administering a shorter version of PREP carries little to no additional weight on either the phonemic decoding fluency or word reading fluency scores. Indeed, Papadopoulos et al. (2003) have shown that delivering a shorter version of PREP makes it difficult to reliably establish the overall effect of the PREP training. However, the interpretation of these differences is part of our on-going research on microgenetic data that could provide insights on which elements of an intervention contribute towards the overall impact of the intervention.

Analysis focused on the Graphogame program showed that the combined GG+PREP group exhibited significant correlation between its instantaneous performance and fluency scores (both phonemic decoding fluency and word reading fluency). The correlation effect appeared after the 16th task and was retained throughout intervention. Similarly, the GG group showed significant correlation but only to phonemic decoding fluency after the 30th task. These results suggest that differences in correlation trace patterns between GG+PREP and GG groups are modulated by the impact of PREP intervention on word reading fluency. The PREP+GG group showed no correlation between its instantaneous performance and fluency scores at any stage of the intervention, perhaps because administering

Graphogame after PREP intervention carries little to no additional weight on either phonemic decoding fluency or word reading fluency. The absence of significant correlation between the performance (and effort) scores and fluency scores observed in the PREP+GG group, and the strong and significant correlation exhibited by the GG+PREP group, suggest that the order of administration of PREP and Graphogame interventions in the combined treatment groups seems to affect the overall effect of the intervention.

Generally, results showed that an improved treatment should start with Graphogame intervention that should be administered for at least 15 tasks for any effect to appear. Moreover, the Graphogame intervention could be terminated by the 25th task (1/4 of the duration of the full program) without significant loss in the final effect on phonemic decoding fluency. The treatment should conclude PREP remediation to boost word reading fluency. We hypothesize that the proposed treatment will have at least the same impact as the full treatment, but can be administered for a shorter period of time. Also, by shortening the duration of the first part of the intervention to a quarter of the full intervention, the second part of the intervention (i.e., PREP remediation) will be free from any fatigue effect and likely to impact positively the overall effect of the treatment.

We have also implemented a general linear model and reported on the predictive power of each independent variable. Results on Graphogame intervention revealed that the performance of participants during intervention is better described by the underlying performance in phonemic decoding fluency measured post-intervention. Results also showed that performance in word reading fluency prior remediation affects performance during Graphogame intervention especially in more difficult tasks. These findings are of great importance as it turns out that reading remedial interventions seem to facilitate more the improvement of phonemic decoding fluency skills. What is also important is that children should have some basic word reading skills prior remediation in order to gain from remediation on word reading fluency.

To our knowledge, our attempt to develop a framework for examining learning progress dynamics in the area of reading remediation using microgenetic methods and computer applications is the first attempted. This makes this attempt to develop ways to help understand the processes through which children acquire the skills and knowledge, while working on specific reading tasks, a very important endeavor. The methods presented here offer a starting point for potential analysis and therefore, further research is needed in order to understand thoroughly these modulations and their implications.

Future Research

Apart from the need to replicate some of the present findings with larger groups of children with reading disabilities, as mentioned above, future studies should also consider using eye-tracking technology to investigate the effort and performance space about the learning progress dynamics of individuals receiving reading remediation. Eye-tracking is a very promising technology that seems to be used gradually more often in the reading research, as it can be used to answer an endless array of research questions in the specific field. For example, with regard to the microgenetic analysis, eye-tracking recording could be used to investigate reading behavior in general, and the possible strategies employed by the readers while performing a set of reading tasks, in particular. Although uncovering what may happen during reading, and what exactly is the link between different eye-movement behaviors and the underlying mental processes is still an ongoing (and hotly debated) topic, the use of eye-tracking recordings is expected to further advance our understanding about how changes in reading behavior occur.

Educational Implications

Regular classroom instruction fails to provide intensive and individualized practice that children with reading difficulties need in order to attain basic literacy skills (Hatcher et al., 2004; Torgesen, 2005). This study provides innovative solutions regarding the treatment of reading difficulties, by proposing new theory-driven and evidence-based treatment methodologies. Although there are numerous studies in English addressing this issue, there are only a handful of studies in languages with transparent orthographies (e.g., Patel et al., 2004; Suggate, 2010) and none that we know of in Greek, at least to the extent the present study addressed this issue.

The results of the present study argue strongly in favor of early reading instruction and intervention practices among struggling readers in Greek. Previous research findings have demonstrated that if children do not improve their reading skills by the end of Grade 3, they will have extreme difficulty overcoming a slow and unsuccessful start in reading (e.g., Blachman et al., 2004; Torgesen, 1998). Torgesen (2001) argues that children who fall behind in the development of proper word reading skills have fewer opportunities to practice reading, and they may require intensive interventions to attain adequate levels of reading accuracy. Moreover, reading fluency may be even more difficult to restore, due to the lost reading practice opportunities (Rashotte, Torgesen, & Wagner, 1997). In Cyprus, children usually learn to decode accurately and fluently by the end of Grade 1, and consequently in Grade 2 the focus is on the further development of reading fluency and comprehension. However, in Grade 3 literacy curriculum focuses on "reading to learn" and not learning to read, and thus poor readers are put at a considerable disadvantage. In more transparent orthographies, like Greek, it is reading fluency that results in individual differences in reading skills, rather than accuracy (e.g., Georgiou et al., 2008; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006).

The type of reading remedial intervention teachers offer in Cyprus classrooms may fail to provide the appropriate learning environment that poor readers need in order to achieve an adequate level in reading. Perhaps, children who are receiving remedial reading support in schools are making little progress, in part because of the lack of effectiveness of reading interventions provided in the resource room (Hatcher et al., 2004; Snow et al., 1998), and the actual amount of time children spend in individualized practice in reading skills, which has been reported to be far from optimal (Torgesen & Barker, 1995; Torgesen, 2005; Hatcher et al., 2004). Moreover, the intensity and quality of intervention teachers provide in order to promote the development of word recognition skills may vary from teacher to teacher and from school to school. Additionally, there is in Cyprus an evident lack of up-to date theory-based and cost-effective remedial packages. Therefore, the present study represents additions to the research literature draw on reading remedial interventions, as it provides new, evidence-based treatment methodologies to treat reading disabilities in a language with a transparent orthography. This attempt to bring new research-based and tested practices to the resource room is notably important, if one considers that no other attempt, to our knowledge, has been made in Cyprus, despite the new theoretical developments in dyslexia research.

These interventions, as well as their combination, proved to be successful in strengthening the foundation of reading skills in Greek-speaking young children. Hence, the results of the study have a profound effect on the individuals themselves as well as the society in large, with an obvious impact on education. The programs could be implemented as free, interactive, web-based literacy applications nation-wide in an effort to battle the alarmingly high percentage of low ability readers. Even more importantly, recognizing the within-child variability and knowing how and when a child may be benefited most from a remediation program can help predict change, analyze change, and understand change mechanisms. Without the recognition of the variability in children's responsiveness to a program's characteristics, such a differentiated and detailed analysis of cognitive and reading growth would have been impossible.

Conclusions

In conclusion, computer-assisted remedial reading interventions can be considered as effective supportive instruments for struggling readers, if they are theory-driven and evidence-based and part of the daily classroom routines. Of course, in spite of the rather promising results reported in the present study, it is not argue that computer applications can typically replace class teachers or special educators or that they may function as the major source of intervention for children with reading difficulties. Instead, they can be used as supplementary tools integrated into a well-structured reading intervention procedure, where teachers can also monitor their children's progress.

Overall, the findings of the current study clearly demonstrate that both PREP and Graphogame remedial programs, as well as their combination, are effective and beneficial for remediating reading difficulties of children in Grade 1 in a transparent orthography, such as Greek. Consequently, these remedial tools, in combination with other remedial reading practices that already class teachers or special educators employ in their classrooms, should form an important part of daily resource room routines. After all, what makes a reading remediation program effective are its theory, methods and structure, the skill and experience of the teacher, the quality of instruction delivered, the ability and motivation of the student, and the amount of time spent learning to read.

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APPENDIX

PASS Reading Enhancement Program (PREP)

Of the ten tasks included in PREP, the following eight were selected and adapted in e-format for use with the participants of the present study: Window Sequencing, Connecting Letters, Joining Shapes, Matrices, Related Memory Set, Transportation Matrices, Tracking and Shape Design. What follows is a description of each of these tasks, including levels that were administered and any modifications made to ensure that the participants could successfully complete the tasks (given that the program was originally designed to for students at the middle elementary level).

Window Sequencing. The focus of this task is successive processing. In the global component, the student's task is to reproduce a series of chips that vary in color and shape in the same order in which they are presented on the screen. The chips are presented one at a time, left to right, through a 2 x 2 inch window. Each chip appears in the window for approximately one second. The series ranges in length from three to six chips. Four series of each length are presented per session, for a total of 12 items. There are three levels of difficulty in this task. Difficulty Level 1 involves sequences of two different types of chips (circles and squares) and holds the color as a constant. Difficulty Level 2 involves different colored chips (white, yellow, blue, and black) and holds the shape as a constant. In Difficulty Level 3, both the color and shape of the chips are manipulated.

The student’s task in the bridging component is: (a) to reproduce a series of letters in the same order in which they are presented on the screen and (b) to state the word that is spelled by the letters. The letters, which the student views for approximately one second through a 2 x 2 inch window, are presented one at a time or in consonant or vowel combinations. There are three levels of difficulty as well as a preliminary level, each corresponding to the phonetic complexity of the words used.

Connecting Letters. Connecting Letters is predominantly a successive processing task. The global component includes eighteen tasks (in pairs of two), which are comprised of a set of items with colored figures and/or pictures at each difficulty level. The student is required to follow a line with his/her eyes to find which figure on the left side of the screen is connected to which figure on the right side of the screen, and click on both of them. Five figures are presented each time on the screen on each side. There are three levels of difficulty. Difficulty Level 1 contains strings that are color-coded to aid in scanning. Difficulty Level 2 contains black lines only. Difficulty Level 3 contains black lines as well as distracter lines that are not connected to any shapes.

The bridging component includes twenty-three tasks (in pairs of two), which are comprised of letters and syllables that form a word. The student is presented each time with five letters/syllables on the left side of the screen and a column of five letters/syllables on the right side of the screen. The letters are connected with lines that run across the page. The student is required to follow each line with his/her eyes, connect the series of letters by clicking on both of them, and state the word that is spelled by the letters. Three levels of difficulty and a preliminary level are provided; each corresponds to the phonetic complexity of the words.

Joining Shapes. This task's focus is also successive processing. The purpose of the global component is to join a series of geometric shapes in response to (a) a series of verbal instructions and (b) a set of rules provided by the loudspeakers. The shapes – triangles, squares, and hexagons – are presented in rows on the screen. Each row of triangles, squares, or hexagons is always separated by a row of circles. Within each session, six items with varying numbers of rows are presented. The first two items contain one row of triangles and one row of squares, with a row of circles in-between. The third and fourth items contain one row of triangles, one row of squares, and one row of hexagons, with rows of circles in-between. The fifth and sixth items contain a row of hexagons, a row of triangles, a row of squares, and another row of hexagons, with rows of circles in-between. There are three levels of difficulty; each corresponds to the number of consecutive instructions to which the student responds.

The format of the bridging component is as follows. The student is presented with several rows of letters on the screen. The purpose of the task is to join the letters from the top row to the bottom row – moving diagonally from left to right and following a set of rules – to produce a word. When the student reaches the bottom, he/she uses the last letter of that word as the first letter of the next word, and then proceeds back to the top in the same manner to produce another word. This is continued until the student reaches the end of the raw. There are three levels of difficulty as well as the preliminary level.

Matrices. Successive processing is the focus of the Matrices task. In the global component, the student is required to memorize a sequence of randomly chosen letters displayed within a five-cell matrix. The matrix is designed as a cross: there is one central cell, with one cell on each of its four sides. The cells of the matrix contain either pictures (Matrix Pictures) or numbers (Matrix Numbers) or even letters (Matrix Letters). The student is shown the complete matrix containing one picture, or number or letter in each of the five cells. After progressing through the sequence, he/she is asked to recall the sequence in the right order as it was presented on the screen. There are three levels of difficulty including in the task.

In the bridging component, the student memorizes the position and sequence of a series of words presented on a cross matrix by using the procedures that were learned during Matrix Pictures, Matrix Numbers and Matrix Letters. Each series consists of five words arranged in a five-cell matrix, with one word in each cell. Four of the words are semantically related, one is not. The student is required to recall the words in their correct position and order.

Related Memory Set. The Related Memory Set task involves both successive and simultaneous processing. The student's task in the global component is to match the front half of an animal with its appropriate back half. The animal pictures are presented on the screen, three pictures each time. Three fronts are presented in a column on the left side of the screen and one back is presented on the right side of the screen. The student is required to point to the front that matches the back. After making this prediction, he/she then matches the front and back together to determine whether the response was correct. The student is then allowed to alter his/her prediction as necessary. There are three levels of difficulty; each corresponds to the difficulty of discrimination required.

The purpose of the bridging component in is to: (a) choose the proper front half of a word to match the back half and (b) to read the word. The student chooses from three front portions of words placed on the left-side of the screen in a column. To the right of this column is the back half of the one of the words. He/she is required to match one of the fronts with the appropriate back and to read the word. There are three levels of difficulty as well as a preliminary level; each corresponds to the complexity of the words.

Transportation Matrices. In the global component of this successive processing task, the student is required to reproduce a series of transportation pictures in the correct order. The pictures are presented in a single-line matrix strip divided into sections (cells). The entire strip is shown, and then each individual picture in the strip is shown from the student's left to right on a horizontal line. There are three levels of difficulty: Level 1 contains six four picture series; Level 2 contains three four and three six picture series; Level 3 contains six picture series.

The student's task in the bridging component is to reproduce a series of letters in the correct order, and then read the word that is formed by the letters. The letters are exposed on a single-line matrix divided into cells to match the number of letters in the word. The letters are presented together, and then one at a time in their respective positions on the matrix. There are three levels of difficulty as well as a preliminary level; each corresponds to the phonetic complexity of the words. There are 15 words for each level.

Tracking. In the global part of this simultaneous processing task, the student is presented with a line drawing map of a "village" (Tracking Map I) and tracking cards illustrating a path from a starting point to either a numbered house (Level 1) or a lettered tree (Level 2). The tracking cards outline the roads and street intersections of the village map. The student's task is to survey each card and the village map, and then locate the number of the house or the letter of the tree on the map.

The bridging component involves a floor plan of West Edmonton Mall on which several key features are identified. The student is allowed some time to become familiar with the locations of the various key features. He/she is then presented with a series of passages (eight in total), one at a time. Each passage specifies a point of departure and two to four key features (listed randomly in the passage) to be visited by the student. Each passage also contains a constraint (e.g., time) under which the student is required to operate. The student's task is: (a) to read each passage as it is presented (with as much assistance as is required); (b) to identify the point of departure and the key features that are to be incorporated into the visit and (c) to use the floor plan to trace a path that will begin at the designated point of departure, incorporate all of the specifies features and move through the mall quickly as possible. The student begins with a passage that specifies two key features (including the point of departure) and finishes with a passage that specifies four features. In this study, when necessary, instructors read the passages to the participants.

Shape Design. Shape Design is predominantly a simultaneous processing task in which the student is required: (a) to study a design that is presented on the screen for ten seconds and (b) to reproduce the design with the colored shapes provided. The shapes include circles, rectangles, squares, and triangles in three colors (red, blue, and yellow) and two sizes. The designs range from a simple combination of three shapes, differing only in color, to a complex combination of six shapes differing along dimensions of color, shape, and size. The task is divided into three difficulty levels with six items in each.

The bridging component required students to read a phrase or story presented on the screen that describes how two to five animals are arranged in relationship to one other. The student visualizes the scene with the animals positioned appropriately. Then he/she is asked to arrange the animals to correspond with the scene as it was described in the phrase or story. Three difficulty levels are presented; each corresponds to the number and complexity of relationships.

Graphogame

On the surface, the game appears to be like any other digital game, or rather educational game, aimed at children in the early stages of their formal education. The outward appearance of the game is simple, with only a few visual elements displayed at a time, accompanied by short segments of speech. For the purposes of the presented study, around 1900 recordings have been performed as well as 252 levels of increasing difficulty in relation to the phonetic complexity of the words, have been designed.

The design of the training content used in the Graphogame method is based on research findings. For languages with transparent orthographies, such as Greek, the nature of the training materials is straightforward. Because each letter represents a specific phoneme and vice versa, the game starts with introducing these correspondences. Using the synthetic phonics approach, the game starts by presenting phonetically and visually distinct grapheme–phoneme correspondences as a group (e.g., α, σ, τ) after which it moves to present correspondences that are phonetically less distinguishable (e.g., μ, ν, λ). Next it introduces psycholinguistically relevant larger sublexical units of the target language, such as syllables or rimes, before introducing words. The expectation is that word decoding is basically achieved by knowing what sound the individual letters represent and simply combining them in an order to arrive at the written words (Richardson & Lyytinen, 2014).

The main task includes multiple-choice trials in which the player is to pair an audio segment (phoneme, syllable, word) with the appropriate visual representation (a letter or longer text segment). Mixed in with these reactive types of trials are the more active tasks, such as **Word Synthesis**, where the child has to construct written words from smaller components, like letters, to match the spoken target words. The word synthesis task also encourages the development of spelling skills, as children have to click on the letters or syllables in the correct order to form the word that they hear. Also, in the **Train Game**, a train drives across the screen and on each of its compartments a different target is printed. The child has to click on the compartments which contain the target words he/she hears. Similarly, in the **Race Cars Game** the child is asked to select the car with the orthographic stimulus that matches the auditory stimulus that is presented through the loudspeakers. Another interactive game is the **Ladder Game**. In this game, each ladder contains an orthographic stimulus. The child is asked to climb the ladder that corresponds to the auditory stimulus, in order to move on to the next level. Finally, the **UFO Game** includes a number of spaceships ranging from two to nine. Each spaceship contains an orthographic stimulus (e.g., syllable, rime, word) and the child has to click on the spaceships which contain the target stimulus he/she hears. Many levels are preceded by a visual demonstration which made phoneme-grapheme correspondences more explicit.

Graphogame provides immediate feedback on the player's accuracy. The player is presented with either positive auditory and visual feedback on the correct response, or visually for an incorrect selection. Typically, the incorrect selection is displayed in red, whereas the correct response is highlighted in green. The significant point is that, in the case of an inaccurate response, the game immediately guides the player to make the correct mapping, thereby teaching the player. In this way, the method emphasizes the correct correspondences of the spoken and written forms. After a short sequence of item mappings, the player is provided performance rewards in the form of game tokens, virtual stickers, and the like. The turnaround in a game is very short, providing rewards after approximately one minute of training time.

One key feature of the Graphogame method is that the game progression varies according to a learner's current skills. The game continually logs the player's performance with both accuracy and time measures. According to the performance in each particular trial, the game is able to provide learning material in subsequent trials or levels aimed at the player achieving about 80% correct responses on each level. This simultaneously provides both sufficient challenge and ample opportunity for success, which together facilitate engagement in the game. Moreover, similar game levels are presented in several graphically different settings in order to keep players interested in repeating the same type of activity hundreds of times. In this way, learners are exposed to the same connections with sufficient repetition for learning to occur, thus providing them the necessary opportunities to build the representations and learn concretely the connections needed at the first stages of the learning-to-read process (Richardson & Lyytinen, 2014).