

School of Psychology and Speech Pathology

**The Effectiveness of a Computer-Supported Intervention
Targeting Phonological Recoding and Orthographic Processing for
Children with Word Reading Impairment**

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**This thesis is presented for the Degree of
Doctor of Philosophy
of
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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #HR111/2011

Signature: 

Date: 12 July 2015

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Abstract

Evidence-based interventions targeting word reading skills in children with reading delay are of critical importance, as word reading predicts later academic achievement. Furthermore, most children with reading delay have impaired word reading with the primary deficit being the inability to use phoneme-grapheme relationships to decode words. While a large body of evidence has supported interventions targeting phonemic awareness combined with alphabet knowledge, recent research has revealed that phonological recoding and orthographic processing also provide unique and significant contributions to the development of word reading skills.

The programme of research for this thesis responded to three issues identified in the literature. Firstly, few studies have investigated reading interventions for children with persistent reading impairment, that is, those children who do not demonstrate an adequate response to initial interventions. Second, it has been difficult to isolate the key element responsible for gains as most interventions contain a number of tasks. Third, in many studies, there is a range of responsiveness with about 25% of children not making significant gains.

In response to these identified gaps in the literature, this research: (a) designed and developed a single component iPad-delivered intervention (the *Decoding Intervention*) specifically targeting phonological recoding and orthographic processing, (b) evaluated its effectiveness on the nonword reading and related literacy skills (word reading, text reading and comprehension, and spelling) of children with persistent reading impairment, and (c) examined the relationships between participant language, phonological, and cognitive profiles, and the child's response to intervention to identify factors that may contribute to the success of this newly developed reading intervention.

Two studies, both with single subject research designs (SSRDs), were completed. The first study was conducted in three phases (Pre-test, Intervention, Post-test) to trial the intervention materials and procedures on three Year 2 children with reading impairment. Study 2 involved eight Year 2 children with reading impairment who were randomly assigned to one of two intervention regimes in a cross-over design, thus introducing three variations to the research design: a comparison intervention (a *Language Intervention* in which no reading materials

were used), a delayed introduction of the Decoding Intervention, and an extended follow-up maintenance phase.

The primary measure of effectiveness was nonword reading, assessed by researcher-developed nonword lists administered at the beginning of each of the baseline and Decoding Intervention sessions. Additional measures of effectiveness were pre- and post-intervention scores on standardised measures of nonword reading accuracy, word and nonword reading efficiency, text reading and comprehension, and a detailed examination of nonword spelling responses on researcher-developed nonword lists. The standardised assessments were administered pre-intervention by the researcher and post-intervention by a speech pathologist blind to the research aims. These data were analysed at the group level using a Generalised Linear Mixed Model, and at the individual participant level using analyses appropriate to SSRD.

The results revealed that the intervention resulted in significant gains in nonword reading with large effect sizes for all participants. Though no significant gains were demonstrated on group analyses of word reading efficiency, text reading and comprehension, and spelling, the SSRD analyses showed clinically significant gains in some areas.

It was concluded that this single component intervention targeting phonological recoding and orthographic processing may be an efficient and powerful adjunct to reading interventions, particularly for children with persistent reading impairment. Future studies aim to replicate the findings with larger numbers delivered by trained educational assistants.

Glossary of Terms and Abbreviations

2SD	Two standard deviations
Alphabet knowledge	Knowledge of grapheme-phoneme relationships
Assessment NW List	Assessment Nonword List
Assessment NW Spelling List	Assessment Nonword Spelling List
CELF-4	Clinical Evaluation of Language Fundamentals-4
Consonant blend	Two consonant sounds spelled by two letters, e.g., <i>st, tr, bl</i>
CTOPP-2	Comprehensive Test of Phonological Processing-2
Decoding	Use of grapheme-phoneme conversion to read words
Digraph	One sound that is spelled with two letters, e.g., <i>sh,</i> <i>ch, ee, ow</i>
Diphthong	Two vowel sounds that occur in one syllable, e.g., <i>boat, boy</i>
D-Plate	Driver Plate module in the Decoding Intervention
GLMM	Generalised Linear Mixed Model
Irregular words	Words that cannot be accurately decoded using grapheme-phoneme conversion, e.g., “said”
Literacy	The broad range of skills used to absorb information (e.g., listening, viewing, reading), and respond flexibly (e.g., speaking, writing, producing digital material), for different purposes and contexts
L-Plate	Learner Plate module in the Decoding Intervention
MOR	Mental Orthographic Representation
NW Rate	Nonword Rate, the number of nonwords correctly read in 60 seconds
NW Spell Legal	Nonword Spelling Legal, the number of sounds legally spelled in responses on the Assessment NW Spelling Lists

NW Spell Omit	Nonword Spelling Omitted, the number of sounds omitted in responses on the Assessment NW Spelling Lists
NW Total	Nonword Total, the total number of nonwords correctly read
Orthographic knowledge	The stored information in memory on how to represent spoken language in written form
Orthographic pattern knowledge	The sub-lexical knowledge of (a) how letters represent speech sounds (i.e., the alphabetic principle), (b) the “legal” combinations of letters in a given language, and (c) the positional and contextual constraints on how letters may be used in a given language
Orthographic processing	The ability to acquire, store, and use this orthographic knowledge (i.e., MORs and orthographic pattern knowledge)
PhAT-2	Phonological Awareness Test-2
Phonological awareness	The ability to detect, manipulate, and analyse the auditory aspects of spoken language, e.g., sounds and syllables
P-Plate Reading	Practice Plate module in the Decoding Intervention Reading involves two basic processes: reading print and understanding what the print means.
R-Vowels	Vowels that include “r” (e.g., <i>ur, ir, er</i>)
SD	Standard deviation
SPC	Statistical Process Control
SSRD	Single subject research design
S-Plate	Speed Plate module in the Decoding Intervention
The Neale	The Neale Analysis of Reading Ability 3 rd Edition
TOWRE-2	Test of Word Reading Efficiency-2
T-Plate	Test Plate module in the Decoding Intervention
WISC-IV	Wechsler Intelligence Scale for Children-Fourth Edition

Word reading	The act of reading words out loud which incorporates two skills: decoding and word recognition
Word recognition	Use of a range of cues (e.g., word families, context, and sight words) when reading words
WPPSI-III	Wechsler Preschool and Primary Scale of Intelligence-Third Edition

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CHAPTER 1: INTRODUCTION

“One of the most daunting and clearly defined current challenges for both researchers and practicing educators is to develop, disseminate, and implement methods for teaching reading that will help all children acquire adequate reading skills.” (Torgesen, 2001, p. 33)

The development of efficient reading skills in children has been one of the main goals of early education for many years. This is a challenging goal for educators due to the complexity of the reading process and the varying skill levels with which children approach this task. Despite a large body of evidence (Department of Education, 2005; National Reading Panel, 2000) supporting approaches that target a combination of phonemic awareness (awareness of the relationship between sounds and words) and alphabet knowledge (knowledge of grapheme-phoneme relations), a substantial number of children have significant difficulty learning to read (ACARA, 2013; Dempsey & Davies, 2013). This research project identified a key skill in reading acquisition, designed a computer-supported intervention to improve that skill in children with persistent reading delay, and evaluated the effectiveness of the intervention using a single subject research design.

This initial overview chapter provides an orientation to key aspects of this research by firstly defining the terms referring to reading development, and then outlining the rationale for the topic (improving word reading skills), the intervention approach (intensive intervention for children with persistent reading delay), and the research design (single subject research design).

Definition of Terms

A variety of terms are used to refer to the complex range of skills involved in reading. Within this thesis, the term *literacy* refers to a broad range of skills that include absorbing information (e.g., listening, viewing, reading), and responding flexibly (e.g., speaking, writing, producing digital material), for different purposes and contexts (Buckingham, Wheldall, & Beaman-Wheldall, 2013).

The term *reading* has been described as an information processing activity with two components: reading aloud refers to the act of transforming print into

speech, and reading comprehension involves transforming print into meaning (Coltheart, 2006) using a range of other language skills and higher language and cognitive functions such as making predictions and forming inferences (Bishop & Snowling, 2004; Snowling & Hulme, 2005). This is consistent with the *simple view* of reading (Gough & Tunmer, 1986) which states that reading is the product of decoding and listening comprehension, where decoding is defined as “(context free) [*sic*] word recognition” (Gough & Tunmer, 1986, p. 7), and listening comprehension as the ability to interpret the meanings of words, sentences and discourses.

Though the simple view of reading has been useful in classifying the main types of reading disorders (Catts, Hogan, & Fey, 2003), more recently, Ouellette and Beers (2010) concluded that the simple view of reading was “not so simple”. Firstly, they highlighted that the use of the term “decoding” (as used in the definition of the simple view of reading) has caused confusion, as it has not differentiated between two different aspects of word reading: decoding (use of grapheme-phoneme conversion), and irregular word reading (use of a range of other skills to read irregular words: those that cannot be read using grapheme-phoneme conversion). Secondly, they found that these two aspects of word reading assumed different degrees of importance depending on the developmental level of the child. In their study involving 123 Grade 1 (n = 67) and Grade 6 (n = 56) English speaking students, they investigated the relationship between decoding, irregular word reading, and other oral language skills (phonological awareness, vocabulary knowledge, and listening comprehension), and progress in reading development. They found that each factor uniquely contributed to reading development and that the influence of each of these factors varied depending on the grade level. Whereas in Grade 1, the word reading skills of phonological awareness (the ability to detect, manipulate, or analyse the auditory aspects of spoken language, e.g., sounds and syllables), decoding, and irregular word reading were the main contributors to reading comprehension, by Grade 6 irregular word reading, vocabulary knowledge, and listening comprehension assumed a greater role with no additional predictive value for decoding skills. This supports the notion that word reading involves at least two processes – decoding and irregular word reading, which need to be considered separately.

With a need to differentiate the specific components of reading, in this thesis, *reading* refers to the process of reading words and comprehending text. *Reading*

comprehension refers to the ability to understand written text (i.e., to map the orthography to meaning). *Word reading* refers to the act of reading words out loud (pronouncing words). Word reading incorporates two skills: *decoding* – use of grapheme-phoneme conversion (assessed by nonword reading), and *word recognition* – use of a range of cues, such as word families, context, and knowledge of sight words (assessed by irregular word reading). The focus of this research is on word reading skills, in particular, decoding.

Importance of Word Reading Skills

The previous discussion of the simple view of reading suggests that mastery of word reading skills is an important goal for children in the early stages of reading acquisition. This was supported by Kamhi (2009) who proposed a narrow view of reading, where reading instruction focuses on word reading, while reading comprehension is taught within the general content areas of the curriculum, such as history, drama, and biology. He argued that this method would simplify the teaching of reading because word reading and comprehension represent two very different abilities. Word reading involves a defined scope of knowledge (letters, sounds, and words), and processes (decoding) that can be systematically taught, whereas reading comprehension is comprised of a set of higher level mental processes that includes thinking, reasoning, imagining, and interpreting. By separating these two sets of skills teaching would be streamlined and assessment would highlight the specific needs of the child.

The importance of word reading skills has been highlighted in studies that identify the predictor skills for reading and learning achievement, and those that outline profiles of reading disability. A recent meta-analysis (García & Cain, 2014) of 110 studies (42,891 readers aged five to 53 years) that examined the relationship between word reading and reading comprehension found that there was a significant relationship between word reading and reading comprehension across all age groups. As there was no point at which the correlation became negligible, it was concluded that efficient word reading skills remain important across the life span, that is, better word reading enables more resources to be devoted to comprehension, and with better reading comprehension word reading skills are increased.

The importance of early proficiency in word reading skills has been further demonstrated by the outcomes of a longitudinal study (Sparks, Patton, & Murdoch, 2014) involving 54 English speaking students from first to tenth grade. Following assessments of reading, spelling, vocabulary, intellectual skills (IQ), and listening comprehension in Grade 1, their progress was monitored through to Grade 10 where levels of reading comprehension, language, and general knowledge were assessed. While first grade language skills predicted language skills at Grade 10, it was found that even after intellectual skills were partialled out, early success in word reading predicted Grade 10 reading comprehension, language, and general knowledge. They concluded that these findings confirm the powerful long term benefits of ensuring that children achieve early success in word reading skills.

Word reading skills have also been found to be a predictor of literacy outcomes for children with language impairment. Botting, Simkin, and Conti-Ramsden (2006) conducted a longitudinal study to examine the associated literacy abilities of 200 children with a history of severe language impairment. The children were assessed at two points (at ages seven and 11 years) on measures of non-verbal intelligence, receptive and expressive language, word reading, and reading comprehension. Word reading skills at age seven years were found to be highly correlated with reading accuracy and comprehension at age 11 years: 82% of poor word readers at seven years had poor reading accuracy at 11 years, and 91% had poor reading comprehension at 11 years. These findings underscore the importance of word reading skills and suggest that most children who have delays in this area will continue to have impairments in reading accuracy and reading comprehension.

Examination of the profiles of children with reading disability also points to the importance of word reading skills. A sizable number of children experience failure in the development of reading. For example, in 2013 the results of the National Assessment Program for Literacy and Numeracy (NAPLAN) revealed that 11.4% of Year 3 Australian children were at or below the minimum standard for reading (ACARA, 2013). Research has demonstrated that most children with reading delay have impaired word reading skills (Catts et al., 2003; Torppa et al., 2007). An investigation into subgroups of poor readers was performed by Catts et al. (2003). Their analysis of the reading profiles of 183 Grade 2 English speaking children with average intelligence yet a reading comprehension delay, revealed that 70% of this group of children with reading comprehension delay had impaired word reading

skills. A follow up investigation two years later found that the children's word reading and listening comprehension skills were relatively consistent across Grade 2 to Grade 4, which indicates that most children with reading disability continue to have delayed word reading skills.

In a longitudinal study of the reading development of 1,700 Finnish children with no history of mental, physical, or sensory impairment (Torppa et al., 2007), word reading and reading comprehension skills were assessed at four points during the first two years of school. Similar to the previous study (Catts et al., 2003), it was found that about 78% of the children with reading delay had impaired word reading skills. For most children, word reading skills were highly correlated with reading comprehension, and in the case of the children with delayed word reading, comprehension skills only developed after their word reading skills improved, thus illustrating the close association between word reading and comprehension.

The results of these studies demonstrate that early proficiency in word reading skills predicts later reading comprehension, language, and learning in the general population, and later literacy development in children with language impairment. Moreover, most children with reading delay have impaired word reading skills, thus highlighting the importance of interventions targeting word reading skills for children with reading delay.

Intervention Approaches

Since the 1970s approaches to intervention for children with learning difficulties have moved from a *discrepancy model* to a *Response to Intervention* model (Hempenstall, 2012). Using the discrepancy model, children were identified as requiring specific intervention if their achievement in a given domain was significantly lower than their measured IQ. This approach has been criticised because of the lack of a uniformly accepted definition and assessment protocol for learning disability, and the observation that children often experienced many years of struggling before the discrepancy was detected (Hempenstall, 2012). Additionally, in the case with reading, it has been found that phonemic awareness, not intelligence, is more highly correlated with reading development (Tunmer & Greaney, 2010).

The Response to Intervention model is a three-tiered framework that promotes early identification of a learning difficulty and a scientific approach to

remedial instruction. In Tier 1, research-validated instruction is provided to all students along with universal screening to identify children in need of extra support. Tier 2 involves additional support (e.g., small group sessions targeting specific skill areas) for students who have been assessed as being at-risk. Students with persistently inadequate responses to the additional support in Tier 2 are given a more intensive Tier 3 intervention. This may involve in-depth assessment leading to intensive small group or individual instruction (Denton et al., 2013; Hempenstall, 2012).

The evidence supporting effective early reading instruction at the Tier 1 level is well established (Department of Education, 2005; National Reading Panel, 2000), and many studies have demonstrated that interventions using explicit instructions targeting phonemic awareness combined with letter-sound knowledge is effective for Tier 2 small group interventions (Berninger, Vermeulen, Abbott, & McCutchen, 2003; Bus & van Ijzendoorn, 1999; Gillon, 2002; Hatcher et al., 2006; Torgerson, Brooks, & Hall, 2006; Wheldall & Beaman, 1999). Fewer studies have examined the outcomes for children requiring intensive Tier 3 instruction (Denton et al., 2013).

In response to this relative gap in the research literature, Denton et al. (2013) conducted a randomized control trial that aimed to investigate an intensive individualised Tier 3 intervention by (a) examining the efficacy of the intervention compared to typical school interventions for at-risk readers, (b) determining the proportion of Tier 3 students who demonstrated an adequate response after the intervention, and (c) examining the characteristics of those students who responded successfully. One hundred and three Grade 2 English speaking students who had failed to respond to Tier 1 and Tier 2 instruction were randomly assigned to a daily Tier 3 intervention (45-minute sessions for 24-26 weeks in groups of two or three students) or a control group (typical school reading intervention) in a 2:1 ratio (experimental group 72 students, control group 31 students). A range of skills were targeted - word study, oral reading fluency, reading comprehension, and written response to text. The results showed that the experimental Tier 3 intervention was associated with significantly greater gains than typical school reading intervention on measures of word reading, phonemic decoding, word reading fluency, and reading comprehension. However, using a stringent criterion of responsiveness that involved three measures (word reading accuracy, word reading fluency, and reading comprehension), they found that the Tier 3 intervention and control groups did not

statistically differ in the proportions of adequate responders. Denton et al. (2013) suggested that this result was likely due to the high variability in responsiveness between individual students: at post-test 72% of the Tier 3 students were in the average range for word reading and decoding, but fewer than half met benchmarks for word reading fluency and comprehension. When examining the attributes of adequate and inadequate responses, they found that measures of phonological awareness and listening comprehension were statistically associated with responder status. Additionally, the graphed responses comparing the cognitive and language profiles of adequate and inadequate responders showed that Tier 3 inadequate responders were more impaired in all language measures, with lower levels on all measures.

These results suggest that the response to interventions for children with persistent word reading disorders is characterised by a large proportion of children who fail to make adequate progress, and patterns of individual variability in response to intervention. It highlights the need for continued research that (a) establishes evidenced based interventions for children with persistent reading disorders (Tier 3), (b) attempts to understand the profile of skills that support an adequate response to intervention, and (c) outlines the role of each component within an intervention, thus enabling an individual approach to reading intervention for these children.

Overview of Research Design

The results of research summarised above highlights the importance of word reading skills in early reading acquisition as a predictor of reading success and a skill that is impaired in most children with reading delay. While there is strong evidence supporting the components of effective early reading instruction (Tier 1), and convincing evidence supporting a number of approaches for those children who are at-risk of reading failure (Tier 2), questions remain about specific intervention methods to support those students who require Tier 3 interventions.

Given that most intervention studies involve group instruction incorporating a number of different strategies (e.g. phonological processing, word reading, and text reading), one question concerns the isolation of the key components contributing to improvement in specific skill areas. A second important question relates to identifying the predictors of successful responses to intervention.

This research aimed to add to the evidence supporting Tier 3 interventions for word reading impairment. Specifically it aimed to:

1. Design and develop an intervention targeting one specific skill (decoding), thus enabling unambiguous assessment of its impact on word reading skills
2. Evaluate the effectiveness of the intervention
3. Examine participant profiles and response patterns to gain insight into the nature of the variability in response to interventions that have been reported in the literature

Overview of Chapters in this Thesis

The following is an outline of the remaining chapters in this thesis:

- Chapter 2: A review of the literature.
This chapter discusses the theoretical basis of single word reading in the developmental stages of reading acquisition, the outcomes of intervention for word reading impairment, and concludes with the research questions posed in this thesis.
- Chapter 3: Research rationale and overview
This chapter describes the rationale for the research, and introduces the three stages in this programme of research: the design and development of the intervention, the trial of the intervention materials and procedures, and the evaluation of effectiveness of the intervention. This is followed by an overview of the research design (single subject research design) and discussion of the hypotheses.
- Chapter 4: Development of the intervention materials
This chapter provides a detailed description of the development of the computer-supported materials that were used in this research.
- Chapter 5: Study 1
Chapter 5 describes the first study which trialled the intervention materials and procedures.
- Chapter 6: Study 2 – Group analyses

This chapter describes the second study which evaluated the effectiveness of the intervention, and discusses the results of the group analyses of outcome measures.

- Chapter 7: Study 2 – Individual participant analyses

After describing the analyses that were used as part of the single subject research design, Chapter 7 presents an individual analysis of each participant: their individual response to intervention, and the influence of pre-intervention profile on response to intervention. It concludes with a discussion of how individual analyses may provide insights into the variability in response to intervention that is characteristic of children requiring Tier 3 interventions.

- Chapter 8: Discussion and conclusions

The thesis concludes with a discussion of the findings of each stage of the research, the outcomes relating to the research questions, and the limitations of this research. It highlights the contribution that this programme of research has made to the literature, discusses future directions, and draws general conclusions.

CHAPTER 2: LITERATURE REVIEW

“The key to understanding how reading skill develops is understanding how beginners learn to recognize written words accurately and automatically.”

(Ehri, 2005, p. 168).

The overview chapter summarised evidence that underlines the importance of word reading skills in the early stages of learning to read. It highlighted that most children with reading delay have impaired word reading skills. Additionally, interventions for children with persistent reading delay demonstrate variability in response to intervention, and a large number of children fail to respond adequately. This provided background to the formulation of the goals of this research, which were to develop and evaluate an intervention for children with persistent reading disorders, and to examine individual participant response to intervention.

This chapter addresses the theoretical basis of word reading, discusses intervention studies relevant to the focus of this research (an intervention targeting accurate word reading for children with persistent reading disorders), and finishes with the research questions that are posed in this thesis.

Theoretical Basis of Word Reading

In the development of new interventions, examination of existing theoretical models allows researchers to focus on relevant information and conduct systematic evaluations of findings to inform further research and interventions (Harn, Stoolmiller, & Chard, 2008). As the goal of this research is an intervention targeting accuracy of word reading (decoding), the focus of this review is on theoretical models relating to word reading.

When designing an intervention for word reading impairment, two factors need to be considered: identification of the skills that need to be mastered, and formation of evidence based procedures to support acquisition of those skills (Coltheart, 2006). Additionally, Byrne (2005) suggests that we also need to consider what the child contributes to the learning process, as this supports formation of appropriate strategies to teach an individual child. While the research design described in Chapter 3 outlines the procedures used in this research to individualise

the intervention (matching intervention goals to the skill level of the child, and examining the individual profile of the learner), this section discusses influential theories and models of word reading that address key processes involved in reading words, and how those processes are acquired. These include:

- The dual-route model (Coltheart, 2006)
- Connectionist models of word reading (Plaut, McClelland, Seidenberg, & Patterson, 1996)
- The dual-route cascaded model: DRC (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001)
- Ehri's phase theory (Ehri, 2005)
- Phonological recoding theory (Share, 1995)

This is followed by a summary of research that provides evidence for factors that impact on the development of word reading skills: orthographic processing, linguistic properties of words, the role of context, dose rate, and grain size.

Models of word reading

Dual-route model

The dual-route model (Coltheart, 2006) explains a skilled reader's ability to read familiar words (sight words) and to decode new and unfamiliar words, by proposing two different paths that are used when reading words aloud. In this model these paths are called routes: the lexical route and the non-lexical route. The lexical route accesses a large bank of well-established sight words in the mental lexicon. This process has been described as a "look up" system where words have local representations which enable instant word recognition. According to Coltheart (2006) the mental lexicon contains three kinds of information about words: knowledge about the visual form (the orthographic lexicon), pronunciation (the phonological lexicon), and meaning (the semantic lexicon). Thus, on encountering a known sight word, the reader can automatically read the word, pronounce it, and understand the meaning. If the word is not represented in the mental lexicon (therefore, unable to be read automatically), the non-lexical route is engaged where the phoneme-grapheme rules of English are employed in a *serial* manner (i.e., moving from one grapheme to the next) to sound out the word - decoding. Under this

model, the non-lexical route can correctly sound out regular words (those that follow typical grapheme-phoneme rules) and nonwords, but will make errors on irregular words (e.g., pronouncing *pint* rhyming with *mint*). An assessment which comprises nonwords is the best method of evaluating the functioning of the non-lexical route. In contrast, the lexical route will successfully pronounce all familiar words (regular words: those that obey grapheme-phoneme correspondence rules of English, e.g., *cat*, *maid* or *cave*, or irregular words: those that violate these rules, e.g., *said*), and will not be able to read unfamiliar words or nonwords (e.g., *nop*). As the lexical route processes known sight words, an assessment which includes irregular words (those that cannot be read via grapheme-phoneme rules) would assess functioning of the lexical route (Castles, 2006).

This model provides a framework for identifying two procedures that support efficient word reading (decoding and word recognition) and profiling the nature of reading impairment. It suggests that children with reading impairment will have measureable differences in their use of the lexical route (irregular word reading), and/or the non-lexical route (nonword reading), and that this pattern would be different to that of a normally developing reader. This proposal was supported by Castles and Coltheart (1993a) in their comparison of 56 children aged 8:6 to 14:11 years with average intelligence and severe reading delay, with 56 normally developing readers. The children were presented with a test battery that allowed for separate assessment of lexical and non-lexical reading procedures. It consisted of 90 items: 30 nonwords, 30 regular words, and 30 irregular words matched for frequency, imageability, grammatical class, and number of letters. The results demonstrated that for the normally developing readers, performance on irregular and nonword reading improved in a linear fashion with increasing age. In contrast, 85% of the reading delayed children demonstrated a dissociation between their irregular word reading and their nonword reading performance: 55% of the total sample displayed poor nonword reading compared with irregular word reading, and 30% were poor at irregular word reading compared to nonword reading. Furthermore, 34% of these children were average in one skill and delayed in the other. A follow up study involving 20 students (with average intelligence and severe reading delay, aged 10:4 to 12:5 years) that assessed auditory comprehension of the irregular words demonstrated that the poor performance on irregular word reading was not due to a language impairment as the children understood the meanings of the words (i.e., had

phonological representation of the words), but were unable to read the words (did not have existing orthographic representations). These results support use of the dual-route model to classify reading impairment in developing readers into two main types: the first is characterised by deficits in word recognition (i.e., use of the lexical route), and the second by a deficit in use of grapheme-phoneme rules (i.e., use of the non-lexical route) which in the Castles and Coltheart (1993a) study characterised the greater number of children.

The finding that most children with reading delay have problems with the non-lexical route is consistent with a meta-analysis conducted by Herrmann, Matyas, and Pratt (2006) which aimed to examine the differences in nonword reading ability in children with reading delay compared to reading-level control groups. The analysis of 34 studies involving 2865 children found that most children with reading impairment have a significant deficit in nonword reading, that is, in using the non-lexical route. The magnitude of this effect was moderate and considered to be robust despite differences in study design and methods for assessing word reading skills.

These results support the dual-route model in its characterisation of skilled word reading as involving two procedures: one that applies grapheme-phoneme rules to read words (the non-lexical route), and another that caters to exception words (the lexical route). Though this model has been used to successfully describe the main types of reading impairment, it does not provide information about how children acquire these processes, and it is unable to provide a framework to support methods of teaching word reading skills for children with reading delay.

Connectionist models of word reading

Connectionist models offer an alternative to the dual-route model where word reading occurs using a single system, with no dichotomy between items according to whether they obey grapheme-phoneme rules and those that are exceptions. Many connectionist models are computational models where a computer program is written that uses a learning algorithm reflecting the nature of cognitive processes involved in reading. These cognitive processes are organised as a layer or a group and are connected by neuron-like units that are weighted based on frequency of use. For example, one group might specialise in encoding print (orthographic), another might encode the spoken form (phonology), and a third might encode meaning (semantics). The whole system is trained by being presented with hundreds of words. The words

are learned gradually and are eventually encoded as long-term knowledge within the system. In these systems, representations of words are *distributed*, that is, words are retrieved following activation of a large number of units distributed across the different layers, rather than activation of a single word unit. This approach does not deny the existence of sequential processes related to orthographic input and articulatory output, but it emphasizes *parallel* interaction among the central lexical information (Plaut, 2005).

A computational model (Seidenberg & McClelland, 1989) for word pronunciation (naming) trained a connectionist network to map the orthography of about 3000 English words (both regular and exception words) to their phonology, and to distinguish between words and nonwords. Though this model accurately pronounced 97.7% of the words, and exhibited similar behaviours to those observed in human readers (e.g., naming more frequent and consistent words faster), it was worse than skilled readers at pronouncing orthographically legal nonwords. However, subsequent simulations of this model (Plaut, 2005; Plaut et al., 1996) report that once the structure of the orthographic and phonological representations was modified to more accurately reflect the orthographic constraints of English words, the network accurately pronounced regular words, nonwords, and exception words as well as skilled readers. Furthermore, by modifying the relative contribution of the phonologic and semantic pathways to simulate damage to the semantic system (during training to simulate developmental reading disorders, or after training as in acquired conditions), the network was successful in modelling human manifestations of reading disorders. This suggests that a connectionist model may be useful in modelling the effects of a range of factors that influence word reading development, such as nature of reading instruction and the sophistication of preliterate phonological representations (Plaut, 2005).

Connectionist models, then, are intended to reflect the properties of learning that are thought to occur in neural networks such as the brain. Though the existing models are limited in size and diversity of vocabulary (Plaut, 2005), and involve aspects that do not closely match human manifestations of learning to read: for example, they require many more exposures compared to human learning and fail to remember words as efficiently as humans (Coltheart, 2006), they have been shown to successfully model how underlying processes impact on word reading development.

However, in the design of an intervention for word reading impairment, connectionist models do not provide an evidence base for teaching strategies.

Dual-route cascaded model

The dual-route cascaded model: DRC (Coltheart et al., 2001), was developed in response to the computational modelling that had been employed in connectionist models of reading (Seidenberg & McClelland, 1989). The DRC as described by Coltheart et al. (2001) is hard-wired (rather than learned) and is based on the dual-route model of reading, with a lexical non-semantic route (analogous to the lexical route in the dual-route model) and a GPC route (grapheme-phoneme conversion: the non-lexical route). Each route is composed of a number of interacting layers which contain sets of units. The units represent the smallest symbolic part of the model, e.g., words in the orthographic lexicon or letters in the letter layer. The lexical route involves accessing an orthographic representation in the model's lexicon of real words, which then activates the word's phonological representation. While nonwords are able to produce activation in the orthographic lexicon (e.g., "sare" can activate words that are orthographically similar, such as "care"), they are read using the non-lexical procedure that applies grapheme-phoneme correspondence rules in a serial left-to-right fashion. Computations of the lexical and non-lexical route occur simultaneously, which means that irregular words and nonwords produce conflict at the phonemic level. Accuracy in pronouncing irregular and nonwords occurs due to use of inhibitory and facilitatory connections between layers in the model (Coltheart, 2005).

Evaluations of this model (Coltheart et al., 2001) indicated that its processing characteristics were similar to that of the human reading system. It made the same errors as humans when reading words (e.g., regularising irregular words), was about 99% accurate when reading nonwords, and was able to perform other tasks in a similar way to humans. For example, when reading aloud and performing lexical decision tasks (identifying a word and deciding if an item is a real or nonword), faster responses were recorded for high-frequency and regular words compared to low-frequency and irregular words. The DRC model was also successful in simulating a range of acquired reading impairments and in predicting accuracy of reading in samples of young normal readers and children with reading impairment.

The results suggested that very young or poor readers have scaled-down versions of the dual-route system used by a skilled reader.

The DRC model, therefore, is able to characterise the main manifestations of impairment in accuracy of word reading, that is, a child may have difficulty in one or both the lexical or non-lexical route. However, it does not provide information of how the child learns to read words, and it fails to account for the importance of skills that underpin word reading development (such as phonemic awareness), as the training procedure represents “instant phonemic awareness” (Share, 1995). Furthermore, it is unable to provide a framework to support methods of teaching word reading skills for children with reading delay.

Ehri’s phase theory

Ehri’s phase theory (2005) describes the progression through four phases in the acquisition of fluent sight word reading: a process where words are read automatically as a single unit. While other strategies may be used for pronouncing unfamiliar words, such as decoding (use of grapheme-phoneme correspondence), analogizing (using letter patterns in known words to read new words), and prediction (use of context to guess words), it is proposed that any word that is often read becomes a sight word. The process of developing sight words is described as a connection-forming process where readers form connections that link written words to their pronunciations and meanings in memory. These connections are formed out of the reader’s pre-existing alphabet knowledge and phonemic awareness: the combination of which supports rapid sight word development in the normally developing reader. Four phases are proposed, each reflecting different degrees and mastery of alphabetic knowledge. The *pre-alphabetic* phase is characterised by whole word recognition (which is totally dependent on contextual cues) of a small number of words. During the second phase, the *partial alphabetic* phase, knowledge of the names or sounds of letters emerges but the child is unable to pay attention to all letters in the word, especially the vowels. In this phase, the child may confuse similarly spelled words such as *pan* and *pin*. The third phase, the *full alphabetic* phase, occurs when the child has mastered most of grapheme-phoneme correspondences, and can therefore decode unfamiliar words and invent spellings that represent all phonemes. This allows the child to remember correct spellings and form sight words in memory. The final stage, the *consolidated* phase, emerges as the

child's knowledge of grapheme-phoneme connections expands to include into larger units (e.g., rimes, syllables, morphemes, and whole words), thus allowing decoding of multi-syllabic words and an increased bank of sight words. Using the terminology described in Chapter 1, efficiency in word reading is characterised by use of the full alphabetic phase (decoding), and the consolidated phase (word recognition) to support the development of a bank of sight words for which the reader has rapid and automatic access to the pronunciation and meaning of a large number of words.

Phase theories of word reading have been supported by many studies (Apel, Wolter, & Masterson, 2006; Deacon, 2012; Deacon, Benere, & Castles, 2012; Hudson, Torgesen, Lane, & Turner, 2012). For example, Hudson et al. (2012) investigated the lexical and sub-lexical skills which best predicted text reading in a study involving 198 Grade 2 children (mean age 8.5 years). They found that the ability to blend sounds predicted the ability to blend larger units which in turn predicted text reading fluency. They concluded that this progression followed Ehri's phase theory, and suggested that teachers need to ensure that automaticity in oral blending of sounds is well established as a foundation for decoding larger letter patterns in order to become successful decoders at the text level.

While phase theories allow the determination of the level of breakdown for a child with reading delay, they do not provide information about the underlying processes contributing to the child's difficulty, and they are unable to inform intervention procedures (Hulme & Snowling, 2009), as they do not include detail about strategies to support learning of each set of skills. This has been explored in theories that address word reading acquisition, such as the phonological recoding theory.

Phonological recoding theory

The phonological recoding theory (Share, 1995) addresses how children acquire efficient word reading skills. It proposes that phonological recoding is a key process that functions as a self-teaching mechanism enabling the child to acquire the detailed orthographic lexicon that is the foundation of skilled word reading: the automatic recognition of printed letter strings (*mental orthographic representations*, or *MORs*) that are linked to phonological, semantic, morphological, and syntactic information (Share, 2004). Phonological recoding is said to occur when the child successfully attends to the internal structure of unfamiliar words by sounding out

(grapheme-phoneme translation) and blending the sounds to then “read” the word. The three key features of this theory are that it is item-based (as opposed to stage-based), which means that formation of an accurate orthographic representation depends on how often the child has correctly recoded the word, rather than the child’s current stage of reading development. Secondly, it predicts that orthographic knowledge becomes increasingly lexicalised, moving from simple letter-sound correspondences to mastering larger units and whole words. Third, it states that self-teaching involves two component processes: phonological and orthographic, with the phonological component - “the ability to use knowledge of spelling-sound relationships to identify unfamiliar words” (Share, 1995, p. 156) assuming the primary role. Thus, over time, each successful phonological recoding of an unfamiliar word provides opportunities to develop word-specific and increasingly “lexicalised” orthographic knowledge which forms the basis of skilled word reading.

Research investigating the use of phonological recoding in the development of MORs has mostly used protocols similar to that used by Share (1999), where the child reads stories containing unfamiliar words. Nonwords are often used in these experiments because they represent new words for which the child would not already have established MORs. After reading the stories, usually aloud, the child is presented with tasks to assess the development of orthographic representations of the items presented in the stories. These include orthographic choice (identifying the target from closely matched homophone alternatives), spelling of target nonwords, and timed reading of target nonwords compared to closely matched words or other nonwords (naming efficiency). While these studies have occurred in different languages, unless otherwise stated, those discussed in this section involved English speaking children.

There is strong evidence that phonological recoding plays a key role in the development of visual word reading skills and the formation of MORs. Cunningham, Perry, Stanovich, and Share (2002) examined the phonological recoding theory in a study involving 34 typically developing Grade 2 children. The aim of the study was to replicate a previous study (Share, 1999) that demonstrated strong support for the phonological recoding theory in Hebrew (a transparent language), and to examine possible sources of variance on measures of orthographic learning. Prior to the experimental sessions, standardised measures of receptive vocabulary, nonverbal reasoning, digit span, and nonword reading were administered, as well as

assessments of rapid naming (colours, letters, and numbers), and orthographic knowledge (an orthographic choice task where the child circled the correctly spelled word from a pair of phonologically similar letter strings, e.g., *gote-goat*). During the experimental sessions the children read aloud, without corrective feedback, 10 short stories that contained six repetitions of a nonword. Orthographic learning was assessed three days later, using a homophone nonword choice task (e.g., which was the coldest town? *yait/yate/yoit/yiat*), a naming task (name the word), and a spelling task. The results provided strong support for the phonological recoding theory, with an accuracy of 74% in the orthographic choice responses, 70% for spelling accuracy, and naming responses were significantly faster for the target nonwords. In addressing the second research question, decoding accuracy (measured by a standardised nonword reading assessment) and prior orthographic knowledge were found to predict orthographic learning, with non-significant predictive values for rapid naming and general cognitive skills. The authors concluded that these results provided robust evidence for the phonological recoding theory under conditions that simulated the self-teaching that is expected to occur in everyday reading situations.

Kyte and Johnson (2006) performed a further exploration of the self-teaching hypothesis using an orthographic learning paradigm that controlled use of phonological recoding. Thirty-two typically developing children (mean age of 10.0 years) were presented with a learning condition (a lexical decision task “which is the real word out of homophone pairs”), followed by an assessment of orthographic learning (orthographic choice, naming, and spelling). Participants were randomly assigned one of two conditions: a read aloud condition (items were read aloud prior to the lexical decision task to promote phonological recoding), and a concurrent articulation condition (phonological recoding was limited as participants repeated the *la* syllable while viewing the homophone pair). The results of analyses of variance on the three orthographic learning tasks indicated that participants were significantly more accurate in the read aloud condition. Additionally, in the read aloud condition, 76% of the errors phonologically matched the target item compared with only 51% in the concurrent articulation. This suggests that as a result of phonologically recoding items in the read aloud condition, participants were more likely to select a phonologically similar item (foil) in the orthographic choice task. Likewise, in the spelling and naming tasks, participants in the read aloud condition correctly spelled significantly more target items and named them more quickly than in the concurrent

articulation condition. These results provided robust support for the role of phonological recoding in orthographic learning and indicated that when phonological recoding is compromised, orthographic learning is reduced.

Bowey and Muller (2005) investigated the phonological recoding theory to determine if self-teaching occurs in more naturalistic conditions such as silent reading. Sixty-three Grade 3 children (aged 7:2 to 9:9 years) were presented with a silent story reading task containing four versus eight repetitions of the target nonwords. Orthographic learning (orthographic choice and list reading) of target items was assessed immediately and after a six day delay. The results presented convincing evidence of rapid orthographic learning on both measures, with the strength of orthographic learning being greater with increased presentations (repetition of the nonwords), and decaying over time. However, the role of accurate phonological recoding during silent reading was discussed, as there were some children who could not read the target nonwords at post-test, suggesting that accurate phonological recoding may not have occurred. Nevertheless, they concluded that phonological recoding was involved as the children's scores on the orthographic choice test were significantly greater than chance ($p=.0005$), therefore unlikely to reflect a Type 1 error. The authors agreed with Share (2004) by suggesting that even partial attempts at phonological recoding would encourage closer attention to the orthography, which, when combined with contextual information, would increase accurate phonological encoding. They concluded that this convincing support for the self-teaching hypothesis provided "strength to claims regarding the central place of instruction in phonological recoding within the reading curriculum, particularly in beginners" (Bowey & Muller, 2005, p. 218).

Nation, Angell, and Castles (2007) conducted a further study to examine whether the relationship between phonological recoding success and orthographic learning holds at an item level. Using the materials devised by Bowey and Muller (2005), 42 Year 3 and 4 children (aged 8 – 9 years) read aloud stories containing nonwords (one, two, or four repetitions). Orthographic learning was assessed following a 1- or 7-day interval using an orthographic choice task (selection of target items from an array of visually and phonologically similar foils). Similar to Bowey and Muller (2005), there were significant effects of exposure (stronger orthographic learning with increased presentations), and duration (more correct responses after one day delay compared to seven days), but limited support was found for the item-

based feature of the theory. The analyses revealed moderate correlations between the children's word reading skills (performance on standardised tests of word and nonword reading, and decoding accuracy of target items) and orthographic learning. However, the relationship did not hold at an item-by-item level, that is, some items were decoded correctly and not recognised, or recognised correctly but not decoded. More recently, Wang, Nickels, Nation, and Castles (2013) in their examination of the reading and language skills associated with orthographic learning in 45 Grade 3 and 4 children (aged 6:10 to 9:7 years) also found that decoding accuracy of target items did not predict orthographic learning at the item-level. In discussing the self-teaching hypothesis (that phonological recoding provides the opportunity to focus on orthographic details and to generate the phonology of the word), they suggested that, while the act of phonological recoding (despite producing errors) may serve as an orthographic learning aid, it might be the focus on orthographic details that is more important for orthographic learning.

The studies examining the phonological recoding theory reviewed above have demonstrated clear evidence that accurate use of phonological recoding plays a key role in MOR development in typically developing English speaking children. The finding that the strong version of the item-based feature of self-teaching hypothesis was not supported (i.e., the relationship between decoding accuracy and MOR development did not hold at the item level), may be influenced by the language, that is, in less transparent languages such as English there may be other factors that influence orthographic learning – the discussion of which follows in the next section. Nevertheless, these results suggest an intervention that focuses on both phonological recoding and orthographic processing would provide optimal conditions for development of accurate orthographic representations, particularly for children with delays in word reading skills.

Summary

The models and theories of word reading reviewed above provide a framework for the development of an intervention programme targeting word reading skills; a process that is impaired for most children with reading delay. The dual-route model outlines the two main routes of word reading: the non-lexical route (which is the weakest skill for most reading impaired children) for decoding unfamiliar words, and the lexical route for known sight words. The focus for the

programme of research presented within this thesis is on supporting children to master accurate use of the non-lexical route to promote formation of accurate orthographic representations thus supporting development of sight words in the lexical route. Ehri's theory describes the phases that children go through as they develop efficient MORs allowing fluent word reading. The children in the research for this thesis have not mastered the partial alphabetic stage and therefore are unable to transition through the full alphabetic to the consolidated phase. The phonological recoding theory proposes a mechanism which provides children with reading impairment with the skills to develop accurate orthographic representations, enabling them to evolve from the partial alphabetic phase through to the consolidated phase, or from predominant use of the non-lexical to the lexical route. Finally, connectionist models provide a framework that may account for the knowledge (orthographic, phonologic, semantic, syntactic, and morphologic) that is implicitly absorbed with each reading experience. While the research reviewed above supports many aspects of the phonological recoding theory, other studies have highlighted a range of additional factors that may influence the development of MORs. These will be explored in the next section.

Factors that influence MOR development

A strong body of evidence drawn from multiple studies with large numbers of children (National Centre for Family Literacy, 2008; National Reading Panel, 2000) has identified six key variables that predict later literacy development:

1. Alphabet knowledge: knowledge of the names and sounds associated with printed letters
2. Phonological awareness: the ability to detect, manipulate, or analyse the auditory aspects of spoken language (including the ability to distinguish or segment words, syllables or phonemes), independent of meaning
3. Rapid automatic naming of digits or letters: the ability to rapidly name a sequence of random letters or digits
4. Rapid automatic naming of objects or colours: the ability to rapidly name a sequence of repeated random sets of pictures of objects (e.g., "car", "tree", "house"), or colours

5. Writing or writing name: the ability to write letters in isolation on request or to write one's own name
6. Phonological memory: the ability to remember spoken information for a short period of time

The aim of this section is to review some of the research findings relating to factors that have been identified by research to impact on the acquisition of MORs in addition to those well-established variables noted above. These factors include (a) the role of orthographic processing, (b) linguistic properties of words in the development of MORs, and (c) other design features within the intervention concerning the presentation of items: whether items need to be presented in context, the frequency of presentation (dose rate), and the type of words or items that optimise performance (grain size).

Orthographic processing

A number of facets relating to orthographic processing are referred to in the literature, including orthographic knowledge, orthographic pattern knowledge, and mental orthographic representations. As there has been inconsistency in the use of terms, the accepted definitions provided by Apel (2011) are used in this thesis. *Orthographic knowledge* refers to the stored information in memory on how to represent spoken language in written form. There are two aspects to orthographic knowledge. The first is *orthographic pattern knowledge*. This pertains to sub-lexical knowledge of how letters can represent speech sounds (i.e., the alphabetic principle), the knowledge of “legal” combinations of letters in a given language, as well as the positional and contextual constraints on how letters may be used in a given language. The second aspect is the stored mental representations of words or word parts (lexical knowledge), referred to as *mental orthographic representations* (MORs), analogous to terms used in other studies such as *mental graphemic representations* and *mental orthographic images*. According to the dual-route theory, individuals read or spell words by accessing these two areas of their orthographic knowledge: their existing MORs (the lexical route), and their orthographic pattern knowledge (the non-lexical route). In contrast to orthographic knowledge, *orthographic processing* refers to the ability to acquire, store, and use this orthographic knowledge, that is, the MORs and orthographic pattern knowledge.

Research examining reading development in the early school years has supported a unique and significant role played by orthographic processing (Badian, 2001; Cunningham, Perry, & Stanovich, 2001). In a longitudinal study involving 39 students from Grade 1 to Grade 3 (aged 6:1 to 8:2 years), Cunningham et al. (2001) examined the amount of variance predicted by phonological processing, orthographic processing, and print exposure on word reading development. A battery of phonological processing tasks (measuring phonemic awareness, nonword repetition, and nonword reading) was administered in Grade 1. In Grade 2, orthographic processing (lexical and sub-lexical orthographic knowledge) and phonological processing (nonword repetition) were assessed. In Grade 3 measures of print exposure, nonword reading, and word reading were administered. Using composite measures of phonological and orthographic processing, the results of a hierarchical regression showed that after the variance in word reading attributable to phonological processing was removed (19.3%), orthographic processing skills accounted for statistically significant additional variance (16.3%), indicating that orthographic processing skills are a unique contributor to word reading development and may not be totally dependent upon phonological processing skills.

Badian (2001) conducted a longitudinal study examining the relationship between pre-literate orthographic and phonological awareness skills and later reading development. Prior to the start of school 96 English speaking children (aged 4:6 to 5:6 years) were administered measures of phonological awareness (syllable segmentation and rhyme detection), orthographic processing (visual matching of letters and numerals), preschool reading achievement, verbal IQ, and verbal memory. Their word reading and comprehension skills were assessed at Grades 1, 3 and 7. Using stepwise and hierarchical regressions the results showed that while the phonological measures explained significant variance in Grade 1 word reading and comprehension scores, it was the orthographic processing measures which predicted significant variance in reading vocabulary and reading comprehension at Grade 3 and Grade 7. These results demonstrate that phonological and orthographic processing skills each make independent and unique contributions to the development of word reading skills.

More recently, Deacon (2012) examined the nature of the changing roles of phonological and orthographic processing as well as morphological processing (the ability to manipulate minimal units of meaning in language) during the early stages

of reading development. The cross-sectional study involving 207 English speaking children in Grade 1 (mean age 6:11 years) and Grade 3 (mean age 9:0 years) investigated the relationship between three reading related variables (phonological awareness, morphological awareness, and orthographic processing at the lexical level), reading skills (real and nonword reading accuracy), and vocabulary knowledge. The results indicated that in this group of children with average reading and vocabulary skills, phonological, orthographic, and morphological awareness each made unique contributions to real and nonword reading accuracy after age and vocabulary knowledge had been accounted for, but that the relative contribution of each changed over time. While the contribution of phonological and morphological awareness was consistent across grades, the impact of orthographic knowledge increased from 5% in Grade 1 to 12% in Grade 3. She concluded that the contribution of these three separate components of word recognition is consistent with Ehri's phase theory: an initial importance of sight word knowledge, followed by phonological awareness and then orthographic consolidation in the final phase of reading development.

The results of these studies demonstrate the significant and unique role of orthographic processing in the development of word reading skills. In response, recent studies have examined issues regarding the definition and measurement of orthographic knowledge (Conrad, Harris, & Williams, 2013), and the direction of the relationship between orthographic processing and word reading skills (Deacon et al., 2012). Due to variations in the definition of orthographic knowledge, the measurement of this skill has involved a range of different tasks, such as spelling recognition (i.e., orthographic choice or homophone choice tasks), exception word reading, and work-likeness tasks (judging which of two nonwords looks like a real word, e.g., *vage/vayj*). Conrad et al. (2013) examined evidence for a multi-dimensional construct of orthographic knowledge which consists of word specific (lexical) and general orthographic knowledge (sub-lexical). Word specific orthographic knowledge consists of knowledge of the spellings of specific words and units within words (MOR development) which may be assessed by orthographic choice, homophone choice, and exception word reading. General orthographic knowledge is the implicit knowledge of the conventions with which letter combinations occur within a language (orthographic pattern knowledge), assessed by tasks such as word-likeness. In this study (Conrad et al., 2013) 41 English speaking

children (aged 7 - 9 years) were administered measures of word reading, phonological skills (nonword reading, phoneme deletion), and two measures of orthographic knowledge: word specific (orthographic choice – *rane/rain*), and general orthographic knowledge (word-likeness). Using regression analyses, the results indicated that after controlling for phonological skills, both types of orthographic knowledge uniquely contributed to word reading.

The direction of the relationship between orthographic processing and word reading skills was explored by Deacon et al. (2012) in a longitudinal study of 100 English speaking children from Grade 1 through to Grade 3 (aged 7 - 9 years) who had average vocabulary, word reading, and non-verbal reasoning scores. Orthographic processing (lexical and non-lexical measures), reading (word reading accuracy), receptive vocabulary, and phonological awareness skills were assessed at the beginning of each grade, and non-verbal reasoning was measured at Grade 3. After controlling for age, vocabulary, non-verbal reasoning, phonological awareness, and earlier word reading skills, neither early lexical nor sublexical orthographic processing made significant contributions to later word reading scores. However, early word reading scores significantly predicted later orthographic processing scores after the other skills were controlled for. They concluded that this finding (that reading determines progress in orthographic processing) is consistent with Ehri's phase theory and Share's phonological recoding theory of reading acquisition, that is, that children acquire orthographic processing skills through their reading experience (Deacon et al., 2012). Nonetheless, the authors noted that the finding that orthographic processing skills did not predict later reading skills may have been due to the orthographic measures used in this study. It was suggested that new measures need to be developed that more precisely capture the ability to form and store orthographic representations. Another issue pertaining to the result found in this study (that orthographic processing did not predict word reading), was the age at which orthographic processing was measured, and therefore the types of measures that were used. When orthographic measures (visual matching of letters) were administered prior to the start of literacy instruction orthographic processing was found to predict word reading (Badian, 2001), but when administered after literacy instruction had commenced using tasks assessing correct spelling of lexical and sub-lexical items, orthographic processing was no longer predictive of word reading (Deacon et al., 2012).

These studies indicate that while phonological and orthographic processing skills each play a separate and significant role in the development of word reading skills, this relationship is likely to be a reciprocal one, that is, a child's pre-literate phonological and orthographic capabilities impact on literacy development, and likewise, early proficiency in word reading influences subsequent development of phonological and orthographic processing skills. A more precise understanding of the range of factors that contribute to a child's proficiency with orthographic processing is necessary to inform the design of interventions and the development of age appropriate measures. Examination of the impact of the linguistic properties of words on MOR development discussed in the next section, is an area that has the potential to shed light on these issues.

Linguistic properties of words

This section discusses research that has investigated the influence of an early sensitivity to the orthographic structure of English on the development of word reading skills.

It has been found that typically developing preschool children, prior to formal reading instruction, are sensitive to the orthographic features of English (Apel et al., 2006). Based on research demonstrating that young children develop phonological representations (spoken words) very quickly (a process referred to as fast-mapping), and that their ability to learn these words is influenced by the phonotactic probability of words (the frequency that phones and biphones occur in English), Apel et al. (2006) examined the factors involved in the early fast-mapping of orthographic information: defined as "the initial stages of word learning [representing] the orthographic information stored regarding a word and its referent after minimal exposures to the label and object" (Apel et al., 2006, p. 26). After assessing the skills that predict literacy (vocabulary, phonemic awareness, letter knowledge, and rapid naming), 45 preschool children (aged 5:1 – 5:11 years) were presented with a written fast-mapping task. Twelve novel words (nonwords) which varied in phonotactic and orthotactic probability (the frequency with which a word's graphemes and bigraphs appear in English), were presented in stories that were read to the participants while they looked at the text. Immediately following each story, orthographic fast-mapping was assessed using a spelling task (writing the nonword to dictation), and an identification task (choosing the correct spelling from three items: the correct

spelling, a foil where one grapheme was changed, and a foil where more than two graphemes were changed). The results indicated that most of these preschool children fast-mapped written words: 64% identified target nonwords at greater than chance, and 29% correctly spelled at least one target nonword. While there was no effect of orthotactic or phonotactic probability on the identification task, there was a significant effect of orthotactic probability on the spelling task. Using composite scores for phonological processing, print awareness, and orthographic processing it was found that phonological processing accounted for 29% of the variance and orthographic processing an additional 15% of the variance in orthographic fast-mapping on the spelling dictation task. The authors concluded that similar to the research on the early acquisition of spoken words, fast-mapping appears to be a mechanism in learning written language, and that better fast-mapping occurs with items of high orthotactic probability.

The influence of the linguistic properties of words on initial MOR development has also been examined in children with language impairment, and those at risk for literacy delay. Using the procedure described by Apel et al. (2006), Wolter and Apel (2010) compared the written fast-mapping skills of 25 language impaired (LI) children (aged 5:7 to 7:0 years) with 31 typically developing (TD) children (aged 5:8 to 6:4 years) in the second semester of their first year of school. Written fast-mapping (MOR development) was assessed using two tasks: spelling generation and nonword identification. On the spelling generation task (which involved items with digraphs, e.g., chan, knal, cerz), the likelihood that children in their first year of school could produce a correct response using phonological recoding on any of the items was less than 20%. For the nonword identification task a probability analysis revealed that the most probable number of correct responses to be identified by chance was four (out of 12 nonwords). The results revealed that 36% of LI and 90% of TD children correctly generated (spelled) at least one nonword, and 68% of LI and 100% of TD correctly identified more than four nonwords. Analyses of variance were conducted to determine differences between the groups and whether phonotactic and orthotactic probabilities influenced performance. It was revealed that the performance of LI group was significantly lower than the TD group on both tasks. While the TD group spelled more items with high orthotactic probability on the spelling generation task, due to a floor effect for the LI group, no influence of either phonotactic or orthotactic probability was demonstrated. Contrary to

expectations, both groups identified more items with low phonotactic probability on the identification task. It was suggested that low phonotactic probability items have less memory demands (as there are fewer similar-sounding alternatives), which therefore positively influenced identification. The authors concluded that these results indicated that LI children were able to fast-map written words and acquire initial MORs but less efficiently than the TD children, and that the performance of both groups was influenced by the linguistic properties of words.

In a similar study (Apel, Thomas-Tate, Wilson-Fowler, & Brimo, 2012), 46 English speaking kindergarten children (aged 5:3 to 7:0 years) at risk of literacy delay (low socio-economic status) with average intelligence, letter knowledge, phonemic awareness, and reading skills (real and nonword) were found to develop initial MORs, but fewer than language impaired children (Wolter & Apel, 2010) and those in middle socio-economic groups (Apel et al., 2006). For example, on the production task (spelling target nonwords), 24% of at-risk children spelled at least one item correctly compared to 29% of the preschool children and 36% of the language impaired children. The authors suggested that the lower performance of the at-risk group relative to the other two groups was likely due to decreased exposure to print and reading experience for children in lower socio-economic groups which resulted in less practice with the written word-learning process. Like the previous studies, initial MOR development was affected by the linguistic properties of the words: the children spelled more words with high orthotactic probability. It was concluded that these results, while not diminishing the well documented role of phonological recoding, highlight the important role of orthographic processing, and suggest that all children, including those with language impairment or at risk of literacy problems are sensitive to the linguistic properties of words, particularly the orthotactic probabilities of words.

The preceding discussion suggests that orthographic processing is multi-dimensional (Apel, 2011; Conrad et al., 2013). Consistent with the connectionist models of word reading and the research regarding the influence of the linguistic properties of words (discussed above), typically developing children in the early phases of word reading development are sensitive to the orthotactic and phonotactic probabilities of words, and are able to use a fast-mapping process to develop initial MORs. Children with language impairment and those at-risk of reading delay, on the other hand, though demonstrating sensitivity to the linguistic properties of words (in

particular orthotactic probability), have a significantly reduced ability to develop MORs.

These findings suggest that the design of an intervention for children with word reading impairment should be cognisant of their reduced ability to form MORs, and respond to this by incorporating activities that teach efficient word reading strategies - accurate phonological recoding and orthographic processing (paying attention to the orthographic patterns in words). Additionally, given that children in the early phases of learning to read are sensitive to orthotactic probability, items within an intervention should be organised to optimise learning potential, for example, initial presentation of items with high orthotactic probability and only later presenting those with low orthotactic probability. Other factors that need to be considered in the design of an intervention for word reading impairment are those that influence the presentation of items, that is, the role of context and the grain size of items.

Factors influencing presentation of items within an intervention

Role of context in the development of MORs

Most studies examining the acquisition of MORs have presented target items (usually nonwords) within a story context which offers additional syntactic and semantic support. To determine the role that context plays in MOR development, Cunningham (2006) used a task that more closely simulated everyday reading, that is, using real word targets as opposed to nonwords. Thirty-five normally developing English speaking first grade children (mean age 7:10 years SD 0.31) read stories out loud that contained real word targets (correct spelling or a pseudohomophone, e.g., *chews* or *chooze*) in *cohesive* text versus *scrambled-story* context (in which the words were scrambled randomly). Half of the children read cohesive and half read scrambled text, also, half read correctly spelled targets and half the pseudohomophone alternative. The real words were selected to be items for which the children would have a phonological but not an orthographic representation, based on pretesting of a comparable sample of children at the same school. Orthographic learning was assessed using an orthographic choice task (e.g., choose, chooze, chaws, chews) and a spelling task. While the cohesive text condition resulted in significantly higher accuracy of word reading (87% correct for cohesive text, 67% for the scrambled text condition), there was a strong correlation between accuracy of

decoding and orthographic learning, and no significant difference in orthographic learning between conditions. Cunningham (2006) concluded that though context supported the ability to decode real words accurately, the ability to use phonological recoding to support orthographic learning was not affected by context.

Nation et al. (2007) reached a similar conclusion in their examination of the role of context in MOR development in a study involving 42 English speaking Year 3 and 4 children (mean aged 7.77 and 8.81 years respectively) with average reading skills. In this study, nonword targets were presented once, twice, or four times in either a story context (read out loud by the child) or as single word sorting task (where the child read items out loud to decide if the item was a real or nonword). Orthographic learning was assessed after one and seven days using an orthographic choice task (e.g., the target *ferd* was paired with *furd*, *ferp*, *furp*). An ANOVA was used to examine the effects of repetition, context versus single word presentation, one versus seven day delay, and grade level. While there was no significant effect of year group or context, there was a significant effect of delay (with more targets correctly identified at day 1 compared to day 7) and exposure (more identified with four compared to one exposure). As these items were nonwords it was concluded that phonological recoding must have been used, highlighting the significant role of phonological recoding and orthographic processing. Though presentation of items within context was not a significant factor, the number of times participants read target items, or dose rate, did affect orthographic learning – an issue that will now be examined.

Dose rate

Using procedures based on those developed by Share (1995), (assessing orthographic learning of novel words presented in a story), a number of studies examining the role of phonological recoding in the development of MORs have shown that repetition (the number of times an item is presented to a child) impacts on MOR development and that this effect varies depending on the language and the presence of a reading delay.

Share (1999) examined the effect of repetition in a series of investigations involving normally developing Grade 2 children who speak Hebrew (a transparent language with consistent grapheme-phoneme correspondence). Forty randomly selected children read stories out loud that contained target nonwords that were repeated either four or six times through the stories. No significant difference in

orthographic learning (assessed three days later using orthographic choice, naming, and spelling) was found between conditions. In a subsequent study (Share & Shalev, 2004), the impact of a reading delay on orthographic learning was examined by comparing the orthographic learning of four groups (each of 20) of Hebrew speaking children: two groups of children between Grades 4 and 6 with reading delay (one with high intellectual skills and poor word reading, and one with low intellectual skills and poor reading), a group matched for chronological age, and a group of Grade 2 children matched for reading level. When presented with nonwords in a story context with either two or six repetitions, it was found that for the three older groups there was no difference in orthographic learning once reading accuracy was accounted for, and that the difference between two and six exposures was minimal. Surprisingly there was no evidence of orthographic learning for the younger normally developing children, suggesting that typically developing novice readers of Hebrew are able to experience a high level of decoding success without requiring a sensitivity to the word-specific orthographic forms of letters. They concluded that in transparent language such as Hebrew, orthographic learning occurs following just one exposure in children above Grade 2 with or without reading delay.

This does not appear to be the case in less transparent languages, such as English. While it has been established that accurate phonological recoding significantly contributes to orthographic learning in typically developing English speaking children (Cunningham, 2006; Cunningham et al., 2002), it has been found that repetition affects the initial establishment of MORs and that there is decay over time. Bowey and Muller (2005) examined the orthographic learning (assessed immediately and after a 6 day delay) of 63 Grade 3 (aged 7:2 to 9:9 years) typically developing children following either four or eight repetitions of nonwords in a silent story reading task. Orthographic learning was assessed using an orthographic choice task (e.g., the target nonword *ferd* was paired with *fard* and *furd*). Rapid orthographic learning occurred in both post-test delay conditions, but orthographic learning was stronger immediately following presentation compared to the 6 day delay, and for eight repetitions compared to four. A similar result was found by Nation et al. (2007) who examined the effect of repetition on orthographic learning in 42 English speaking children aged 7 – 9 years presented with nonwords (one, two, or four repetitions) and tested for orthographic learning after one and seven days. A significant effect of exposure and delay was found with greater orthographic learning

occurring following one day compared to the seventh day, and following four repetitions compared to one.

The effect of repetition was also demonstrated in an intervention study investigating the effects of phonemic awareness training on phonemic awareness and decoding skills (Carmichael & Hempenstall, 2006). Sixty-nine Year 1 (aged 5:0 to 6:4 years) students received phonemic awareness instruction either twice or five times weekly for twelve sessions. The comparison between the standard group (twice per week), the higher frequency group (daily), and the control group (those on a wait list), indicated that there was a significant impact of treatment frequency on phonemic awareness skills: the higher frequency group made significantly greater gains than the standard or control groups but there was no evidence to suggest that the phoneme awareness training enhanced decoding skills (measured by a standardised test of nonword reading). These results indicate that repetition optimises skill learning for children in the early stages of learning to read English, and further suggests that the resultant learning is specific to the skill being taught.

Grain Size

The term grain size refers to the strategy used to decode words. A small grain size strategy involves taking note of the grapheme-phoneme correspondence, while a large grain size strategy enables the reader to decode larger chunks of the word, such as onset and rime. For example, the large grain item “dactory” can be read quickly due to its analogous real word “factory”, whereas a small grain items such as “daik” has no close neighbours in the mental lexicon as it is more than one letter away from a close phonological neighbour, such as “cake”. Items with 1:1 letter sound correspondence, such as “hult” have the smallest grain size as decoding involves use of grapheme-phoneme knowledge for each letter. It has been proposed by Goswami, Ziegler, Dalton, and Schneider (2003) that in transparent orthographies, such as Hebrew, readers rely on small grain size units, but in English with its inconsistent grapheme-phoneme correspondence, readers need to establish a variety of grain size units, from whole word phonology to units corresponding to rhymes, down to phoneme-grapheme units. This means that children learning to read English are usually required to switch between small and large grain size strategies.

In an investigation to determine the optimal presentation of stimuli for children decoding unfamiliar words, Goswami et al. (2003) conducted a cross-language study between German and English: two languages which are similar in

orthography and phonology but differ in the consistency of correspondences at small grain sizes. Seventy-two typically developing English speaking children aged seven to nine years, matched for reading level with 68 typically developing German speaking children, were presented with a “word” reading task involving lists of nonwords containing both small and large grain units. The large-unit nonwords (e.g., *dake, bicket*) had analogous real word neighbours (e.g., *cake, ticket*), whereas the small-unit nonwords had no orthographic rhyme neighbours (e.g., *daik, bikket*). Half the children received a blocked condition (where the small and large grain items were grouped together), and the other half the unblocked condition (where the small and large grain items appeared in a randomly mixed order). It was found that the English speaking children demonstrated a significant effect of blocking: more items were correctly read in the blocked condition (67% in the blocked and 49% in the unblocked condition compared to 89% and 90% for the German children), and the blocking effect occurred for both small and large grain units for English with no difference for the German children. It was concluded that while English readers ultimately develop the ability to switch from one grain size to another, these data revealed significant switching costs for children in the early stages of reading development when decoding items presented in mixed lists.

These results suggest that in the design of interventions for children in the early stages of learning to read English, particularly for those with reading impairment, presentation of items in a blocked fashion (i.e., requiring the same grain size strategy), may optimise performance.

Summary

Thus far, in establishing a theoretical basis for the development of an intervention for children with word reading impairment, this chapter has addressed models which describe two main procedures used by skilled readers (lexical and non-lexical routes), the phases of word reading development, and a process (phonological recoding) that supports transition from predominant use of the non-lexical route to automatized use of fully specified MORs in the lexical route. Factors (additional to the six well-established predictors of reading development: phonological awareness, alphabet knowledge, rapid automatic naming, phonological memory and writing name), that contributed to the intervention developed for this research were discussed. These include orthographic processing, the linguistic properties of words,

the role of context, dose rate (repetition), and grain size. This body of research suggests that an intervention targeting word reading impairment may be presented with or without contextual support, but should encourage orthographic processing with accurate phonological recoding, provide many repetitions of core skills, and present items of the same grain size. To provide further background to the research questions addressed in this thesis, the outcomes of some of the previous interventions will now be reviewed.

Intervention for Word Reading Impairment

Over the past 20 years, evidence has supported interventions for word reading skills that focus on phonological and phonemic awareness, combined with letter-sound knowledge at all levels: Tier 1 (whole class instruction), Tier 2 (small-group instruction for struggling readers) and Tier 3 (intensive individual instruction for children who do not respond to Tier 2 interventions). The research summarised above has revealed that orthographic processing also makes an additional and unique contribution to the development of mental orthographic representations (MORs) and therefore to efficient word reading skills. This section reviews some of the research supporting interventions based on phonemic awareness and alphabet knowledge at each of the three levels, and then discusses studies that focus more specifically on orthographic processing and MOR development.

Interventions targeting phonemic awareness and alphabet knowledge

Evidence for Tier 1 interventions

Phonological and phonemic awareness have been the focus of many intervention studies because these skills have long been established as predictors of the development of reading (Bishop & Snowling, 2004; Herrmann et al., 2006). A number of meta-analyses examining the effectiveness of reading instruction approaches (Bus & van Ijzendoorn, 1999; Ehri et al., 2001; National Centre for Family Literacy, 2008; Torgerson et al., 2006) have demonstrated that approaches focusing on phonemic awareness combined with letter-sound relationships report statistically significant positive effects on word reading skills with moderate to large effects on a broad range of literacy outcomes (including comprehension and

spelling). However, though there was strong evidence for these interventions for all students regardless of age or skill level, there was a smaller effect size for reading disabled compared to at-risk or normally developing students (Ehri et al., 2001). This suggests that there is a strong evidence base for reading instruction focusing on phonemic awareness and the alphabetic principle at Tier 1 and Tier 2, but that for children with persistent reading impairment who require Tier 3 interventions other factors may need to be addressed.

Evidence for Tier 2 interventions

Studies examining Tier 2 interventions have generally involved similar targets to Tier 1 (phonemic awareness combined with letter-sound relationships), but have been delivered in smaller groups and with increased intensity. Gillon (2000) examined the impact of a phonological awareness intervention for children at risk of literacy delay (disordered speech sound production) on speech production, phonological awareness, and reading development. Ninety-one children with average intellectual skills (61 with speech sound disorders and 30 typically developing) in their first year of school (aged 5:6 to 7:6 years) were assigned to four intervention conditions – experimental (1 hour weekly sessions of phonological awareness training over 20 weeks), traditional (2 x 1 hour sessions per week for 20 sessions of traditional speech therapy targeting production of speech sounds), minimal intervention (home programmes for those unable to access intensive intervention), and a control group. The results indicated that, while there was no significant difference between groups in the magnitude of gains in speech production skills, children in Group 1 (the experimental group) made significantly more gains in phonological awareness and word reading (real and nonwords) than Groups 2 and 3, and matched the gains of the typically developing children. However, it was reported that the large group design in this study masked the wide range of responses to intervention, as some children demonstrated very limited gains in word reading skills. Heterogeneity of speech and language deficits may also have been a factor, as the three groups with speech production disorders scored significantly lower than the normal comparison group on measures of receptive language and expressive syntax. In a follow up investigation 11 months later (Gillon, 2002), the long term benefits of this phonological awareness intervention on phonemic awareness and word reading skills (word recognition and nonword reading) were examined in a cohort of 60

children from the original sample of children (20 from each of Groups 1, 2, and 4). The results indicated that the phonemic awareness skills of Group 1 were significantly better than Group 2, and there was no significant difference between Group 1 and typically developing children (Group 4). With respect to word reading skills, while Group 1 made more progress than Group 2 on word and nonword reading measures, both groups improved over time, and there was a wide variation and overlap in performance between the groups. These results suggest that though phonological awareness training for children at risk of reading delay resulted in significant gains in phonemic awareness and word reading skills, there was wide variation in word and nonword reading, with some children displaying minimal response to intervention.

Ryder, Tunmer, and Greaney (2008) demonstrated the effectiveness of a similar intervention (targeting phonemic awareness and alphabet decoding) in a study involving 24 Year 2 and 3 children (6 – 7 years old) with word reading impairment who were randomly assigned to an intervention and control group. The intervention group received 30 minute group sessions (three per group) four times per week over 24 weeks. Intervention activities targeted phonemic awareness, letter-sound relationships, silly sentence reading to assess comprehension, and reading of decodable texts. The results showed that the intervention group significantly outperformed the control group on measures of phonemic awareness, nonword decoding, and context free word reading; and the two-year follow up data revealed that the positive effects of the intervention were maintained and had generalised to word reading accuracy in text.

More recently, Ritter, Park, Saxon, and Colson (2013) replicated these findings in a study comparing the response of two groups of children with language impairment (intervention versus control) across Grades 1 to 3 (aged 5:6 to 10 years). The intervention group received an intervention targeting phonemic awareness and letter-sound knowledge within the context of meaningful text, delivered in 15 minute sessions twice per week over 12 weeks. Though there was a significant treatment effect across all skills (phonemic awareness, nonword reading, and reading comprehension) for all grades, the treatment effect size was greatest for phonemic awareness and smaller for decoding and comprehension, and effect sizes decreased from Grade 1 to Grade 3. It was concluded that the older groups may need a more

intense treatment, and as there were a number of tasks involved, it was difficult to partial out the specific effects of the treatment.

Other larger scale Tier 2 interventions for children with word reading impairment also demonstrate significant and positive results from interventions targeting phonemic awareness and grapheme-phoneme knowledge, and as was the case in the previous studies, a range of evidence based procedures were involved. In Australia, Wheldall and Beaman (1999) reported the results of research on *MULTILIT (Making up Lost Time in Literacy)* involving 142 reading impaired students with a mean age of 10.5 years. Participants received four hours of intense literacy instruction each day over two terms targeting decoding skills, automatic recognition of sight words, connected text reading, auditory awareness, repeated reading, and comprehension, in a mix of individual and group sessions. They found that after two terms most made gains, but at a six month follow up about 25% of the students had not maintained or had lost those gains.

Hatcher et al. (2006) conducted a randomised controlled trial of the *Sound Linkage Reading Intervention* programme. Seventy-seven Year 1 children (aged six years) with the lowest reading scores (based on a composite measure of letter identification, early word reading, and phoneme manipulation) were randomly assigned to one of two groups: a 20-week intervention group who received 20 minutes intervention per day (a combination of individual and small group sessions) for two consecutive 10-week periods, and a 10-week intervention group who received the same intervention for the second 10 weeks. The intervention targeted letter identification, phonemic awareness, writing, sight word reading, text reading, word study, and shared reading. The results indicated that after 10 weeks of intervention the 20-week group had significantly better scores in letter knowledge, phonemic awareness, and word reading than the 10-week group (the waiting control group). After 20 weeks, the progress of the children who had received the first phase of intervention slowed down and the 10-week intervention group caught up, suggesting that after about 10 weeks there may be diminishing gains from phoneme awareness training. Additionally, within the overall gains there was wide variation in the amount of progress as about 25% of children did not respond to the intervention.

More recently *MiniLit - Meeting Initial Needs In Literacy*, (Buckingham, Wheldall, & Beaman, 2012) was developed to meet the needs of students requiring Tier 2 intervention by comprising all the evidenced base elements for effective early

literacy, such as phonemic awareness, letter-sound knowledge, sight word development, and text reading using decodable books. A randomised control trial was used to evaluate the programme in a study involving 22 typically developing children in Kindergarten and Year 2 (mean age of 5.7 and 7.7 years respectively) with reading delay (scores in the bottom quartile for nonword reading). Matched pairs of participants were randomly allocated to the treatment group (which received one hour sessions four times per week for 27 weeks) or the control group who remained in class for their usual classroom literacy instruction. Using pre- post-measures of word reading, nonword reading, word reading fluency, and spelling, the results indicated that after two terms, statistically significant positive effects were found for two measures (word and nonword reading), with no significant differences between the means of the two groups for spelling and word reading fluency. While stronger positive treatment effects were demonstrated on all measures after three terms, the statistical measures remained the same. The authors concluded that, though there was a group of children (about 27%) who failed to respond, overall this programme was effective in a school setting in improving phonic word attack skills and reading single words, with positive but less pronounced results in spelling and oral reading fluency.

The research investigating Tier 2 interventions reviewed above suggests that while programmes targeting explicit phonemic awareness combined with grapheme-phoneme correspondence result in significant gains in phonemic awareness skills and word reading skills, smaller gains are made in other skills (such as spelling, reading fluency, and comprehension), effect sizes are smaller for older students, and about 25% of students fail to respond or maintain skills. In response to the observation that interventions which primarily target phonological processes result in fewer gains on measures of reading fluency, an intervention (RAVE-O: Retrieval, Automaticity, Vocabulary, Elaboration, Orthography) which targets all five components of reading fluency (semantics, phonology, syntax, orthography, morphology) was developed (Wolf & Katzir-Cohen, 2001). A randomized control trial evaluating the effectiveness of this intervention (Morris et al., 2012) showed that RAVE-O combined with a phonological intervention resulted in significant gains on a range of reading outcome measures (decoding, word reading, reading comprehension, and reading fluency) compared to three other intervention conditions - phonological plus word reading strategies, phonological control, and a maths intervention. However, as

with the interventions primarily targeting phonemic awareness combined with the alphabet principle discussed previously, it is difficult to isolate the active ingredient responsible for some of the gains in these multi-component interventions.

Evidence for Tier 3 interventions

The few studies that have examined Tier 3 interventions have demonstrated similar outcomes to the Tier 2 interventions described above. Torgesen (2001) compared two phonemically-based interventions delivered intensively in two daily 50 minute sessions over eight to nine weeks (69 hours in total). Both interventions targeted explicit systematic instruction in phonemic awareness, word reading and phonemic decoding, reading and writing, but differed in depth and extent of instruction in phonemic awareness and phonemic decoding. The participants, typically developing children (8 – 10 years of age) who scored above a standard score of 75 for a verbal IQ measure and more than 1.5 SD below the mean on a combined score of word and nonword reading, were randomly assigned to one of the two interventions. A control group was not used as pre-intervention growth rates over the previous 16 months were available. Measures of phonological awareness, phonological memory, rapid naming, reading (word and nonword reading accuracy and efficiency, and reading comprehension), educational achievement, language, and intellectual skills, were administered pre- and post-intervention, and at one and two year intervals following post-test. The results indicated that both interventions resulted in significant gains for all reading measures. At the 2- and 3-year follow-up both groups showed continued growth in sight word reading and reading comprehension with declines in nonword reading and reading fluency. Effect sizes calculated for change during the pre-intervention phase, the intervention, and post-intervention phase, demonstrated a significant effect of intervention on the composite reading score, phonemic awareness and language scores, but no effect on general achievement. This indicates that the intervention was specific to reading and language skills and did not have a generalised impact on general academic performance. The authors concluded that though these interventions resulted in significant gains in reading accuracy and comprehension for most students, measures of reading fluency remained severely delayed and about a quarter of the participants either did not respond to the intervention or maintain their skills.

More recently, Denton et al. (2013) evaluated the effectiveness of an explicit Tier 3 intervention, and examined the proportion and cognitive characteristics of children who failed to respond. Seventy-two students who had not met criteria for adequate response to Tier 1 and Tier 2 (i.e., continued to achieve standard scores below 90 on tests of word and nonword reading accuracy or efficiency, or were below average on a measure of oral reading fluency) were randomly assigned to an intervention group who received the research intervention in daily sessions of 45 minutes for 24 – 26 weeks, or a control group who received typical school intervention and instruction. The research intervention was tailored to individual needs based on diagnostic assessment, and focused on word study (phoneme-grapheme associations to “sound out” words, and recognition of orthographic and morphemic patterns), reading fluency, comprehension, and written response. While the intervention group made significantly greater gains than the control group on word and nonword reading, and word reading fluency, the gains on nonword reading fluency, text reading fluency and comprehension did not reach significance. A benchmark of standard scores above 90 on the reading measures (word and nonword reading accuracy and fluency, reading comprehension) was used to categorise children as adequate responders. Using this criterion it was found that 25% of the intervention group and 20% of the control group demonstrated an adequate response, that is, the groups did not statistically differ in the proportion of adequate responders. An analysis of pre-intervention scores on phonological awareness, rapid naming, and language skills showed that phonological awareness and listening comprehension were significantly correlated with responder status. The authors concluded that this intensive research intervention can be efficacious for students requiring Tier 3 intervention, particularly in improving word reading and phonemic decoding skills. However, the responsiveness of individual students was highly variable, and most students remained severely impaired in text reading fluency and comprehension.

These results indicate that, similar to Tier 1 and 2 interventions, interventions that provide an intense focus on phonemic awareness and letter-sound knowledge within the context of other evidence-based elements are effective for most students who require Tier 3 reading intervention. However, there remain a proportion of students who demonstrate inadequate response to Tier 3 interventions. This suggests that there are aspects of reading impairment that are not being addressed for a substantial number of these children, and/or that the mix of components within an

intervention are not matched to the individual needs of the child. Two areas of research that may address this problem are (a) clarification of the impact of each component of an intervention, and (b) identification of the specific needs of children who have failed to respond to previous reading interventions.

In addressing the first issue, all of the studies discussed above involve a number of components making it difficult to identify which aspect/s of the intervention are responsible for specific gains. Thus, there is a lack of evidence to support selection of specific intervention components to match individual need. This is particularly important for children who have failed to respond to previous reading interventions. Regarding the second issue, the Denton et al. (2013) study described above, examined the predictors of response using a group analysis of pre-intervention cognitive characteristics of participants. However, it is possible that group analyses may mask individual variability between children. Additionally, though these results (Denton et al., 2013) identified language skills (phonemic awareness and oral language) as being closely associated with responder status (suggesting that increased focus on these areas is required), the pre-intervention levels of phonological and phonemic awareness skills were not reported. Hence it is not possible to determine if these areas were significantly below average and in need of continued training. Furthermore, given that other research has demonstrated that in addition to phonological processing, orthographic processing is a significant predictor of word reading skills (Badian, 2001; Cunningham et al., 2001), and that its contribution increases from Grade 1 to Grade 3 (Deacon et al., 2012), it is possible that other skills such as orthographic processing may require a sharper focus in interventions for some children requiring Tier 3 intervention.

Though most of the previously reviewed interventions include activities targeting aspects of orthographic processing (such as grapheme-phoneme decoding), there are only a few studies that have either specifically targeted orthographic processing, attempted to isolate the specific effects of components within the intervention, or have employed research designs that enable analysis of individual response to intervention. These are reviewed in the next section.

Interventions targeting orthographic processing

The studies reviewed in this section have focused on orthographic processing skills appropriate to children in the early stages of learning to read, that is, encouraging the children to pay attention to each letter in the word and use knowledge of grapheme-phoneme correspondence to read the word – decoding. As few studies reported in the literature have examined Tier 3 interventions, the studies in this section fall into the category of Tier 2 interventions.

McCandliss, Beck, Sandak, and Perfetti (2003) conducted a study to examine the nature of the decoding difficulties of children with reading delay, and to investigate the effectiveness of an intervention (*Word Building*) that specifically targeted decoding skills, on word and nonword reading, comprehension, and phonemic awareness. Twenty-four typically developing children (aged 7 – 10 years) who had completed at least their first year of school and demonstrated reading delay, were randomly assigned to an intervention (20 x 50 minute individual sessions, three times per week) or control group. Participants in each group were matched for age, sex, and pre-intervention reading skills. The intervention consisted of two tasks. The first task was a manipulative letters activity that involved progressive minimal contrasts (changing one letter at a time to form chains of words that differed by a single letter transformation) to teach grapheme-phoneme units (consonant-vowel-consonant [CVC] to CCVCC and vowel digraphs); the second was a sentence reading activity which contained a high proportion of words that had just been decoded in the manipulative letters activity. Intervention effectiveness was evaluated using pre- post-intervention scores on researcher-developed nonword lists, and standardised assessment of phonemic awareness, and word and nonword reading. The results of a fine grained analysis of pre-intervention decoding responses using experimental nonword lists (128 monosyllabic words constructed by sampling words from the *Word Building* intervention) revealed a consistent pattern of decoding errors. There was greater accuracy in decoding initial consonants, followed by final consonants and then the vowel. In initial consonant clusters, there was greater accuracy with the first consonant, and in final consonant clusters there was greater accuracy with the final consonant. The effectiveness of the intervention was analysed using repeated measures ANOVA. The results indicated that the intervention group showed significantly greater gains in decoding accuracy for all positions of the word

form (on the experimental nonword lists), and on the decoding, comprehension, and phonemic awareness measures. The lack of an intervention effect on word reading scores was attributed to the nature of the word reading measure which contained a high proportion of irregular words. It was suggested that this measure would not be sensitive to the target of the intervention which was accurate decoding of words with regular pronunciations. To examine responses to intervention, the individual pre-post-intervention performance scores were reported, and an a priori learning criterion was developed: children who demonstrated improvements exceeding one third of a grade level over the four month intervention period were classified as passing the learning criterion. While 11 of the 12 children in the intervention group compared to four of the 12 in the control group passed the learning criterion for word reading scores, examination of the individual responses showed that gains ranged from nominal (for three children) to gains of several grade levels. The authors concluded that this research provided evidence about the nature of the decoding impairment (unable to use accurate alphabet decoding), and that the intervention (which involved two components) resulted in significant gains in decoding, comprehension, and phonemic awareness. However, the design of the intervention provided no direct evidence about which part of the intervention was responsible for the reported gains. There were two possible limitations of this study. The first was that the experimental nonword lists were related to the targeted items in the intervention, thus reducing the generalisation of the findings to general decoding skills. The second was the control group did not receive an equal amount of individual therapy time, which means there was no control for the effect of individual time spent with the intervention group.

Another study with a similar focus on orthographic processing (Pullen, Lane, Lloyd, Nowak, & Ryals, 2005) used a multiple baseline single subject research design to investigate the effectiveness of an intervention on decoding skills (nonword reading), and whether the effects occur immediately or accumulate gradually. Nine first grade children (second year of school) identified as struggling readers (i.e., scored the lowest on invented spelling and nonword reading tests), received explicit decoding instruction (the independent variable) in groups of three. Two activities were used: decodable book reading (students read the book out loud, together with the instructor), and a manipulative letters activity (target words, selected from the book, were segmented, blended, and manipulated using magnetic letters, e.g., went, sent, send, sand). The condition sequence for the multiple baseline design was

baseline (no treatment), followed by intervention. The intervention phase began for the first group immediately after the first baseline, and the subsequent groups began when improvement in prior groups' reading was evident. The dependent variable was nonword reading rate (the number of nonwords read correctly in one minute using lists of nonwords that were related to the lexical pattern introduced during the intervention). This was administered during each baseline session and at the end of each intervention session. The results indicated that, though the effects of intervention on nonword reading appear gradually, the intervention was effective. After 10 sessions, which involved about 25 manipulations of letters per session, the students' ability to read nonwords improved from an average of 46.5% correct to 86.5% correct. However within that positive result there was a range of responsiveness, from a 15% increase to 67% increase in nonword reading efficiency. The authors concluded that further studies should address some limitations in this design: the number of pre-intervention baseline sessions should be increased, and the dependent variable should be administered at the start of the intervention sessions rather than at the end. Additionally, they suggested that future research should examine the separate and combined effects of each component. As with the (McCandliss et al., 2003) study, the items in the dependent variable were related to the targeted patterns in the intervention session, hence may not be a true indicator of generalised increases in decoding skill.

In response to the issue regarding identification of the active ingredient in an intervention, Lane, Pullen, Hudson, and Konold (2009) investigated a one-to-one intervention that targeted a range of skills: decoding (using manipulative letters), phonemic awareness, fluency, writing, and extending literacy (an exploration of a variety of text genres). One hundred first grade students (second year of school) with the lowest scores on a normed researcher-developed invented spelling test, were randomly assigned to one of four intervention conditions (the complete intervention, intervention without a manipulative letter activity, without the writing activity, and without extended literacy) and a control group. Students received an average of 39 sessions, each lasting about 35 minutes. Intervention effectiveness was evaluated using four measures. Three were developed by the researchers: phonological awareness (word, syllable, onset-rime, and phoneme levels), nonword reading (20 consonant-vowel-consonant nonwords assessing short vowel decoding), and sight word reading (high frequency words); and the fourth was a standardised measure of

nonword reading. Using analysis of covariance procedures, the results indicated that students who received the full intervention condition performed significantly better than the control group on the measures of phonological awareness, sight word reading, and decoding. Post hoc analyses revealed that when the word work with manipulative letters or the written word work were removed from the model (i.e., tasks specifically targeting orthographic processing), the group failed to perform statistically better than the control group on measures of decoding (standardised and researcher-developed), or word reading skills. This suggests that the tasks targeting orthographic processing were the essential components.

To further identify the contribution of each component in an intervention, Pullen and Lane (2014) conducted a study to examine the effects of an intervention targeting explicit and systematic instruction in the alphabetic principle, and to determine if using manipulative letters to teach decoding skills (orthographic processing) was a key component. Ninety-eight first grade students (second year of school) who scored below the 20th percentile on a normed researcher-developed invented spelling test were randomly assigned to three conditions: treatment (book reading activity plus decoding using manipulative letters), comparison (book reading activity only), and control (business-as-usual). The intervention groups received a total of 30 x 30 minute sessions in groups of three children, three times per week over seven to 10 weeks. Treatment effectiveness was examined using a series of analyses of covariance on the pre- post-intervention researcher-developed measures of phonological awareness (word, syllable, onset-rime, and word levels), decoding of words and nonwords (separate lists of CVC words and nonwords), and sight word reading (high frequency words); as well as standardised tests of word and nonword reading. The results indicated that the group that received the full intervention (book reading plus magnetic letters) significantly outperformed the comparison and control groups on the phonological awareness and both decoding measures. While the full intervention and comparison group performed better than the control group on the sight word reading measure, only the group that included magnetic letters reached significance. This suggests that decoding practice using a task that focused on orthographic processing (magnetic letters activity) may result in improved sight word reading. Though there were limitations with this study (small numbers, and the treatment group received slightly longer intervention times), it was concluded that the results suggest that the manipulative letters task was the key component, and an

effective method for improving phonological and decoding skills for students a risk of reading failure. Furthermore, it was suggested that future research should include a fourth intervention group: one that received only the task focusing on orthographic processing – the manipulative letters task.

These results suggest that these Tier 2 interventions with a specific focus on orthographic processing resulted in significant gains in phonemic awareness and decoding, with indications of generalisation to sight word reading and comprehension. Additionally, there is evidence that the orthographic processing task was the key component. However, similar to the Tier 1, 2, and 3 interventions targeting phonemic awareness and a range of evidence based skills (including orthographic processing), there was a range of variability in response to intervention. It is therefore possible that children with persistent reading disorders may require interventions with a sharper focus on particular aspects of an intervention (such as orthographic processing), and that an understanding of the pre-intervention profiles of these children may enable a more precise match of intervention to individual need. The research questions posed in this thesis aim to address these issues.

Research Questions

The literature reviewed thus far has highlighted the importance of word reading skills in the early stages of learning to read: most children with reading delay have impaired word reading, and this skill is a predictor of later reading development. The theoretical basis of word reading presented in this chapter suggests that children pass through a number of phases in their acquisition of skilled reading: a process that involves two components - a lexical route and a non-lexical route. Phonological recoding and orthographic processing have been shown to each contribute to the transformation of predominant use of the non-lexical route to substantial use of the lexical route, leading to the establishment of a bank of words that can be automatically read by sight. While skilled readers and typically developing children are able to use these processes efficiently, research suggests that the performance of children with language impairment and reading delay is optimised with interventions that promote accurate use of phonological recoding, increased repetition, and presentation of items with similar grain size.

Though research into interventions for word reading impairment has demonstrated strong support for interventions that focus on phonemic awareness combined with grapheme-phoneme correspondence for most children requiring Tier 1 and Tier 2 interventions (with fewer studies examining Tier 3 interventions), a substantial number of children fail to demonstrate adequate response. This suggests three issues for further research. The first is to gather more evidence regarding Tier 3 interventions. The second is delineation of the specific impact of each component within interventions, as this would enable more precise matching of intervention strategy to the identified needs of the child. The results of recent investigations into the key components of interventions have concluded that the orthographic processing component was the essential ingredient for children with delayed reading in their second year of school. This suggests that further investigation of interventions targeting orthographic processing is warranted. The third issue is clarification of the specific needs of children who have not responded to Tier 1 and Tier 2 interventions. Recent efforts to identify predictors of response to intervention have employed group analyses. However, it is possible that the group analyses may mask the individual variation between children.

The programme of research in this thesis aimed to add to the existing literature firstly, by focusing on Tier 3 intervention for word reading impairment. To address the second issue: difficulty identifying the key element, a new intervention that involved one component targeting two key skills (phonological recoding and orthographic processing) was developed. These two skills have been shown to contribute to efficient use of the non-lexical route; a process that is delayed for most children with reading impairment (Herrmann et al., 2006; Ricketts, Bishop, Pimperton, & Nation, 2011), preventing the formation of orthographic representations and automatic use of the lexical route. The aim was to design, develop, trial, and then evaluate the effectiveness of this intervention on the primary measure used to assess the non-lexical route (nonword reading), and also on a range of other related skills (word reading, text reading, reading comprehension, and spelling). To address the third issue (examination of the characteristics of responsiveness), a single subject design which is discussed in detail in Chapter 3 was employed.

The research questions were as follows:

1. Does an intervention that targets phonological recoding and orthographic processing increase nonword reading skills in Year 2 children with persistent word reading impairment?
2. Does an intervention that targets phonological recoding and orthographic processing result in gains on standardized measures of a range of reading related skills (nonword reading accuracy, word and nonword reading efficiency, text reading, and reading comprehension) and spelling, in Year 2 children with persistent word reading impairment?
3. Do pre-intervention scores on language, intellectual, and phonological processing skills influence outcome measures of nonword reading, text reading, reading comprehension and nonword spelling?

CHAPTER 3: RESEARCH RATIONALE AND OVERVIEW

“The hallmark of skilled reading is the rapid and virtually effortless recognition of printed letter strings. This fluency depends, first and foremost, on the acquisition of word-specific orthographic representations linked to phonological, semantic, morphological, and syntactic information. The development of orthographic representations is a central issue in literacy research and practice.” (Share, 2004, p. 267)

The previous two chapters have provided an orientation to the focus of this research (intervention for word reading impairment), the theoretical basis for key processes involved in word reading, research evidence supporting different approaches to intervention, leading to the three research questions. This chapter outlines the rationale for this research, an overview of the research design, and the research hypotheses.

Research Rationale

The preceding discussion has established that the development of word reading skills is an essential step in early reading development, and that most children with reading disorders have impaired word reading skills. Over the past 20 years the evidence has supported the effectiveness of Tier 1 and Tier 2 level interventions which target phonemic awareness, letter-sound knowledge, and incorporate a range of evidence-based components, such as small group work, repeated reading for fluency, and the use of reading-level appropriate texts.

The issues that have been highlighted in the literature review are that (a) only a small number of studies have investigated Tier 3 interventions (Denton et al., 2013; Torgesen, 2001), (b) in many studies, there is a range of responsiveness with about 25% of children not making significant gains, and (c) most intervention programmes target a number of skills, making it difficult to identify which aspect or aspects are responsible for the gains observed in the different skill areas, though recent investigations have identified orthographic processing as an essential component (Lane et al., 2009; Pullen & Lane, 2014).

This research aimed to respond to these issues by developing a single component Tier 3 intervention targeting key processes (phonological recoding and orthographic processing) that have been shown to predict later reading achievement (i.e., efficient use of the non-lexical route), and evaluating its effectiveness using a research design (single subject research design) that would allow examination of the response patterns of individual participants. Additionally, the newly developed intervention incorporates features which have been shown to impact on the development of word reading skills, such as ensuring accurate phonological recoding, supporting orthographic processing, providing repetition of key skills, matching intervention targets to the orthographic knowledge of each participant, and presenting items of similar grain size.

Research Overview

The research in this thesis was conducted in three stages. First, the intervention procedure was designed and developed (see Chapter 4). Second, the intervention was trialled on a small number of participants (Study 1: described in detail in Chapter 5), and finally its effectiveness was evaluated on a larger number of participants (Study 2: discussed in Chapters 6 and 7).

This chapter provides an overview of the programme of research by outlining: (a) the key attributes of the intervention procedure: the independent variable, henceforth called the *Decoding Intervention*; (b) the outcome measures: the dependent variable as the primary outcome measure (nonword reading), and the other related outcome measures (nonword reading accuracy, nonword and word reading efficiency, text reading and comprehension, and spelling); and (c) the research design: the single subject research designs used in Study 1 and Study 2.

The intervention procedure: key attributes

The Decoding Intervention is one of five modules delivered by a computer program called *WordDriver* (the development of which is detailed in Chapter 4). The use of computer-supported materials is increasing within many educational programmes. Though a systematic review of randomised control trials examining the effectiveness of computer based technologies for helping children in learning to read found only small and nonsignificant effect sizes (Torgerson & Zhu, 2003), a more

recent series of randomised control trials evaluating a web based classroom-level reading program (ABRACADABRA) showed that when methodological issues (implementation fidelity, quality of the technology, and theoretical coherence of the intervention) were addressed, significant advantages over controls occurred in a range of early reading skills (Comaskey, Savage, & Abrami, 2009; Savage et al., 2013; Savage, Abrami, Hipps, & Deault, 2009). This suggests that computerised delivery has the potential to support reading interventions.

WordDriver is delivered on an iPad in individual sessions as a Tier 3 intervention, thus responding to the first issue highlighted in the literature review. It targets development of the non-lexical route, as research has indicated that this process is impaired in most children with word reading disorders (Catts, Adlof, & Weismer, 2006; Torppa et al., 2007). Finally, it involves one component, hence addressing the second issue: difficulty isolating the key element(s) in interventions that involve a range of intervention activities.

During the intervention task, the child is presented with an item (a word or a nonword) and is required to sound out each letter and then blend the sounds and read the word out loud (phonological recoding). The researcher provides corrective feedback following instances of inaccurate phonological recoding. Once accurate phonological recoding has been achieved, the researcher tells the child whether the item is a word or a nonword and provides semantic reinforcement for words (using the word in a sentence), and a similar length verbal reinforcement for nonwords (telling the child the item is not a real word and has no meaning). This task is similar to the judgement task used by Nation et al. (2007) in a study investigating the phonological recoding theory, where the child used phonological recoding to decode the item and then decided if the item was a word or nonword. In the intervention used in this research, the researcher tells the child whether it is a word or nonword, thus decreasing the cognitive demands required by a decision-making process and ensuring that the task involved one element (use of phonological recoding).

A number of evidence-supported features are incorporated into the design of the Decoding Intervention. These include:

1. Presentation of single items (words and nonwords) without story context. It has been shown that the development of MORs occurs with or without context (Cunningham, 2006; Nation et al., 2007).

2. Accurate phonological recoding. The intervention procedure requires the child to verbally phonologically recode each item out loud until accuracy is achieved. This is consistent with the results of many studies which have concluded that accurate phonological recoding optimises MOR development and that compromised phonological recoding results in reduced MOR development (Cunningham, 2006; Cunningham et al., 2002; Kyte & Johnson, 2006; Share, 1999).
3. Orthographic processing. Verbal phonological recoding, reinforced by visual prompting of left to right decoding as the corrective strategy, draws the child's attention to each letter in the word, thus supporting orthographic processing: a skill that has been shown to have a unique contribution to MOR development (Badian, 2001; Conrad et al., 2013; Cunningham et al., 2001).
4. Development of the non-lexical route. Use of phonological recoding and orthographic processing ensures that the child is using grapheme-phoneme correspondence to decode nonwords and unknown words: a process that has been shown to be impaired for most children with delayed word reading skills (Catts et al., 2006; Torppa et al., 2007).
5. Presenting items of a similar grain size. All the items in the intervention have 1:1 grapheme-phoneme correspondence. Thus the child is not required to switch grain size strategies, consistent with research demonstrating that children reading English performed better when reading words of similar grain size (Goswami et al., 2003).
6. Use of orthotactic probability values. All items are organised according to orthotactic probability values, starting at highest (easiest) and progressing to items with the lowest orthotactic values. This is consistent with research indicating that MOR development was more efficient with items of higher orthotactic value (Apel et al., 2006; Wolter & Apel, 2010; Wolter, Self, & Apel, 2011).
7. Repetition. The intervention involves one component (a task encouraging accurate use of phonological recoding) and was constructed to ensure that at least twenty-three items were presented for phonological recoding. This is consistent with the procedure used in the Pullen et al. (2005) study and provides the child with repeated practice at phonological recoding.
8. Intervention matched to the child's orthographic knowledge. The intervention

is designed to be presented in levels of difficulty, starting with 2-letter and progressing to 6-letter items, all of which have 1:1 letter-sound correspondence - based on the research (McCandliss et al., 2003) demonstrating that children aged 7 – 10 years with reading delay have not mastered accurate decoding of 3- and 4-letter words. This enabled each child, following initial assessment, to begin the intervention at a level that matched their grapheme-to-phoneme conversion accuracy, as it has been shown that prior orthographic knowledge was a significant predictor of MOR development (Cunningham, 2006; Cunningham et al., 2002).

Overview of outcome measures

There are three sets of outcome measures (described in more detail in Chapters 5, 6 and 7) which relate to each of the three research questions. The primary measures of intervention effectiveness addressing the first research question are nonword reading rate (*NW Rate*: the number of nonwords read out loud in 60 seconds) and the total number of nonwords read correctly (*NW Total*: the number correctly read to a ceiling of 6 errors out of 8 consecutive items), from 39 researcher-developed nonword lists each containing 70 letter strings – the *Assessment NW Lists*. These measures were administered at the beginning of every session (baseline and intervention). Nonword reading measures the child's ability to use phonological recoding to decode unfamiliar words, and strongly predicts reading development (Badian, 2001).

The additional measures of intervention effectiveness concerning the second research question are standardised assessments of nonword reading accuracy, word and nonword reading efficiency, text reading and comprehension; and an in-depth assessment of nonword spelling. These were administered by the researcher prior to the intervention, and by a speech pathologist unfamiliar with the children and blind to research aims during the post-intervention baseline sessions. The standardised measures include the decoding subtests of the *Phonological Awareness Test 2* (PhAT-2: Robertson & Salter, 2007), the *Test of Word Reading Efficiency 2* (TOWRE-2: Torgesen, Wagner, & Rashotte, 2012), and the *Neale Analysis of Reading Ability 3rd edition* (Neale, 1999). The impact of the Decoding Intervention on spelling is evaluated using a measure of nonword spelling which is assessed using

researcher-developed nonword spelling lists (*Assessment NW Spelling Lists*). These were developed using the same method as the Assessment NW Lists (used to measure the dependent variable), and were analysed using the *Spelling Sensitivity Scoring* procedure (SSS: Masterson & Apel, 2010).

The third research question aimed to examine if pre-intervention profiles of language, intellectual, and phonological processing skills influenced participant response to the intervention. These measures were administered prior to the intervention phase and included standardised tests of language: the *Clinical Evaluation of Language Fundamental 4* (CELF-4: Semel, Wiig, & Secord, 2003), phonological processing: the *Comprehensive Test of Phonological Processing 2* (CTOPP-2: Wagner, Torgesen, Rashotte, & Pearson, 2013), and intellectual skills: the *WISC IV Australian* (Wechsler, 2003).

Research design

Over the last decade, use of *evidence based practice (EBP)* in the development and delivery of intervention procedures has been emphasised. EBP is a process where the most rigorous scientific research informs clinical practice decisions, and involves an integration of three elements: the best research evidence, practitioner expertise, and knowledge of client attributes (Johnson, 2006; Rubin, 2010; Speech Pathology Australia, 2010). Though the “gold standard” methodology for research is considered to be a randomised controlled trial (RCT), the benefits of single subject research designs (SSRDs), also called single-case experimental designs (SCEDs), have been highlighted (Beeson & Robey, 2006; Tate et al., 2008). These methods allow for examination of individual differences associated with participants; a feature that is missing in designs such as RCTs where comparisons between groups of participants are the focus of analysis (Plavnick & Ferreri, 2013).

A single subject research design (SSRD) was employed in this research for two reasons. Firstly, it allows for a detailed evaluation of response patterns throughout the intervention, and examination of the relationship between participant language and cognitive profiles and responses to intervention; thus addressing the third research question. Secondly, it is an appropriate methodology for the investigation of a new intervention procedure, as it allows for examination of effectiveness on a small number of individuals, and exploration of causal factors

(Beeson & Robey, 2006; Johnson, 2006) prior to use of larger well-controlled group designs to test efficacy in naturalistic and real-life environments.

The main features of SSRDs are that they involve small numbers (a single case or several subjects), observations are taken at many time points (resulting in a larger set of measures of how one variable changes across many time points for one case), and there are at least two testing periods or phases: a baseline phase (A) prior to treatment, and an intervention phase (B). Each subject is exposed to both treatment and control (or comparison) conditions, so that the subject acts as their own control. The focus of SSRDs is on patterns of change within each case over time, not on group analyses of data across many cases (Rubin, 2010).

As with other experimental designs, SSRDs require the same attention to design, control and statistical analyses, to ensure that research hypotheses can be formed and tested based on the expected relationship between an independent variable (the intervention) and the dependent variable: the participant response which is observable, quantifiable, and a valid indicator of treatment effectiveness (Portney & Watkins, 2009). When the independent variable is manipulated under the control of the experimenter, and the dependent variable is clearly defined and measured consistently at the same time in each experimental condition, a causal analysis of the effect of the independent variable is possible (Plavnick & Ferreri, 2013).

The two studies in this research used a SSRD with different methodology (described in more detail in Chapters 5 and 6), to match the specific goals of each study. Study 1 was a pilot study with two objectives. The first was to gather initial evidence of the effectiveness of the Decoding Intervention in improving nonword reading in children with word reading impairment. The second was to trial the program function and implementation procedure in order to make adjustments prior to the second study. Three participants were involved in an A-B-A design with three phases: a baseline phase (A¹) of 8 sessions, an intervention phase (B: using the Decoding Intervention) of 15 sessions, and a post-intervention baseline phase (A²) of 8 sessions to assess maintenance of skills.

The second study used a multiple treatment cross-over design to gather evidence addressing the three research questions. This study involved two intervention conditions: the Decoding Intervention which targeted word decoding skills, and the Language Intervention which did not involve word reading activities. This enabled a comparison of the effect of each intervention on the dependent

variable (nonword reading), strengthening the evidence base for a causal relationship between the Decoding Intervention and the dependent variable. Eight participants were randomly allocated to one of two intervention sequences. The first group of four participants were presented with a baseline of 8 sessions (A¹), the Decoding Intervention 15 sessions (B), baseline 8 sessions (A²), Language Intervention 15 sessions (C), and final baseline of 8 sessions (A³). The second group of four participants followed a similar sequence but completed the Language Intervention before the Decoding Intervention.

The SSRD design employed in this research is consistent with the highest level of evidence (level 1) as outlined by Logan, Hickman, Harris, and Heriza (2008) and Tate et al. (2008). It involved more than the minimum of three participants (i.e., four in each group to allow for drop out), who were randomly assigned to an alternating-treatment crossed design, where a stable baseline was established with more than the minimum of three data points, and the post-intervention assessor was independent from the researcher.

Research Hypotheses

The first research question aimed to determine if an intervention targeting phonological recoding and orthographic processing (the Decoding Intervention) would significantly increase nonword reading skills (measured by responses on researcher-developed nonword lists) in Year 2 children with persistent word reading impairment. It was expected that this intervention would have a significant and positive impact on participant's use of phoneme-grapheme knowledge to decode unknown words (the non-lexical route), for two reasons. Firstly, the procedure was designed to teach accurate use of phonological recoding and orthographic processing, thus directly targeting skilled use of the non-lexical route which was assessed by the dependant variable - nonword reading. Secondly, as the intervention was matched to participants' existing orthographic knowledge, it was expected that participant decoding skill would gradually improve.

The second research question raised the issue of generalisation: would an intervention targeting phonological recoding and orthographic processing also improve scores on standardised measures of reading (nonword reading accuracy, word and nonword reading efficiency, text reading, and reading comprehension), and

an in-depth assessment of spelling (assessed by researcher-developed nonword lists) in this group of children. The expectation was that the impact of this intervention may result in improved scores on some of the related reading outcome measures. There were two reasons for this. Firstly, as the intervention involved a single component, the teachers were not advised of the specific goals or the strategies used. Thus, the participants were not given additional support to use their improved decoding skills in other reading activities. While it was a possibility that the children may have generalised their improved decoding skills to text reading, it was also likely that these children with severe and persistent reading impairment may require significantly more support to generalise skills. Secondly, as this research targeted accurate decoding of items with 1:1 grapheme-phoneme correspondence (to match the skills of participants), the criteria for inclusion was that participants were within the normal range in their knowledge of consonant and short vowel letter names and sounds. It is possible that some participants may not have mastered knowledge of consonant and vowel digraphs (a digraph refers to a sound that is spelled with two letters, e.g., *sh*, *ch*, *ee*, *ow*). Thus, even if participants made significant gains in decoding words with 1:1 grapheme phoneme correspondence, they may require additional intervention to master orthographic knowledge of consonant and vowel digraphs to support generalisation of improved decoding skill.

The third research question explored factors that may contribute to the sizable number of children reported in the literature who experience an inadequate response to intervention. Specifically, do pre-intervention language, cognitive, and phonological processing skills influence responses to intervention in this Tier 3 intervention. Examination of other Tier 3 interventions (Denton et al., 2013; Torgesen, 2001) involving children of a similar age and measuring similar pre-intervention profiles to the research in this thesis, suggests that receptive language, phonological awareness, teacher ratings of attention, and pre-intervention measures of word reading skills are significant predictors of response to intervention. In the Torgesen (2001) study, 60 children (aged 8 – 10 years) completed 69 hours (twice daily 50 minute sessions over 8 – 9 weeks) of intervention. Pre-intervention measures included complete standardised assessments of language and intellectual skills, subtest measures of phonological awareness and rapid naming, as well as teacher questionnaires of behaviour and attention. The outcome measures (administered pre-intervention, immediately following intervention, and at 10

months post-intervention) comprised word and nonword reading accuracy and efficiency, reading comprehension, and reading rate. The results of the regression analyses showed that the predictor variables most reliably associated with gains were teacher ratings of attention, receptive language, and pre-intervention measures of reading.

Denton et al. (2013) also examined predictors of response to intervention. This study involved 47 students in the intervention group (mean age of 7.8 years), who received daily sessions of 45 minutes duration over 25 weeks (93 hours in total). The pre-intervention profile measures were similar to the Torgesen (2001) study except that they involved selected subtests (instead of full assessments) assessing receptive vocabulary, general knowledge, listening comprehension, phonological awareness, rapid naming, and nonverbal reasoning, and did not include measures of attention and behaviour. The outcome measures included word and nonword reading accuracy and efficiency, reading comprehension, and reading fluency. To analyse predictors of response to intervention, participants were categorised into adequate and inadequate responders, based on a criterion of a standard score greater than 90 on all three measures of word reading accuracy, word reading efficiency, and reading comprehension. The results of a MANOVA and follow up univariate analyses yielded statistically significant group differences for only the phonological awareness and listening comprehension measures. Hence in this study, the predictor variables associated with response to intervention were phonological awareness and listening comprehension (a measure of receptive language).

While the common significant predictor in both of these studies was receptive language, neither study found that measures of intelligence were related to performance on the outcome measures. The finding that phonological awareness was a predictor in one study but not the other may be explained by the different measures used, and/or the different procedures in analysing predictors of response: Denton et al. (2013) categorised participants into responder status first and then examined predictors associated with belonging to the responder group, while Torgesen (2001) examined which measure predicted the greatest gain for the whole group of participants. Another difference between these two studies was the breadth of skills that were assessed as predictors: Torgesen (2001) included all pre-intervention measures as possible predictors and thus found initial word reading scores to be a predictor, whereas Denton et al. (2013) restricted their examination of predictors to

the cognitive variables. The Tier 3 intervention in the programme of research for this thesis included pre-intervention measures of language skills, intellectual skills, and phonological processing. Considering the results of the Tier 3 interventions discussed above, it was hypothesised that pre-intervention language and phonological processing skills may influence response to intervention.

To summarize, the hypotheses for this research were that (a) the intervention targeting phonological and orthographic processing will result in significant gains in nonword reading; (b) the intervention would result in gains on some of the reading related skills as measured by standardised assessments of nonword reading accuracy, word and nonword reading efficiency, text reading and comprehension, and an detailed assessment of phonemic encoding (nonword spelling); and (c) that response to intervention would be influenced by pre-intervention language and phonological processing skills.

CHAPTER 4: DEVELOPMENT OF THE INTERVENTION MATERIALS

“At the current state of knowledge, it is adequate to conclude that the systematic instruction of letter-sound-correspondences and decoding strategies, and the application of these skills in reading and writing activities, is the most effective method for improving literacy skills of children and adolescents with reading disabilities" (Galuschka, Ise, Krick, & Schulte-Korne, 2014, p. 9)

This chapter describes the development of the Decoding Intervention materials which are based on the evidence-based principles outlined in Chapter 3, that is, the intervention:

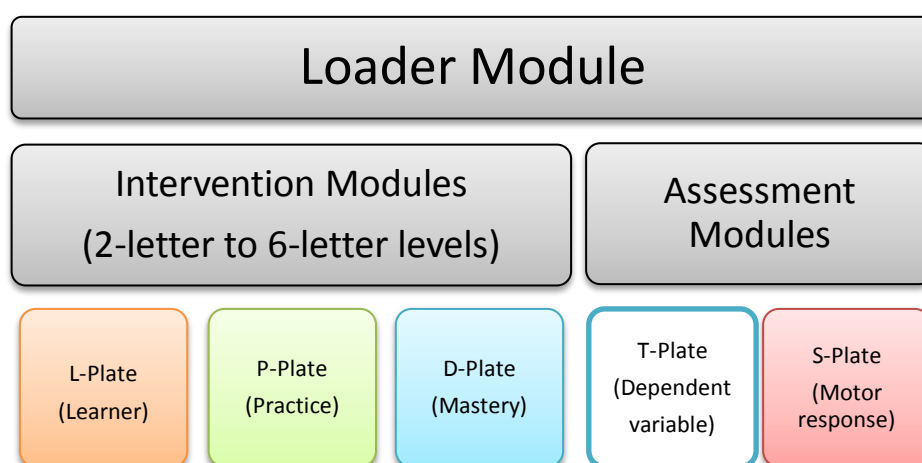
- Targets use of the non-lexical route
- Teaches accurate phonological recoding (by sounding out and blending) and orthographic processing (paying attention to each letter in the item)
- Presents single items (without story context) of similar grain size (i.e., blocked, so there is no switching of grain size), starting with easier items (higher orthotactic probability) and progressing to hard items (lower orthotactic probability)
- Provides repetition of key skills, and
- Matches intervention targets to the decoding skill level of each participant

Firstly an overview of WordDriver (the computer program designed and developed to deliver all aspects of the intervention) will be presented. This provides a context for discussion of the preparation of the stimuli (words, nonwords, sound files, and sentences), followed by a more detailed description of each module within the program, outlining for each one, the interface, organisation of the stimuli, and a flow diagram depicting the program logic. Finally the data logging and storage will be described.

Overview of WordDriver

WordDriver is a computer program which is best described as a web app at the functional prototype stage. It was written by Rob Seiler (computer programmer) in collaboration with the researcher in HTML/Java Script/CSS with server support in Perl. It is delivered on an iPad and contains six modules which present all intervention stimuli. Five of the modules (the Intervention and Assessment Modules) are used interactively with the child, and the sixth module (Loader Module) manages data and is used by the researcher to select the appropriate module for a specific child (see Figure 1)

Figure 1: Diagram of Word Driver



The five interactive modules (L-Plate, P-Plate, D-Plate, T-Plate, and S-Plate) all use the analogy of learning to drive a car, that is, the iPad depicts the driver's perspective with a dashboard, dial, windscreen, and a street sign on which the stimuli are presented. Three of these modules are used to deliver the independent variable (the Decoding Intervention) during phase B. These include the L-Plate (Learner), P-Plate (Practice), and D-Plate (Driver). The remaining two modules are used at the start of every session during the three baseline phases (A^1 , A^2 , and A^3) and the Decoding Intervention phase (B) to deliver the dependent variable (Assessment NW Lists) and a measure of motor response – the T-Plate (test) and S-Plate (speed) respectively.

The three Decoding Intervention modules (L-Plate, P-Plate, and D-Plate) are delivered at each of the five intervention levels: 2-letter, 3-letter, 4-letter, 5-letter, and 6-letter items.

- The L-Plate (Learner) is used to introduce the program and demonstrate the phonological recoding strategy. For each level, stimuli are 12 items (words and nonwords) presented in a predetermined order, with matching audio files for each sound and a matching sentence for each word.
- The P-Plate (Practice) enables the child to practise the task until mastery is reached (90% accuracy). For each level, stimuli are 24 items (words and nonwords) presented in a predetermined order, with matching audio files for each sound and a matching sentence for each word.
- The D-Plate (Driver) provides repeated practice of phonological recoding until the child reaches mastery (90% accuracy) at their current level. Stimuli are word-nonword pairs which vary in number depending on the level (155 at the 3-letter level, 234 at the 4-letter, 130 at the 5-letter, and 120 at the 6-letter level). As with the L- and P-Plate modules, each item has matching audio files for each sound and a matching sentence for each word. The stimuli are organised according to difficulty (from easiest to hardest), and are presented adaptively in response to the accuracy of participant response, that is, an easier item is presented following an inaccurate response, and a more difficult item following an accurate response.

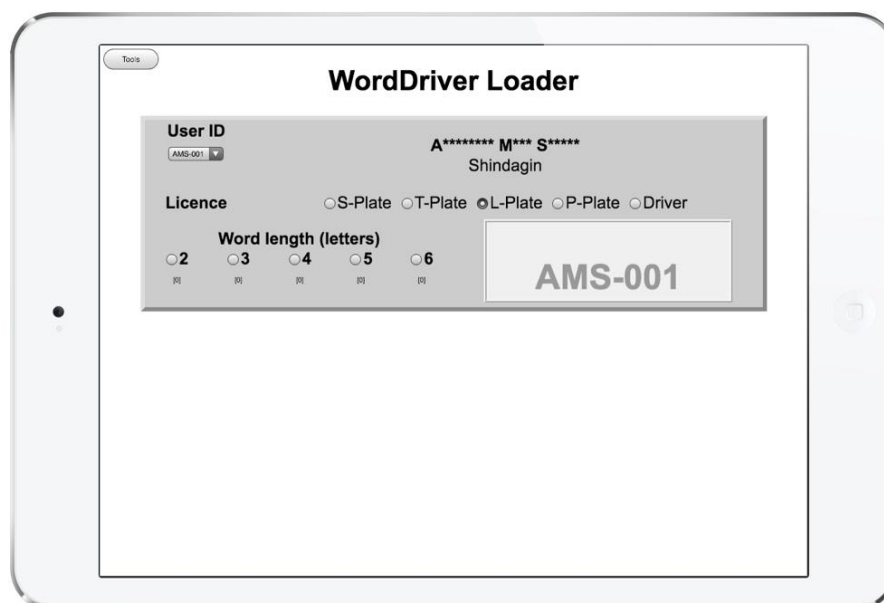
Each participant begins the program at a level that matches their decoding skill which is determined by pre-intervention decoding assessment using a standardised assessment – the Decoding subtests of the Phonological Awareness Test-2 (Robertson & Salter, 2007). For example, participants who demonstrate decoding errors on 3-letter items begin at the 3-letter level, and complete the L-Plate, P-Plate, and D-Plate at that level. On reaching the criterion of 90% accuracy on the D-Plate at the 3-letter level, the child progresses to the 4-letter level, where the L- P- and D-Plates at that level are completed in the same fashion. The child continues this sequence through as many levels as possible over the 15 Decoding Intervention sessions, ensuring that the criterion of 90% accuracy is reached at each of the levels.

The following two components are administered at the beginning of each of the baseline and intervention sessions (and are described in detail in a subsequent section):

- The T-Plate (Test) delivers the dependent variable: the Assessment NW Lists, to assess accuracy of nonword reading. Stimuli in each Assessment NW List are nonwords ranging from 2- to 6-letters, organised according to difficulty level (from easiest to hardest).
- The S-Plate (Speed) is presented after the T-Plate to measure the motor component of the task. This data allows an investigation as to whether improved scores are related to gains in use of the iPad (motor component) or gains in nonword reading. The stimulus is colour change on the street sign, and the participants respond by touching an onscreen button as soon as the colour changes to black.

The sixth module, the *WordDriver Loader* (see Figure 2) manages data storage procedures, and provides the interface for the researcher to select intervention modules. For example, to select a module for a specific child, the researcher firstly selects the User ID for the participant who is completing the session (e.g., AMS-001), then the module (e.g., S-Plate, T-Plate), and then the appropriate level (e.g., 2-letter, 3-letter). Once the selection is completed, the number plate is touched to launch the module.

Figure 2: Screenshot of WordDriver Loader Module



Preparation of Stimuli

This section describes the linguistic properties and selection procedures of the stimuli (words and nonwords), and the preparation of the sound files and sentences. Two programs were written to manage these processes: the *StimulusMatcher*, and the *Nonword Assessment List Generator*.

Word and nonword requirements

The Decoding Intervention required words and nonwords with 1:1 letter sound correspondence in sets from 2- to 6-letter strings, and the T-Plate (Assessment NW Lists) required nonwords in similar sets. For each item (word or nonword) the following linguistic properties were obtained:

- Orthotactic probability (the frequency that the item's letter combination occurs in English words of the specified length, e.g., 2-letter, 3-letter etc.) so that each set could be organised from high to low orthotactic value.
- Phonotactic probability (the frequency that the item's sound combination occurs in English words of the specified length) for later additional analyses.
- A phonetic representation of each sound in the item, so that a sound file could be linked to each letter enabling the child to listen to the item being "sounded out" as part of the corrective feedback following an incorrect response.

Selection of words

The words were generated from the second version of the MRC psycholinguistic database (Coltheart, 1981). This is an online computer useable resource designed for researchers. It accesses a dictionary (which is a compilation of a number of smaller dictionaries) of 150,837 words, and provides a range of linguistic properties, such as number of syllables, phonemes, spoken and written frequencies, and part of speech for each word.

A separate selection was done for each level. First the 2-letter words were selected, then the 3-letter words and so on. For each set the selected output field was "word", and the length of the word was defined by the upper and lower limit of letters and sounds. For example, for the 3-letter word selection the minimum number

of letters was 3 and the maximum number of letters was 3. Hence, only 3-letter words were generated. To select for words with 1:1 letter-sound correspondence, the minimum and maximum number of sounds was also 3. The total number of retrieved words in each set is listed in Table 2.

Each set was then processed using N-Watch (Davis, 2005) to eliminate obscure words and obtain the phonetic transcription, and the N-Watch algorithm was used to calculate the orthotactic and phonotactic probability values. N-Watch is a freely available Windows program (downloadable from <http://www.pc.rhul.ac.uk/staff/c.davis/Utilities/>). It has been used by researchers to generate a broad range of statistics concerning the properties of word stimuli, for example, the orthographic neighbourhood spread of words (Yates, 2013), and information about frequency and regularity of words (Kohnen, Nickels, Castles, Friedmann, & McArthur, 2012). It accesses a smaller dictionary of 30,605 words that has been filtered (to eliminated words that occur very rarely) from the CELEX dictionary (Baayen, Piepenbrock, & van Run, 1995). N-Watch was employed in the research in this thesis as the program and its frequency tables enabled the processing of thousands of items (words and nonwords), and the ability to rank items according to orthotactic probability values.

Obscure words were eliminated by entering the output from the MRC database into N-Watch. Items given a zero value were not in the N-Watch dictionary, indicating that they were obscure words (e.g., brig, copt) and so were deleted.

The phonetic transcription for each of the remaining words was saved using the DISC_PRON format. DISC_PRON (Burnage, 1990) is a computer phonetic alphabet made up of distinct single characters that provides one character for one phoneme, enabling efficient processing by a computer.

A computer program called StimulusMatcher was written in Perl script using the N-Watch algorithm (Davis, 2005) to calculate the orthotactic and phonotactic probability values: in N-Watch called BF_TK (Bigram Frequency Token) and BPF_TK (Biphone Frequency Token) respectively. This was necessary because N-Watch does not calculate statistics for nonwords. In the preparation of StimulusMatcher an error in the calculation of the BF_TK was detected in the N-Watch program which was discussed with the author via email (see Appendix A). To obtain orthotactic probabilities, the BF_TK calculation was used: a similar calculation to that used by a series of studies (Apel, 2009; Apel et al., 2012; Apel et

al., 2006; Wolter et al., 2011) examining the influence of orthotactic and phonotactic probability on MOR acquisition. The BF_TK is a position and length sensitive average of the frequencies of each bigram in the word. For example, the word “spot” has three bigrams (*sp*, *po*, & *ot*). For the first bigram (*sp*), there are twelve 4-letter words that have this bigram in the first position (span, spar, spat, spec, sped, spew, spin, spit, spot, spry, spun, & spur). The token frequency for “*sp*” in the first position of a 4-letter word is the sum of the word frequencies for these 12 words (sum = 98). The token frequencies for the second and third bigrams (*po* and *ot*) are calculated in a similar way: *po* = 328, *ot* = 348. The BF_TK, or orthotactic probability value, for the entire word (or letter string) is the average of the three bigrams token frequencies, $(98 + 328 + 348)/3 = 258$. Position and length sensitivity was a desirable attribute for item organisation in this research, as it supported the development of both specific and general orthographic knowledge (Conrad et al., 2013), that is, the spelling patterns of sequences of sounds in words (specific orthographic knowledge), as well as the implicit knowledge of spelling conventions, e.g., that *nt* only appears at the ends of words (general orthographic knowledge). The phonotactic probability values were calculated using the BPF_TK, an analogous method to the BF_TK except it uses the biphone frequency values. The bigram and biphone frequency values were generated using frequency data in the N-Watch package.

These procedures resulted in five lists of words (i.e., a list of 2-letter, 3-letter, 4-letter, 5-letter, and 6-letter words). Each word had a phonetic transcription (DISC_PRON), the BF_TK value (orthotactic probability), and the BPF_TK value (phonotactic probability). Each list was ordered from highest to lowest BF_TK values, that is, according to orthotactic probability.

Selection of non-words

The non-words were generated using the ARC database (Rastle, Harrington, & Coltheart, 2002), employing a similar procedure as described above for words. The selection criteria were for “nonwords”, with “orthographically existing onsets”, “orthographically existing bodies”, and “legal bigrams” to ensure that the nonwords were letter strings consistent with English language spelling patterns. To achieve letter strings with 1:1 letter-sound correspondence, upper and lower limits were set for letters and phonemes. For example, for 3-letter words, the upper and lower limit

for letters was 3, and the upper and lower limit for phonemes was 3. A separate selection was done for each level, that is, first the 2-letter strings, then 3-letter strings etc. Visual inspection of the lists revealed errors in the output, for example, inclusion of consonant and vowel digraphs, such as “shex, bued, sply, thwinx”. To exclude these unwanted patterns, each list was screened, using the DISC_PRON symbols, to exclude sounds that did not conform to the selection criteria of 1:1 letter-sound correspondence. For example, all items with consonant or vowel digraphs were excluded as these sounds do not have one letter per sound.

To obtain the orthotactic and phonotactic probability values, the output from the ARC database was processed using the same program (StimulusMatcher) as the words, as described above. This produced five lists of nonwords (i.e., a list of 2-letter, 3-letter, 4-letter, 5-letter and 6-letter nonwords). For each nonword there was a phonetic transcription (DISC_PRON), the orthotactic probability value (BF_TK), and the phonotactic probability (BPF_TK). Each list was ordered from highest to lowest BF_TK values, that is, according to orthotactic probability.

Preparation of audio files

The audio files were mp3 recordings (48,000 Hz: 128 kbps: mono) of the researcher producing each of the sounds used in the word and nonword stimuli. As the requirement for this research was for words and nonwords with 1:1 letter-sound correspondence, only twenty-two of the forty-four English phonemes were recorded: /p, b, t, d, k, g, f, v, s, z, l, m, n, r, h, y, w, a, e, i, o, u/. The appropriate audio file was indexed to each letter, available to be presented by the program as part of the corrective reinforcement. That is, following an error the child listened to phonological recoding of that item as each letter was “sounded out”.

Preparation of sentences

Sentences were used as standardised reinforcement following the decoding of words. A sentence was prepared for each word and included in an interactive web page which indexed each word to its corresponding sentence. This enabled the researcher to access the web page on a separate portable computer, and quickly retrieve the sentence which was then read to the participant to illustrate the meaning of the word. The criteria used when formulating the sentences was that the topic and

sentence structure should relate to the interests and conversational speech patterns of a child aged 7 – 8 years. Table 1 provides examples of reinforcement sentences for words and nonwords, and Appendix B includes the complete set of sentences for each level (i.e., 2-letter, 3-letter level etc.).

Table 1: Reinforcement sentences for decoding intervention

Stimulus item	Reinforcement sentence
am	I am going swimming today
dig	My dog likes to dig a hole and bury his bone
hens	The hens were sitting on a dozen eggs
gifts	She got many gifts for her birthday
plants	The plants grew very quickly after the rain
blat	That's a made up word. It has no meaning.

Description of Each Module

This section firstly outlines the procedure that was used to organise the stimuli (words and nonwords) across all modules. This is followed by a detailed description of each module (L-Plate, P-Plate, D-Plate, T-Plate, and S-Plate) which outlines the goal, graphical interface on the iPad, organisation of stimuli, and program logic.

Organisation of stimuli

The selection of words and nonwords (described previously) for the Decoding Intervention and the Assessment NW Lists resulted in five lists of words (i.e., 2-, 3-, 4-, 5- and 6-letter) and five lists of nonwords (i.e., 2-, 3-, 4-, 5- and 6-letter), each ordered from highest to lowest orthotactic probability. The next step was to organise these items for inclusion into each of the modules (L-Plate, P-Plate, D-Plate, and Assessment NW Lists). At each level the L-Plate stimuli were organised first, followed by the P-Plate, the D-Plate, and finally the Assessment NW Lists.

With regard to the three intervention modules (L-Plate, P-Plate, and D-Plate), the L- and the P-Plates are organised in a different manner to the D-Plate. Based on

the findings of McCandliss et al. (2003) who found a hierarchy of decoding accuracy (i.e., highest accuracy for initial letter, followed by the final letter, and lowest for middle letters), the items for the L-Plate and P-Plate are organised so that for the first few items the first letter changes, then a series where the final letter changes, then the middle letter/s, and finally a few items where the whole sequence changed. For example, the changes within a 3-letter sequence starting with “*cat*” is “*cat mat lat lal lan lap lip lup lep cup das and*”. The rationale was thus that this sequence of presentation allows the researcher to train the child to pay attention to all letters in the letter string across a set. To achieve this order, the researcher constructed the items in a set linear fashion using words and nonwords from the appropriate lists. These items were then removed from the stimulus lists so that no demonstration or practice item (in the L- and P-Plates) would appear in other modules, that is, the D-Plate and T-Plate (Assessment NW Lists). The organisation of items for the D-Plate and T-Plates will be discussed in the relevant sections describing those modules.

Table 2 illustrates the overall organisational process by depicting:

- The available number of items (words and nonwords) at each level following selection from the MRC and ARC databases
- The number of items removed for L-Plates and P-Plates at each level
- The remaining number of items (nonwords) available for Assessment NW List construction

Table 2: Selection of items for Decoding Intervention modules

	2-letter		3-letter		4-letter		5-letter		6-letter	
	W	NW	W	NW	W	NW	W	NW	W	NW
Available	10	46	174	663	250	2484	146	3445	24	1881
L-Plate	3	2	6	6	6	6	6	6	1	11
P-Plate	7	8	11	13	10	14	10	14	2	21
D-Plate	0	0	155	155	234	234	130	130	21	120
										+99NWs
Remaining										
NWs		36		489		2230		3295		1630

Note: W = word; NW = nonword; Ax NW List = Assessment NW List; L-Plate = Learner; P-Plate = Practice; D-Plate – Driver (mastery)

Table 2 shows, as an example, that in the organisation of 3-letter items, there were 174 words and 663 nonwords available following selection from the MRC and ARC databases. Six words and six nonwords were used in the L-Plate, and 11 words and 13 nonwords were used in the P-Plate. In the construction of the D-Plates for the 3-, 4- and 5-letter levels, all available words were used and paired with nonwords that were closely matched for orthotactic probability. Continuing with the example for the 3-letter items, following the D-Plate construction, there were 489 nonwords available for the Assessment NW Lists. Due to the small number of available items at the 2- and 6-letter levels, modifications were needed for the L- and D-Plates, which will be discussed in the relevant sections.

L-Plate

Goal

The aim of the L-Plate is to demonstrate the Decoding Intervention procedure and to model use of phonological recoding to decode items.

Interface

The iPad screen depicts the driver's perspective as seen in Figure 3. The yellow L-Plate on the bottom left differentiates the L-Plate from other modules, and the participant number plate on the bottom right provides a visual check that the data is logged to the appropriate participant. The road sign displays the stimuli – in this screenshot at the 3-letter level. The Go Button is used to advance through the module, and yellow buttons are touched to provide feedback about accuracy of response - “tick” for correct, “question mark” for help (incorrect). The dial provides visual feedback of the percentage correct following each response. The Book and Bin buttons are used to sort stimuli: words into the Book and nonwords into the Bin.

Figure 3: Screenshot of WordDriver L-Plate interface



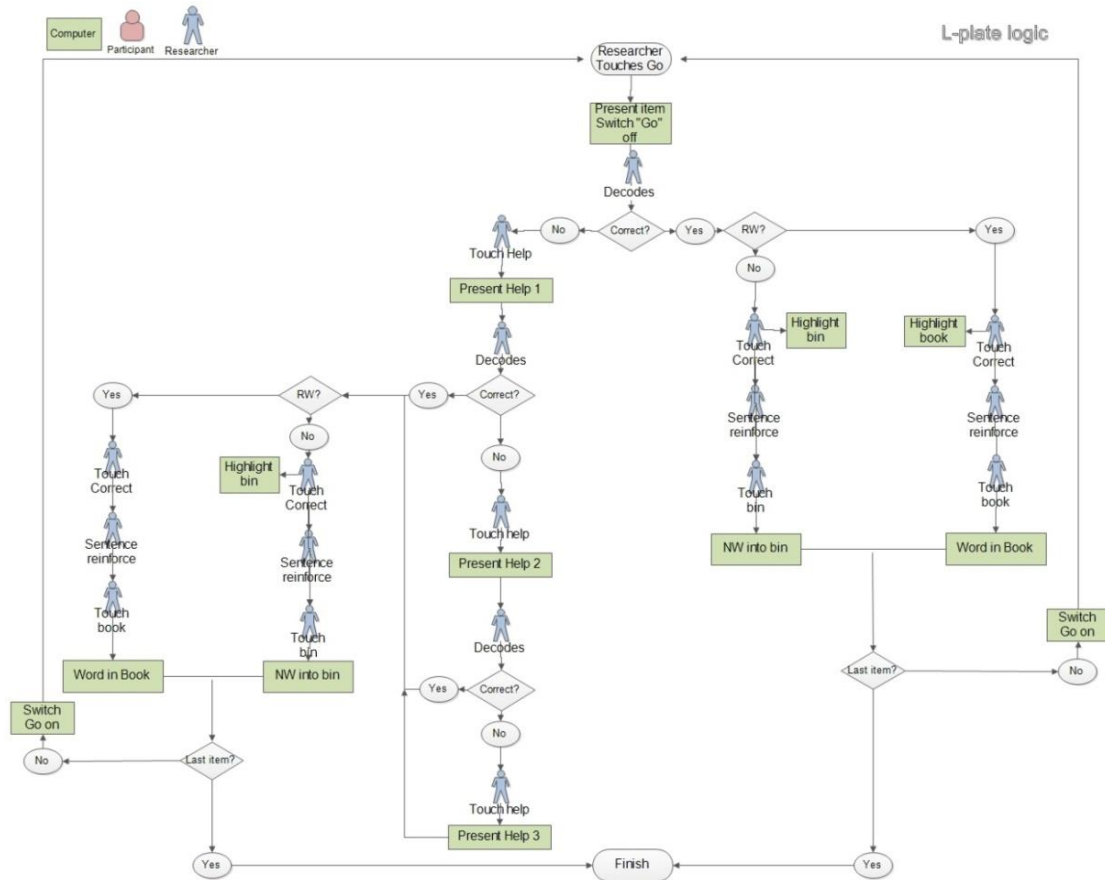
Organisation of stimuli

The L-Plate consists of 12 trials (because there are 12 stimuli), except for the 2-letter level where there are only five trials. Due to smaller numbers of available items for 2-letter and 6-letter L-Plates, three words and two nonwords were used in the 2-letter L-Plate, and one word and eleven nonwords for the 6-letter L-Plate. As described previously, the items are organised in a pre-determined sequence so that initially the first letter changes, then the last, then the middle and then all letters.

Program logic

As the primary aim of the L-Plate is to model use of the program and phonological recoding, the researcher performs all of the interactions with the iPad. Figure 4 illustrates the program logic for the L-Plate.

Figure 4: Program logic L-Plate



The researcher touches the Go button and the first item appears on the road sign image on the screen. The researcher performs phonological recoding (sounding out and blending). In the case of accurate phonological recoding the researcher touches the “Correct button” (the yellow button with a smiley-face and tick image), which automatically enables the Book button (for a word) or the Bin button (for a nonword) turning it blue, and all other buttons are disabled (depicted by a colour change to grey). Words are reinforced by the researcher reading the scripted sentence accessed from a separate portable computer, and nonwords by a sentence explaining that the item is not a real word and has no meaning. Following this demonstration of corrective feedback the researcher touches the Book or Bin button which automatically animates the removal of the word to the appropriate bin, enables the Go button (depicted by a colour change from grey to yellow) and disables all other buttons, ready for the next item.

In the case of incorrect responses the researcher touches the “Help” button (yellow button with a question mark), which automatically enables the Book or Bin buttons as above, and disables all other buttons. There are three levels of help. For the first level (represented by a question mark and a letter icon on the help button), the stimuli letters are successively highlighted in red to visually prompt phonological recoding. The second level of help (represented by a question mark and an audio icon) provides the child with visual and auditory prompting: the letters, highlighted as in level 1 help, are synchronised with the matching audio output (the sound for that letter). For the third level of help (represented by a question mark and an icon of a person) the researcher touches each letter and performs phonological recoding and blending. Once the corrective feedback is completed the researcher touches the blue button as above, signalling the completion of that item and readiness for the following item with the automatically enabled Go button.

The dial under the Go button provides immediate visual feedback about accuracy of response. Following a correct response (touching the Correct button), the dial moves forward, and following an error (touching the help button), the dial moves back, showing percentage correct over time. A red bar on the dial indicates progress through the current set of stimuli.

The researcher modelled about 50% correct/incorrect responses in a quasi-random fashion. At the completion of the list of stimuli all buttons are disabled and the “All done!” text is displayed on the road sign image.

P-Plate

Goal

The goal of the P-Plate module is for the child to practice phonological recoding on a controlled set of words at each level until mastery is reached, which is defined as 90% accuracy.

Interface

The P-Plate interface is the same as the L-Plate except for the small green P-Plate on the bottom left of the screen and the green participant number plate on the bottom right of the screen. The screenshot of a P-Plate illustrated in Figure 5 shows the iPad screen with a nonword on the road sign at the 4-letter level. The Correct and

Help buttons are both active, ready for the researcher to provide feedback to the child about accuracy of response.

Figure 5: Screenshot of WordDriver P-Plate



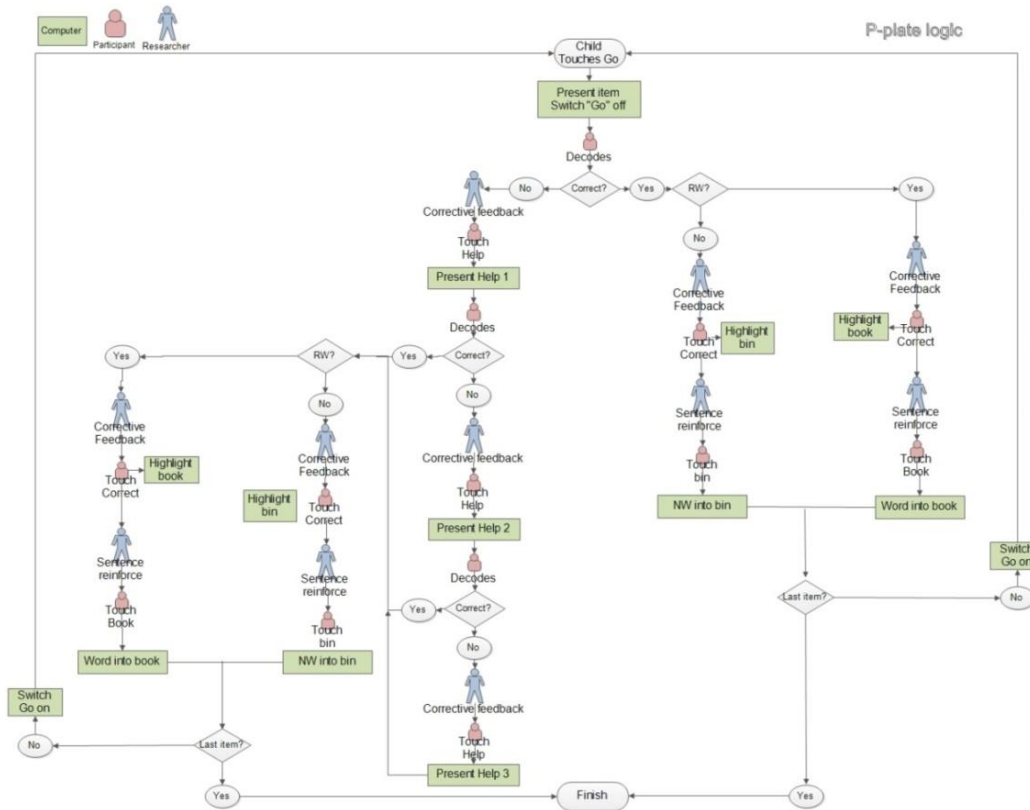
Organisation of stimuli

The items that remained after the L-Plate stimuli had been removed were then used to construct the P-Plate stimuli. The items were organised in a similar way to the L-Plate (i.e., first letter changing for the first few, then final letter, and so on) to encourage the child to pay attention to all letters in the stimulus. The difference between the L- and P-Plate was that the P-Plate contained more items at each level (i.e., more trials). The 3-letter, 4-letter and 5-letter levels each involved 24 words and nonwords, with fewer in the 2- and 6-letter levels due to the reduced availability of items: fifteen 2-letter and twenty-three 6-letter items (see Table 2).

Program logic

Figure 6 illustrates the program logic for the P-Plate which is similar to the L-Plate: the difference being that the child performs some of the functions (as the aim of this module is for the child to practice accurate use of phonological recoding at each level).

Figure 6: Program logic P-Plate



The child touches the Go button and performs phonological recoding. The researcher provides feedback about accuracy of response, and the child touches the Correct or Help button which automatically enables the Book or Bin buttons as in the L-Plate. Corrective feedback is provided as described previously in the L-Plate, concluding each item with the child touching the Book or Bin button to re-enable the Go button ready for the next item. Once all items have been completed “All done!” is displayed on the road sign image. The child progresses to the D-Plate once mastery (90% accuracy) has been achieved.

D-Plate

Goal

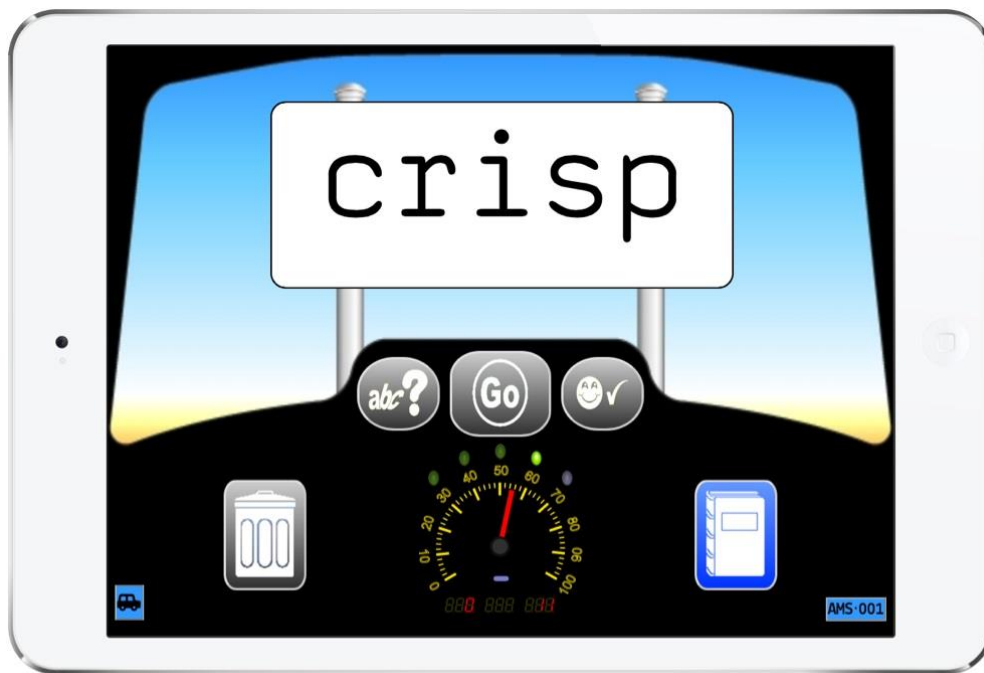
The aim of the D-Plate is to provide repeated and varied practice at each level (i.e., 2-, 3-, 4-letter level and so on) until the participant reaches mastery - 90% accuracy on nonword items.

Interface

The D-Plate interface is the same as the L- and P-Plate except for the small blue D-Plate on the bottom left of the screen and the blue participant number plate on

the bottom right of the screen. The screenshot depicted in Figure 7 shows a real word stimulus item at the 5-letter level. Only the blue Book graphic is active which means that the child has accurately decoded the item, corrective feedback has occurred and the child is ready to touch the Book graphic to put the real word in the book.

Figure 7: Screenshot of WordDriver D-Plate



Organisation of stimuli

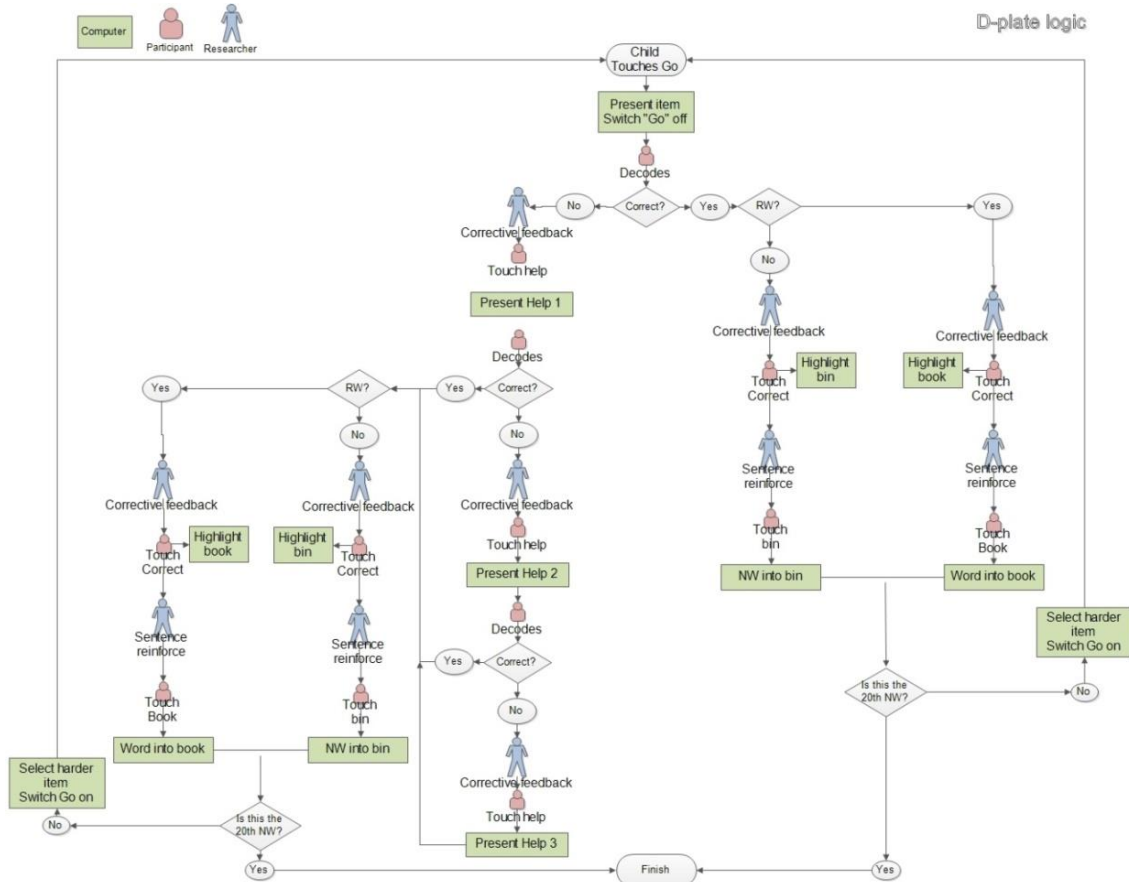
The items that remained after the L- and P-Plate stimuli had been removed were used to construct the D-Plate stimuli which consisted of a series of paired items (word and nonword), closely matched for orthotactic value. This matching process was managed by StimulusMatcher - the computer program that initially calculated the orthotactic and phonotactic values (described above). The StimulusMatcher received the input for each level (i.e., the word and nonword lists with their orthotactic values) and matched each word with a nonword with the closest BF_TK value (orthotactic probability). In this process, all available words were used resulting in one hundred and fifty-five 3-letter pairs, two hundred and thirty-four 4-letter pairs, and one hundred and thirty 5-letter pairs. Due to the small number of 2-letter and 6-letter words, there was no 2-letter D-Plate, and the 6-letter D-Plate was organised differently: there were twenty-one 6-letter words available, so 21 pairs were constructed of “word: nonword” and 99 pairs were “nonword: nonword”,

making a total of 120 pairs (see Table 2). Appendix C shows the complete set of paired items (words and nonwords) for the D-Plates at each level. These nonwords were removed from the lists, leaving the remainder for the T-Plate (the Assessment NW List) preparation. The items at all levels were hierarchically organised from highest to lowest orthotactic probability value, which means that the child is presented with easier items first (high orthotactic probability), progressing to more difficult items (low orthotactic probability).

Program logic

The D-Plate differs from the previous two plates in that (a) the items are word: nonword pairs organised from high to low orthotactic probability, (b) there are many more items at each level, (c) the items are presented adaptively in response to participant error, and (d) the session is completed once the child has been presented with 20 nonwords. Figure 8 depicts the program logic for the D-Plate.

Figure 8: Program logic D-Plate



The interaction between the participant, the researcher, and WordDriver outlined in Figure 8 is similar to the P-Plate, but an adapted PEST procedure (McArthur, Ellis, Atkinson, & Coltheart, 2008; Taylor & Creelman, 1967) was written into the program to manage the various processes involved in stimulus selection and presentation. The child touches the Go button, and is presented with either the word or nonword of a paired item in a randomised fashion. The child reads the item out-loud, the researcher provides corrective feedback as described in the P-Plate, and the child touches the Correct or Help button. Following an incorrect response the program automatically presents an easier item (higher orthotactic probability), and following a correct response, with a harder item (lower orthotactic probability). The stimuli continued to be presented in this fashion until 20 nonwords had been presented.

The child repeats the D-Plate module until mastery is reached at that level. To ensure that the full range of orthotactic difficulty within each letter level had been presented (i.e., from the easiest to the hardest item), the program calculated an appropriate *step size* for each level. The *step* is the number of items (word: nonword pairs) that are skipped to move through the available items. As each level had a different number of items, the step size varied between levels. The program calculated the step size by dividing the total number of items by 20. For example, the 155 items at the 3-letter word level was divided by 20 resulting in a step size of 8 (rounded up from 7.75). To avoid presentation of the same set of words on successive attempts, the size of the first step was randomised thus leading to different step points on repeated runs of a level.

T-Plate

Goal

The aim of the T-Plate is to present the Assessment NW Lists – the dependent variable.

Interface

The T-Plate interface looks similar to the L-, P- and D-Plates with two differences: the red T-Plate on the bottom left and red participant number on bottom right, and the only enabled button is the Go button, as in this module there is no corrective feedback, and the stimuli are all nonwords. Figure 9 illustrates the T-Plate.

It shows that though the screen is similar to the other modules, only the Go button is enabled.

Figure 9: Screenshot of WordDriver T-Plate



Organisation of stimuli

The forty-two Assessment NW Lists (Appendix D) were created last: 24 for the three baseline phases, 15 for the Decoding Intervention, two for the nonword spelling assessments (the Assessment NW Spelling Lists), and one extra list (Appendix E). Each Assessment NW List is comprised of 70 items, as informal testing by the researcher found that a skilled adult would take longer than one minute to read 70 nonwords, thus satisfying the research methodology requiring “number of nonwords read in 60 seconds” as a dependent variable. There is no repetition of items within or between lists (apart from the 2-letter items), so the number of remaining items, after the D-Plates were constructed, somewhat dictated the structure of each 70 item list, which was 2 x 2-letter, 11 x 3-letter, 25 x 4-letter, 19 x 5-letter, and 13 x 6-letter strings. To achieve lists of equal difficulty, the items were matched across the lists for orthotactic probability values using the Perl script, *Nonword Assessment List Generator*. The following steps were completed using the 3-letter word lists as an example:

- First, the remaining 3-letter nonwords (489) were ranked from highest

to lowest in orthotactic probability value.

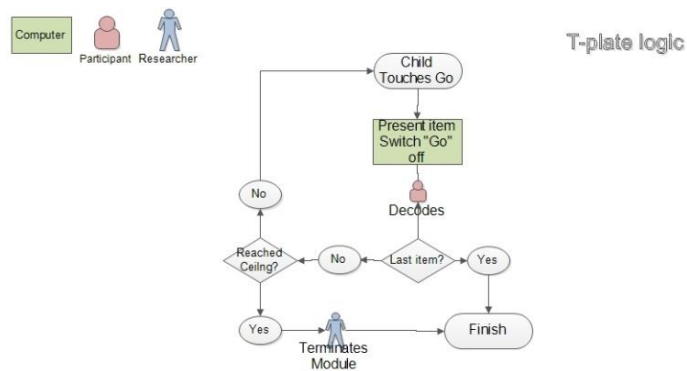
- Then the total number of 3-letter nonwords was divided by the number required in each list, that is, the list of 489 available 3-letter nonwords was divided by 11 (as 11 x 3-letter nonwords were required for each list), resulting in 11 groups of 44 nonwords (the unused items were discarded).
- Then the top 42 (highest orthotactic probability) of each of these 11 groups was randomly assigned to the 42 lists, starting with the highest orthotactic probability value progressing to the lowest. So the 1st of the 11 groups (with the highest orthotactic probability value) was randomly assigned to the 42 Assessment NW Lists, then the 2nd of the 11 groups was randomly assigned, and so on.

The 4-, 5-, and 6-letter items were distributed using the method described above. The 2-letter items in each list were allocated using a different methodology as there were not enough 2-letter items for the requirement of two per list. The 36 available 2-letter nonwords were randomly assigned to the first 18 Assessment NW Lists. These 36 items were re-shuffled so that no pairs were repeated and were randomly assigned to the next 18. This process was repeated for the remaining five lists.

Program logic

As the aim of the T-Plate is to assess the child's ability to use accurate phonological recoding on a sequence of nonwords, no corrective feedback is provided from the researcher. The child touches the Go button to view each item, performs phonological recoding, and then touches the Go button again for the next item. The researcher notes accuracy of response and, using a visual timer displayed on the screen, stops the child after 60 seconds (if six errors are made in eight consecutive items), or after the child makes six errors in eight consecutive items. Figure 10 depicts the program logic for the T-Plate.

Figure 10: Program logic T-Plate



S-Plate

Goal

The aim of the S-Plate is to measure the motor component of the child's response.

Interface

The S-Plate interface was similar to the T-Plate except for the small red S-Plate at the bottom left and red participant number plate at the bottom right. As with the T-Plate, only the Go button is enabled. Figure 11 illustrates the S-Plate. The road sign is white and all buttons are inactive. Once the road sign changes to black, the Go button becomes active (turns green).

Figure 11: Screenshot of WordDriver S-Plate



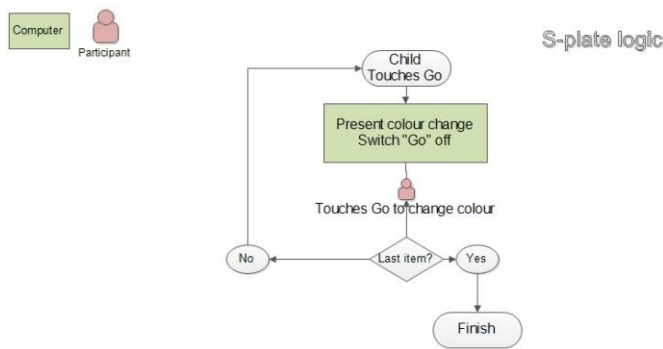
Organisation of stimuli

The stimulus is the change in colour on the road sign image from white to black.

Program logic

The child touches the Go button to reveal a white blank road sign. The child is instructed to touch the Go button as quickly as possible after the sign turns black. The timing of colour change is randomised to be one, two, or three seconds. The program automatically concludes the task once 20 items are completed, by displaying “All done!” on the road sign. Figure 12 depicts the program logic for the S-Plate.

Figure 12: Program logic S-Plate

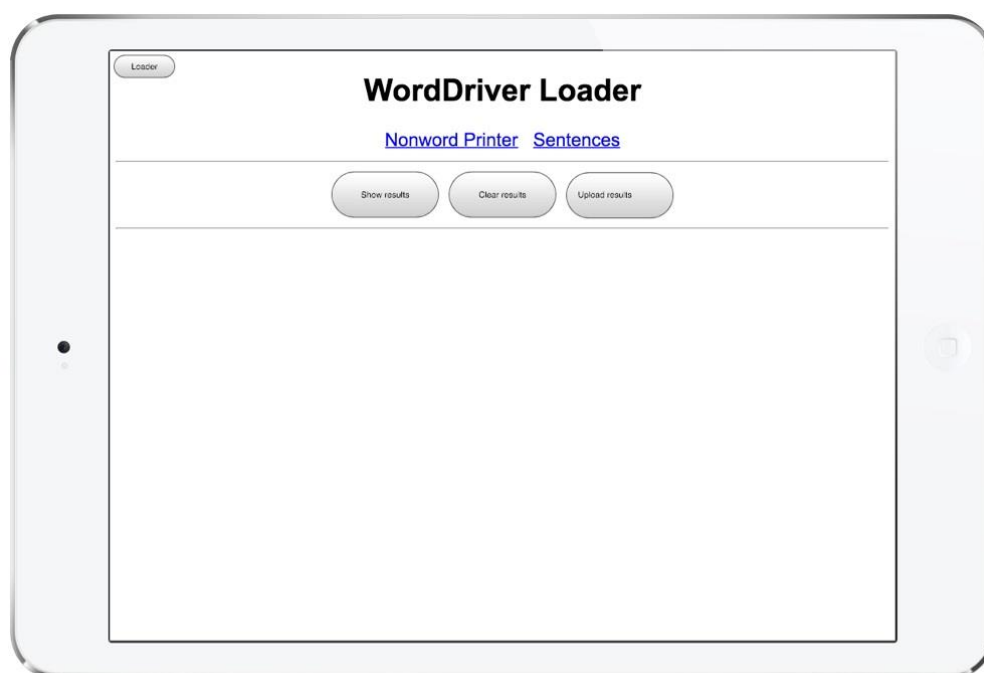


Data Logging and Storage

WordDriver is a web app which means that it requires internet connection to load each module following selection using the *WordDriver Loader* (as described in the Overview, see Figure 1). Once the module is loaded it no longer requires continuous internet connection, thus alleviating disruption or loss of data in the case of an unreliable internet connection.

As the participant progresses through a module, the data logged from that session is stored within the local iPad storage using HTML5 Local Web Storage. At the end of each day the researcher uploads the data to the server using the “Upload results” function in the WordDriver Tools (see Figure 13). Once the data is successfully backed up, the researcher clears the data from the local iPad storage using the “Clear results” function in the WordDriver Tools.

Figure 13: Screenshot of WordDriver Tools



A range of data is logged for each module. For all modules this includes the unique identifier for each participant, the location using the IP address, and the start and end time for each item within the modules. For the L-, P-, and D-Plates additional data includes a correct/incorrect marker for each item, the overall percentage correct, and for the D-Plate, the PEST level of each item.

Apart from the T-Plate, which is delivered in the same order for all participants, the researcher chooses the level (e.g., 2- letter, 3-letter) and module (e.g., L-Plate, P-Plate) for each participant. The researcher manually logs each completed module, including the T-Plate, in the *Control File* on the server. The Control File contains a summary of all completed modules: the T-Plate, and the percentage correct for the L-, P-, and D-Plates. The researcher uses the Control File to judge mastery at each level, and WordDriver accesses the completed T-Plate information to automatically load the appropriate T-Plate for each participant when requested via the WordDriver Loader.

CHAPTER 5: STUDY 1

“Among the issues that have come into better focus in the past decade is the fact that treatment outcome research is best conducted in phases, so there is a logical, principled progression in rehabilitation research that encompasses single-subject as well as group research designs...New treatments should first be examined with a small number of individuals to test the therapeutic effect...” (Beeson & Robey, 2006, p. 162)

This chapter describes the first study, the results of which have been recently published (Seiler, Leitão, & Blosfelds, 2013) – see Appendices M and N. Study 1 trialed the Decoding Intervention procedure and gathered preliminary data regarding effectiveness of the intervention. The literature discussed in Chapter 1 demonstrated the importance of skilled word reading: delays in this area affect most children with reading impairment, and word reading skills predict later reading achievement. Chapter 2 presented a discussion of the theoretical bases of word reading development, the factors that influence the development of efficient word reading skills, and the results of intervention studies for children with reading difficulties. Research supports the view that skilled word reading develops in phases and involves two main processes: the lexical route (for reading familiar sight words) and the non-lexical route (where grapheme-phoneme rules are used to decode unfamiliar words); and that delayed development of the non-lexical route underlies most word reading disorders. Evidence demonstrating the effectiveness of interventions targeting phonemic awareness and the alphabetic principle was presented, along with studies that have established the importance of phonological recoding and orthographic processing in the formation of well-developed *mental orthographic representations* (MORs) or sight words – a hallmark of the skilled reader.

In reviewing the literature relating to interventions for word reading impairment, three issues were identified. While many studies have examined Tier 1 and Tier 2 reading instruction and interventions, fewer studies have investigated Tier 3 interventions for children with persistent reading impairment. Secondly, most intervention methodologies involve a number of components, resulting in difficulty isolating the effects of each component. And finally, in most studies, about 25% of children fail to demonstrate an adequate response, suggesting that these children may

require a more targeted or modified approach, and that examination of individual profiles may clarify the nature of their response to the intervention.

The rationale of this research, outlined in Chapter 3, was to address these issues by designing a Tier 3 intervention (an iPad web app called WordDriver, described in Chapter 4) that involved a single component, thus enabling isolation of its specific effect on word reading skills. The intervention aimed to improve use of the non-lexical route by targeting processes (phonological recoding and orthographic processing) that have been shown to contribute unique variance to MOR development, and include a range of other evidence based features such as repetition, presenting items of similar grain size, and incorporating linguistic properties of words (orthotactic probability) in the presentation of items. The investigation of the effectiveness of this intervention on word reading skills aimed to use a research design that (a) was appropriate for evaluating a newly designed intervention procedure, and (b) allowed for examination of individual language, cognitive and phonological processing profiles.

Consistent with the first phase of research evaluating new interventions (Beeson & Robey, 2006), the main aims of Study 1 were to examine the effectiveness of this newly developed intervention in improving use of the non-lexical route (assessed by nonword reading) on a small number of participants, and to trial the function and implementation procedure of the intervention. Additionally it aimed to gather preliminary evidence about the impact of any changes in non-word reading on standardised measures of word reading, text reading, and reading comprehension; and the relationship between participant profile and response to intervention.

The research questions for Study 1 were:

1. Is an intervention that targets phonological recoding and orthographic processing effective in increasing nonword reading skills in Year 2 children with persistent word reading impairment?
2. What is the preliminary evidence regarding (a) the impact of improved nonword reading (as measured within the program) on standardised assessments of nonword reading accuracy, real and nonword reading efficiency, text reading and comprehension; and (b) the influence of pre-

intervention scores on language, intellectual and phonological processing skills on the outcome measures of real and nonword reading?

3. Are there modifications to the WordDriver program or to the implementation procedure that would enable increased efficiency in delivery of this intervention?

Method

Study design

This study used a single subject research design with three phases, as depicted in Figure 14.

Figure 14: Study 1 research design



The first phase (A¹) consisted of eight sessions in which the child's nonword reading skills were assessed to establish a pre-intervention baseline. In the second phase (B) the child received 15 Decoding Intervention sessions. This was followed by the third phase (A²) in which nonword reading skills were assessed post-intervention over eight sessions. Assessment of participant language, intellectual, and phonological processing skills was completed during the pre-intervention baseline sessions. Standardised assessments of word and nonword reading were also administered during the pre-intervention baseline phase by the researcher, and by a speech pathologist blind to the goals of the research during the post-intervention baseline phase.

Participants

Three Year 2 children (in their third year of school) aged 7 to 8 years - two girls and one boy, participated in this study. Teachers from a Victorian government school were asked to identify children they considered to have typically developing

oral language and intellectual skills, yet who continued to have problems with word reading despite previously completing reading intervention programmes, such as Reading Recovery (see Appendix F for the information and consent forms that were provided to schools). Reading intervention would typically have been delivered in the second year of school for children who had not progressed adequately in response to Tier 1 instruction in their first year of school. Hence the participants were representative of those children reported in the literature who demonstrate inadequate response to both classroom instruction (Tier 1) and additional reading interventions (Tier 2). The inclusion criteria were as follows:

- A score of more than 1 standard deviation (SD) below the mean on the Phonemic Decoding Efficiency subtest of the Test of Word Reading Efficiency 2 (TOWRE-2; Torgesen et al., 2012);
- A Core Language Score within 2SD of the mean on the Clinical Evaluation of Language Fundamentals-4 (CELF-4; Semel et al., 2003);
- No developmental or sensory impairment, as screened using a parent questionnaire (Claessen, Leitao, & Barrett, 2010);
- Hearing and vision in the normal range (school nurse screening);
- Intellectual skills in the average range using the Wechsler Intelligence Scale for Children IV Full Scale Score (WISC-4; Wechsler, 2003);
- Letter sound knowledge in the average range for consonants and short vowels using the Grapheme subtest of the Phonological Awareness Test-2 (PhAT-2; Robertson & Salter, 2007).

Approval for this research was granted by the Curtin University Human Research Ethics Committee (Appendix G) and the Victorian Department of Education (Appendix H). Procedures complied with confidentiality guidelines, and both caregivers and participants provided informed consent to participate. A final report was submitted to the Victorian Department of Education (Appendix I) following completion of the research.

Materials

The web app called WordDriver (the design and development of which was described in Chapter 4), was delivered on an iPad to present all items (words and nonwords) used in this study. WordDriver involved five modules; all using the analogy of learning to drive a car (see Figure 1, Chapter 4). Three modules were used in the intervention sessions at each of the five intervention levels (i.e., 2-, 3-, 4-, 5- and 6-letter strings): The L-Plate (Learner) was used to demonstrate phonological recoding, the P-Plate (Practice) provided practice, and the D-Plate (Driver) ensured mastery at each intervention level. The other two modules were administered at the beginning of all sessions (i.e., each baseline and intervention session): The T-Plate (Test) assessed nonword reading using the researcher-developed Assessment NW Lists (the dependent variable), and the S-Plate (Speed) assessed the motor component of the response when using the Driver interface.

The items were letter strings with 1:1 letter sound correspondence, thus presenting letter strings of similar type (Goswami et al., 2003). The Assessment NW Lists (T-Plate) used nonwords, and the intervention modules (L-Plate, P-Plate, and D-Plate) used both words and nonwords. In the intervention modules, the letter strings were presented with an increasing level of difficulty, starting with 2-letter strings at the first intervention level, and progressing through to 6-letter strings. Additionally, within each level the letter strings for the L- and P-Plate were presented in a pre-determined order (to teach the child to take note of each letter in a letter string), while those for the D-Plate were ordered from items with high (easy) and progressing to items with low (harder) orthotactic probability. Each of the 31 Assessment NW Lists required for the 16 baseline and 15 intervention sessions in Study 1 contained 70 items (2 x 2-letter, 11 x 3-letter, 25 x 4-letter, 19 x 5-letter, and 13 x 6-letter items). They were constructed to be of equal difficulty by use of a systematic allocation of nonwords according to their orthotactic probability value. The MRC Psycholinguistic Database (Coltheart, 1981) was the source for the real words and the ARC Database (Rastle et al., 2002) for the nonwords. The orthotactic probability values of both words and nonwords were calculated using the N-Watch method (Davis, 2005) which enables users to obtain a broad range of statistics (e.g., word frequency, orthotactic and phonotactic probability).

An iPad was used to present the stimuli in a systematic manner and record the child's responses, but unlike many other programs that are completed without the presence of an adult, the interactive role of the researcher was central to provide reinforcement and feedback regarding reading accuracy.

Measures

This research used three sets of measures to address the three research questions. The first set, addressing question one, measured the dependent variable (nonword reading accuracy) using two measures: nonword reading rate (NW Rate), and the total number of nonwords read accurately (NW Total), assessed by researcher-developed nonword lists (*Assessment NW Lists*: the generation of which is discussed in Chapter 4). These were administered at the start of each session (baseline and intervention) by the researcher. Nonword reading has been shown to predict later reading fluency (Good, Baker, & Peyton, 2008; Hudson et al., 2012), and has been used extensively in the literature to measure the child's mastery of grapheme-phoneme correspondence and phonological recoding (Good et al., 2008; Hempenstall, 2008; Hudson, Pullen, Lane, & Torgesen, 2009; McCandliss et al., 2003; Torgesen, 2001), which was the main goal of the intervention.

The second set, addressing question two, was employed to assess the impact of the intervention on a range of related literacy skills. These measures were administered during the pre-intervention baseline sessions by the researcher, and during the post-intervention sessions by an independent speech pathologist. They included:

- The *Test of Word Reading Efficiency-2* (TOWRE-2: Torgesen et al., 2012): A standardised test that assesses the accuracy and efficiency of an individual's ability to read words and nonwords out loud. It provides standard scores, percentile ranks, and age and grade equivalents. As reported in the test manual (Torgesen et al., 2012) this test demonstrated high test-retest reliability, with coefficients of .90 to .97, and high inter-rater reliability of .99. The concurrent validity was high when compared to the Woodcock Reading Mastery Test Revised (WRMT-R) with correlations between equivalent subtests ranging from .89 to .94. The TOWRE has adequate

content and construct validity.

- The Decoding subtests of the *Phonological Awareness Test-2* (PhAT-2: Robertson & Salter, 2007): A standardised test that assesses decoding accuracy with eight subtests: VC (vowel-consonant), CVC (consonant-vowel-consonant), Consonant Digraphs (digraph refers to one sound spelled by two consonants, e.g., *sh*), Consonant Blends (two consonant sounds spelled by two letters, e.g., *st*), Vowel Digraphs (one vowel sound spelled by two letters, e.g., *ow*), R-Controlled Vowels (vowels that include “r”, e.g., *ur, ir, or*), CVCe patterns (items where the final “e” affects the vowel sound, e.g., *mate*), and Vowel Diphthongs (two vowel sounds that occur in one syllable, e.g., *boat, boy*). It provides standard scores and percentile ranks. As reported in the test manual (Robertson & Salter, 2007), this test demonstrated high test-retest reliability, with coefficients of .80 to .84, and high inter-rater reliability of .97. Only one form is available for this test. However, since the Decoding Intervention presented hundreds of nonwords, it was judged unlikely that a practice effect would occur between baselines.
- The *Neale Analysis of Reading Ability 3rd edition* (Neale, 1999): A standardised test that assesses accuracy, rate, and comprehension of text reading using Australian norms. It provides stanine scores, percentile ranks, and reading age equivalents. As reported in the test manual (Neale, 1999) this test has demonstrated high internal consistency, with Kuder-Richardson reliability coefficients above .91 for rate and accuracy, and .71 for comprehension. Its criterion-related validity has been established with a range of tests (Holborn Reading Test, Vernon and Schonell Reading Tests, and the DART) with significant correlations between .70 and .77. It has well substantiated validity with respect to content and construct validity. Two forms are available for pre- and post-intervention testing.

The third set of measures, addressing question three, was administered prior to Study 1 by the researcher, to determine if pre-intervention language, phonological processing, and intellectual skills influenced participant response to intervention. These included:

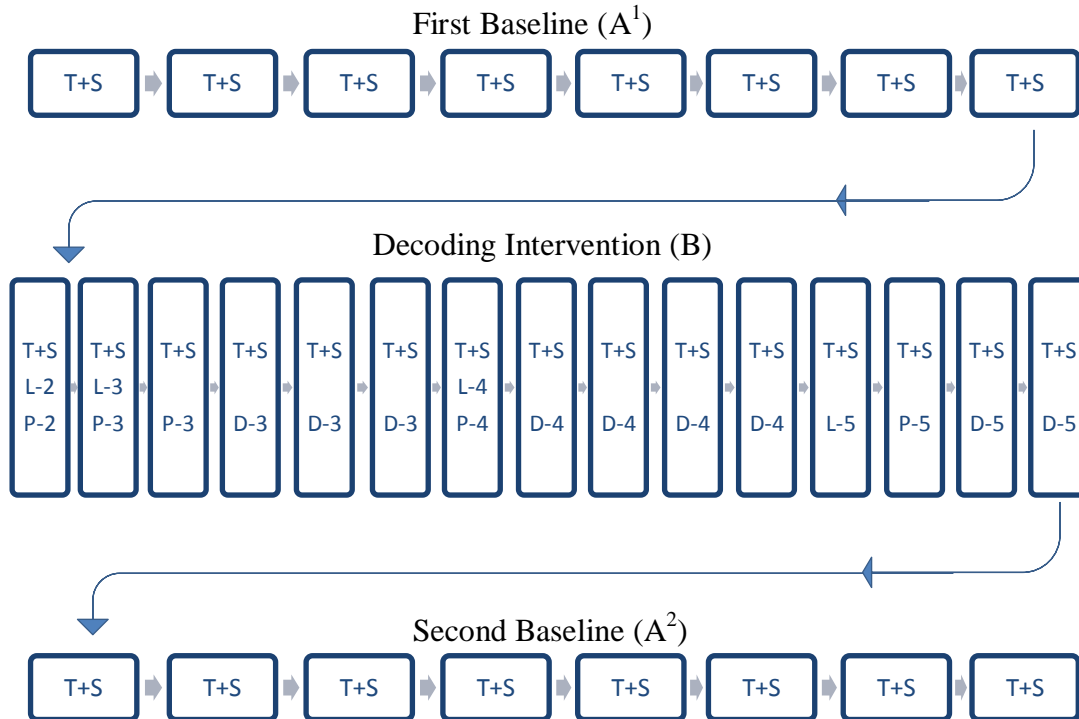
- The *Clinical Evaluation of Language Fundamentals 4* (CELF-4: Semel et al., 2003): A commonly used clinical assessment tool with Australian norms which measures a range of language skills in children. As reported in the test manual (Semel et al., 2003) this test demonstrates high inter-scorer reliability (with scores between .99 and 1.0 across all 18 subtests), high internal consistency (with reliability coefficients ranging from .70 to .92).
- The *Comprehensive Test of Phonological Processing 2* (CTOPP-2: Wagner et al., 2013): This test uses words and nonwords to assess three components of Phonological Processing - Phonological Awareness, Phonological Memory and Rapid Naming. It generates standard scores, percentile rank, and age and grade equivalents. As reported in the test manual (Wagner et al., 2013) The CTOPP-2 evidences a high degree of reliability with respect to content, time and scorer, with coefficients between .78 and .99. The criterion-prediction validity with reference to the WRMT-R was reported as moderate to strong with correlations ranging from .55 to .66.
- Intellectual skills were assessed by the *WISC IV Australian* (Wechsler, 2003). The researcher administered the WISC IV for research purposes (as requested by the Department of Education and Early Childhood Development Victoria) under the guidance of a psychologist. This test is an individually administered instrument for assessing the cognitive ability of children between the ages of 6 and 16 (Wechsler, 2003). It has Australian norms, and generates percentile rank and standard scores. As reported in the test manual (Wechsler, 2003) it has high internal consistency (with reliability coefficients of subtests ranging from .75 to .95), and high inter-rater reliability coefficients (.99).

Procedure

Each participant was involved in a total of 31 sessions of 15 to 20 minutes duration undertaken at their school. Figure 15 illustrates the expected progression through the modules that might occur during each phase (A¹, B, and A²), and

Appendix J presents a manual which provides a detailed script for each of the intervention modules.

Figure 15: Presentation sequence of modules



Note: T = T-Plate; S = S-Plate; L-2 = L-Plate 2-letter level; P-2 = P-Plate 2-letter level; D-3 = D-Plate 3-letter level; L-4 = L-Plate 4-letter level (and so on)

Figure 15 shows a typical example progression through the eight pre- and eight post-baseline sessions (A¹ and A²) in which two tasks, the Assessment NW List (T-Plate) and the speed of the motor response (S-Plate), are administered. During the 15 Decoding Intervention sessions (B), the child begins each session with the T-Plate (Test, the Assessment NW List) followed by the S-Plate (Speed, assessing the motor component of the task), and then completes one or more of the intervention modules - the L-Plate (Learner), P-Plate (Practice), or D-Plate (mastery), thus completing each 20 minute intervention session.

In the typical example depicted in Figure 15, during the first Decoding Intervention session, after completing the T- and S-Plate, the child completes the L-Plate and P-Plate at the 2-letter level. The second intervention session involves a similar sequence at the next level, the 3-letter level (as there is no D-Plate at the 2-letter level), but does not reach criterion on the P-Plate. During the third intervention session (following the T- and S-Plates) the child repeats and reaches criterion on the

P-Plate at the 3-letter level. During the fourth intervention (following the T- and S-Plates) the child is presented with the D-Plate at the 3-letter level, does not reach criterion, thus repeats the D-Plate at the 3-letter level until the sixth session when the criterion of 90% accuracy is reached. The child then moves to the L- and P-Plates at the 4-letter level in the seventh intervention session. Hence, at each level, the child completes the L- and P-Plate. Once criterion is reached for the P-Plate the child moves to the D-Plate at that level. After achieving criterion on the D-Plate, the child moves to the next level.

To complete the T-Plate the child observes a demonstration from the researcher and is instructed to say each item as quickly and accurately as possible. The child then touches the *Go* button on the iPad, reads the item out loud, and continues to touch the *Go* button to view the following items. No feedback about accuracy is given and responses are recorded on a digital recorder for later analysis. The child is told to stop after one minute (if they have made six errors in eight consecutive items in that time period), or after they make six errors in eight consecutive items. This generates two scores: NW Rate (the number of items read correctly in one minute) and NW Total (the total number of items read correctly).

The S-Plate presents 20 items using the same interface as the T-Plate except no letter string is presented. The child is instructed to touch the *Go* button to reveal the white road sign, and as soon as the sign changes to black, to touch the *Go* button again as quickly as possible to change the colour from black back to white. The speed of motor response (time in milliseconds from colour change of the screen to black to the *Go* button being touched) is automatically recorded by the WordDriver program.

The L-Plate is the starting point at all of the Decoding Intervention levels (2-, 3-, 4-letter strings etc.). The researcher demonstrates use of the task and the process of phonological recoding (i.e., sounding out and blending the sounds to read the item) at that level. This is followed by the P-Plate (where the child practices phonological recoding with a controlled set of words). Following mastery on the P-Plate the child is presented with the D-Plate (full driver's license).

The D-Plate procedure involves the child touching the *Go* button and reading out loud the randomly presented item (word or nonword). Following verbal feedback about accuracy of response from the researcher the child touches the *Correct* button for accurate phonological recoding, or the *Help* button following an inaccurate

response. The child then puts real words in the Book and nonwords in the Bin by touching either graphic, and touches the Go button when they are ready to start the next trial. The D-Plate uses a PEST algorithm, based upon that used by McArthur et al. (2008) in which the computer program responds to the accuracy of the child's response. As errors are made the program presents increasingly easier letter strings (higher orthotactic probability). If the child's responses are accurate, the program presents letters strings of increasing difficulty (lower orthotactic probability). The child is required to reach 90% accuracy to move on to the next level (i.e., to move from 2- to 3-letter, or from 3- to 4-letter items).

Three levels of help are available for inaccurate responses:

- Visual highlighting of each letter to prompt phonological recoding
- Visual highlighting with auditory cues showing how to sound out the word
- Demonstration by the researcher of phonological recoding to read the real or nonword.

To strengthen MOR development, the verbal feedback involved a scripted sentence (see Appendix B) for real words explaining the meaning of the word, and for nonwords, a sentence explaining that it was not a word and thus had no meaning. At the completion of the intervention task, the program calculated percentage correct responses.

Results

The aims of this study were three fold. Firstly it evaluated the effectiveness of the intervention (independent variable) on improving nonword reading skills (dependent variable) assessed by nonword reading rate (NW Rate) and accuracy (NW Total) using researcher-developed Assessment NW Lists. Secondly, it examined initial evidence about (a) the impact of improved nonword reading on standardised assessments of nonword reading accuracy, word and nonword reading efficiency, and text reading and comprehension; and (b) the influence of pre-intervention profiles of language, intellectual, and phonological processing profiles, on response to intervention. Thirdly, the intervention procedure and materials were trialled to determine if modification were required prior to Study 2.

This section initially displays each participant's progression through the Decoding Intervention modules. Following this, the results for each of the research aims are presented:

1. Nonword reading rate and accuracy
2. a) Standardised assessment results
2. b) Participant profiles of language, intellectual, and phonological processing skills
3. Modifications to intervention procedure and materials

Participant Decoding Intervention record

While the two baseline phases (A¹ and A²) were identical for each participant, progression through the Decoding Intervention (B) varied between participants. Table 3 shows the record of Decoding Intervention modules (L-Plate, P-Plate, and D-Plate) completed by each participant during the 15 Decoding Intervention sessions.

Table 3: Study 1 participant Decoding Intervention record

		Decoding Intervention session number														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P1	L2	L2	L2	L3							L4					
	P2	P2	P2	P3							P4	P4				
					D3	D3	D3	D3	D3	<u>D3</u>			D4	D4	D4	<u>D4</u>
P2	L2	L2	L2		L3	L3	L3									L4
	P2	P2	P2	P2		P3	P3									P4
								D3	D3	D3	D3	D3	D3	D3	<u>D3</u>	
P3	L2	L3			L4						L5	L5		L5		L5
	P2	P3			P4											P5
			D3	<u>D3</u>		D4	D4	<u>D4</u>	<u>D4</u>				D4		<u>D4</u>	

Note: Pn = Participant number; L2 = L-Plate 2-letter level; P2 = P-Plate 2-letter level; D3 = D-Plate 3-letter level; Dn (underlined) = criterion reached for the D-Plate

This record shows that at the completion of the Decoding Intervention two participants reached the criterion of 90% accuracy at the 4-letter level (P1 and P3), and P2 reached criterion at the 3-letter level. Individual notes of each participant's progress are as follows:

- P1 took four sessions to master the phonological recoding strategy during the initial P-Plates at the 2- and 3-letter level. Her scores on the 3-letter level D-Plate ranged from 80% to 85% accuracy reaching 100% accuracy in session nine. Scores on the 4-letter D-Plate ranged from 71% to 85% reaching criterion of 90% in session 15.
- P2 took seven sessions to master the phonological recoding strategy. His scores on the 3-letter level D-Plate ranged from 50% to 85% reaching criterion of 90% at session 14.
- P3 mastered the phonological recoding strategy within two sessions, and reached criterion of 90% on the 3-letter level D-Plate in session four. This child was extremely distractible, hence, though she reached criterion of 90% on the 4-letter level D-Plate in session eight, this module was re-presented in session nine to consolidate skills and boost her confidence. When attempting the next level (5-letter L-Plate) in the following two sessions her distractibility increased. Though she failed to reach criterion on the 4-letter level D-Plate in session 12, she again reached criterion at the 4-letter level in session 14.

Nonword reading rate and accuracy

The initial starting point for this intervention was determined by the pre-intervention assessments of nonword reading assessed by the decoding subtests of the Phonological Awareness Test-2 (Robertson & Salter, 2007). All participants began at the 2-letter level (as each made errors on items with two letters) but reached different levels: Participant 1 (P1) progressed to four letter strings, Participant 2 (P2) to three letter strings, and Participant 3 (P3) to five letter strings. Two data sets were analysed to evaluate the effectiveness of intervention on nonword reading: the Assessment NW Lists (T-Plate), and the speed of motor response (S-Plate).

Assessment NW Lists: T-Plate

Effectiveness was examined through analyses of the primary measures, NW Rate and NW Total, using visual inspection of the graphed responses and the 2SD band method (Portney & Watkins, 2009; Rubin, 2010).

Visual inspection involves analyses of within-phase characteristics of stability of the graphed responses (how variable responses are), and trend (direction of change); and between-phase changes in level, trend, and slope of data points across adjacent phases (from baseline to intervention phase). For each participant, three sets of data were graphed. The first two were the measures of the dependent variable: NW Rate (number of nonwords accurately read in 60 seconds), and NW Total (the total number of nonwords accurately read to a ceiling of six errors in eight consecutive items). The third was the number of nonwords attempted in 60 seconds (*NW Attempted*) which provided additional information for the interpretation of individual response. For example, a small number of correct responses could occur because the child was slow and accurate (e.g., attempted five items with four correct), or because the child attempted many items but was predominantly inaccurate (e.g., attempted 20 items with four correct). By including both sets of data (NW Attempted and NW Rate) the characteristics of each child's pattern of decoding accuracy was mapped. Additionally, as each Assessment NW List was comprised of 2 x 2-letter, 11 x 3-letter, 25 x 4-letter, and 13 x 6-letter items (total of 70 items), the NW Rate and NW Total scores provided information about the child's decoding level. For example, scores below 13 on NW Attempted and NW Rate indicate that the child attempted and made errors on 2-letter and 3-letter items, while scores above 30 or 40 indicate that the child accurately decoded 4- and 5-letter items.

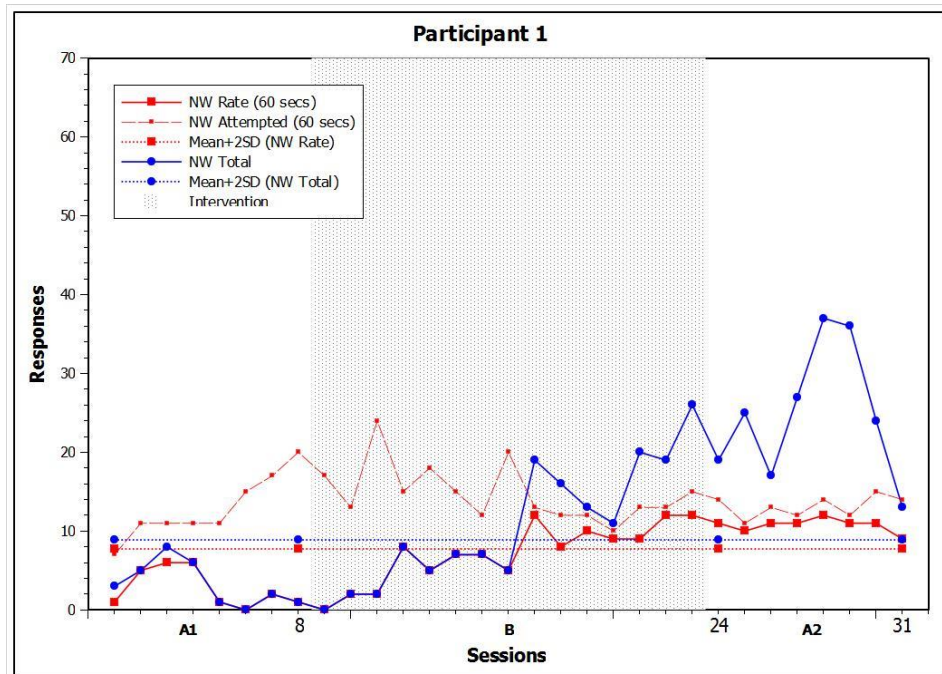
The 2SD band method (Portney & Watkins, 2009; Rubin, 2010) assessed whether there was a statistically significant difference between the first baseline and the intervention phase. After the variability of responses in the first baseline was established using the mean and standard deviation (SD), the 2SD band was drawn on the first baseline phase and extended across the intervention and remaining baseline phase. If at least two consecutive data points in the intervention phase fall outside the 2SD band, changes from the first baseline are considered significant (Portney & Watkins, 2009). The stability of the first baseline was also evaluated using Statistical Process Control (SPC) where responses that fall within 3SD are considered to be within common cause (Portney & Watkins, 2009).

The graphed data for each participant are presented with an analysis of the visual inspection and the statistical analysis using the 2SD band method.

Participant 1 (P1)

The graphed responses for P1 are depicted in Figure 16.

Figure 16: 2SD band analysis for P1



Note: NW Rate (60 secs) = number of correct responses in 60 secs; NW Attempted (60 secs) = number of attempted items in 60 seconds; Mean+2SD (NW Rate) = 2SD band for NW Rate; NW Total = total number of correct responses; Mean+2SD = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for both NW Rate and NW Total as all data points fell within the 2SD band, therefore consistent with the SPC definition of stability (i.e., within 3SD of the mean). There was no clear trend as scores were variable for both measures.

Phase B: After the eighth intervention session the number of correct responses (i.e., the level of response) increased and the trend was for increasing accuracy of response for both measures. The slope for NW Total was more pronounced than for NW Rate.

Phase A²: The level remained constant and there was no trend or slope for NW Rate indicating stable maintenance of skill. The first four data points for NW Total also demonstrated stability in level, trend, and slope. This was followed by a sharp increase and then decrease in level for the last 4 data points, indicating that the skill level remained above the 2SD band, but that there was some variability.

Visual inspection of the number of nonwords attempted in 60 seconds (NW Attempted) compared to the NW Rate score indicates that while the number of attempted items remained reasonably constant, the proportion of accurate responses in 60 seconds (NW Rate) increased. During A¹ the mean NW Attempted score was 12.88 (SD 4.16) and NW Rate was 2.75 (SD 2.49) compared to A² with a mean NW Attempted of 13.13 (SD 1.36) and NW Rate 10.75 (SD 0.89). This indicates a higher proportion of correct responses in A² compared to A¹, and that by the 9th intervention session responses were correct for most attempted items.

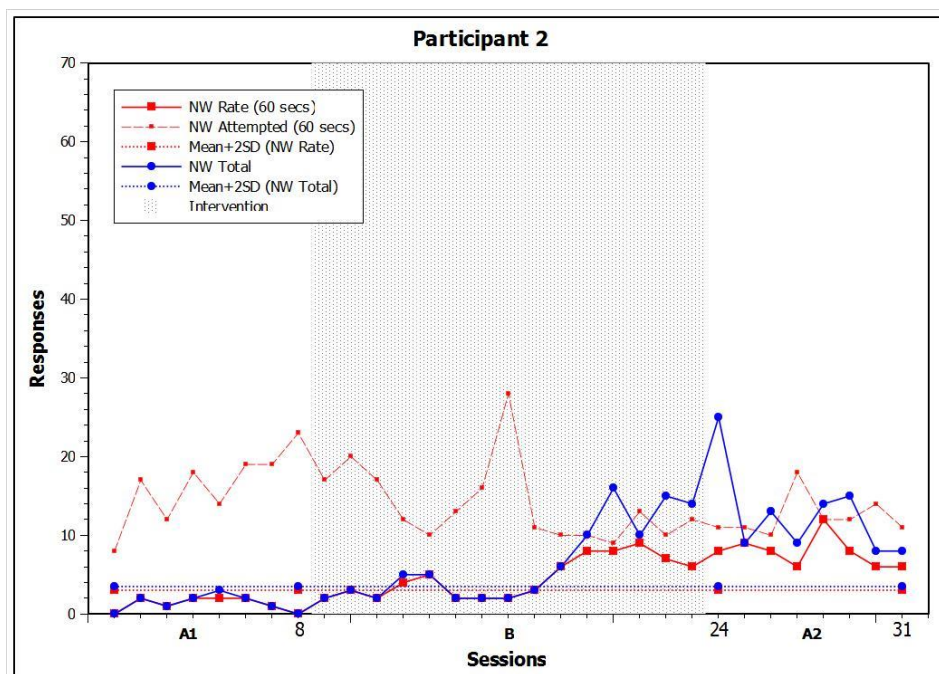
2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. Within the intervention phase (B) eight consecutive data points from session nine to 15 were above the 2SD band for both measures. This was sustained throughout A² indicating that the effects of intervention were maintained.

Participant 2 (P2)

The graphed responses for P2 are depicted in Figure 17.

Figure 17: 2SD band analysis for P2



Note: NW Rate (60 secs) = number of correct responses in 60 secs; NW Attempted (60 secs) = number of attempted items in 60 seconds; Mean+2SD (NW Rate) = 2SD band for NW Rate; NW Total = total number of correct responses; Mean+2SD = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points fell within the 2SD band. There was no clear trend as scores remained at a similar level for both measures.

Phase B: After the third intervention session scores increased for two consecutive sessions, but subsequently fell for the next four sessions. From the tenth to the fifteenth session scores increased with a trend for increasing accuracy of response for both measures. The slope for NW Total was more pronounced than for NW Rate.

Phase A²: Scores plateaued with minor variability, and there was no trend or slope for either NW Rate or NW Total indicating stable maintenance of skill.

Visual inspection of the number of nonwords attempted in 60 seconds (NW Attempted) compared to the NW Rate score indicates that apart from an outlier at session 16, the number of attempted items remained reasonably constant and the

proportion of accurate responses in 60 seconds (NW Rate) increased. During A¹ the mean NW Attempted score was 16.25 (SD 4.71) and NW Rate was 1.25 (SD 0.89) compared to A² with a mean NW Attempted score of 12.38 (SD 2.56) and NW Rate 7.88 (SD 2.03). This indicates a higher proportion of correct responses in A² compared to A¹, and that by the 11th intervention session most of the attempted items were correct.

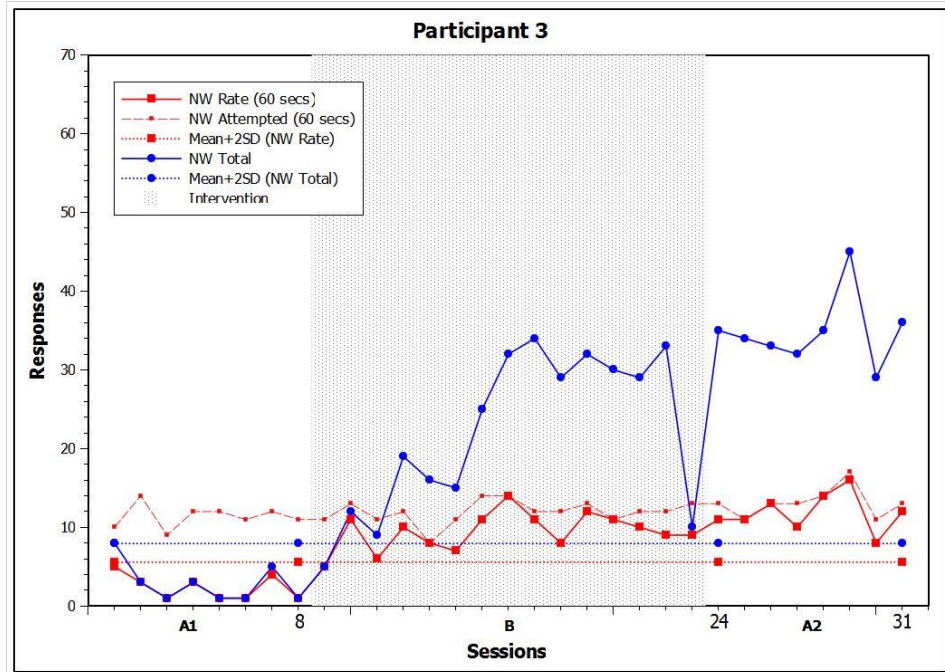
2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. Within the intervention phase (B), two consecutive data points (sessions 4 and 5) and a further six consecutive data points (sessions 10 to 15) were above the 2SD band for both measures. This was sustained throughout A² indicating that the effects of intervention were maintained.

Participant 3 (P3)

The graphed responses for P3 are depicted in Figure 18.

Figure 18. 2SD band analysis for P3



Note: NW Rate (60 secs) = number of correct responses in 60 secs; NW Attempted (60 secs) = number of attempted items in 60 seconds; Mean+2SD (NW Rate) = 2SD band for NW Rate; NW Total = total number of correct responses; Mean+2SD = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points fell within the 2SD band. There was no clear trend as scores were variable for both measures.

Phase B: After the third intervention session scores increased and the trend was for increasing accuracy of response for both measures. The slope for NW Total was more pronounced than for NW Rate. An outlier data point was observed for NW Total on session 15 where the score fell dramatically but was still over the 2SD band.

Phase A²: Scores remained constant and there was no trend or slope for NW Rate or NW Total indicating stable maintenance of skills.

Visual inspection of the number of nonwords attempted in 60 seconds (NW Attempted) compared to the NW Rate score indicates that while the number of attempted items remained constant, the proportion of accurate responses in 60 seconds (NW Rate) increased. During A¹ the mean NW Attempted score was 11.38 (SD 1.51) and NW Rate was 2.38 (SD 1.60) compared to A² with a mean NW

Attempted score of 13.13 (SD 1.89) and NW Rate 11.88 (SD 2.47). This indicates a higher proportion of correct responses in A² compared to A¹, and that by the 2nd intervention session, responses were correct for most of the attempted items.

2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. Within the intervention phase (B), fourteen consecutive data points from session two to 15 were above the 2SD band for both measures. This was sustained throughout A² indicating that the effects of intervention were maintained.

Summary

The results of the visual inspection of the graphs indicated that all participants achieved a stable pre-intervention baseline (as all data points fell below the 2SD band and therefore within 3SD of the mean). During the intervention phase scores increased (i.e., the level of response increased), the trend was for increasing accuracy of response for both measures, and the slope for NW Total to become more pronounced than NW Rate. The results of the 2SD band analyses indicated that all participants demonstrated a statistically significant difference between the pre-intervention baseline and intervention phases (two or more consecutive data points fell above the 2SD band during the intervention phase), and that this was maintained during the post-intervention phase. P1 achieved significance for NW Rate and NW Total on the 9th intervention session, P2 on the 11th, and P3 on the 2nd intervention session.

Speed of motor response: S-Plate

The speed of response to the motor component of the task (S-Plate) was evaluated to determine if increased proficiency with using the iPad-delivered materials contributed to the NW Rate score. Table 4 presents the means and SDs of each session and phase (A¹, B, A²) for each participant, and Figure 19 depicts the graphed mean response times for each participant.

Table 4: Study 1 participant mean S-Plate times

S-Plate		P1		P2		P3	
Phase	n	M	SD	M	SD	M	SD
A ¹	8	1.1	0.7	1.0	0.5	1.6	1.2
B	15	0.8	0.5	0.9	0.8	1.0	0.7
A ²	8	0.7	0.3	0.8	0.6	1.0	0.7

Table 4 shows that the mean response times for these three participants ranged from 0.7 to 1.6 seconds with standard deviations from 0.3 to 1.2 seconds. These results suggest that there was minimal change in motor response time for any of the participants.

Figure 19: Study 1 S-Plate graphed responses

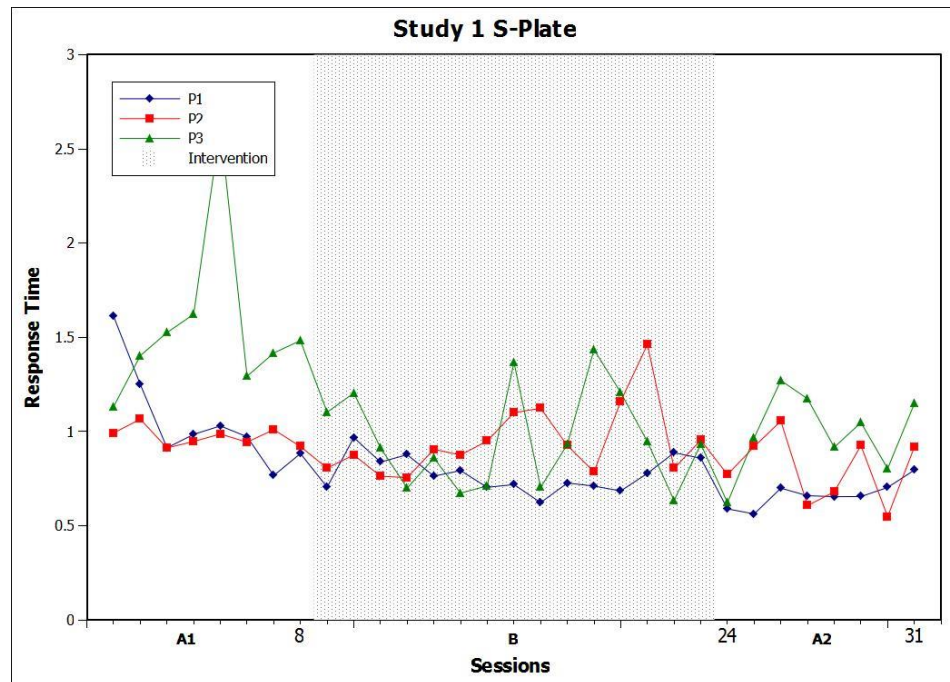


Figure 19 shows the mean response times for each participant. It suggests that apart from one outlier data point for P3, participant responses remained within one to 1.5 seconds across all phases.

Standardised assessment results

The second research question related to preliminary evidence regarding the impact of improved nonword reading (assessed by the two measures of the dependent variable), on the pre- post- intervention scores on standardised assessments of real and nonword reading efficiency, nonword reading accuracy, and text reading and comprehension. Results of the pre- post-intervention scores on the standardised reading assessments for which clinically significant changes occurred are presented in Table 5 (see Appendix K for all the complete set of results). A clinically significant change was judged to occur when a standard score moved

across a boundary as defined in the test manual (e.g., from “below average” to “average” in the case of the TOWRE-2), or from below 1SD to the average range.

Table 5: Study 1 scores on pre- and post-intervention standardised tests

Tests	P1		P2		P3	
	Pre	Post	Pre	Post	Pre	Post
TOWRE-2: standard score (average range 90-110)						
SWE	91	92	79	76	78	87*
PDE	76	91*	66	67	69	76*
PhAT-2 Decoding: standard score (normal range 86 – 115)						
VC	84	114*	87	93	87	112
CVC	97	112	75	108*	75	114*
Cons Dig	87	100	<73	73	73	100*
Cons Blend	81	103*	<77	77	<77	90*
Total Score	82	94*	73	78	77	88*
Neale Analysis: percentile rank (reading age)						
Accuracy	6(6.0)	10(6.3)	4(<6.0)	10(6.3)	4(<6.0)	11(6.4)
Comp	12(6.7)	15(6.9)	1(<6.0)	10(6.3)	10(6.3)	15(6.9)
Rate	21(6.10)	9(6.1)	8(6.0)	11(6.4)	16(6.8)	13(6.5)

Note: SWE – Sight Word Efficiency; PDE = Phonemic Decoding Efficiency; VC = Vowel Consonant; CVC = Consonant Vowel Consonant; Cons Dig = Consonant Digraph; Cons Blend = Consonant Blends; Comp = Comprehension; * clinically significant positive change

The TOWRE-2 assesses efficiency of real word (Sight Word Efficiency) and nonword (Phonemic Decoding Efficiency) reading. Using the TOWRE-2 descriptors (very poor, poor, below average, average, above average, superior, very superior) two participants made clinically significant gains in nonword reading (phonemic decoding) efficiency: P1 moved from poor to average, and P3 from very poor to poor. Word reading efficiency improved for P3 (from poor to below average), and remained the same for P1 (in the average range), and P2 (in the poor range).

The PhAT-2 decoding subtests assess accuracy of nonword reading using eight subtests. All participants made clinically significant gains in one or more areas targeted in this intervention (VC, CVC, and Consonant Blends). P1 moved from <1SD below the mean to normal range in two areas (VC and Consonant Blends). P2 improved from moderate impairment to normal range in one area (CVC), and P3 from moderate impairment to normal range in two areas (CVC and Consonant

Blends). Two participants generalized skills to a non-targeted area, and made clinically significant gains in the Total Score (overall decoding): Consonant Digraphs (P3), Total Score (P1 and P3).

The Neale Analysis of Reading Ability 3rd edition assesses accuracy, comprehension, and rate of text reading. While all participants made gains in reading accuracy, only P3 made gains in reading age (gain of more than 4 months) which exceeded the level which would be expected between pre- to post-test assessments from March to June. Comprehension scores did not change for P1, made the expected gain for P2, and demonstrated a 6 months gain for P3. Rate of reading decreased for P1 and P3, and increased for P2.

Participant pre-intervention profiles

The second research question also investigated preliminary evidence regarding the influence of participant profiles of language, intellectual, and phonological processing skills on response to intervention. Given the small number of participants in this study, the impact of participant profiles on response to intervention was explored by comparing the number of pre-intervention scores that fell below 1SD (Table 6) to the number of areas where clinically significant gains were made for each participant (Table 5).

Table 6: Study 1 scores on pre-intervention profile assessments

Tests	P1	P2	P3
CELF-4 (normal range 86 – 115)			
Core Language Score	100	96	82*
Receptive Language Score	111	72*	84*
Expressive Language Score	102	102	86
WISC IV (normal range 86 – 115)			
Full Scale	96	81*	89
Verbal Comprehension	102	96	93
Perceptual Reasoning	92	90	100
Working Memory	91	80*	86
Processing Speed	100	70*	88
CTOPP-2 (normal range 86 – 115)			
Phonological Awareness	85*	82*	94
Phonological Memory	91	91	64*
Rapid Naming	91	73*	91

Note. *scores >1SD below the mean

Tables 5 and 6 indicate that P1 scored >1SD below the mean on one pre-intervention profile skill (phonological awareness) and made four clinically significant gains (TOWRE-2 Phonemic Decoding Efficiency; PhAT-2 VC, Consonant Blends, and Total Score). P2 scored >1SD below the mean on five pre-intervention profile skills (CELF-4 Receptive Language; WISC IV Full Scale, Working Memory, and Processing Speed; and CTOPP-2 Phonological Awareness, and Rapid Naming), and made one clinically significant gain (PhAT-2 CVC). P3 scored >1SD below the mean on three pre-intervention profile skills (CELF-4 Core Language, and Receptive Language; and CTOPP-2 Phonological Memory) and made six clinically significant gains (TOWRE-2 Sight Word Efficiency and Phonemic Decoding Efficiency; PhAT-2 CVC, Consonant Digraphs, Consonant Blends, and Total Score). These results on this small sample of children suggest that the child (P2) with the greatest number of pre-intervention profile scores that fell >1SD below the mean made the least number of clinically significant gains, but no other patterns emerged.

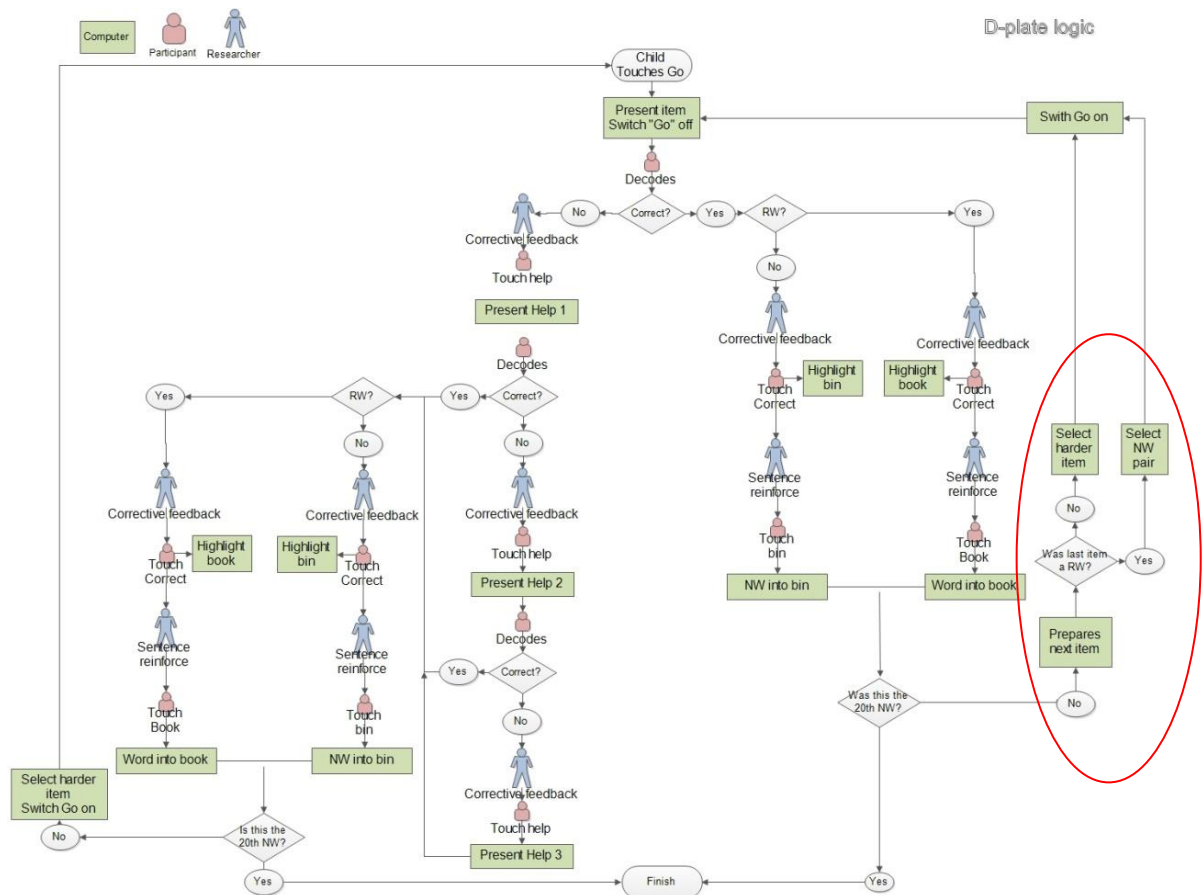
Modifications to intervention procedure and materials

The third aim of Study 1 was to trial the intervention procedure and the iPad-delivered intervention materials. Six minor modifications were made to the iPad-delivered materials and procedures during the first few sessions of the trial.

The first two related to decreasing visual distractions of the graphic display on the iPad. The timer (which displayed time elapsing in seconds) on the Assessment NW lists was removed as participants began looking at how much time had gone past, which diverted their attention from decoding. The dial on the D-Plate which provided feedback about percentage correct (dial moved forward or backwards following touching of the Correct or Help button respectively) was modified to show only the progress through the sequence for each run. This change was prompted because some participants did not want the Help button touched as this resulted in the dial moving backwards.

Two modifications were made to the WordDriver program. Firstly, the PEST settings that are used in the D-Plate required adjustment, as at the end of some of the D-Plate sessions the same word was presented repetitively. The D-Plate is constructed of paired real and nonwords. In the original setting, the PEST randomly presented real or nonwords until 20 nonwords had been attempted. Incorrect responses resulted in presentation of harder items, and correct responses easier items. If, by chance, a series of real words was presented, the child was more likely to produce correct responses (as they may know those words as sight words), and thus progress quickly through the sequence of available pairs. Having reached the end of the sequence, the PEST would continue to present the same item until 20 nonwords had been attempted. To remedy this, the program was modified to respond differently to an accurate response on a word versus a nonword. While a correct response on a nonword continued to result in presentation of a harder item (one with a lower orthotactic probability value), an accurate response on a word was changed so that WordDriver presented the matching nonword of the pair. Figure 20 depicts the revised D-Plate logic, with the changed logic circled in red.

Figure 20: D-Plate logic post Study 1

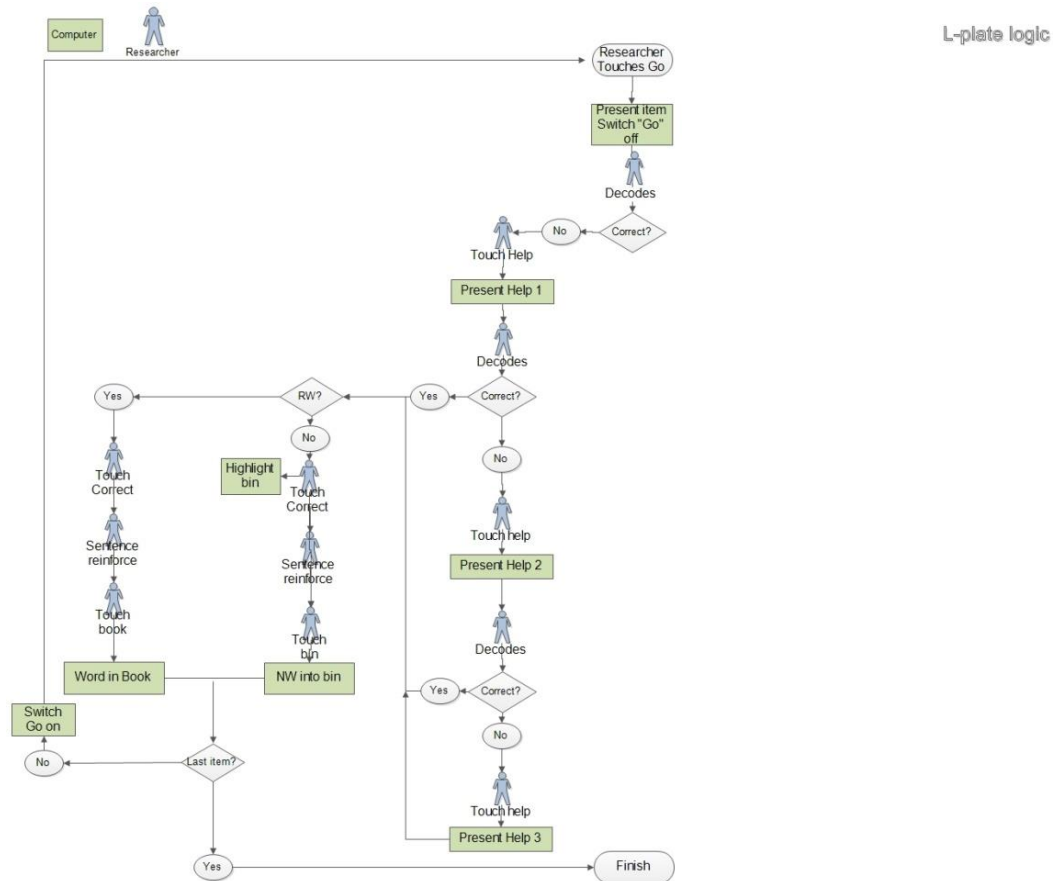


This modification ensured that the child is presented with a nonword from each level of difficulty and would not progress through the session by reading sight words, which occurred when, by chance, a series of real words were presented. Additionally, the weighting of random selection was changed from 50:50 to 60:40 in favour of nonword selection. The original setting of 20 nonwords per run was unchanged.

The second minor modification to WordDriver related to the role and function of the L-Plate module. Within the first two Decoding Intervention sessions it was observed that researcher demonstration of phonological recoding (i.e., sounding out and blending) did not result in participant adoption of phonological recoding to decode items: they continued to use their existing strategy which was to use the first letter as a cue and guess. The role of the L-Plate module was changed from that of demonstration to one of explicit teaching of the phonological recoding strategy. To support this, the WordDriver program was modified to display the procedure following an incorrect response on all items, that is, to show two or three

levels of Help for each item thus providing participants with a visual and auditory depiction of the phonological recoding strategy. Figure 21 displays the modified L-Plate logic, showing that the procedure for correct response has been removed.

Figure 21: L-Plate logic post Study 1



This modification was successful in encouraging participants to attend to the visual demonstration of phonological recoding (at the first and second levels of Help), and to observe the researcher perform phonological recoding at the third level of Help.

The remaining two modifications related to procedural aspects in the delivery of the intervention materials. The procedure for providing feedback about accuracy of response was changed. Originally, after the child attempted phonological recoding on an item, verbal feedback from the researcher regarding accuracy was provided, and the child touched the Correct or Help button. However, participants sometimes mistakenly touched the Correct button, which meant the PEST automatically presented increasingly difficult items and calculated an inaccurate score. The

procedure was changed so that the researcher performed both tasks (i.e., provided verbal feedback about accuracy and touched the Correct or Help button). The second modification to procedure related to the use of the scripted sentences. These were originally used by the researcher as feedback following decoding of real words to illustrate the meaning and support formation of MORs. However, participants tended to spontaneously produce their own sentences. This was considered to be more motivating than listening to the scripted sentence, and provided a more meaningful and salient context for MOR development.

In sum, six minor modifications were made during the first four to five intervention sessions to reduce distractibility of the graphics and repetition of items, and to streamline the delivery of the intervention. These modifications did not influence the accuracy of data collection.

Discussion

This study investigated three research questions. In relation to the first question, it was found that, though each participant progressed through the Decoding Intervention at different rates and achieved different levels of mastery, the iPad-delivered intervention designed to target phonological recoding and orthographic processing was effective in significantly increasing nonword reading rate and accuracy as measured by the dependent variable, and the effects remained significant during the follow-up baseline phase. The improved nonword reading performance was not related to increased speed in the motor aspects of using the iPad-delivered materials, as there were minimal changes to the speed of motor response measurements as participants progressed through the three phases of the intervention. Furthermore, inspection of the graphed responses revealed that while the number of attempted items in 60 seconds remained reasonably constant, the proportion of correct responses increased during and following the Decoding Intervention. This indicates that the low pre-intervention scores were due to inaccurate decoding (rather than slow decoding or that few items were attempted) and that the proportion of correct responses increased once intervention was introduced. Direct replication across three participants is considered sufficient to demonstrate that findings are not a result of chance (Portney & Watkins, 2009), hence the results of Study 1 suggest that this intervention significantly improved nonword reading, a skill that has been

shown to predict reading success (Good et al., 2008; Hempenstall, 2008; Schatschneider et al., 2004).

In addressing the second research question, the results provide preliminary evidence that the improvements in nonword reading were reflected in clinically significant gains in some standardised tests. All participants made clinically significant gains in accuracy of nonword reading in those areas targeted in the intervention (VC, CVC, and Consonant Blends) and trends for generalisation were observed in one of the non-targeted areas – Consonant Digraphs. However, there was no change in performance in other non-targeted skills (i.e., vowel spelling patterns: Vowel Digraphs, R-Vowels, CVCe, and Vowel Diphthongs). Inspection of pre-intervention decoding responses on the PhAT-2 revealed that all participants demonstrated knowledge of consonant digraph letter-sound correspondence (i.e., pre-intervention errors on those items were due to incorrect decoding of the vowel or final consonant), but no participant had mastered knowledge of vowel digraphs. This suggests that the improved orthographic processing targeted in this intervention supported generalisation to items where the letter-sound correspondence was already mastered (i.e., consonant digraphs) and that this group of children may require a specific intervention to develop letter-sound knowledge of vowel spelling patterns. With respect to generalisation to word reading and reading comprehension, one participant (P3) demonstrated a trend for improvements in these areas, but overall the higher scores, particularly in text reading and comprehension, were more likely due to the passage of time. An interesting observation was that the post-intervention rate of text reading slowed for two participants, suggesting that the intervention encouraged increased attention to accuracy of reading rather than guessing. These outcomes are consistent with a recent Cochrane review (McArthur et al., 2012) which found that phonics interventions (defined as programmes that target use of letter-sound decoding) for children with poor reading skills has a large effect on nonword reading and a smaller effect on word reading accuracy and reading comprehension.

The second research question also addressed preliminary evidence relating to the influence of pre-intervention participant profiles (language, intellectual, and phonological processing) on responses to the intervention. This study found that the participant (P2) who had the largest number of pre-intervention language, intellectual, and phonological processing scores which fell $>1SD$ below the mean,

and who began with the lowest pre-intervention reading levels, took longer to progress through the Decoding Intervention levels (reaching mastery at the 3-letter level), and made the least number of clinically significant gains. This is consistent with research that concluded that inadequate responders are generally more impaired on all language measures (Denton et al., 2013), and that response to intervention is predicted by pre-intervention measures of reading and receptive language (Torgesen, 2001). A closer look at the language and cognitive profiles of the participants reveals factors that may have influenced performance. The child who improved from below average to normal range in both accuracy and efficiency of nonword reading, P1, scored in the normal range on all language and cognitive measures. In contrast, P3, whose cognitive scores were average but language scores were mildly impaired, improved from moderate impairment to normal range in nonword accuracy and word reading efficiency, but remained below average in nonword efficiency. P2, despite scoring in the average range for expressive language, verbal comprehension and perceptual reasoning, scored significantly below average on subtests that placed demands on some aspects of mental processing (i.e., processing speed and rapid naming), though unexpectedly his scores on the phonological memory subtest were in the average range. This complex profile suggests that weaknesses in a number of specific processing skills may have contributed to P2's reading impairment and his response to intervention. He demonstrated clinically significant gains in the targeted areas only, did not generalise skills, and when faced with the pressure of the timed test (TOWRE-2), his reduced processing speed resulted in him reverting to pre-intervention patterns of guessing, with no change in word and nonword reading efficiency.

Differences on the standardised assessments, such as the nature of the stimuli and scoring, may have also influenced performance. The PhAT-2 subtests assess accuracy of nonword reading at different levels (e.g., CV, CVC, Consonant Blends) and is not timed. In contrast, the TOWRE-2 is timed, presents mixed stimuli (e.g., consonant-vowel-consonant, digraphs), and encourages the child to read quickly and skip items they cannot read. All children made clinically significant gains in accuracy of nonword reading (PhAT-2), but the pattern was less clear on the TOWRE-2 which may be explained by the task being timed and the inclusion of items which were not targeted in the intervention (digraphs).

In addressing the third research question, six minor modifications were made to the iPad-delivered materials (WordDriver) and intervention procedure. As the aim of the intervention was to teach phonological recoding and orthographic processing, the changes to the presentation of items in WordDriver were successful in preventing repetition of items and delivering more nonwords than words in each D-Plate presentation, thus providing focused decoding practice combined with the interest of detecting which items were real words. Removal of features such as the timer and the dial (which originally provided immediate feedback regarding accuracy), reduced the negative feedback and visual distraction for this group of children who perhaps have heightened sensitivity to failure. Modifying the function of the L-Plate provided a mechanism to deliver specific teaching of the phonological recoding process, as two of the three children in this study did not benefit from modelling alone – they continued to guess items based on the first letter. And finally, though the scripted sentences provided standardised feedback for real words, participants were motivated to think of their own sentence, often referencing recent events that happened within their family’s environment, thus providing a salient context to develop efficient links between orthographic, semantic, and phonological representations, and consolidate MOR development. These modifications were made early in the intervention phase and were not related to the core goals of the intervention or the data collection. Hence they were not considered to influence the analyses of the outcome measures or the results.

Conclusions

Study 1 achieved its three-fold aim. Firstly, it provided initial evidence that the iPad-delivered intervention targeting phonological recoding (through the provision of corrective feedback as the child attempted to sound out and blend) and orthographic processing (through encouraging attention to letter-sound mapping) resulted in significant gains in nonword reading. Prior to intervention, all children were unable to decode 2- and 3-letter strings; after intervention all had made gains in accurate phonological recoding (even those with severe impairments in some processing areas). The targets (letter strings of increasing length with 1:1 letter sound correspondence) were appropriate to the needs of each participant and aimed to develop MORs by increasing their ability to take note of each letter rather than guess

based on the first letter. Secondly, it gathered preliminary evidence about the impact of improved nonword reading on other reading related skills, and the patterns of pre-intervention language, intellectual, and phonological processing profiles that may influence response to intervention. While all children showed significant improvement even though they started with quite different language and cognitive profiles, the child with the weakest pre-intervention profile made the fewest gains. Thirdly, it trialled the newly developed intervention materials and procedure resulting in modifications which streamlined the technical aspects of the intervention.

There were a number of limitations to this study. First, one of the aims of Study 1 was to trial the intervention materials and procedure, therefore minor modifications occurred early in the intervention phase. Second, the small number of participants limited generalisation of the findings to other children with word reading difficulties. Third, the short duration of the maintenance period prevented investigation of the sustained effects of the intervention. And finally, the research design did not include randomisation or intervention comparisons which would strengthen the evidence regarding the impact of this intervention. These limitations were addressed in Study 2.

CHAPTER 6: STUDY 2 - GROUP ANALYSES

“The special appeal of single-subject research is that it focuses on clinical outcomes and can provide data for clinical decision making. With this intent, then, it is not sufficient to demonstrate these outcomes during an experimental period. It is also necessary to show that improvements or changes in behaviour will occur with other individuals under conditions that differ from experimental conditions, and will be sustained after the intervention has ended.” (Portney & Watkins, 2009, p. 268)

This programme of research aimed to respond to three issues that were identified in the literature investigating intervention for word reading disorders: the need for studies that (a) examine clinical outcomes for Tier 3 interventions, (b) isolate the active ingredient in intervention procedures (as most interventions involve a number of components), and (c) investigate the predictors of response to intervention (as in many studies, about 25% of participants demonstrate inadequate response). To address these issues, a single-component Tier 3 intervention (targeting skills that have been shown to underpin the development of efficient MORs) was developed, and its effectiveness was evaluated using a research design (single subject research design, SSRD) that allows examination of the influence of pre-intervention participant profiles on response to intervention.

In the evaluation of clinical outcomes, Portney and Watkins (2009) suggest that in addition to demonstrating effectiveness during an experimental study, evidence of external validity is also required, that is, that the intervention effects generalise to other individuals with similar characteristics and other conditions that differ from the experimental conditions, and that the effects are sustained after the intervention has ended. They proposed the following sequence of research phases:

- Direct replication involves repeating the same research study across at least three participants.
- Systematic replication occurs after direct replication, and involves changing the variables in the original study to see if the target behaviour generalises to other similar, but not identical, situations.
- Clinical replication is a stage of field testing where the intervention is evaluated in more realistic settings, for example, with patients who

have multiple behaviours (or disorders) that tend to cluster together. It can only occur after direct and systematic replications have supplied the researcher with well-defined relationships between treatment components and patient characteristics.

- Social validation extends beyond the question of external validity, and is based on an evaluation of the significance of the goals of intervention, the acceptability of the procedures and the importance of treatment effects.

Study 1 trialled the intervention materials and procedures with three participants, thus satisfying the requirements for direct replication. Using a single subject research design with three phases (A¹, B, A²), it demonstrated that the intervention resulted in significant gains for all participants on the dependent variable (nonword reading, measured by researcher-developed nonword lists), and it gathered preliminary evidence about (a) generalisation to skills assessed by standardised reading assessments (nonword and word reading, text reading, and comprehension), and (b) the influence of participant profiles on responses to intervention. The results suggested that while clinically significant gains were demonstrated in targeted skills on standardised tests of nonword reading (with generalisation to items that involved previously mastered letter-sound knowledge - consonant digraphs), improvements in text reading and comprehension were more likely due to the passage of time. Furthermore, there appeared to be a relationship between pre-intervention scores on standardised assessment of phonological processing, language, and intellectual skills and response to intervention: the child with the poorest pre-intervention profile (most number of scores >1SD below the mean) made the least number of clinically significant gains on standardised assessment of word and nonword reading, text reading, and comprehension. The limitations of Study 1 were that it was a trial with a small number of participants and a short maintenance phase. Though the single subject research design did involve a control condition (each participant acts as their own control during the initial baseline phase), there was no randomisation or intervention comparisons.

This chapter describes the second study which aimed to address these limitations and incorporate variations to satisfy the requirements for systematic replication – the second phase of research demonstrating external validity of an

intervention (Portney & Watkins, 2009). In addressing the limitations, Study 2 incorporated the minor modifications to the intervention materials and procedure made during Study 1, increased the number of participants to eight, and employed randomised allocation of participants to treatment regime. In addition to this, three variations were added to the research design: a comparison intervention, a delayed introduction of intervention, and an extended follow-up maintenance phase.

The comparison intervention (the *Language Intervention*) used iPad-delivered materials (ELRSoftware) that were individually selected to address identified language weaknesses of each participant based on the results of the language assessment used in the selection process - the Clinical Evaluation of Language Fundamentals-4 (Wiig, 2006). As such, the Language Intervention condition fulfilled language therapy requirements for each child and provided evidence about changes in word reading skills in the absence of the experimental intervention being evaluated in this research: the iPad-delivered intervention targeting phonological recoding and orthographic processing (the Decoding Intervention). Half of the children completed the Language Intervention followed by the Decoding Intervention (a delayed introduction of the experimental condition), and half completed the Decoding Intervention followed by the Language Intervention last (allowing for an extended follow-up phase).

Study 2 had four objectives: three relating to the three research questions, and the fourth to perform additional exploratory analyses examining aspects of the Decoding Intervention relating to efficiency, target selection, and design features. As in Study 1, the first objective was to evaluate the effectiveness of the Decoding Intervention on the dependent variable - nonword reading (measured by accuracy and rate of responses on the researcher-developed Assessment NW Lists). The second objective was to determine if improvements in nonword reading generalised to other reading related skills as measured by standardised assessments of nonword reading accuracy, word and nonword reading efficiency, text reading and comprehension; and an additional outcome measure - spelling (assessed by nonword spelling). The effect of the intervention on spelling was investigated as previous studies have shown that targeted work on orthographic processing to improve spelling also improved word-level reading (Apel & Masterson, 2001). It was possible that this research may demonstrate a reverse effect, that is, that targeting orthographic processing for word reading skills may result in improved spelling. Nonword

spelling was used to assess spelling as this task closely mirrors the dependent variable, nonword reading. The third objective of this research was to determine if pre-intervention profiles (phonological processing, language, and cognition) influenced responses to the intervention.

The three research questions were as follows:

1. Does an intervention that targets phonological recoding and orthographic processing increase nonword reading skills in Year 2 children with persistent word reading impairment?
2. Does an intervention that targets phonological recoding and orthographic processing result in gains on standardized measures of a range of reading related skills (nonword reading accuracy, word and nonword reading efficiency, text reading, and reading comprehension) and spelling, in Year 2 children with persistent word reading impairment?
3. Do pre-intervention scores on language, intellectual, and phonological processing skills influence outcome measures of nonword reading, text reading, reading comprehension and nonword spelling?

The hypotheses, as discussed in Chapter 3 were that, (a) the single component Tier 3 intervention (the Decoding Intervention) developed for this research will significantly improve the nonword reading ability of Year 2 children with word reading impairment; (b) the intervention will result in gains on some of the reading related skills as measured by standardised assessments of nonword reading accuracy, word and nonword reading efficiency, text reading and comprehension, and an assessment of spelling (nonword spelling); and (c) that response to intervention would be influenced by pre-intervention language and phonological processing skills.

The fourth objective was to perform additional exploratory analyses to (a) examine the efficiency of the intervention (*Mean Intervention Time analysis*), (b) find evidence to validate the intervention targets - items with 1:1 letter sound correspondence (*Decoding Error Pattern analysis*), and (c) investigate support for a key design feature in the Decoding Intervention module - use of orthotactic probability as an indicator of decoding difficulty (the *Orthotactic-Phonotactic Decoding Accuracy analysis*).

The Mean Intervention Time analysis (number of minutes spent completing the Decoding Intervention) aimed to enable a comparison of the efficiency of this single-component intervention with other interventions reported in the literature.

The Decoding Error Pattern analysis sought to justify the target selection (items with 1:1 letter sound correspondence) used in this study, and to replicate a similar analysis conducted by McCandliss et al. (2003) who reported statistically significant position effects in decoding accuracy in their intervention study with twenty-four 7 to 10 year old children with reading delay. Their results indicated that decoding accuracy was highest for the first consonant, followed by the last consonant and then the vowel. In words with initial consonant blends, the first consonant was more accurate than the second, and in words with final consonant blends, the last consonant was more accurate than the first. This suggested that children with this error pattern had not mastered the alphabetic principle (attending to all letters in a word, sounding out and blending). This is a central skill underpinning phonological recoding and orthographic processing, the improvement of which is the goal of this intervention. An analysis of the Decoding Error Pattern of the participants in this study would provide further evidence that the intervention targets were appropriate, that is, that the participants needed to consolidate phonological recoding and orthographic processing of words with 1:1 letter-sound correspondence.

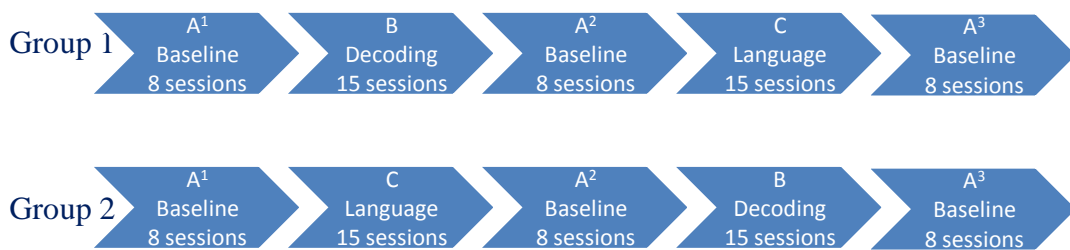
The Orthotactic-Phonotactic Decoding Accuracy analysis aimed to examine evidence relating to one of the design features (organisation of items according to orthotactic probability) in the Decoding Intervention module. Previous studies have demonstrated that MOR development in the early stages of reading acquisition (Apel, 2010) and for children who are at risk for reading delay (Apel, 2009; Apel et al., 2012) is more efficient for items with high orthotactic probability. The items (words and nonwords) in the Decoding Intervention were organised from high to low orthotactic probability (i.e., from easier to harder), the assumption being that children may have more success in decoding items of high orthotactic probability as these items more readily form MORs. The aim of this analysis, therefore, was to determine if, prior to intervention (before they were taught phonological recoding), participants were more successful in decoding words of high orthotactic probability.

Method

Study design

This study used a single subject cross-over design with multiple treatments across eight participants. There were two treatments: the Decoding Intervention and the Language Intervention which formed a comparison to the Decoding Intervention, thus controlling for the effect of individual therapy time with the researcher. Each of the eight participants progressed through five phases after random allocation to one of two groups, depicted in Figure 22.

Figure 22: Study 2 research design



Both groups began with eight baseline sessions (A^1) where pre-intervention skills on the dependent variable (nonword reading) and the speed of response on the motor component of the iPad tasks were assessed. Following this, Group 1 completed 15 Decoding Intervention sessions (which included measurement of the dependent variable and speed of motor response) and Group 2 fifteen Language Intervention sessions (during which neither the dependent variable nor speed of motor response were administered). The second baseline (A^2) reassessed nonword reading skills and the motor component of the iPad tasks over eight sessions. The intervention conditions were then swapped: Group 1 completed 15 Language Intervention sessions and Group 2 completed 15 Decoding Intervention sessions. Finally both groups completed eight baseline sessions (A^3) where post-intervention nonword reading and the motor component of the iPad tasks were assessed.

Participants

Eight Year 2 children (three boys and five girls aged 7 – 8 years in their third year of school) participated in this study. The selection procedure was as for Study 1. Teachers from three Victorian government schools were asked to identify children who presented with typically developing oral language and intellectual skills, and who continued to have problems with word reading, despite having received previous reading intervention programmes – thus representing children requiring Tier 3 intervention, that is, having demonstrated inadequate response to Tier 1 and Tier 2 intervention. The inclusion criteria were as for Study 1, with the addition of an assessment of speech sound production – The Quick Screener (Bowen, 1996), to eliminate children with significant expressive speech sound disorders.

- A score of more than 1 standard deviation (SD) below the mean on the Phonemic Decoding Efficiency subtest of the Test of Word Reading Efficiency 2 (TOWRE-2: Torgesen et al., 2012);
- A Core Language Score within 2SD of the mean on the Clinical Evaluation of Language Fundamentals 4 (CELF-4: Semel et al., 2003);
- No developmental or sensory impairment, as screened using a parent questionnaire (Claessen et al., 2010);
- Hearing and vision in the normal range (school nurse screening);
- Intellectual skills in the average range using the Wechsler Intelligence Scale for Children IV Full Scale Score (WISC-IV: Wechsler, 2003);
- Letter-sound knowledge in the average range for consonants and short vowels using the Grapheme subtest of the Phonological Awareness Test 2 (PhAT-2: Robertson & Salter, 2007);
- Speech sound production within average range as assessed by The Quick Screener (Bowen, 1996). This screener requires the child to name a series of pictures, the names of which include all the consonants and vowels of English in all positions of the word. It has been used to assess accuracy of speech sound production in children (Bowen, 2010).

The eight participants selected for Study 2 matched the language, intellectual, and speech sound development criteria, had hearing and vision with normal range,

and had mastered letter-sound knowledge for consonants and short vowels. Despite having received previous Tier 2 reading intervention all participants were severely delayed on nonword reading efficiency (TOWRE-2 PDE) with percentile rank scores that ranged from 1st to the 8th percentile (P1 8th percentile, P2 8th percentile, P3 3rd percentile, P4 <1st percentile P5 1st percentile, P6 5th percentile, P7 1st percentile, and P8 1st percentile).

Approval for this research was granted by the Curtin University Human Research Ethics Committee and the Victorian Department of Education. Procedures complied with confidentiality guidelines, and both caregivers and participants provided informed consent to participate.

Materials

The materials were delivered by an iPad in all five phases: the three baseline phases, and the two intervention conditions - Decoding and Language Interventions. The web app called WordDriver presented the material for the three baseline phases and the Decoding Intervention, while the Language Intervention used an app called *Extra Language Resources* (ELRSoftware).

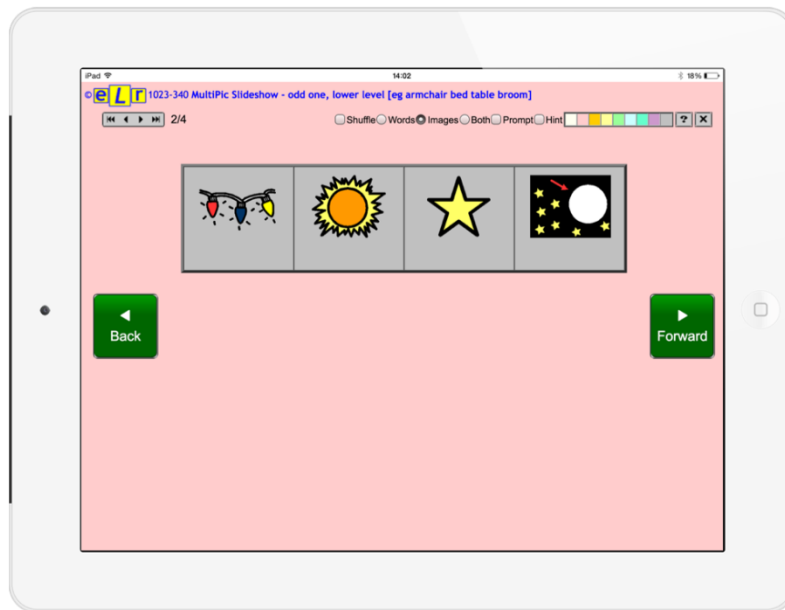
The design and development of WordDriver was outlined in Chapter 4 and each of the five intervention modules was described in detail in Chapter 5, along with the minor modifications (reduction of visually distracting features on the screen, prevention of repetition of items in the D-Plate, change of L-Plate role, and modification to the sentence reinforcement procedure) that were made as a result of the trial in Study 1. Briefly, three modules were used in the intervention sessions at each of the five intervention levels (2- to 6-letter strings): the L-Plate (Learner) taught phonological recoding, the P-Plate (Practice) provided practice, and the D-Plate (Driver) ensured mastery at each level (90% decoding accuracy). The remaining two components were administered at the beginning of each baseline and Decoding Intervention session: the T-Plate (Test) assessed nonword reading using the researcher-developed Assessment NW Lists (the dependent variable), and the S-Plate (Speed) assessed the motor component of the response when using WordDriver.

The items were letter strings of 1:1 letter sound correspondence: words and nonwords for the three intervention modules (L-Plate, P-Plate and D-Plate), and

nonwords for the dependent variable (T-Plate - Assessment NW Lists). As the L- and P-Plates were designed to teach and provide practice, the words and nonwords were organised so that only one letter changed from one item to the next. The items for D-Plate were organised from high to low orthotactic probability (i.e., from easy to harder items) and incorporated the PEST procedure to deliver items responsively to participant accuracy: easier items following an error, more difficult items following a correct response. Orthotactic probability was used to organise the items because research has demonstrated that children at risk of reading delay were more able to develop MORs with letter strings of high orthotactic probability (Apel, 2009; Apel et al., 2012). Each of the 39 Assessment NW Lists (eight for each of the three baseline phases, and 15 for the intervention sessions) presented a sequence of nonwords, starting at 2-letter and progressing to 6-letter items. Within each set of items (2-letter, 3-letter, 4 letter etc.), the items were organised from high to low orthotactic probability (i.e., from easy to harder items), and each list was constructed to be of approximately equal difficulty by matching items across lists according to orthotactic probability values. The S-Plate required the child to respond to a colour change on the screen and automatically measured response time.

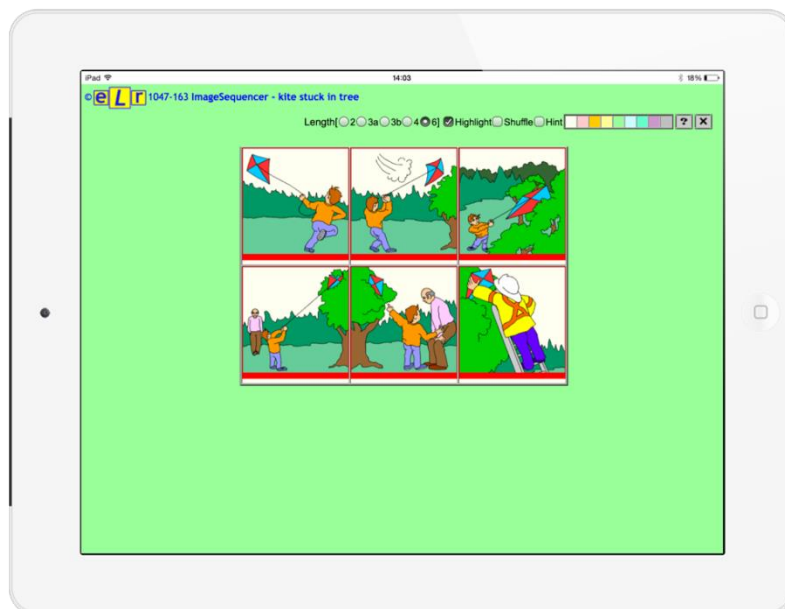
The Language Intervention condition used the Extra Language Resources app (ELR Software), and was designed to target participant-specific language weaknesses that were identified in the pre-intervention language assessment. No words were displayed as part of the language activities, as the focus was on oral language skills. Thus no extra reading practice occurred during these sessions and the T-Plate was not administered. Examples of typical language tasks are displayed in Figures 23, 24, and 25.

Figure 23: Language Intervention “Odd One Out”



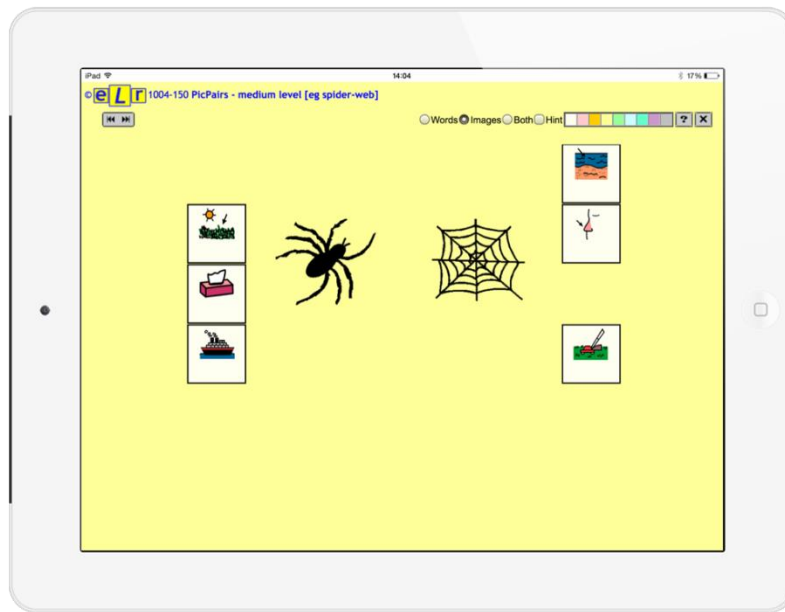
Note: A receptive language (understanding categories), and expressive language (using specific vocabulary to explain reasons) task. The child names each picture, decides which one is the “odd one out”, and then uses expressive language to give a reason, e.g., “the lights are the odd one out because the others are outside”

Figure 24: Language Intervention “Oral Narrative”



Note: An expressive language task. The child uses oral narrative skills (e.g., who, what happened, where), to tell the story depicted in the picture.

Figure 25: Language Intervention “Association”



Note: A receptive language (detecting associations), and expressive language (using sentences to explain associations) task. The child names each picture, clicks on a picture on the left, decides which is the matching picture on the right, and then explains the relationship, e.g., “the spider goes with the web because spiders make spider webs to catch insects”.

Measures

The measures for Study 2 were the same as those in Study 1, with one additional measure: nonword spelling. To answer the first research question, three sets of data were graphed. The first two were the measures of the dependent variable: NW Rate (number of nonwords read correctly in 60 seconds), and NW Total (the number of nonwords accurately read to a ceiling of six errors in eight consecutive items). The third was the number of nonwords attempted in 60 seconds (NW Attempted) which provided additional information for the interpretation of individual response.

To address the second research question, tests of word and nonword reading, text reading and comprehension, and spelling were administered prior to intervention by the researcher and after the intervention by a speech pathologist unfamiliar with the children and blind to research aims. These included three standardised tests (which were described in Chapter 5 - Study 1), and a spelling test using researcher-developed *Assessment Nonword Spelling Lists*. The standardised tests are listed, and the researcher-developed nonword spelling assessment is described below:

- The Test of Word Reading Efficiency-2 (TOWRE-2: Torgesen et al., 2012). Four different forms are available in this test, so Form A was used in the first baseline (A¹), Form B in the second baseline (A²), and Form C in the third baseline (A³).
- The Decoding subtests of the Phonological Awareness Test-2 (PhAT-2: Robertson & Salter, 2007). Only one version is available for this test. However, since the Decoding Intervention presented hundreds of nonwords, it was judged unlikely that a repetition effect would occur between baselines.
- The Neale Analysis of Reading Ability 3rd edition (Neale, 1999). Two forms are available, so Form A was used in baseline one (A¹), Form B in baseline two (A²), and Form A in baseline three (A³). As there was a gap of six months between A¹ and A³ it was reasoned that a repetition effect for Form A was unlikely.
- The Assessment Nonword Spelling Lists consisted of six lists, each containing 20 items. Two lists were administered during each of the three baseline sessions (40 items at each baseline – divided into two lists to cater for the attention span of participants in completing this task). Each list contained five 3-letter, five 4-letter, five 5-letter and five 6-letter items with 1:1 letter-sound correspondence, organised according to orthotactic probability using the same methodology (described in Chapter 4) as the Assessment NW Lists (the dependent variable). None of the spelling items occurred in the Assessment NW Lists or were repeated between the Assessment NW Spelling lists. Participant responses were scored using the Spelling Sensitivity Score (Masterson & Apel, 2010) procedure which resulted in two scores: the number of phonemes omitted (NWSpell Omit), and the number of legally spelled phonemes (NWSpell Legal).

The measures relating to the third research question (determining if pre-intervention profiles influenced response to intervention), were the same as for Study 1 - standardised tests of language, phonological processing, and intellectual skills. The language and intellectual assessments were administered as part of the selection process, and the phonological processing test was administered during the first

baseline phase (A¹). The intellectual assessments for two participants (the WISC-IV for one and the WPPSI-III for the other) had been previously administered by a psychologist so these were not repeated. Each test was described in Chapter 5 and is listed below:

- The Clinical Evaluation of Language Fundamentals-4 (CELF-4: Semel et al., 2003)
- The Comprehension Test of Phonological Processing-2 (CTOPP-2: Wagner et al., 2013)
- The WISC-IV Australian (Wechsler, 2003)

Procedure

Each participant was involved in a total of 54 sessions of 15 to 20 minutes duration, three times per week over two school terms situated in a quiet location at their school. The eight participants were randomly divided into two groups (each of four participants). To achieve randomisation, participants were numbered from one to eight. Using an online random number generator (www.random.org) the numbers were randomly ordered, and the participants with the first four numbers in the randomised sequence were assigned to Group 1, and the second four to Group 2. By chance, this resulted in an even spread across the three schools: the first school had one child in Group 1 and two in Group 2, the second had two in Group 1 and one in Group two, and the third had one in each group. Both groups progressed through the five phases of the research as depicted in Figure 1.

Phase 1

At the beginning of each of the eight pre-intervention baseline sessions (A¹), one Assessment NW List (the T-Plate – the dependent variable) and a speed of motor response (S-Plate) was administered to each participant by the researcher. The other pre-intervention reading related assessments (TOWRE-2, Decoding subtests of the PhAT-2, the Neale Analysis of Reading Ability, and the Assessment NW Spelling Lists) were also administered by the researcher, spread over the baseline sessions so that each session was restricted to a 15 to 20 minute time slot.

To complete the T-Plate (as described in Chapter 5, Study 1), the child touched the Go button, read out-loud the nonword letter string (which was displayed

on the graphic of a road sign), and touched the Go button to view the next and successive items. No feedback about accuracy of response was provided. The researcher stopped the child after 60 seconds (if the child had made six errors in eight consecutive items) or allowed the child to continue until the criterion of six errors in eight consecutive items was reached. All responses were recorded on a digital recorder for later analysis. The S-Plate involved the same graphical interface and procedure, but displayed a randomly presented colour change of the road sign from white to black instead of letter strings. The child touched the Go button to see a white coloured road sign. As soon as the road sign turned black the child touched the Go button again, and the time between the colour change to black and the touching of the Go button was automatically recorded for later analysis. The child continued to touch the Go button as soon as they saw the black road sign for a total of 20 colour change events.

Phase 2

Following the pre-intervention baseline (A¹), all participants completed 15 sessions of either Decoding Intervention (Group 1) or Language Intervention (Group 2). The procedure for the Decoding Intervention was the same as for Study 1. The child began each session with the T-Plate, followed by the S-Plate, and then completed one or two of the intervention modules (L-Plate, P-Plate, or D-Plate) ensuring that all modules were completed within the 20 minute session. All participants began at the level of 2-letter strings, as all participants had made errors on decoding 2-letter strings in the pre-intervention assessment (Decoding subtests of the PhAT-2). For the intervention modules, the L-Plate was the starting point at all levels (2-, 3-, 4-letter strings etc.), where the researcher taught phonological recoding and blending. This was followed by the P-Plate where the child practiced phonological recoding using a controlled set of words (where only one letter changed from one item to the next); and finally by the D-Plate which used the PEST algorithm (McArthur et al., 2008) to present items in a sequence which automatically responded to accuracy of participant response, that is, following an error the program presented an easier item (higher orthotactic probability), and an accurate response resulted in the presentation of a more difficult item (low orthotactic probability).

During the L-Plate (incorporating the modifications from Study 1), the researcher explicitly taught phonological recoding by demonstrating the Help

procedure on each item, thus providing the child with a visual and auditory depiction of the phonological recoding strategy on the iPad. The researcher touched the Go button to display each item. After decoding the item with an inaccurate response, three levels of help were available: visual highlighting of letters to stimulate phonological recoding, visual plus auditory feedback to demonstrate phonological recoding, and finally the researcher touched each letter and verbally performed phonological recoding. The researcher demonstrated approximately one third of the items with the first level, one third with the second level, and one third with all three levels of help. Following each item the researcher modelled the sentence feedback procedure - production of a sentence to demonstrate the meaning of a word, and for a nonword, a sentence explaining that the item “was not a real word, it had no meaning”.

The P-Plate and D-Plate followed this procedure except that the child performed more of the actions. The child touched the Go button, and read out-loud a randomly presented word or nonword. Use of phonological recoding on each item was encouraged during the P-Plate, but if the child accurately read the entire word (or nonword) during the D-Plate this response was accepted. The researcher then provided verbal feedback about accuracy of response, touching the Correct button for correct responses, and the Help button following an inaccurate response. The help procedure was delivered as described for the L-Plate with up to three levels of help depending on the child’s decoding accuracy. To consolidate MOR development, the meaning of real words was highlighted either by the researcher using that word in a scripted sentence, or, as was the case for most participants, the child was allowed to spontaneously use the word in a sentence that related to their own experience. The researcher provided feedback about nonword items using a sentence explaining that the item “was not a real word, it had no meaning”. The child then put the item in the Book or the Bin (for words or nonwords respectively) by touching either graphic, and touched the Go button when they were ready to start with next trial. A criterion of 90% accuracy was required on the P-Plate to move to the D-Plate (within each level), and similarly a criterion of 90% accuracy on the D-Plate allowed progression to the next level (e.g., from 3- to 4-letter).

The Language Intervention sessions were scheduled in the same way as the Decoding Intervention sessions (approximately 20 mins, three times per week), and involved materials that were also delivered on the iPad using an app that targets a

range of language skills – Extra Language Resources (ELRSoftware). Unlike the Decoding Intervention, none of the WordDriver modules were used in these sessions, that is, no T-Plate, S-Plate etc., and no other reading material was presented. Activities were selected targeting participant-specific weaknesses, that is, those areas that were more than 1SD below the mean on the language assessment completed as part of the selection process – the CELF-4. For example, if the language assessment indicated weaknesses in vocabulary knowledge and expressive language, the Language Intervention focused on vocabulary development (e.g., category knowledge - detecting which picture did not belong, providing the category name and the reason it did not belong) and oral narrative (e.g., retelling and/or formulating a story based on a picture sequence). Prior to the commencement of language therapy, data regarding mastery of each of the targeted areas was gathered to ensure that the activity was at a suitable difficulty level for that child, that is, that they scored less than 85% accuracy. Thus the Language Intervention condition, while providing therapy for an identified need for each child, did not involve any exposure to individualised reading tuition, and formed a control for the effects of individual time spent with each child.

Phase 3

Following the Decoding Intervention (for Group 1), and the Language Intervention (Group 2), all participants completed eight baseline two sessions (A²). During A² the researcher administered the T-Plate and S-Plates to both groups. The post-intervention reading related assessments (TOWRE-2, Decoding subtests of the PhAT-2, the Neale Analysis of Reading Ability, and the Assessment NW Spelling Lists) were administered to Group 1 (who completed the Decoding Intervention first) by the speech pathologist blind to the research aims. The researcher administered these tests to Group 2 who were still in a pre-Decoding Intervention phase.

Phase 4

During this phase, the cross-over design used in this research entailed a swap of intervention conditions for each group. Group 1 (who had completed the Decoding Intervention in Phase 2) were presented with 15 Language Intervention sessions, and Group 2 (who had completed Language Intervention in Phase 2), were presented

with 15 Decoding Intervention sessions. The procedures for each intervention condition were identical to those described in Phase 2.

Phase 5

Finally, all participants completed eight baseline three sessions (A³). As this was post-intervention for all participants, the researcher presented the T-Plate and S-Plate, and the independent speech pathologist administered the other reading related tests (TOWRE-2, Decoding subtests of the PhAT-2, the Neale Analysis of Reading Ability, and the Assessment NW Spelling Lists).

Results

Study 2, with its increased participant number and more robust research design (comparison intervention and randomised allocation to intervention condition) compared to Study 1, had four aims: three aims relating to the three research questions, and the fourth, to perform the additional analyses examining efficiency and design aspects of the iPad-delivered intervention. The cross-over design with eight participants (two groups of four, randomly assigned to two different intervention schedules) who completed three baselines each with eight sessions, provided a large data set which allowed group analyses for the first two research questions. Group analyses were not performed on the data for the third research question as there was an increased risk of Type 1 and Type 2 errors, due to the large number of moderators (11 measures of language, intellectual, and phonological processing skills) and the small number of participants. This chapter therefore discusses the group results for the first two research questions (to enable examination of broad patterns in the data and to provide a context for exploration of individual participant responses to intervention), and the additional analyses. The use of a single subject research design which allowed a fine grained examination of participant data relating to the first two research questions and the influence of pre-intervention profiles on response to intervention (the third research question) is discussed in Chapter 7.

A Generalised Linear Mixed Model (GLMM) was implemented to test for a Group x Time interaction. The GLMM was implemented through SPSS's (Version 22) GENLIMIXED procedure. The GLMM represents a special class of regression model. The GLMM is 'generalised' in the sense that it can handle outcome variables

with markedly non-normal distributions; the GLMM is ‘mixed’ in the sense that it includes both random and fixed effects. For the present GLMMs, there was one nominal random effect (participant) and two categorical fixed effects: Group (a between-subjects factor consisting of Group 1 and Group 2) and Time (a within-subjects factor consisting of Time 1, Time 2, and Time 3). Although cell sizes were small, GLMM has proven to be robust to small cell sizes.

This section reports firstly on the results of the group analyses of data relating to the first two research questions, followed by the three additional exploratory analyses (Mean Intervention Time, Decoding Error Pattern, and Orthotactic-Phonotactic Decoding Accuracy) as follows:

Question 1

- a) Assessment NW Lists, NW Rate
- b) Assessment NW Lists, NW Total

Question 2

- a) TOWRE-2
- b) PhAT-2
- c) Neale Analysis of Reading Ability 3rd edition
- d) Assessment NW Spelling Lists

Additional Analyses

- a) Mean Intervention Time
- b) Decoding Error Pattern
- c) Orthotactic-Phonotactic Decoding Accuracy

Question 1

The first question investigated whether the Decoding Intervention resulted in significant gains in nonword reading assessed by participant scores on the Assessment NW Lists. Each of the eight participants provided NW Rate and NW Total scores in response to 24 lists of nonwords (eight lists during each baseline - T1, T2, and T3). The eight participants were partitioned into two groups of four depending on when they received the treatment. For each of the two groups, the aim was to determine whether the two response measures varied significantly across time, and to examine and compare the nature of these effects.

For this GLMM, there were two nominal random effects (word list and participant), two categorical fixed effects (group and time), and the Group x Time interaction. Intra-participant dependencies in the outcome measure were controlled by specifying a GLMM in which word list was nested within participants.

For a repeated measures design such as this one, the following assumptions need to be satisfied: Normality, homogeneity of variance, sphericity, and independence of observations. The GLMM 'robust statistics' option will generally take care of violations of normality and homogeneity of variance. Violations of sphericity can be accommodated by changing the covariance matrix from the default of compound symmetry to autoregressive. Finally, by specifying the multilevel nature of the current data (word list nested within participant) in the GLMM syntax, GLMM can accommodate intra-participant dependencies in the outcome measure. Also, GLMM is robust to small group sizes.

In order to optimise the likelihood of convergence, a separate GLMM analysis was run for each of the two response measures. Analysing each response measure independently of the other will of course inflate the familywise error rate. The traditional per-test alpha of .05 will therefore need to be corrected to $\alpha = .025$ (Bonferroni correction) to reduce the likelihood of Type 1 error for this next set of analyses.

Assessment NW Lists, NW Rate

Figure 26: GLMM - NW Rate

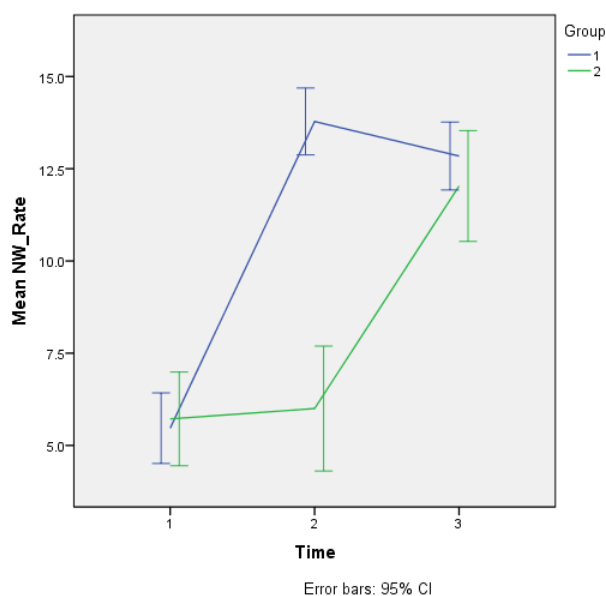


Figure 26 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of NW Rate scores for Group 1 (blue) and Group 2 (green). The Group x Time interaction was significant ($F[2,186] = 16.04, p < .001$) indicating that each main effect is unable to be interpreted independently of the other. Least Significant Difference (LSD) contrasts conducted across the simple main effects of time indicated a significant T1-T2 increase for Group 1 ($t[186] = 8.31, p < .001$), but the difference between T1-T2 was not significant for Group 2 ($t[186] = 0.23, p = .821$); a non-significant T2-T3 decrease for Group 1 ($t[186] = 2.26, p = .025$); and a significant T2-T3 increase for Group 2 ($t[186] = 4.21, p < .001$). The T1-T3 increase was significant for Group 1 ($t[186] = 9.43, p < .001$) and Group 2 ($t[186] = 5.75, p < .001$). These results demonstrated that the NW Rate score significantly improved for Group 1 immediately following Decoding Intervention (from T1 to T2), with no significant change during and after the Language Intervention, from T2 to T3. Group 2 demonstrated no change in NW Rate following Language Intervention (T1 to T2), but a significant improvement following Decoding Intervention (T2 to T3).

Assessment NW Lists, NW Total

Figure 27: GLMM - NW Total

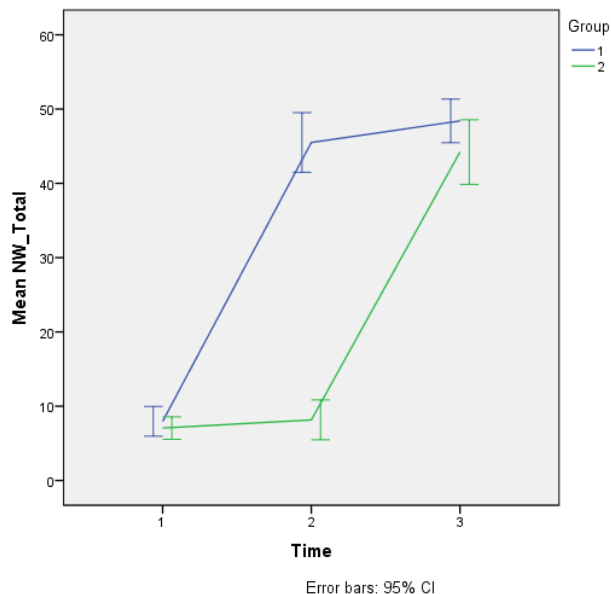


Figure 27 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of NW Total scores for Group 1 (blue) and Group 2 (green). The Group x Time

interaction was significant ($F[2,186] = 52.90, p < .001$) indicating that each main effect is unable to be interpreted independently of the other. LSD contrasts conducted across the simple main effects of time indicated a significant T1-T2 increase for Group 1 ($t[186] = 9.99, p < .001$), but the difference between T1-T2 was not significant for Group 2 ($t[186] = 0.54, p = .593$); a non-significant T2-T3 decrease for Group 1 ($t[186] = 1.52, p = .131$), and a significant T2-T3 increase for Group 2 ($t[186] = 8.99, p < .001$). The T1-T3 increase was significant for Group 1 ($t[186] = 16.63, p < .001$) and Group 2 ($t[186] = 7.59, p < .001$). These results indicated that Group 1 demonstrated significant gains in NW Total score following Decoding Intervention (T1 to T2), and maintained skills during and after Language Intervention (T2 to T3), whereas Group 2 made no gains in NW Total during Language Intervention (T1 to T2), but significant gains during and after Decoding Intervention (T2 to T3).

Summary

These analyses reveal that Decoding Intervention resulted in significant increases in both NW Rate (the number of nonwords read correctly in 60 seconds) and NW Total (the total number of nonwords read correctly) for both groups. Furthermore, neither group demonstrated a significant change in NW Rate or NW Total following the comparison condition (Language Intervention).

Question 2

Question 2 examined whether the Decoding Intervention resulted in improvements in other reading related skills: word and nonword reading efficiency (TOWRE-2: Sight Word Efficiency and Phonemic Decoding Efficiency), nonword reading accuracy (PhAT-2), text reading and comprehension (Neale Analysis of Reading Ability-3), and nonword spelling (researcher-developed nonword spelling lists – Assessment NW Spelling Lists). Though all subtests of the PhAT-2 were administered, only those which measured skills targeted in this intervention (VC, CVC, Consonant Blends) or where generalisation occurred (Consonant Digraphs) were analysed, as both pre- and post-intervention, all participants scored zero (or close to zero) on the subtests assessing vowel spelling patterns.

This section reports on the results of these measures that were administered during each of the three baselines: T1 by the researcher, T2 and T3 by the speech pathologist blind to intervention goals and unfamiliar with the participants. All T2 and T3 scores were recoded by the researcher resulting in inter-rater reliability of more than 99%. The raw scores for each measure were analysed using the GLMM procedure.

TOWRE-2

TOWRE-2: Sight Word Efficiency

The TOWRE-2 SWE is a timed measure of word reading accuracy – the number of words accurately read in 45 seconds.

Figure 28: GLMM - TOWRE-2 Sight Word Efficiency

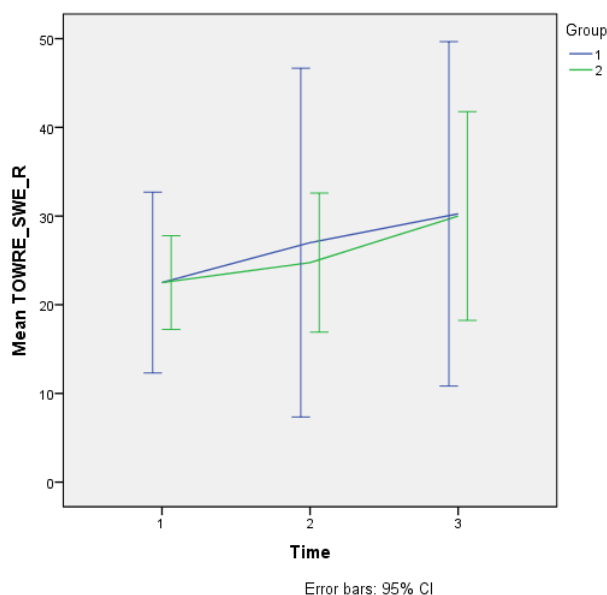


Figure 28 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of TOWRE-2 Sight Word Reading Efficiency raw scores (SWE_R) for Group 1 (blue) and Group 2 (green). Though there are big differences in variability between groups, the GLMM is robust to violations of homogeneity of variance. The Group x Time interaction was non-significant ($F[2,18] = 0.54, p = .589$), as was the main effect for group ($F[1,18] = 0.03, p = .863$). The main effect for time, however, was significant ($F[2,18] = 7.75, p = .004$). Post-hoc LSD contrasts across the main effect of time indicated that both groups showed a significant increase from T2 to T3 ($p =$

.002) and from T1 to T3 ($p = .003$). Neither group changed significantly between T1 and T2 ($p = .089$). These results indicate that there was no significant change in sight word reading efficiency (the number of sight words read accurately in 45 seconds) from T1 to T2 for either group, but that both groups made significant gains from T2 to T3 and from T1 to T3.

TOWRE-2: Phonemic Decoding Efficiency Score

The TOWRE-2 PDE is a timed measure of nonword reading accuracy – the number of nonwords accurately read in 45 seconds.

Figure 29: GLMM - TOWRE Phonemic Decoding Efficiency

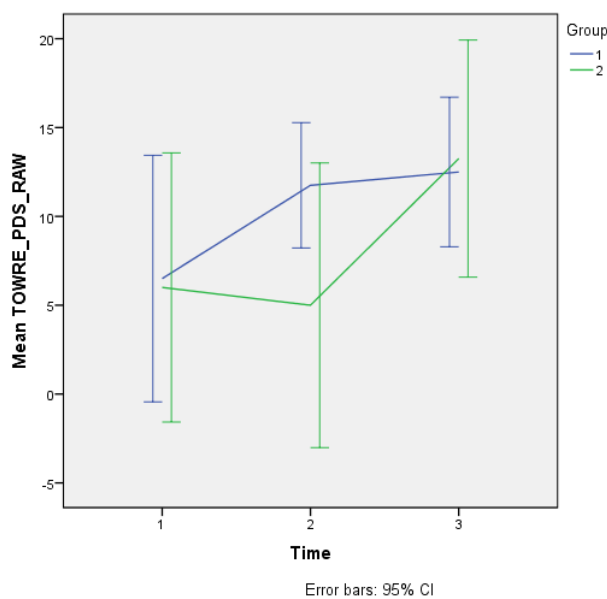


Figure 29 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of TOWRE-2 Phonemic Decoding Efficiency raw scores (PDS Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was significant ($F[2,18] = 7.09, p = .005$). Post-hoc LSD contrasts conducted on the simple main effects of time indicated that Group 1 (Decoding/Language) produced a significant increase in Phonemic Decoding Efficiency scores from T1 to T2 ($p = .016$) and from T1 to T3 ($p < .001$), but no significant change from T2 to T3 ($p = .583$). In contrast, Group 2 (Language/Decoding) showed no change between T1 and T2 ($p = .174$), but significant increases between T2 and T3 ($p < .000$) and between T1 and T3 ($p < .000$). This result indicates that Group 1 made significant gains in Phonemic Decoding Efficiency scores (the number of nonwords accurately read in 45 seconds) following Decoding Intervention and maintained those skills during and after

Language Intervention. Group 2 (who completed Language Intervention followed by Decoding Intervention), did not make significant gains during Language Intervention, but demonstrated significantly improved nonword reading efficiency as a result of the Decoding Intervention.

PhAT-2

PhAT-2 Vowel-Consonant nonword reading

The PhAT-2 VC assesses accuracy of nonword reading of items with two letters.

Figure 30: GLMM - PhAT Vowel-Consonant

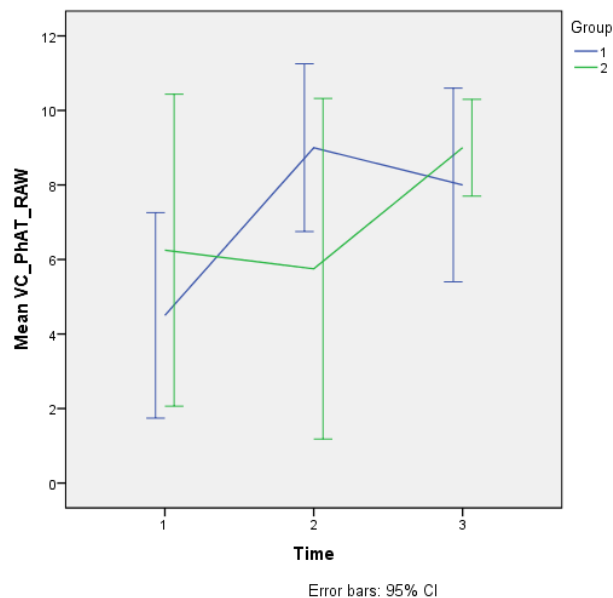


Figure 30 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the PhAT-2 Vowel-Consonant subtest raw scores (VC PhAT Raw) for Group 1 (blue) and Group 2 (green). In this analysis one participant (P6) was excluded due to ceiling effects across all three assessments. The Group x Time interaction was significant ($F[2,18] = 10.37, p = .001$). Post-hoc LSD contrasts conducted on the simple main effects of time indicated that Group 1 (Decoding/Language) showed a significant increase from T1 to T2 ($p < .001$) and from T1 to T3 ($p = .001$), but no significant change from T2 to T3 ($p = .248$). In contrast, Group 2 (Language/Decoding) showed no change between T1 and T2 ($p = .558$), but significant increases between T2 and T3 ($p = .001$) and between T1 and T3 ($p =$

.004). This result indicates that Group 1 made significant gains in the ability to decode consonant-vowel (CV) nonwords following Decoding Intervention and maintained those skills during and after Language Intervention. Group 2 (who completed Language Intervention followed by Decoding Intervention), did not make significant gains during Language Intervention, but demonstrated significantly improved CV nonword reading following Decoding Intervention.

PhAT-2 Consonant-Vowel-Consonant nonword reading

The PhAT-2 CVC assesses accuracy of nonword reading of items with three letters.

Figure 31: GLMM - PhAT Consonant-Vowel-Consonant

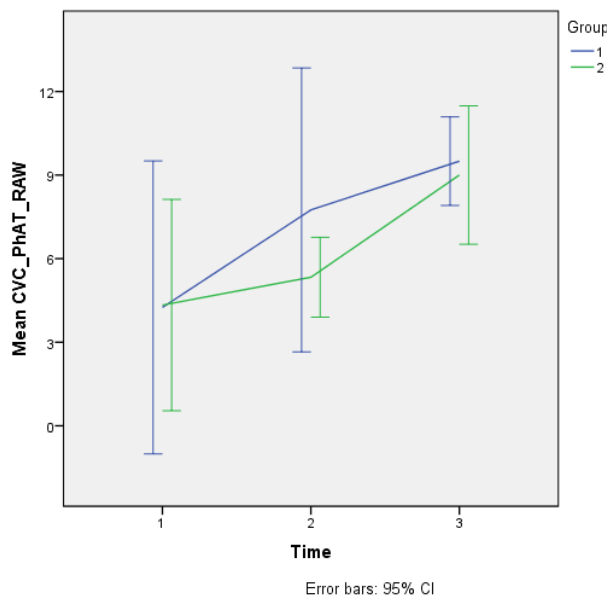


Figure 31 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the PhAT-2 Consonant-Vowel-Consonant subtest raw scores (CVC PhAT Raw) for Group 1 (blue) and Group 2 (green). In this analysis one participant (P6) was excluded due to ceiling effects across all three assessments. The Group x Time interaction was non-significant ($F[2,15] = 2.09, p = .158$), as was the main effect for group ($F[1,15] = 0.89, p = .360$). The main effect for time, however, was significant ($F[2,15] = 32.32, p < .001$). Post-hoc LSD contrasts across the main effect of time indicated that both groups showed a significant increase from T1 to T2 ($p = .016$), from T2 to T3 ($p < .001$), and therefore from T1 to T3 ($p < .001$). This result indicates that both groups made significant gains in decoding CVC nonwords from

T1 to T2, from T2 to T3, and from T1 to T3. Although examination of Figure 10 suggests that there was a trend for differential response to intervention conditions (i.e., that each group made greater gains as a result of the Decoding Intervention compared to their response following Language Intervention) the interaction was not significant.

PhAT-2 Consonant Blends nonword reading

The PhAT-2 Consonant Blends assesses accuracy of nonword reading of items that contain consonant blends. A consonant blend refers to two sounds spelled with two letters (e.g., st, nt, bl).

Figure 32: GLMM - PhAT Consonant Blends

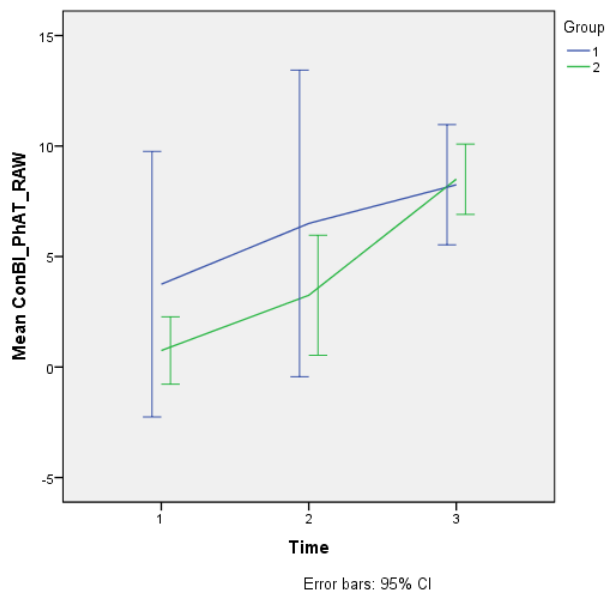


Figure 32 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the PhAT-2 Consonant Blends subtest raw scores (ConBl PhAT Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was non-significant ($F[2,18] = 2.81, p = .087$), as was the main effect for group ($F[1,18] = 2.42, p = .137$). The main effect for time, however, was significant ($F[2,18] = 31.80, p < .001$). Post-hoc LSD contrasts across the main effect of time indicated that both groups showed a significant increase from T1 to T2 ($p = .005$), from T2 to T3 ($p = .001$), and from T1 to T3 ($p < .001$). This result indicates that both groups made significant gains in decoding items with consonant blends from T1 to T2, from T2 to T3 and from T1 to T3.

PhAT-2 Consonant Digraphs nonword reading

The PhAT-2 Consonant Digraphs assesses accuracy of nonword reading of items that contain consonant digraphs. A consonant digraph refers to one sound spelled with two letters (e.g., sh, th).

Figure 33: GLMM - PhAT Consonant Digraphs

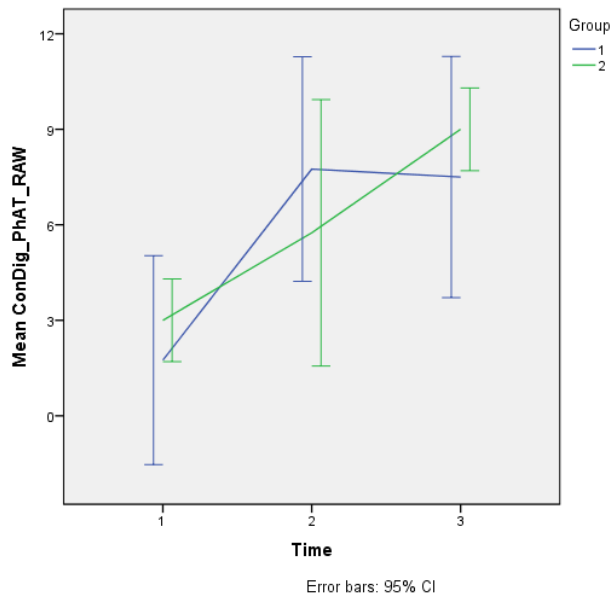


Figure 33 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the PhAT-2 Consonant Digraphs subtest raw scores (ConDig PhAT Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was non-significant ($F[2,18] = 2.93, p = .079$), as was the main effect for group ($F[1,18] = 0.18, p = .679$). The main effect for time, however, was significant ($F[2,18] = 28.93, p < .001$). Post-hoc LSD contrasts across the main effect of time indicated that both groups showed a significant increase from T1 to T2 ($p = .015$), from T2 to T3 ($p = .002$), and from T1 to T3 ($p < .001$).

PhAT-2 Total Score nonword reading

The PhAT-2 Total Score represents the combined results of all PhAT-2 subtests: VC, CVC, Consonant Digraphs, Consonant Blends, Vowel Digraphs, R-Vowels, CVCe and Diphthongs.

Figure 34: GLMM - PhAT Total

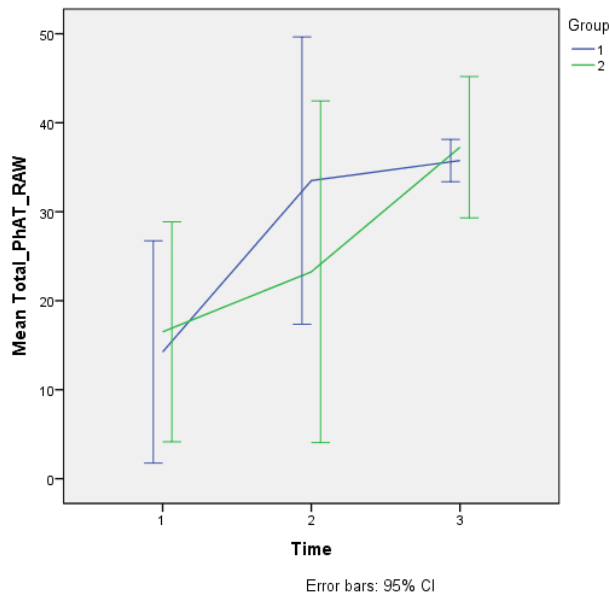


Figure 34 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the PhAT-2 Total raw scores (Total PhAT Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was significant ($F[2,18] = 8.85, p = .002$) thereby confounding the main effects of group and time. Post-hoc LSD contrasts conducted on the simple main effects of time indicated that Group 1 (Decoding/Language) showed a significant increase from T1 to T2 ($p < .001$) and from T1 to T3 ($p < .001$), but no significant change from T2 to T3 ($p = .561$). In contrast, Group 2 (Language/Decoding) showed significant increases between T1 and T2 ($p = .006$), between T2 and T3 ($p = .001$), and between T1 and T3 ($p < .001$). This indicates that the overall nonword decoding score significantly improved for Group 1 following Decoding Intervention (T1 to T2) and was maintained during and following Language Intervention. Though Group 2 showed a trend on the graph for greater gains following Decoding Intervention the gains following Language Intervention and Decoding Intervention both reached significance ($p = .001$ and $p = .006$ respectively).

Neale Analysis of Reading Ability 3rd edition

Neale Analysis Accuracy

The Neale Analysis of Reading Ability-3: Accuracy assesses word reading accuracy in a story reading task.

Figure 35: GLMM - Neale Analysis Accuracy

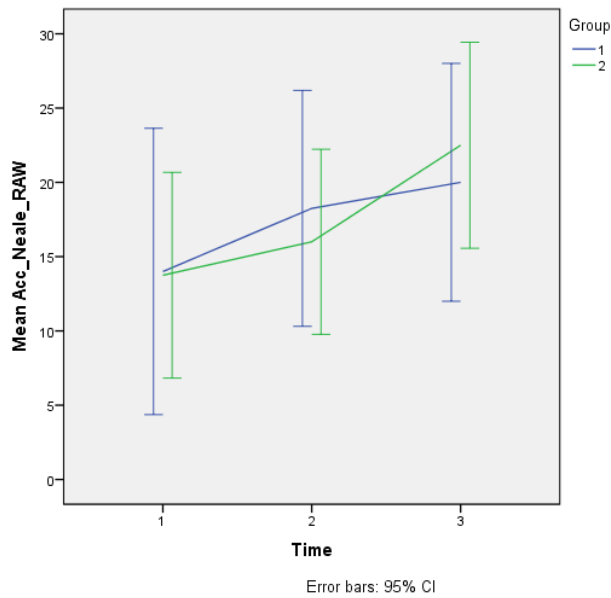


Figure 35 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the Neale Analysis Accuracy raw scores (Acc Neale Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was non-significant ($F[2,18] = 3.39, p = .056$), as was the main effect for group ($F[1,18] = 0.00, p = 1.000$). The main effect for time, however, was significant ($F[2,18] = 149.20, p < .001$). Post-hoc LSD contrasts across the main effect of time indicated that both groups showed a significant increase from T1 to T2 ($p < .001$) and from T1 to T3 ($p < .001$). Neither group changed significantly between T2 and T3 ($p = .155$). This indicates that both groups made significant gains over the course of the study and did not respond differentially to the Decoding and Language Interventions.

Neale Analysis Comprehension

The Neale Analysis of Reading Ability-3: Comprehension assesses text reading comprehension in a story reading task.

Figure 36: GLMM - Neale Analysis Comprehension

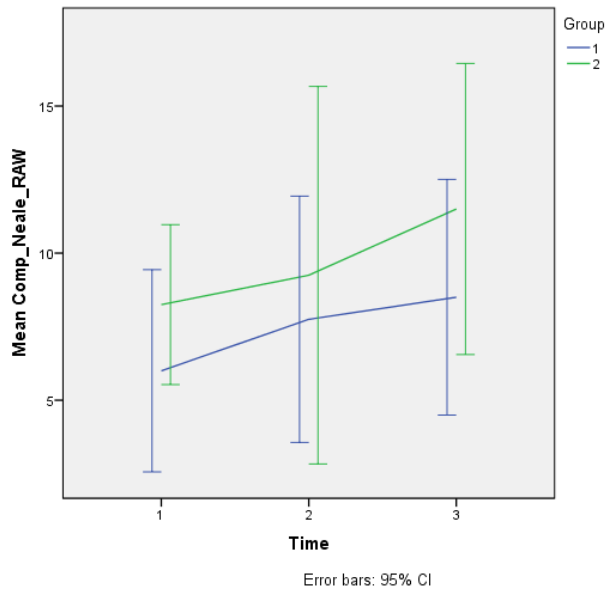


Figure 36 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the Neale Analysis Comprehension raw scores (Comp Neale Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was non-significant ($F[2,18] = 0.89, p = .427$), as was the main effect for group ($F[1,18] = 2.17, p = .427$). The main effect for time, however, was significant ($F[2,18] = 18.68, p < .001$). Post-hoc LSD contrasts across the main effect of time indicated that both groups showed a significant increase from T2 to T3 ($p = .034$) and from T1 to T3 ($p < .001$). Neither group changed significantly between T1 and T2 ($p = .102$). These results indicate that both groups improved over the course of the study and did not demonstrate differential responding to Decoding or Language Intervention.

Neale Analysis Rate

The Neale Analysis of Reading Ability-3: Rate assesses rate of text reading in a story reading task.

Figure 37: GLMM - Neale Analysis Rate

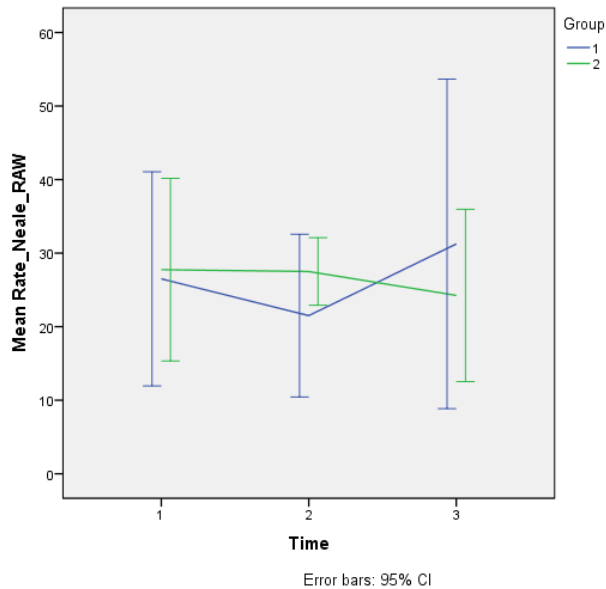


Figure 37 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the PhAT-2 Neale Analysis Rate raw scores (Rate Neale Raw) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was significant ($F[2,18] = 7.93, p = .003$) thereby confounding the main effects of group and time. Post-hoc LSD contrasts conducted on the simple main effects of time indicated that Group 1 (Decoding/Language) showed a significant decrease from T1 to T2 ($p < .001$), a significant increase from T2 to T3 ($p < .001$), but no significant change from T1 to T3 ($p = .061$). In contrast, Group 2 (Language/Decoding) showed no significant change between T1 and T2 ($p = .927$), between T2 and T3 ($p = .229$), and between T1 and T3 ($p = .490$). These results indicate that Group 1 demonstrated a significantly slower rate of reading following Decoding Intervention, but that group 2's reading rate did not significantly change after the Decoding intervention.

Assessment NW Spelling List

Nonword spelling was assessed using responses on researcher-developed Assessment NW Spelling Lists analysed by the researcher using two measures of the Spelling Sensitivity Scoring Procedure (SSS): the number of omitted phonemes (NWSpell Omit), and the number of phonemes that were legally spelled (NWSpell Legal). The researcher checked reliability by re-scoring one de-identified randomly selected Assessment NW Spelling List per participant. The re-scored responses were checked against the original scoring resulting in 98% consistency, that is, the scoring of two percent of elements differed (e.g., differences in interpretation of hand writing, and decisions about which element was omitted).

Nonword spelling phonemes omitted (NWSpell Omit)

Figure 38: GLMM - SSS Phonemes Omitted

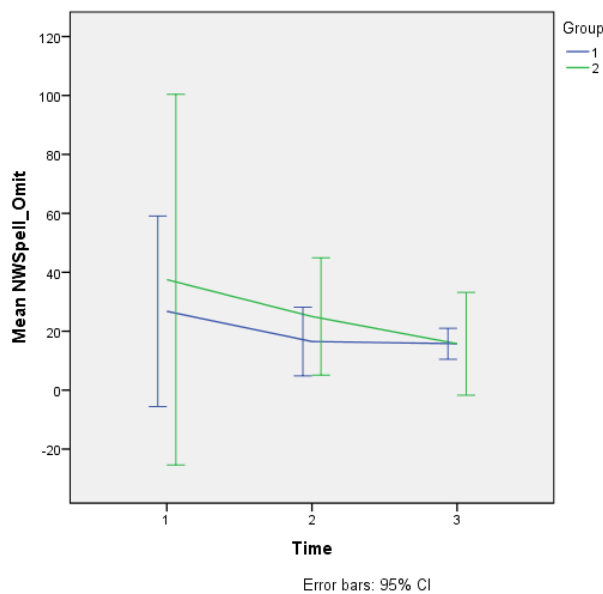


Figure 38 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the SSS (Spelling Sensitivity Score) phonemes omitted scores (NWSpell Omit) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was significant ($F[2,18] = 3.78, p < .042$) thereby confounding the main effects of group and time. Post-hoc LSD contrasts conducted on the simple main effects of time indicated that there were no changes in error rate of omitted phonemes for Group 1 (Decoding/Language) from T1 to T2 ($p = .127$), T2 to T3 ($p = .802$), or T1 to T3 ($p = .171$). Similarly, Group 2 (Language/Decoding) showed no significant change between T1 and T2 ($p = .418$), but did show a significant decrease in errors from T2

and T3 ($p < .001$). Curiously, Group 2 showed no significant change between T1 and T3 ($p = .169$). These results indicate that there was no significant change in the number of phonemes omitted for Group 1 for any time period. Though there was also no significant change for Group 2 between T1 to T3, there were significantly fewer phonemes omitted from T2 to T3 following Decoding Intervention.

Nonword spelling phonemes legally spelled (NWSpell Legal)

Figure 39: GLMM - SSS Phonemes Legal

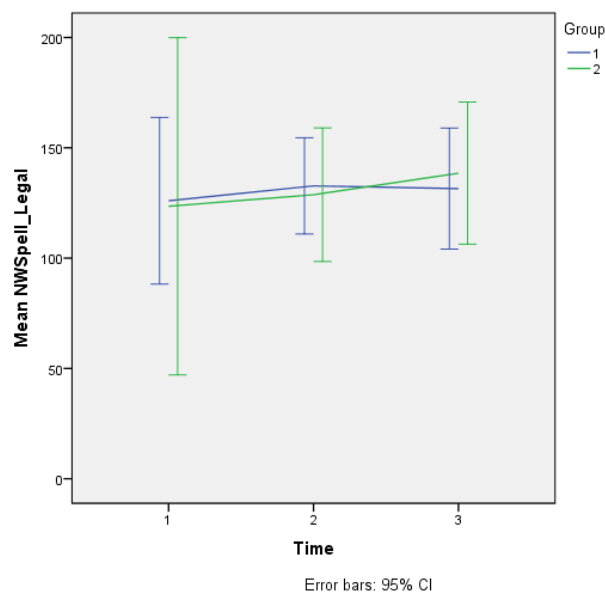


Figure 39 shows the mean and SD (error bars) at Time 1 (A^1), 2 (A^2), and 3 (A^3) of the SSS (Spelling Sensitivity Score) phonemes legal scores (NWSpell Legal) for Group 1 (blue) and Group 2 (green). The Group x Time interaction was non-significant ($F[2,18] = 2.50, p = .110$), as was the main effect for group ($F[1,18] = 0.00, p = .991$) and time ($F[2,18] = 1.05, p = .370$). There were no significant changes for either group in the number of phonemes that were legally spelled.

Summary

These analyses indicate that, compared to the Language Intervention condition, the Decoding Intervention (the independent variable) resulted in significant changes in a small number of the other reading related outcome measures. To demonstrate a causative role for Decoding Intervention on the dependent variable and the other outcome measures, the expected pattern was that Group 1 would make

significant change from T1 to T2 and T1 to T3, but not from T2 to T3, and Group 2 would make significant change from T2 to T3 and T1 to T3, but not from T1 to T2. Significant changes consistent with this pattern occurred for TOWRE-2 Phonemic Decoding, the PhAT-2 VC, and there was a trend for the PhAT-2 Total. Additionally, trends were observed for a slowed rate of text reading for Group 1 and fewer phonemes omitted in nonword spelling for Group 2 following Decoding Intervention. In relation to the second research question, this indicates that the Decoding Intervention resulted in significant improvements in some of the standardised measures of nonword reading, but did not impact significantly on word reading efficiency, text reading accuracy, reading comprehension, nor the number of phonemes legally spelled in nonword spelling.

Additional Analyses

Three additional analyses were performed to examine the efficiency of the intervention (Mean Intervention Time analysis), to justify the intervention targets (Decoding Error Pattern analysis), and to investigate support for one of the design features of the Decoding Intervention (Orthotactic-Phonotactic Decoding Accuracy analysis).

Mean Intervention Time

The computer program used in the Decoding Intervention (WordDriver) automatically recorded time (milliseconds) that each participant spent doing all WordDriver components. These included the dependent variable (Assessment NW Lists - the T-Plate), the intervention modules (L-Plate, P-Plate, D-Plate), and the module assessing the motor aspect of the WordDriver tasks (S-Plate). Table 7 presents the group analysis of time spent completing the intervention modules (L-Plate, P-Plate, D-Plate), as well as the T-Plate administered at the beginning of each of the intervention sessions, as this may have served as extra decoding practice once the participant started to become more proficient with phonological recoding.

Table 7: Study 2 Mean Intervention Time analysis

	Time spent in intervention phase (minutes)					
	Decoding		Ax NW Lists		Combined	
	Total	Session	Total	Session	Total	Session
P1	92.90	6.19	78.20	5.21	171.10	11.41
P2	107.37	7.16	78.07	5.20	185.43	12.36
P3	89.17	5.94	63.33	4.22	152.50	10.17
P4	103.73	6.92	27.80	1.85	131.53	8.77
P5	111.40	7.43	61.05	4.07	172.45	11.50
P6	95.03	6.34	70.92	4.73	165.95	11.06
P7	120.08	8.01	77.28	5.15	197.37	13.16
P8	107.63	7.18	76.60	5.11	184.23	12.28
Av	103.41	6.89	66.66	4.44	170.07	11.34

Note: Pn = Participant number; Decoding = Decoding Intervention; Ax NW List = Assessment NW List (dependent variable); Combined – Decoding Intervention + Ax NW List; Av = average per participant

These results indicate that the average Decoding Intervention time was 6.89 minutes per session, a total of approximately 103 minutes per participant over 15 sessions. The average time spent completing the Assessment NW Lists during the Decoding Intervention was approximately four minutes per session, a total of approximately 67 minutes per participant over 15 sessions. The total time spent completing word reading activities (Decoding Intervention plus Assessment NW Lists) was approximately 11 minutes per session, a total of 170 minutes over 15 sessions.

Pre-intervention Decoding Error Pattern

An analysis of the pre-intervention decoding error pattern was conducted to validate use of target items with 1:1 letter-sound correspondence and to replicate the findings of McCandliss et al. (2003) who reported significant position effects in decoding accuracy in children of similar age with reading impairment. The decoding accuracy of each letter position of the pre-intervention Assessment NW List items (A¹ for Group 1 and A² for Group 2) were recorded. Similar to the McCandliss et al. (2003) study these were analysed at the group level.

Table 8: Study 2 Decoding Error Pattern analysis

Res	3-letter			4-letter							
	CVC			CVCC				CCVC			
	C	V	C	C	V	C	C	C	C	V	C
Total	580	580	580	354	354	354	354	192	192	192	192
% C	83	61	69	87	64	55	75	90	59	57	69

Note: Res = Responses; Total = Total items read; %C = Percentage correct; CVC = consonant-vowel-consonant; CVCC = consonant-vowel-consonant-consonant; CCVC = consonant-consonant-vowel-consonant

Table 8 displays the decoding accuracy of each letter position (percentage correct) for 3-letter and 4-letter items. No participant reached 5-letter level in the pre-intervention Assessment NW List module. The analysis indicated that participants demonstrated the greatest accuracy for the initial, followed by the final and then the medial letter position in 3- and 4-letter items; and in 4-letter items, the first letter in an initial consonant blend and the last letter in a final consonant blend. These results were consistent with those of (McCandliss et al., 2003) and confirmed that items of 1:1 letter-sound correspondence were an appropriate target for these participants.

Orthotactic-Phonotactic Decoding Accuracy

This analysis aimed to examine evidence relating to the use of orthotactic probability to organisation items (from easiest to hardest) in some of the WordDriver modules (Decoding Intervention, Assessment NW Lists, and the Assessment NW Spelling Lists). The decoding accuracy on the pre-intervention Assessment NW List items (which were classified according to their orthotactic and phonotactic probability values) was examined at the group level. A computer program was written to assign the items (the nonwords) to one of four categories - high orthotactic-high phonotactic (HO-HP), high orthotactic-low phonotactic (HO-LP), low orthotactic-high phonotactic (LO-HO), and low orthotactic-low phonotactic (LO-LP). To achieve this categorisation, the median value for orthotactic and phonotactic probabilities in the Assessment NW List items was calculated, and the orthotactic and phonotactic score for each item was assigned to either the high or low category ("high" was any score above the median, and "low" any score below the median). Thus each item fell into one of the four categories. For example, if an

item's orthotactic score was above the median and its phonotactic score was below the median, that item was classified as high orthotactic-low phonotactic (HO-LP).

Table 9: Study 2 Orthotactic-Phonotactic Decoding Accuracy analysis

	3 letter NWs				4 letter NWs			
	HO HP	HO LP	LO HP	LO LP	HO HP	HO LP	LO HP	LO LP
Total Read	223	146	131	198	295	139	43	78
Total Correct	106	65	53	79	81	34	11	27
% Correct	48	45	40	40	28	25	26	35

Note: HO – high orthotactic probability; HP = high phonotactic probability; LO = low orthotactic probability; LP = low phonotactic probability; NW = nonwords

Table 9 displays the percentage correct in each of the categories (HO-HP, HO-LP, LO-HP, LO-LP) for 3-letter and 4-letter items (as no participant reached the 5-letter level in the pre-intervention phase). The results indicate that prior to the intervention, participants attempted more 3-letter items than 4-letter items, and that there were more attempted items in the HO-HP category than the other three categories. Within the 3-letter items, participants were more accurate with HO-HP, and incrementally less for the other three categories. Within the 4-letter words, the overall accuracy was below that of the 3-letter words with greater accuracy for LO-LP.

Discussion

The study reported in this chapter (Study 2) evaluated the Decoding Intervention using a robust single subject research design (SSRD) which incorporated a comparison intervention condition and randomised allocation to treatment regime, thus satisfying the requirements of systematic replication (the second phase of research in the evaluation of clinical outcomes). Eight participants were randomly allocated to either A¹-B-A²-C-A³ or A¹-C-A²-B-A³, and the Language Intervention (with no reading element) controlled for the possible effects of individual time spent with each child. The cross-over design meant that the results for half of the children (Group 1) provided data about maintenance of skills over one

school term (two months), while those for the other half (Group 2) represented a delayed treatment regime.

While the use of a single subject research design (SSRD) with eight participants allowed a fine grained examination of individual profiles (discussed in Chapter 7), the use of a cross-over design with randomisation also allowed analyses at the group level for the first two research questions (due to the large data set, i.e., three baseline sessions, each of eight session, for each of the eight participants). The group results are discussed in this chapter to present overall findings and to provide context for the individual analyses. The third research question was only analysed using SSRD procedures as use of group analyses for this data set increased the risk of Type 1 and Type 2 errors: a large number of pre-intervention moderators, a small number of participants, and a smaller number of outcomes (two) for which a significant effect was demonstrated at the group level. The additional analyses presented information about the efficiency of the Decoding Intervention (Mean Intervention Time), the appropriateness of skills that were targeted (Decoding Error Pattern), and the usefulness of using orthotactic values to organise the items (Orthotactic-Phonotactic Decoding Accuracy).

The following section will discuss the results of the group analyses of the first two research questions within the context of other reported interventions, leaving theoretical implications to the final chapter. This will be followed by a discussion of the additional analyses (Mean Intervention Time, Decoding Error Pattern, and Orthotactic-Phonotactic Decoding Accuracy).

Hypothesis 1

The hypothesis addressing the first research question was that the Decoding Intervention would result in significant increases in nonword reading assessed by the Assessment NW Lists. The results of the group analyses demonstrated strong support for this hypothesis. Group 1, who received Decoding Intervention followed by Language Intervention, made significant gains in NW Rate (number of nonwords accurately read in 60 seconds), and NW Total (total number of nonwords accurately read) following the Decoding Intervention with no significant decrease following the Language Intervention, indicating that their skills were maintained for a period of over 2 months. In contrast, Group 2 made no significant gains following Language

Intervention but significant gains as a result of the Decoding Intervention. Furthermore, the gains in scores in nonword reading for both groups were highly significant ($p < .001$). Given the cross over design used in this study, these results support the conclusion that there is a direct relationship between the Decoding Intervention and the significant gains in nonword reading which were made immediately after the intervention and maintained for two months.

The interpretation of these results in the context of other studies that have evaluated intervention effectiveness using group analyses of researcher-developed nonword reading outcome measures (Lane et al., 2009; McCandliss et al., 2003; Pullen & Lane, 2014) will focus on the construction of the dependent variable, the research design and resulting analyses, and finally, the outcomes.

Researcher-developed outcome measures were employed because in contrast to standardised tests (which generally lack sensitivity in measuring short-term growth in skills for beginning readers), they provide a more detailed measure of skills targeted in interventions at a particular developmental level (Lane et al., 2009). Compared to studies that included similar intervention targets and researcher-developed nonword assessments, the dependent variable (Assessment NW Lists) and research design used in Study 2 were more comprehensive. For example, using pre-post intervention designs to assess decoding accuracy, McCandliss et al. (2003) administered the same list of 128 monosyllabic nonwords (containing short vowels and vowel digraphs ranging from CVC to CCCVCC) which were constructed by sampling words from the intervention material and recombining onset and rime to form novel nonwords. In the Pullen et al. (2005) study the same list of 20 CVC nonwords was used, and an undisclosed number of CVC nonwords was used by Pullen and Lane (2014). In contrast, Study 2 employed 39 separate Assessment NW Lists (each containing 70 items) that were matched for difficulty level and, apart from the two 2-letter items in each list, contained no repeated items. Furthermore, the research design (two groups of participants each completing three baseline phases with the same number of sessions) allowed for rigorous statistical analyses at both the group and individual level.

The outcomes of Study 2 compare favourably with the studies described above (i.e., those that targeted similar skills and used researcher-developed nonword reading lists as an outcome measure analysed at the group level). The Tier 2 intervention conducted by McCandliss et al. (2003) investigated a two-component

intervention (manipulative letters and a sentence reading task) targeting decoding skills, with random assignment of participants to a treatment and control group. The results of a repeated measures ANOVA on pre- post-intervention researcher-developed nonword lists indicated significant gains in nonword reading ($p < .0005$). Lane et al. (2009) also targeted decoding in a Tier 2 intervention comprising a range of components (manipulative letters, phonemic awareness, fluency, writing, and extending literacy) with random assignment of participants to intervention, comparison, and control groups. The results of a multivariate ANCOVA of the nonword reading outcome measure (researcher-developed nonword lists) indicated that the intervention group demonstrated significantly greater gains in nonword reading ($p = .01$) than the control and comparison groups. In a more recent Tier 2 study, Pullen and Lane (2014) examined the effectiveness of a two component intervention (magnetic letters and decodable book reading tasks) where children were seen in small groups after random assignment to intervention, comparison, and control conditions. The results of ANCOVA analyses on the researcher-developed CVC nonword reading measure revealed that the treatment group significantly outperformed the comparison and control groups ($p = .003$ and $.009$ respectively).

When the results of Study 2 are considered within the context of these studies with similar aims and group analyses of researcher-developed nonword assessments, it is concluded that the Decoding Intervention developed for this research resulted in highly significant outcomes. Unlike the other studies reviewed in this section, the Study 2 participants required Tier 3 intervention and demonstrated significant gains in nonword reading rate and accuracy ($p < .001$) as a result of the Decoding Intervention. These skills have been shown to underpin sight word development (Cunningham, 2006), fluency of text reading (Hudson et al., 2012), and subsequently reading comprehension (Schatschneider et al., 2004). The impact of this improved nonword reading on other reading related outcome measures in this research, Hypothesis 2, will now be discussed.

Hypothesis 2

The second hypothesis, that the effect of the Decoding Intervention on standardised assessments of reading (word and nonword reading, text reading and comprehension) and a detailed assessment of nonword spelling would vary, was

somewhat supported. With respect to reading skills, the results indicated that the significant gains in nonword reading that occurred in the Assessment NW Lists were reflected in standardised tests assessing nonword reading of items with 1:1 letter-sound correspondence (PhAT Vowel-Consonant and PhAT Total). While these skills were also generalised to a measure of nonword reading efficiency: a test that involved a range of orthographic patterns (TOWRE-2 Phonemic Decoding Efficiency), no significant changes were observed in word reading efficiency (TOWRE-2 Sight Word Efficiency) or text reading accuracy or comprehension (Neale Analysis of Reading Ability).

While there was an intervention effect on one aspect of nonword spelling (decreased omission of letters following Decoding Intervention) for Group 2, the overall minimal gains in spelling skills is consistent with other studies (Buckingham et al., 2012; McArthur et al., 2012). The use of the Spelling Sensitivity Score in Study 2 enabled a fine grained analysis of spelling where each spelling response was scored according to how many sounds were correctly encoded. Given the focus of this intervention was items with 1:1 letter-sound correspondence, it was, in fact, a positive outcome that Group 2 demonstrated significant gains in their ability to encode sounds when spelling.

Factors that may have impacted on the lack of generalisation to measures of word reading efficiency and text reading accuracy relate to the nature of the outcome measures, the research design (single component), the assessments used in the selection criteria, the target population (Tier 3 intervention), and finally the brief nature of the intervention.

Firstly, the measurement of word reading efficiency (TOWRE-2 Sight Word Efficiency) was a timed assessment (number of words read in 45 seconds). The lack of generalisation to a timed measure of word reading in Study 2 was similar to the Buckingham et al. (2012) study in which participants demonstrated significant changes in an untimed, but not a timed measure of word reading. It is possible that the Study 2 participants may have demonstrated gains on an untimed measure of word reading accuracy.

Secondly, Study 2 investigated a single-component intervention (the Decoding Intervention) to enable an unambiguous analysis of its effect on a range of outcome measures. As teachers were not informed about the goals or strategies being taught in the intervention and each of the schools subscribed to a whole language

reading intervention for struggling readers (Reading Recovery), it was unlikely that the participants would have been encouraged to use alphabetic decoding during classroom text reading. Therefore, apart from the Decoding Intervention sessions, there would have been minimal reinforcement of alphabet decoding when reading words. It is likely that students with persistent word reading impairment need to be reinforced to use decoding strategies during text reading.

Thirdly, the selection criteria did not involve an assessment of all letter-sound correspondences, so the lack of generalisation of phonological recoding to word and text reading may have occurred because prior to intervention, participants may have not have mastered orthographic knowledge of consonant and vowel digraphs. Hence, even though they had mastered phonological recoding as a result of the Decoding Intervention, they may have been unable to accurately decode consonant and vowel digraphs. Delays in orthographic knowledge of digraphs may also have been a factor in the McCandliss et al. (2003) study which had a similar outcomes to that of Study 2, that is, significant gains on researcher-developed nonword lists and standardised measures of nonword reading but no significant gains on standardised measures of word reading. McCandliss et al. (2003) conducted a two-component intervention (involving a decoding and a sentence reading task) targeted items with a range of spelling patterns. Though the authors postulated that the lack of gains in word reading was due to the nature of the items on the word reading test (i.e., that the test items contained irregular words which would not have been sensitive to gains in the intervention targets which were words with regular pronunciations), there is an alternative explanation which is related to the nature of the intervention materials. The decoding component in the McCandliss et al. (2003) intervention involved a manipulative letters activity with real words: changing one letter at a time to form chains of words that differed by a single letter transformation. The examples provided involved short vowels, for example, *sat, sap, tap, top, stop, top*. It is possible that participants may have quickly developed MORs for the target words, as it has been shown MOR development can occur following as few as four exposures (Bowey & Muller, 2005; Cunningham et al., 2002; Kyte & Johnson, 2006; Nation et al., 2007) which would have occurred in this intervention task. Additionally, as semantic information was provided in the sentence reading task, the children may have developed sight words for the items. This may have enabled participants to progress through each level in the intervention by reading the words as sight words,

without necessarily implicitly learning orthographic knowledge for vowel digraphs. Hence delays in orthographic knowledge for vowel digraphs may also have contributed to the lack of generalisation to word reading skills.

Fourth, as a Tier 3 intervention, participant pre-intervention phonemic decoding skills in Study 2 ranged from the 1st to the 10th percentile (mean of 4th percentile). Compared to Study 2, the Tier 3 studies reviewed previously (Denton et al., 2013; Torgesen, 2001) reported a range of participant pre-intervention phonemic decoding skills: Denton et al. (2013) reported a mean of 16th percentile, and Torgesen (2001) was similar to Study 2 with a mean at the 4th percentile. However, in both studies there were a significant number of children with inadequate response, with about one third remaining below average in phonemic decoding and word reading in both studies. This suggests that even though these studies targeted a broad range of skills, a large proportion of children with severely impaired pre-intervention phonemic decoding may require a closer match of intervention target to their existing phonemic decoding skills, or a more intense focus on key skills.

When discussing the outcomes of Study 2 in the context of other studies, a further factor to consider is that while these Tier 2 and Tier 3 interventions discussed above address a broad range of skills, two studies that attempted to isolate the essential ingredient/s in multi-component interventions (Lane et al., 2009; Pullen & Lane, 2014) concluded that the “word work” element – specifically the tasks that targeted orthographic processing (letter manipulation), were the key elements. They found that when that element was removed there was no significant difference in outcomes between the intervention and control groups. This suggests that a strong focus on orthographic processing (phonemic decoding) may account for a large portion of the gains made in some multi-component interventions; and furthermore, that a specific focus on this key element may be beneficial for the 25% of children who fail to respond to many Tier 2 and Tier 3 interventions. Though Study 2, with its sole focus on decoding (phonological recoding and orthographic processing), failed to result in significant gains on standardised measures of some related literacy skills, it was successful in demonstrating a direct relationship between the Decoding Intervention and accurate phonological recoding for nonword reading: a skill that predicts word reading and fluency (Good et al., 2008; Hudson et al., 2012). With its goal of mastering accurate phonological recoding of items with 1:1 letter-sound correspondence (to ensure a match with participant decoding skills and an intense

focus on a key skill), it may represent a “first stage” intervention. Follow up stages that target items with consonant and vowel digraphs may be required to enable generalisation to word and text reading accuracy and spelling.

Finally, in evaluating the outcomes of Study 2, the brief nature of this intervention needs to be considered. This is discussed in the following section: the additional analyses, which included the Mean Intervention Time analysis.

Additional analyses

Mean Intervention Time

The Mean Intervention Time analysis (Table 10) revealed that participants in Study 2 spent an average of seven minutes per session (two hours over 15 sessions) completing the Decoding Intervention: a task that targeted phonological recoding and orthographic processing, specifically, sounding out and blending to read words. This amount of intervention time is substantially smaller compared to the word decoding component in other Tier 3 reading interventions, and those Tier 2 interventions with a specific focus on decoding that have been previously discussed.

Table 10: Study 2 Decoding Intervention time comparison

Study	Minutes per Session Decoding	Number of sessions	Total hours Decoding	Total hours Intervention
Study 2	7	15	1.8	1.8
Torgesen (2001)	10	80	13.3	67
Denton et al. (2013)	5	125	10.4	93
McCandliss et al. (2003)	30	60	30	17
Lane et al. (2009)	10	39	6.5	23
Pullen and Lane (2014)	6	30	3	11

The Tier 3 intervention reported by Torgesen (2001) involved two 50 minute sessions per day, five days per week for 8 – 9 weeks (67 hours in total). Fifty students were randomly assigned to two multi-component treatments, both targeting phonemic decoding skills, with about 10 minutes per session (13 hours in total) spent on activities specifically targeting phonemic decoding. A more recent Tier 3 intervention reported by Denton et al. (2013), which involved 47 Year 2 students compared to a control group, was also multi-component. While the complete programme consisted of word attack skills, fluency, comprehension, and written work, the time spent completing specific word decoding skills was five minutes, five times per week over 25 weeks (10 hours in total). This indicates that the time devoted to tasks comparable to the Decoding Intervention in these two Tier 3 multi-component interventions was about five to 10 minutes per session, a total of about 12 hours. However, it is difficult to make comparisons regarding outcomes, as it is possible that the other components in the interventions also impacted on decoding.

To provide a perspective on the efficiency of the Decoding Intervention, it is useful to also consider studies with similar goals to Study 2 (which have been discussed in detail in previous sections). Though these studies were Tier 2 interventions, they incorporated tasks to explicitly teach alphabetic decoding using strategies comparable to those in Study 2 targeting phonological recoding and orthographic processing. The McCandliss et al. (2003) study involved individual intervention sessions of 50 minutes, three times per week for 20 lessons, with about 30 minutes per session (total of 10 hours) spent on the decoding task. In the Lane et al. (2009) study, participants received 30 individual sessions with about 10 minutes per session (6.5 hours in total) spent on decoding, while the Pullen and Lane (2014) study delivered 30 small group intervention sessions with about six minutes per session spent on the decoding tasks (three hours total).

This analysis of time spent completing analogous intervention tasks to the Study 2 Decoding Intervention indicates that the multi-component Tier 3 interventions involved about eight minutes per session (12 hours total). Those studies that had a similar focus to Study 2 ranged from six minutes per session (3 hours total) to 30 minutes per session (30 hours total). This indicates that the mean intervention time of the single component Tier 3 Decoding Intervention in Study 2 of seven minutes per session (2 hours total) is substantially shorter than most of the multi-component studies. When the results of Study 2 are considered within the

context of these other Tier 3 studies and those Tier 2 with similar aims, it can be concluded that the Decoding Intervention developed for this research resulted in highly significant outcomes with greater efficiency.

Decoding Error Pattern

The Decoding Error Pattern analysis was performed to validate the targets used in Study 2 - items with 1:1 letter sound correspondence. A fine-grained analysis of the responses on the pre-intervention Assessment NW Lists was performed. Participant's responses for each item were phonetically transcribed, the accuracy of each phoneme was scored, and the percentage correct was calculated at the group level for 3- and 4-letter words (CVC, CVCC and CCVC), as no participant was able to decode 5- or 6-letter strings prior to intervention. It was found that in 3-letter words the accuracy of the initial consonant was highest (83%), followed by the final consonant (68%) and then the vowel (61%). In words with consonant blends, accuracy for the 1st consonant in an initial blend was highest (90%), followed by the last consonant in a final blend (75%), vowels (about 60%), then the second consonant in an initial blend (59%) and the lowest accuracy was the first consonant in a final blend (55%).

These results mirror those of McCandliss et al. (2003), and demonstrate that prior to the intervention the participants in Study 2 had not mastered accurate phonemic decoding of 3- and 4-letter items. Research has demonstrated that accuracy in phonemic decoding predicts early literacy success (Good et al., 2008; Hudson et al., 2012) which subsequently predicts literacy and language outcomes in later years (Sparks et al., 2014). It is therefore clear that the aim of the Decoding Intervention of Study 2 (phonological recoding and orthographic processing of items with 1:1 letter-sound correspondence starting at 2-letter and progressing to 6-letter items) was appropriate for these participants who required Tier 3 intervention.

Orthotactic-Phonotactic Decoding Accuracy

The Decoding Intervention used in Study 2 was designed to present items (words and nonwords) that increased in difficulty according to orthotactic probability values. This was based on research demonstrating that MOR development for children in the early stages of reading acquisition and those at risk of reading delay (Apel, 2009; Apel et al., 2012) is sensitive to the linguistic properties of words, that

is, orthotactic and phonotactic probability values. The Orthotactic-Phonotactic Decoding Accuracy analysis was performed to determine if use of orthotactic probability values to order the items was reflected in accuracy of decoding, that is, that as a group, participants were more accurate on items of high orthotactic probability prior to intervention. The items in the Assessment NW Lists were classified into high orthotactic-high phonotactic (HO-HP), high orthotactic-low phonotactic (HO-LP), low orthotactic-high phonotactic (LO-HP), and low orthotactic-low phonotactic (LO-LP), and the decoding accuracy in each category was examined.

The analysis indicated that there were twice as many HO-HP items than any other category. This outcome is expected, since by definition the combination of letters and sounds in these items occurs more frequently in English. It was also revealed that participants were presented with more 3-letter than 4-letter items (698 compared to 555), also expected, as prior to intervention participant decoding accuracy was generally low, especially once the items contained more than 3 letters. The results suggested higher accuracy on items with high orthotactic probability within the 3-letter items. Although there were less clear results for 4-letter items (as 20% fewer items were attempted), the higher accuracy on low phonotactic probability items is interesting, as similar results have been found in a spoken word fast-mapping study (Apel, 2010) in which the authors suggested that low phonotactic items trigger the acquisition of novel phonological representations.

This preliminary analysis suggests that the linguistic properties of words may impact on the ease of decoding in a similar way that this feature impacts on MOR development. Furthermore, this analysis suggests that items of high orthotactic probability may have been more accurately decoded than those of low orthotactic probability at the easier level (3-letter items). However to more reliably test the relative impacts of orthotactic and phonotactic probability on decoding, a specifically designed experiment needs to be performed where participants are presented with equal numbers in each category. This may be pursued in subsequent research studies.

Conclusions

The aim of Study 2 was to test three research hypotheses and to perform further analyses to examine aspects of the intervention relating to efficiency, target

selection, and a key design feature of the independent variable (the Decoding Intervention). The research design (a single subject cross-over design with multiple treatments across eight participants – two groups of four children) enabled both group and individual analyses of all outcome measures.

The results of the group analyses reported in this chapter provided strong support for the first hypothesis: that the Decoding Intervention would result in significant gains in the dependent variable (rate and accuracy of nonword reading on the Assessment NW Lists) for both groups. The second hypothesis, that the intervention would result in gains on standardised measures of some of the reading related skills (word and nonword reading efficiency, text reading and comprehension, nonword spelling) was partially supported. Significant gains were made on the measures of nonword reading efficiency and accuracy, with minimal gains in word reading efficiency, text reading accuracy and comprehension, and spelling.

Further analyses revealed that while the Decoding Intervention involved substantially less time than other Tier 2 and Tier 3 interventions, it resulted in highly significant gains in nonword reading – one of the most predictive skills for word reading achievement. The second additional analysis justified the intervention target (items with 1:1 letter-sound correspondence) as being appropriate to the pre-intervention decoding levels of participants. Finally, the third additional analysis suggested that use of orthotactic probability values to organise the intervention items may have contributed to ease of decoding but that further investigation of the influence of the linguistic properties of items (words and nonwords) on decoding success is needed.

One of the main limitations of Study 2, especially in relation to the group analyses of data, was the small number of participants. However, the single subject design also enabled an investigation of the effectiveness of the Decoding Intervention on the outcome measures for each participant, as well as examination of the influence of pre-intervention profiles of phonological processing, language, and intellectual on response to intervention. This analysis will be presented and discussed in Chapter 7.

CHAPTER 7: STUDY 2 - INDIVIDUAL PARTICIPANT ANALYSES

“The important contribution of single-subject research is that the specific characteristics of the treatment and the circumstances in which the treatment is successful can be delineated. . . . visual inspection of individual performance allows the researcher to observe clinically strong effects that would not necessarily have been statistically significant (and would therefore have been ignored). Therefore, results from single case designs may actually provide more “real world” insight and understanding of individual responses than data from group studies.” (Portney & Watkins, 2009, p. 268).

The single subject research design used in Study 2 enabled analyses at both group and individual levels because two types of outcome measures were gathered and the participants were divided into two groups. The outcome measures involved pre- post-intervention assessments (as used in group designs), as well as repeated measures - systematic collection of data at regular intervals (a defining feature of single subject research designs). The eight participants each completed five phases (three baseline phases administered before, between, and after two intervention conditions), thus each formed their own single subject design. Additionally, they were randomly divided into two groups of four depending on the sequence of intervention conditions – $A^1-B-A^2-C-A^3$ (*decoding-first*) and $A^1-C-A^2-B-A^3$ (*language-first*), allowing for the group analyses of the pre- post intervention outcome measures reported in Chapter 6. However, group analyses do not permit examination of trends, patterns and variability of response within each individual. This type of individual analysis provides insight into factors that may contribute to the substantial proportion of children who demonstrate an inadequate response to intervention and supports an evidence-based approach to clinical decision making (Portney & Watkins, 2009).

This chapter presents the results of the repeated measures (the dependent variable) collected for each participant at the beginning of each baseline and Decoding Intervention session, and the individual participant gains on standardised assessments of other reading related skills. Additionally, it examines the influence of pre-intervention language, phonological processing, and cognitive profiles on the child’s response to intervention. Thus, use of analyses appropriate for single subject

research design (SSRD) allowed measurement of individual response to intervention and exploration of a range of participant response characteristics.

Research Questions and SSRD Analyses

This section provides a review of the three research questions and describes the SSRD analyses that were used to examine the data.

Question 1

The first research question examined the effectiveness of the Decoding Intervention on the dependent variable - nonword reading assessed by the researcher-developed Assessment NW Lists. The two primary measures of the dependent variable (NW Rate and NW Total) were examined using similar procedures to those described for Study 1: visual inspection of the graphed responses and the 2SD band method (Portney & Watkins, 2009; Rubin, 2010), with an additional statistical analysis using a calculation of effect size (Beeson & Robey, 2006).

Visual inspection of graphs involved examination of within-phase characteristics of stability (or variability), and trend (or direction of change), and between-phase changes in the level, trend, and slope of data points across adjacent phases (e.g., from baseline to intervention phase). The 2SD band method assessed if there was a statistically significant difference between the baseline and intervention phase, and whether a stable baseline was achieved. First, the variability during the baseline phase was established using the mean and standard deviation (SD) of data points within that phase. The 2SD band was drawn on the baseline phase and extended into the intervention and post-intervention phase. If at least two consecutive data points in the intervention phase fall outside the 2SD band, changes from the baseline are considered significant (Portney & Watkins, 2009). Statistical process control (SPC) was used to determine if a stable baseline was achieved, that is, if the baseline responses were within the limits of common cause variation which is defined as data that fall within 3 SD of the mean (Portney & Watkins, 2009).

Effect sizes (Beeson & Robey, 2006) were calculated to provide a standardised measure of the amount of change in the dependent variable from pre- to post-intervention. While effect size is usually used to enable comparison with other

reported interventions (Dunst, Hamby, & Trivette, 2004), in this thesis it was used to interpret the responses to intervention for each participant relative to the other participants, and to provide additional insights into the influence of pre-intervention profiles on the magnitude of response to intervention. There were two reasons for this. Firstly, as noted by Beeson and Robey (2006, p. 8), “the interpretation of the magnitude of effect sizes is not an easy task. It requires an informed means of developing benchmarks to discern magnitude of small, medium, and large effect sizes for a particular treatment”. For example, those stated by Cohen (1988) based on between-group designs, were 0.2, 0.5 and 0.8 for small-, medium-, and large-sized effects, while those for an aphasic lexical retrieval treatment using a single-subject design were 4.0, 7.0, and 10.1 (Beeson & Robey, 2006). The point, that effect size can only be interpreted with reference to other similar studies was articulated by Cohen (1988):

“Effect size is indispensable in power analysis, as it is generally in science, and conventional operational definitions of ES have their use, but only as characterizations of absolute magnitude. However, the *meaning* of any given ES is, in the final analysis, a function of the context in which it is embedded.” (Cohen, 1988, p. 535)

As there were no effect sizes reported in the previous studies that targeted decoding and used researcher-developed nonword reading lists as an outcome measure (Lane et al., 2009; McCandliss et al., 2003; Pullen et al., 2005), there were no documented benchmarks applicable to the dependent variable outcome measures used in Study 2. The second reason that effect size was used to compare the magnitude of response between the eight participants rather than with other reported studies, is that Galuschka et al. (2014) in their meta-analysis of the effectiveness of reading interventions, suggested that researcher-developed measures that are related to the intervention materials may over-estimate the true magnitude of an effect and may not generalise to material that hasn't been specifically taught.

Based on the work of Beeson and Robey (2006), effect size was calculated by comparing the level of performance from the first baseline (A^1) to that of the second (A^2) and third (A^3) baselines using a variation of Cohen's d statistic:

$$d = \frac{X_{A2} - X_{A1}}{S_{A1}}$$

Where A_1 and A_2 are pre- and post-treatment phases, respectively; X_A is the mean of the data collected in a phase; and S_A is the corresponding standard deviation. Three effect sizes were calculated for NW Rate and NW Total (A^1 to A^2 , A^1 to A^3 , A^2 to A^3), that is, six for each participant.

A Speed of Motor Response analysis was completed for each participant to determine if increased proficiency in using the iPad-delivered materials contributed to any changes in the NW Rate score. The S-Plate module was administered following the T-Plate (Assessment NW List) at the start of each baseline and Decoding Intervention session, that is, not during the Language Intervention phase. It required the child to touch the Go button as soon as they saw the road sign graphic change from white to black (thus assessing speed of motor response). The computer program (WordDriver) that delivered all intervention modules, automatically recorded the time taken from colour change to the touch of the Go button. The analysis involved calculating the mean and standard deviation of response times in each of the four phases where the S-Plate was delivered (A^1, B, A^2, A^3), to determine if the child's overall speed of response changed over time.

Question 2

The second research question investigated the effect of the Decoding Intervention on standardised measures of reading. The Decoding Intervention aimed to teach use of phonological recoding targeting items with 1:1 letter sound correspondence, starting at 2-letter (CV, VC) and 3-letter items (CVC), and progressing to 6-letter items (those with consonant blends). Though it did not target items with consonant or vowel digraphs, most of the standardised outcome measures used in this research assessed mastery of items that contained all spelling patterns. While the group analysis presented in Chapter 6 revealed that both groups demonstrated significant gains in two of the measures (nonword reading efficiency and accuracy), this analysis examined any clinically significant changes that were made by each participant in the standardised reading outcome measures: nonword reading accuracy (PhAT-2: Robertson & Salter, 2007), word and nonword reading efficiency (TOWRE-2: Torgesen et al., 2012), text reading accuracy, comprehension, and rate (Neale Analysis of Reading Ability-3); and the Spelling Sensitivity Score (SSS: Masterson & Apel, 2010) analysis of nonword spelling.

Four methods of determining clinically significant change for the standardised tests were used, depending on the type of score. Firstly, a clinically significant gain on standard scores was judged to occur when the score moved from one category to the next as defined in the specific test manual, for example, from *severe delay* to *moderate delay* or from *moderate delay* to *average range*. Second, the TOWRE-2, in addition to standard scores, also provides an interpretation of change in the raw score using a percentage probability that the difference is not due to error (Torgesen et al., 2012, pp. 30-33). For example, if the child's raw score improved from 8 to 14 (a difference of six) the TOWRE-2 manual states that there is a 95% probability that the change is real and not due to random variation in testing error. Third, the Neale Analysis of Reading Ability-3 (Neale, 1999) provides percentile rank and a reading age score. A clinically significant change in percentile rank was judged to occur when the score moved from one performance descriptor to another (e.g., from *very low* to *below average*); and fourth, the "a priori learning criterion" as described by McCandliss et al. (2003, p. 91) was used to determine clinically significant changes in reading age scores. Using this method, a reading age gain that was greater than the three month gap between pre- and post-assessment was considered to be clinically significant as the child had advanced beyond what would be expected of a typical child over a similar time span. Drawing on these two methods to interpret the data for the Neale provided a more conservative judgement about clinically significant change for these measures of text reading.

The responses on the Assessment NW Spelling Lists were analysed using the SSS procedure (Masterson & Apel, 2010). The SSS procedure was designed to allow a more sensitive evaluation of incremental increases in linguistic knowledge compared to traditional correct/incorrect scoring systems. When using the SSS, target items (words or nonwords) are divided into individual elements (e.g., phonemes in the case of single syllable words, and affixes in the case of multi-syllabic words). As an example relevant to the items in Study 2, the nonword *yic* has three elements (phonemes), /y-i-c/. While the first two elements have only one legal spelling, the final element "c" has two legal spellings – "c" as in *tic*, and "ck" as in *tick*. The outcome measures selected for analysis were *Elements Omitted*: the number of elements (phonemes) that were not represented in the spelling response, and *Elements Legally Spelled*: the number of elements represented by a legal spelling option. These two measures were considered to be sensitive to the likely changes

following an intervention that focused on teaching phonological recoding and orthographic processing, in other words, an increased ability to take note of each letter in the target item may result in an increased ability to represent each phoneme when spelling, which may also lead to gains in the ability to legally spell those phonemes. All participants completed an equal number of nonword spelling responses (two Assessment NW Lists each of 20 items, a total of 40 items) at each of the three baselines (A¹, A² and A³). Therefore, in this individual analysis, the percentage correct was used to compare any changes in nonword spelling that occurred following the Decoding Intervention.

Question 3

The third research question examined whether pre-intervention profiles of language, phonological awareness, and intellectual skills influenced the responses to the intervention. As discussed in Chapter 6, this data was not analysed at the group level as there was a risk of Type 1 and Type 2 errors, due to the large number of pre-intervention moderators (11), the small number of participants, and the smaller number of outcomes (two) for which a significant effect was demonstrated. Therefore, similar to Study 1 (see Chapter 5) this analysis examined the number and pattern of pre-intervention profile scores to informally investigate individual patterns of response.

Results

This section first of all presents the tables and graphs relevant to each of the three research questions, as follows:

Question 1:

- Table 11: Completed Decoding Intervention modules
- Table 12: Comparison of NW Attempted to NW Rate
- Table 13: Effect size calculation
- Table 14: Speed of motor response, S-Plate
- Figures 40 and 41: the graphed S-Plate responses

Question 2:

- Table 15: Pre- post-intervention scores on standardised reading assessments (in which clinically significant changes occurred)
- Table 16: Pre- post-intervention performance on nonword spelling

Question 3:

- Table 17: Pre-intervention profile assessments (scores on measures of phonological processing, language, and intellectual skills)

Next, individual analyses (which make reference to these seven tables and graphs) will be presented for each participant. Each individual analysis reports on:

- Decoding Intervention modules completed – Table 11
- Nonword reading rate and accuracy (visual inspection, 2SD band method, effect size, and speed of motor response) – Tables 12, 13 and 14; and Figures 40 and 41
- The clinically significant pre- post-intervention changes that occurred on the standardised tests of reading (nonword reading accuracy, word and nonword reading efficiency, text reading accuracy, comprehension and rate), and on the nonword spelling measure – Tables 15 and 16. Appendix L shows the complete set of scores on the pre- post-intervention standardised tests for all participants.
- The participant's pre-intervention profile of phonological awareness, language, and intellectual skills – Table 17.
- Clinical Observations (a summary of factors that were observed to impact on response to intervention)
- Summary and interpretation of that participant's response to intervention.

The final section of this chapter will provide a discussion of the results of the individual participant analyses.

Results of standardised assessments and analyses

The next section displays the seven tables and graphs described above.

Table 11: Study 2 participant Decoding Intervention record

Participant	Modules completed in each Decoding Intervention session														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	L2 P2	P2 L3 P3	D3	D3	D3 L4	P4 P4	D4	D4	D4	L5 P5	P5	D5	D5	L6	P6
2	L2 P2	L3 P3	D3	D3	D3	L4 P4	P4	D4	D4	L5 P5	P5	D5	D5	D5	D5
3	L2 P2	L3 P3	D3	D3	D3	D3	L4 P4	P4	D4	D4	L5	P5	D5	D5	D5
4	L2 P2	P2 L3	P3	D3	D3	D3	L4 P4	P4	P4	D4	D4	D4	D4	D4	D4
5	L2 P2	L3 P3	D3	D3	L4	P4	D4	D4	D4	D4	D4	D4	D4	D4	D4
6	L2 P2 L3	P3 D3	L4 P4	D4	L5 P5	D5	D5	D5	L6	P6	P6	D6	D6	D6	D6
7	L2 P2	P2 L3	P3	D3	L4 P4	D4	D4	D4	L5	P5	D5	D5	D5	D5	D5
8	L2 P2	P2 L3	P3	D3	D3	L4 P4	P4	D4	D3	D3	D4	D4	D4	D4	D4

Note: L2 = L-Plate 2-letter level; P2 = P-Plate 2-letter level; D3 = D-Plate 3-letter level; **D3** (bold) = criterion reached for the D-Plate

Table 12: Study 2 comparison of NW Attempted to NW Rate

Phase	NW Measure	P1		P2		P3		P4		P5		P6		P7		P8	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
A1	Attempted	12.0	2.0	9.5	3.2	22.6	5.6	21.1	4.6	13.4	1.6	21.6	2.6	14.3	3.3	9.5	1.5
	Rate	5.8	0.7	5.9	2.7	8.0	1.3	2.3	1.5	5.5	3.3	9.8	3.5	3.5	1.4	4.1	1.7
A2	Attempted	15.1	2.2	14.3	1.6	16.9	2.1	15.5	1.3	13.1	2.0	19.1	2.6	15.9	3.1	10.5	2.4
	Rate	14.3	2.8	12.5	2.4	15.1	3.0	13.3	0.9	1.9	1.5	12.9	3.1	3.8	1.5	5.5	2.0
A3	Attempted	13.9	2.8	11.9	1.4	17.5	1.2	16.0	1.5	13.8	1.8	19.5	0.8	13.0	1.6	9.4	1.9
	Rate	12.8	2.6	11.1	1.5	15.6	1.3	11.9	2.2	10.8	2.7	17.8	1.3	12.3	1.6	7.4	1.1

Note: Attempted = NW Attempted (number attempted in 60 seconds); Rate = NW Rate (number correct in 60 seconds)

Table 13: Study 2 effect size calculation

Cohen's <i>d</i>	P1		P2		P3		P4		P5		P6		P7		P8	
	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total
A1-A2	12.02	9.60	2.46	4.98	5.44	27.79	7.39	15.36	-1.10	-1.10	0.90	1.51	0.18	-0.07	0.80	0.52
A2-A3	-0.54	0.67	-0.58	-0.12	0.16	0.04	-1.55	2.33	6.09	20.85	1.55	7.14	5.71	28.90	0.94	4.72
A1-A3	9.90	10.31	1.95	4.89	5.82	27.86	6.47	20.77	1.59	8.67	2.32	10.57	6.19	24.83	1.88	7.93

Note: Rate = NW Rate; Total = NW Total

Table 14: Study 2 participant mean S-Plate times

S Plate Phase	N	P1		P2		P3		P4		P5		P6		P7		P8	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
A1	8	1.0	0.6	0.9	0.2	1.0	0.5	0.9	0.5	1.1	0.5	0.8	0.2	1.0	0.8	1.1	0.6
A2	8	1.5	1.2	1.4	1.2	1.2	1.4	1.0	0.5	1.2	0.6	0.9	0.5	1.3	1.4	1.3	1.7
A3	8	1.7	1.1	1.5	1.0	1.3	0.7	1.2	0.6	1.1	0.5	1.0	0.3	1.5	1.2	1.4	1.1
B	15	1.0	0.5	1.0	0.5	0.8	0.5	0.7	0.5	1.4	1.1	1.0	0.2	2.2	1.8	1.5	1.2

Note: S Plate = speed of motor response; A1= baseline 1; A2 = baseline 2; A3 = baseline 3; B = intervention; N = number of trials; M = mean time; SD = standard deviation

Figure 40: Study 2 Group 1 S-Plate graphed responses

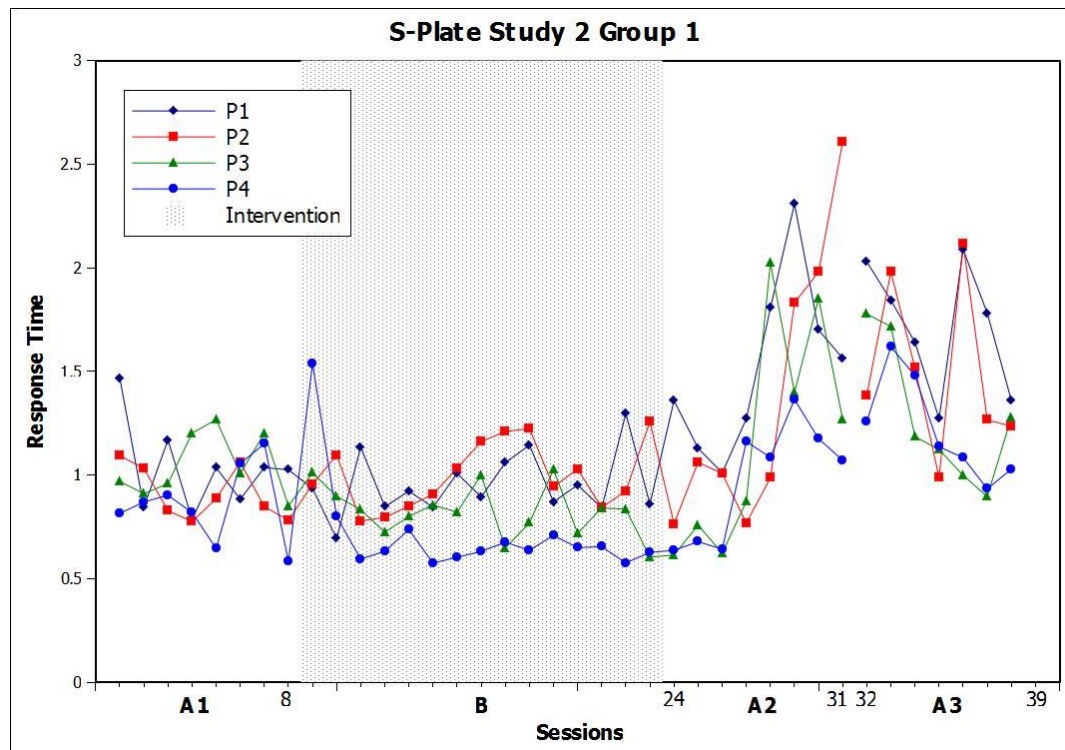


Figure 41: Study 2 Group 2 S-Plate graphed responses

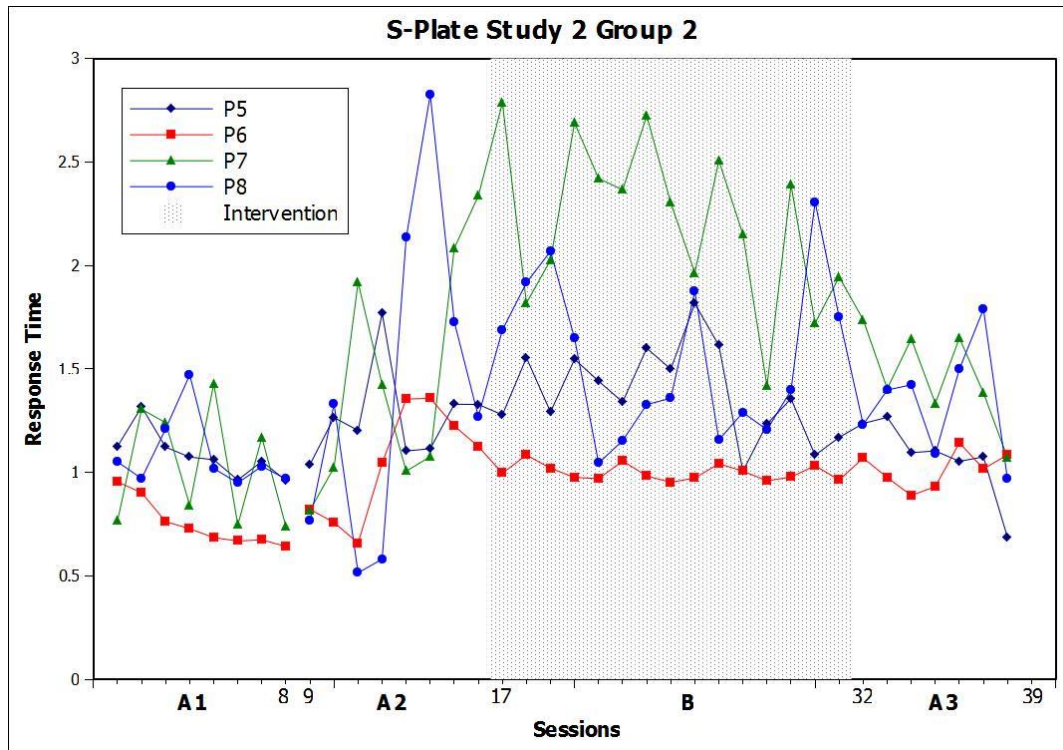


Table 15: Study 2 scores on pre- post-intervention standardised tests

Test	P1		P2		P3		P4		P5		P6		P7		P8	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TOWRE-2																
SWE SS	76	74	66	56	74	77	66	70	80	81	69	74*	69	69	55	55
PDE SS	79	81	79	75	73	78	58	78*	62	84*	75	85*	66	79*	60	68
SWE raw	27	29	17	12	29	42* ⁹⁵	17	25* ⁹⁵	23	33* ⁹⁵	26	32* ⁸⁵	23	23	21	25* ⁶⁰
PDE raw	9	13* ⁷⁰	9	9	8	14* ⁹⁵	0	11* ⁹⁵	0	13* ⁹⁵	12	19* ⁹⁵	4	12* ⁹⁵	4	9* ⁸⁵
PhAT-2 Decoding: standard score (normal range 86-115)																
VC	84	111*	81	111*	70	103*	62	91*	74	100*	111	111	77	103*	63	103*
CVC	89	114*	64	108*	98	105	69	70	86	108*	112	112	89	112	74	97*
C Dig	78	112*	82	95*	<64	104*	<73	84*	100	104	98	111	67	104*	80	103*
C Bl	99	109	102	104	<67	108*	<77	<69	85	107*	85	102*	69	114*	73	99*
V Dig	<74	<74	<78	<74	<66	<66	<78	79	<78	<78	66	72*	<74	<66	<65	<65
Diph	<78	<78	<82	<78	<74	93*	<82	78	<82	<82	79	79	<78	<74	<65	<65
Total	75	88*	77	83	<64	83*	69	82*	79	88*	83	86*	68	81*	<64	71*
Neale Analysis: percentile rank (PR)/reading age (RA)																
Acc PR	10	18*	4	5	15	20	8	10	17	14	18	21	7	17*	4	14*
RA	6:4	6:11*	<6	6:5*	6:9	7:0	6:1	6:6*	6:8	6:7	6:10	7:1	6:5	6:10*	6:4	6:7
CompPR	10	24*	7	12*	19	24*	11	13	15	15	52	53	20	42*	13	22
RA	6:3	7:4*	6:2	6:6*	6:11	7:4*	6:5	6:8	6:10	6:9	8:1	8:0	7:2	7:7*	6:8	7:1*:
Rate PR	10	5	6	4	27	20*	16	9*	15	21	13	10	20	11	9	5
RA	6:3	6:3	<6	6:1	7:2	6:11	6:6	6:5	6:9	6:10	6:5	6:3	6:11	6:4*	6:6	<6*

Note: SWE = Sight Word Efficiency; PDE = Phonemic Decoding Efficiency; VC = Vowel Consonant; CVC = Consonant Vowel Consonant; C Dig = Consonant digraphs; C Bl = Consonant Blends; V Dig = Vowel digraphs; “*” = clinically significant gain; “*nn” = probability that the difference is not due to error

Table 16: Study 2 pre- post-intervention scores on nonword spelling

Measure (%)	Phase	P1	P2	P3	P4	P5	P6	P7	P*
Omit	Pre	8.94	7.82	11.17	31.84	9.04	7.34	18.08	22.03
	Post	5.08	6.78	11.30	14.12	3.41	3.98	12.50	15.91
Legal	Pre	71.51	81.01	77.65	51.40	76.27	85.31	59.89	69.49
	Post	75.71	80.23	80.23	63.84	82.39	93.18	71.59	67.61

Table 17: Study 2 scores on pre-intervention profile assessments

Tests	P1	P2	P3	P4	P5	P6	P7	P8
CELF-4 (normal range 86-115)								
Core Language Score	75*	90	84*	73*	79*	90	81*	79*
Receptive Language Score	84*	98	77*	82*	68*	84*	74*	84*
Expressive Language Score	72*	91	86	76*	80*	91	78*	76*
WISC-IV (normal range 86-115)								
Full Scale	83*	90	80*	83*	82*	100	92	80*
Verbal Comprehension	81*	85*	87	77*	87	99	87	89
Perceptual Reasoning	88	82*	77*	86	86	100	98	88
Working Memory	91	97	88		86	94	99	80*
Processing Speed	88	118	85*		85*	106	97	78*
CTOPP-2 (normal range 86-115)								
Phonological Awareness	82*	94	94	97	100	94	85*	88
Phonological Memory	79*	85*	76*	79*	76*	85*	82*	82*
Rapid Naming	88	91	103	103	85*	97	88	70*

Note: *scores >1SD below the mean

Individual analysis of each participant

Participant 1

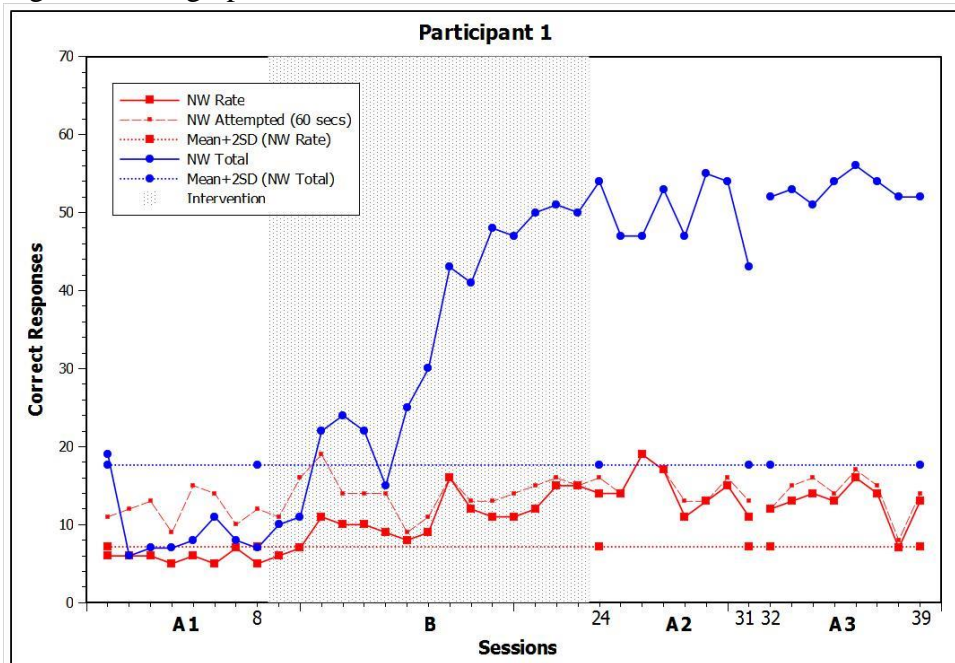
Decoding Intervention modules completed

Participant 1 (P1) was randomised to the A¹-B-A²-C-A³ intervention regime (decoding-first), that is, she received Decoding Intervention followed by the Language Intervention. Table 11 shows that P1 reached criterion for 3-letter items in session five, 4-letter items in session nine, and 5-letter items in session 13.

Nonword reading rate and accuracy

The graphed responses for P1 are depicted in Figure 42.

Figure 42: P1 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs; NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate, and all but one was below 2SD for NW Total. The one data point above 2SD for NW Total was below 3 SD, consistent with the SPC definition of stability. There was no trend as scores were variable.

Phase B: After the third intervention session the number of correct responses (i.e., the level of response) increased for both NW Rate and NW Total, and the trend

was for increasing accuracy. The slope for NW Total was more pronounced than for NW Rate indicating that NW Total continued to improve with a levelling out of gains in NW Rate.

Phase A²: Scores remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains were maintained immediately following intervention.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A³: Scores remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains were maintained two months following intervention.

Visual inspection of NW Attempted (number of items attempted in 60 seconds) compared to NW Rate (number correct in 60 seconds) indicates that while the number attempted remained reasonably constant across all phases, the proportion of correct responses increased, and from about the 7th intervention session there was a close match of number attempted to number correct indicating that during intervention and thereafter this participant was correct on most attempted items. During A¹ (see Table 12) the mean NW Attempted score was 12.0 (SD 2.0) and NW Rate was 5.8 (SD 0.7) which indicates that P1 attempted most of the 2- and 3-letter items, but was predominantly inaccurate on these responses. This compares to A² and A³ with the mean NW Attempted score of 15.1 (SD 2.2) and 13.9 (SD 2.8), and NW Rate 14.3 (SD 2.8) and 12.8 (SD 2.6) respectively, indicating that she was accurate on most of the 2- and 3-letter items attempted in 60 seconds in the post-intervention baseline phases. In contrast, visual inspection of the graph reveals that while the NW Total scores were similar to NW Rate during A¹, during and following Decoding intervention her NW Total scores ranged from 41 to 55, showing that she accurately decoded 4- and 5-letter items.

2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. From the third intervention session, all data points were above the 2SD band for NW Rate, and all but one of the NW Total data points. This was sustained throughout out A² and A³ indicating that the significant intervention effect immediately following intervention was maintained 2 months later.

Effect size

Table 13 indicates that the effect size for P1 from A¹ to A² (pre- post-intervention) was 12.02 for NW Rate, and 9.60 for NW Total, compared to -0.54 NW Rate and 0.67 NW Total from A² to A³. The overall effect size (A¹ to A³) was 9.90 for NW Rate and 10.31 for NW Total. Thus, for NW Rate and NW Total, the pre-post-intervention effect sizes (A¹ to A² and A¹ to A³) were substantially greater than the post-intervention baselines phase (A² to A³) where minimal change was demonstrated.

Speed of motor response

Table 14 indicates that P1's S-Plate mean response time for the three baseline phases was 1.0 seconds (SD 0.6) for A¹, 1.5 seconds (SD 1.2) for A², 1.7 seconds (SD 1.1) for A³, and 1.0 seconds (SD 0.5) for the decoding intervention phase (B). Therefore, P1's response became slightly slower from A¹ to A³. This is confirmed by the graphed responses depicted in Figure 1, which shows that her mean response time was reasonably constant during A¹ and B slowing by about one second during A² and A³.

Pre- post-intervention assessments

Table 15 indicates that P1 made clinically significant gains in three subtests of nonword reading accuracy on the PhAT-2: two targeted areas (VC from 84 to 111, below average to average; and CVC from 89 to 114, average to high average), and one non-targeted area (Consonant Digraphs from 78 to 112, below average to average). The Total score also increased from 75 to 88, from below average to average. Decoding of all vowel spelling digraphs (measured by scores on the Vowel Digraphs, R-Vowels, CVCe and Diphthong subtests) remained in the severely delayed range. There were no clinically significant changes on the TOWRE-2 standard scores (word and nonword reading efficiency), though there was a 70% probability that the increased raw score on nonword reading efficiency was due to the intervention and not to testing error. There were three clinically significant gains in text reading on the Neale. The reading age score for accuracy increased by 7 months (from 6:4 years to 6:11 years) over the 3 months period, and changed from very low to below average on the percentile rank descriptor. The comprehension reading age score increased 13 months (from 6:3 years to 8:4 years), but there was no clinically significant change in rate of reading.

Table 16 shows a notional gain in nonword spelling skills: prior to intervention P1 omitted 8.94% of phonemes and legally spelled 71.5%; following intervention she omitted 5.1% (about 4% fewer) and legally spelled 75.7% (about 4% more) phonemes in the target items.

Pre-intervention profile

Table 17 indicates that seven of the eleven pre-intervention profile scores were below average. All language areas (CELF-4) were more than 1SD below the mean (Core Language 75, Receptive Language 84, Expressive Language 72). Two scores on the intellectual assessment (WISC-IV) were more than 1SD below the mean (Full Scale 83, Verbal Comprehension 81), with scores in the average range for Perceptual Reasoning (88), Working Memory (91), and Processing Speed (88). Two of the phonological processing areas (CTOPP-2) were below average (Phonological Awareness 82 and Phonological Memory 79), with average skills in Rapid Naming (88).

Clinical Observations

P1 enthusiastically accompanied the researcher to the intervention sessions. It was noted that she was frequently absent from school, and both parent and teacher reported challenging behaviour. For example, her mother stated that during the previous school term, P1 often refused to go to school, but that currently she looked forward to the intervention sessions and her behaviour had improved since the previous term. Her teacher expressed frustration that on many occasions P1 would not comply with class tasks. During the intervention she was reluctant to attempt items she perceived to be difficult. For example, she knew that she had trouble decoding items with final consonant blends, and sometimes commented “I can’t do that one”. Use of praise and demonstration that she was progressing through the intervention levels helped P1 complete the intervention items presented to her.

Summary and interpretation

These results indicate that prior to intervention, P1 presented with average rapid naming and nonverbal intellectual skills (perceptual reasoning, working memory and processing speed), impairments in language, phonological awareness, and phonological memory, and frequent instances of challenging behaviour. During the pre-intervention baseline, P1 inaccurately decoded 2- and 3-letter words on the dependent variable (Assessment NW Lists). Standardised reading assessments revealed that she scored more than 1SD below the mean for word and nonword

reading efficiency (TOWRE-2), and nonword reading accuracy (PhAT-2 Total Score). Her decoding accuracy profile (PhAT-2) showed that she was in the average range for two targeted areas (CVC, Consonant Blends), but below average on the remaining targeted area (VC) and all other areas (Vowel Digraphs, R-Vowels, CVCe, Diphthongs). Her text reading scores (Neale) for accuracy and rate were in the very low range, and were below average for comprehension.

P1 demonstrated a significant response to intervention on the dependent variable following the third intervention session, and she continued to improve to a level which indicated accurate decoding of 5-letter items. These gains were maintained immediately following intervention and two months later, and were not due to increased skill in the motor component of the task. The greater gains that were observed for NW Total compared to NW Rate were expected, as there is a limit to the number of items that can be attempted in 60 seconds, hence the slope of NW Rate levelled out. The comparison of number of correct compared to attempted items indicated that P1 attempted about the same number of items across all phases. Prior to intervention (the pre-intervention baseline) she accurately decoded about half of the attempted items (which were 2- and 3-letter items), while after the 7th intervention session her accuracy increased so that most attempted items were correct.

Her improved scores on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading. Her nonword reading accuracy scores (PhAT-2) increased in two of the three targeted areas: items with 2-letters (CV, VC) improved from below average to average, and 3-letters (CVC) from average to high average. Though these gains were generalised to one non-targeted area (Consonant Digraphs), there was no generalisation to decoding of vowel spelling patterns (Vowel digraphs, R-Vowels, CVCe and Diphthongs). Examination of her responses indicated that prior to intervention, P1 had mastered letter-sound knowledge of consonant digraphs (e.g., *ch* and *th*), as her errors were due to inaccurate decoding of the short vowel rather than the consonant digraph, for example pronouncing *thamp* as /thump/. However, she had not mastered letter-sound knowledge for any of the vowel spelling patterns. Hence her increased use of phonological recoding enabled her to generalise skills to those items which involved orthographic pattern knowledge she had previously mastered. In addition to these clinically significant gains in nonword reading accuracy, her scores on the TOWRE-

2 PDE suggest trends for improved nonword reading efficiency, as there was a 70% probability that the increased raw score was due to the intervention and not to testing error.

There was a trend for gains in some areas of word and text reading skills. While there was no clinically significant gain in word reading efficiency (TOWRE-2 SWE), the scores on the Neale suggest a trend for improved accuracy (reading age score changed from very low to below average with a gain 7 months over the 3 month period), and reading comprehension (reading age score gain of 13 months). There was a notional change in nonword spelling skills with 4% fewer phonemes omitted and 4% increase in phonemes legally spelled.

These results suggest that though this child had below average scores in seven out of eleven pre-intervention profile areas (language, phonological processing and intellectual skills), and was displaying frequent instances of challenging behaviour, she made significant gains in nonword reading on the dependent variable, and clinically significant gains on standardised tests of nonword reading accuracy, with trends for generalisation to nonword reading efficiency, text reading accuracy and reading comprehension following 15 sessions of the Decoding Intervention. While her relative lack of generalisation to word reading may have been due to her decreased letter-sound knowledge of vowel spelling patterns or weak language skills (reducing access to semantic and syntactic cues to support word reading), her relatively unchanged nonword spelling skills may have been due to her below average phonological awareness.

Participant 2

Decoding Intervention modules completed

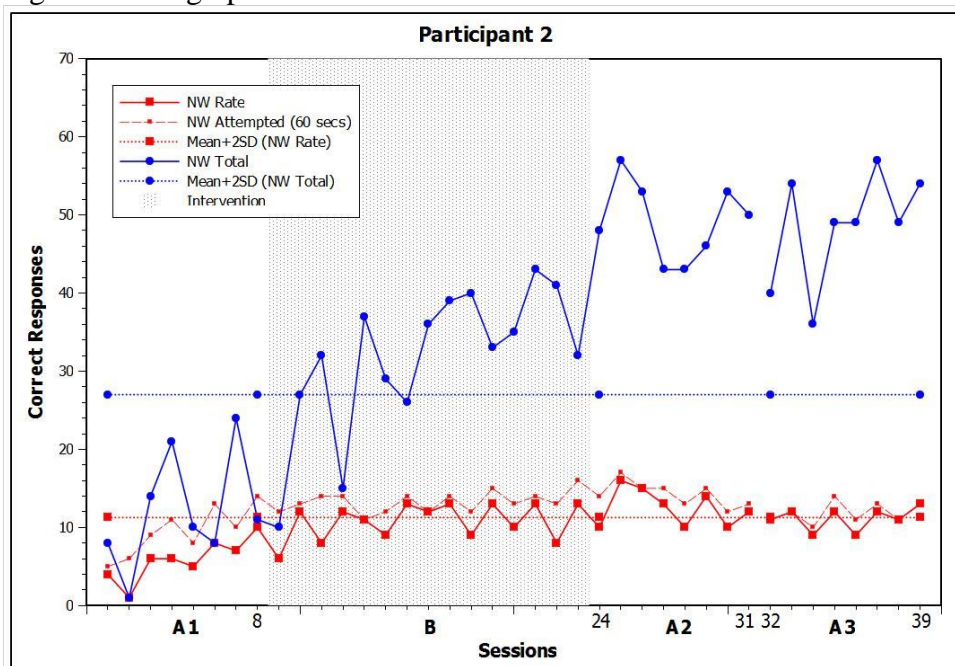
Participant 2 (P2) was randomised to the A¹-B-A²-C-A³ intervention regime (decoding-first): Decoding Intervention followed by the Language Intervention.

Table 11 shows that P2 reached criterion for 3-letter items in session five, 4-letter items in session nine, and 5-letter items in session 14.

Nonword reading rate and accuracy

The graphed responses for participant 2 (P2) are depicted in Figure 43.

Figure 43: P2 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs); NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD, consistent with the SPC definition of stability. There was no trend as scores were variable, with NW Total demonstrating greater variability than NW Rate.

Phase B: The NW Total scores increased (i.e., the level increased) with less variability after the first seven intervention sessions. The slope indicated a trend for increasing accuracy. A less pronounced increase in level and slope was observed for NW Rate, suggesting that this child was a slow decoder.

Phase A²: Variability of response decreased, scores remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains were maintained immediately following intervention.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A³: The NW Total response was characterised by variability for the first three sessions which decreased in the remaining five sessions. Scores remained constant and there was no slope or trend. NW Rate scores remained constant with no trend or slope. This indicates that the gains, which were more pronounced for NW Total, were maintained 2 months following intervention.

Visual inspection of NWs Attempted (number of items attempted in 60 seconds) compared to NW Rate (the number correct in 60 seconds) indicates that while the proportion of correct responses increased following the 4th intervention session, there was a reasonably close match between the two measures throughout. During A¹ (see Table 12) the mean NWs Attempted score was 9.5 (SD 3.2) and NW Rate was 5.9 (SD 2.7). This indicates that this child was a slow decoder as prior to intervention she only attempted about half of the 2- and 3-letter items with about 50% decoding accuracy. During A² and A³ she attempted more items, with NWs Attempted scores of 14.3 (SD 1.6) and 11.9 (SD 1.4), and her accuracy increased with NW Rate scores of 12.5 (SD 2.4) and 11.1 (SD 1.5) respectively. Visual inspection of the graph revealed that her NW Total scores ranged from 30 to 40 after the 7th intervention session indicating that she accurately decoded 4- and 5-letter items, and following intervention her scores reached 50 and 60 indicating that she maintained accuracy at the 5-letter level.

2SD band method

A significant intervention effect was demonstrated for both NW Rate and NW Total. Following the 7th intervention session all the NW Total data points fell above the 2SD band, with three data points above the 2SD band for NW Rate from the 7th intervention session.

Effect size

Table 13 indicates that the effect size for P2 from A¹ to A² (pre- post-intervention) was 2.46 for NW Rate, and 4.98 for NW Total, compared to -0.58 NW Rate and -0.12 NW Total from A² to A³. The overall effect size (A¹ to A³) was 1.95 for NW Rate and 4.89 for NW Total. Thus, for NW Rate and NW Total, the pre-

post-intervention effect sizes (A^1 to A^2 and A^1 to A^3) were greater than the post-intervention baselines phase (A^2 to A^3), and greater gains were made in NW Total compared to NW Rate.

Speed of motor response

Table 14 indicates that P2's S-Plate mean response time for the three baseline phases was 0.9 seconds (SD 0.2) for A^1 , 1.4 seconds (SD 1.2) for A^2 , 1.5 seconds (SD 1.0) for A^3 , and 1.0 seconds (SD 0.5) for the decoding intervention phase (B). Therefore P2's response became slightly slower from A^1 to A^3 . This is confirmed by the graphed responses depicted in Figure 1, which shows that her mean response time was reasonably constant during A^1 and B slowing by less than one second during A^2 and A^3 .

Pre- post-intervention assessments

Table 15 indicates that P2 made clinically significant gains in three subtests of nonword reading accuracy on the PhAT-2: two targeted areas (VC from 81 to 111, CVC from 64 to 108), and one non-targeted area (Consonant Digraphs from 82 to 95), where scores improved from severe or below average to average. Decoding of all vowel spelling patterns (measured by scores on the Vowel Digraphs, R-Vowels, CVCe and Diphthong subtests) remained in the severe range with raw scores of zero. There were no clinically significant changes in word and nonword reading efficiency on the TOWRE-2, though it is notable that her scores on these two timed measures decreased. Three clinically significant gains occurred in text reading on the Neale: the reading age for text reading accuracy increased by 5 months (from <6 years to 6:5 years) over the 3 month period, the comprehension percentile rank score improved from very low to below average, and the reading age for comprehension increased 4 months over the 3 month period.

Table 16 indicates that there were no changes in P2's nonword spelling skills: prior to intervention P2 omitted 7.8% and legally spelled 81% of the phonemes in the target items, while following intervention she omitted 6.8% and legally spelled 80.2%.

Pre-intervention profile

Table 17 indicates that three of the eleven pre-intervention profile scores were more than 1SD below the mean. All language areas (CELF-4) were in the average range (Core Language 90, Receptive Language 98, Expressive Language 91). However, two scores on the intellectual assessment (WISC-IV) were more than

1SD below the mean (Verbal Comprehension 85, Perceptual Reasoning 82), with average scores on Working Memory (97), Processing Speed (118), and Full Scale (90). One phonological processing area (CTOPP-2) was below average (Phonological Memory 85), with scores in the average range for Phonological Awareness (94) and Rapid Naming (91).

Clinical Observations

P2 was a very cooperative child who demonstrated enthusiasm for each research phase; however, she had a high rate of absence from school. The most prominent factors influencing this child's response to intervention were her severe "b/d" confusion and her slow rate of decoding. During the 1st baseline and up until the middle of the intervention phase, her ability to discriminate and accurately produce "b/d" letter-sound correspondence was inconsistent and explained the initial variability displayed in the graphed responses. During some sessions she was predominantly inaccurate, and during other sessions she was observed to purposefully pause and think about each "b" and "d" which increased her accuracy. Her cautious approach to all reading tasks contributed to her reduced number of attempted words in 60 seconds (NW Attempted), and therefore the minimal gains in level for NW Rate.

Summary and interpretation

These results indicate that prior to intervention, P2 presented as a cooperative child, with average language skills and predominantly average phonological processing skills (with weak phonological memory). Her overall intellectual skills were average with mildly reduced scores in Verbal Comprehension and Perceptual Reasoning. Interestingly, though her Processing Speed on the WISC-IV was more than 1SD above the mean and her Rapid Naming was in the average range, she demonstrated severe "b/d" confusion and was a slow decoder. During the pre-intervention baseline, her decoding accuracy on the dependent variable (Assessment NW Lists) was inconsistent, and she was predominantly inaccurate on 3-letter strings. Standardised reading assessments revealed that she scored more than 2SD below the mean for word reading efficiency (TOWRE-2 SWE), and more than 1SD below the mean for nonword reading efficiency (TOWRE-2 PDE) and nonword reading accuracy (PhAT-2 Total Score). Her decoding accuracy profile (PhAT-2) showed that she was in the average range for one targeted area (Consonant Blends 102), and below average in two targeted areas (VC 81, mild delay; CVC 74 moderate

delay), with severe delays for all vowel spelling patterns. Her text reading scores (Neale) for accuracy and rate were in the very low range, and were below average for comprehension.

P2 demonstrated a significant response to intervention on the dependent variable following the fourth intervention session for NW Total and the sixth for NW Rate, and she continued to improve to a level indicating accurate decoding of 5-letter items. The variability in decoding accuracy which characterised her pre-intervention baseline sessions (due to “b/d” confusion), reduced during intervention and her significant gains were maintained following intervention and after the 2 month gap for language therapy. Her slow and cautious approach to decoding contributed to less spectacular gains in NW Rate. The minimal changes in the speed of motor response task (S-Plate) across the three baseline and the intervention sessions, suggested that her gains in nonword reading were not influenced by changes in the motor component of the task. The greater gains that were observed for NW Total compared to NW Rate were expected, as there is a limit to the number of items that can be attempted in 60 seconds, and for this child, her slow decoding style, further amplified this outcome.

Her gains on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading accuracy (PhAT-2). Though her pre-intervention scores were in the average range for one targeted area (Consonant Blends), her skills in the remaining two targeted areas (VC and CVC) improved from mild and moderately delayed to scores in the average range, and were generalised to one non-targeted area (Consonant Digraphs, from below average to average). There were no gains in decoding of vowel spelling patterns which remained in the severe range. Examination of her pre-intervention responses indicated P2 had mastered letter-sound knowledge for most of the consonant digraphs (e.g., *sh* and *ch*), as her errors on that subtest were due to decreased blending skills (e.g., pronouncing *pash* as /p-a-s-sh/) and inaccurate decoding of b/d (e.g., pronouncing *whib* as /wid/). However, she had not mastered the range of vowel spelling patterns. Thus, her increased use of phonological recoding supported generalisation of skills to those items which involved orthographic pattern knowledge she had previously mastered (consonant digraphs). Her slow decoding style may have contributed to her lack of gains in nonword reading efficiency (TOWRE-2).

Minimal gains were demonstrated in word and text reading accuracy, and nonword spelling. While there was a trend for increased text reading accuracy on the Neale (reading age increased more than five months over the three month period), her standard score on the timed measure of word reading efficiency decreased. This was most likely due to her generally slow and cautious approach to decoding, particularly as she became increasingly focused on correct responses for items with “b” or “d”. Her text reading comprehension, however, increased from below average to average and gained 4 months, possibly supported by her age appropriate strong oral language skills.

These results indicate that though P2 presented with predominantly average pre-intervention language, phonological processing and intellectual skills (with weaknesses in three of the eleven areas assessed), prior to intervention she demonstrated severe decoding and word reading skills with “b/d” confusion and a slow decoding style. She made significant gains in nonword reading on the dependent variable, clinically significant gains on standardised tests of nonword reading accuracy, marginal trends for improved reading comprehension, but minimal gains in nonword reading efficiency and word reading accuracy.

Participant 3

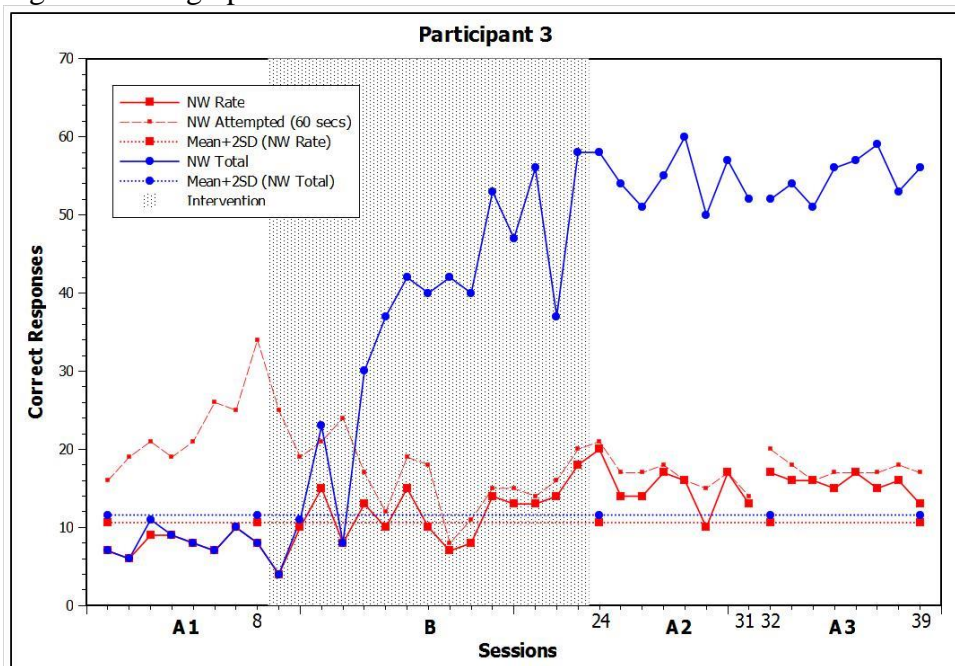
Decoding Intervention modules completed

Participant 3 (P3) was randomised to the A¹-B-A²-C-A³ intervention regime (decoding-first): Decoding Intervention followed by the Language Intervention. Table 11 shows that P3 reached criterion for 3-letter items in session six, and 4-letter items in session ten. She did not reach criterion for 5-letter items.

Nonword reading rate and accuracy

The graphed responses for participant 3 (P3) are depicted in Figure 44.

Figure 44: P3 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs; NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate and NW Total, consistent with the SPC definition of stability. There was no trend as scores were variable.

Phase B: After the fourth intervention session scores increased for NW Total (i.e., the level increased), and after the tenth session for NW Rate. The trend was for increasing accuracy. The slope for NW Total was more pronounced than for NW Rate indicating that NW Total continued to improve with a levelling out of gains in NW Rate.

Phase A²: Apart from one outlier NW Rate data point (sixth A² session), the level remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains were maintained immediately following intervention.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A³: The level remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains were maintained 2 months following intervention.

Visual inspection of NW Attempted compared to NW Rate indicated that prior to intervention there was a large gap between the number attempted and the number of correct responses in 60 seconds. As accuracy increased she attempted fewer items (NW Attempted slope decreased), suggesting that she took longer on each item. From about the 5th intervention session there was a close match of NW Attempted to NW Rate indicating that during intervention and thereafter this participant was correct on most attempted items in 60 seconds. During A¹ (see Table 12) the mean NW Attempted was 22.6 (SD 5.6) and NW Rate was 8.0 (SD 1.3) which demonstrates that P3 attempted 2- 3- and 4- letters items but was predominantly inaccurate. This compares to A² and A³ with the mean NW Attempted score of 16.9 (SD 2.1) and 17.5 (SD 1.2), and NW Rate 15.1 (SD 3.0) and 15.6 (SD 1.3) respectively, which shows that she was accurate on most of the 2- and 3-letter items attempted in 60 seconds in the post-intervention baseline phases. In contrast, while the NW Total mirrored the NW Rate scores for A¹, during and following Decoding intervention her NW Total scores ranged from 40 to 59, indicating that she accurately decoded 4- and 5-letter items.

2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. From the fifth intervention session all data points were above the 2SD band for NW Total, and from the 11th intervention session for NW Rate. Apart from one NW Rate data point in the second baseline, this was sustained throughout out A² and A³ indicating that the significant intervention effect immediately following intervention was maintained 2 months later.

Effect size

Table 13 indicates that the effect size for P3 from A¹ to A² (pre- post-intervention) was 5.44 for NW Rate, and 27.79 for NW Total, compared to 0.16 NW

Rate and 0.04 NW Total from A² to A³. The overall effect size (A¹ to A³) was 5.82 for NW Rate and 27.86 for NW Total. Thus, for NW Rate and NW Total, the pre-post-intervention effect sizes (A¹ to A² and A¹ to A³) were substantially greater than the post-intervention baselines phase (A² to A³) where minimal change was demonstrated.

Speed of motor response

Table 14 indicates that P3's S-Plate mean response time for the three baseline phases was 1.0 seconds (SD 0.5) for A¹, 1.2 seconds (SD 1.4) for A², 1.3 seconds (SD 0.7) for A³, and 0.8 seconds (SD 0.5) for the decoding intervention phase (B). These results demonstrate that P3's speed of motor response ranged from 0.8 to 1.3 seconds with SDs of 0.5 to 1.4, suggesting that there was minimal change from A¹ to A³. This is confirmed by the graphed responses depicted in Figure 1, which shows that her mean response time was reasonably constant across all phases, with slightly longer response times during A³ of less than one second.

Pre- post-intervention assessments

Table 15 indicates that P3 made clinically significant gains in five subtests of nonword reading accuracy on the PhAT-2: two targeted areas (VC from 70 to 103, PhAT Consonant Blends from <67 to 108) where scores improved from severe to average range, and two non-targeted areas (Consonant Digraphs from <64 to 104, Diphthongs from <74 to 93) which also changed from severe to average range). The Total Score improved from <64 to 83, severe to below average. While there were no clinically significant gains in the standard score of word and nonword reading efficiency (TOWRE-2), there was 95% probability that the gains in raw scores (Sight Word Efficiency from 29 to 42, and Phonemic Decoding Efficiency from 8 to 14) were due to the intervention. Clinically significant gains were demonstrated in reading comprehension on the Neale (percentile rank change from below average to average, and a gain in reading age of five months over the three month period), but not for reading accuracy. Reading rate decreased from average to below average.

Table 16 indicates that there was no change in nonword spelling skills: prior to intervention P3 omitted 11.2% and legally spelled 77.7% of phonemes in the target items, while following intervention she omitted the same number (11.3%) and legally spelled slightly more phonemes (80.2%).

Pre-intervention profile

Table 17 indicates that six of the eleven pre-intervention profile scores were below average. Two language areas (CELF-4) were more than 1SD below the mean (Core Language 84, Receptive Language 77) with a score in the average range for Expressive Language (86). Three scores on the intellectual assessment (WISC-IV) were more than 1SD below the mean (Full Scale 80, Perceptual Reasoning 77, and Processing Speed 85), with Verbal Comprehension (87) and Working Memory (88) in the average range. One of the phonological processing areas on the CTOPP-2 was below average (Phonological Memory 76), with scores in the average range for Phonological Awareness (94) and Rapid Naming (103).

Clinical Observations

P3 was keen to accompany the researcher to intervention sessions; however she had frequent absences from school. During intervention sessions she often took a while to settle to the task and was easily distracted by events outside the room. This sometimes interrupted the timed tasks, such as the Assessment NW Lists. She responded well to positive comments from the researcher increasing her ability to maintain attention to task.

Summary and interpretation

These results indicate that prior to intervention, P3 presented with weaknesses in language, intellectual and phonological processing skills, with scores in the average range for Expressive Language (CELF-4), Verbal Comprehension and Working Memory (WISC-IV), and Phonological Awareness and Rapid Naming (CTOPP-2). During the pre-intervention baseline, though she attempted a large number of items in 60 seconds on the dependent variable (Assessment NW Lists), P3 inaccurately decoded 2- and 3-letter items. Standardised reading assessments revealed that she scored more than 1SD below the mean for word and nonword reading efficiency (TOWRE-2), and more than 2SD below the mean for nonword reading accuracy (Total Score PhAT-2). Her decoding profile (PhAT-2) shows that she was in the average range for one targeted area (CVC 98), but in the severe range for all other targeted areas (VC 70, Consonant Blends <67), non-targeted areas (Consonant Digraphs <64), and all vowel spelling patterns (from <66 to <74). Her text reading scores (Neale) were below average for accuracy and comprehension and in the average range for rate of reading.

P3 demonstrated a significant response to intervention on the dependent variables following the fourth intervention session for NW Total and the tenth for NW Rate, and she continued to improve to a level which indicated accurate decoding of 5-letter items. These gains were maintained immediately following intervention and two months later, and were not due to increased skill in the motor component of the task. As with previous participants, the greater gains in NW Total compared to NW Rate were expected due to the timed nature of NW Rate. The comparison of number of attempted items to correct items in 60 seconds indicated that prior to intervention P3 attempted a large number of items but was predominantly inaccurate, but that following the tenth intervention session she was accurate on most attempted items.

These gains in nonword reading on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading. Her nonword reading accuracy scores (PhAT-2) increased in two of the three targeted areas (VC and Consonant Blends, from severe to average range), and were generalised to two non-targeted areas (Consonant Digraphs and Diphthongs, from severe to average range). Her Total score increased from severe to below average, but there was no generalisation to most of the other vowel spelling patterns (Vowel Digraphs, R-Vowels, CVCe). Examination of her responses indicated that prior to intervention she had mastered letter-sound knowledge for consonant digraphs (e.g., *sh* and *ch*), as her pre-intervention errors were due to errors on other letters, for example, pronouncing *thip* as /thik/. Hence her increased skill in use of phonological recoding enabled generalisation to items containing consonant digraphs. Her unexpected generalisation to decoding of diphthong vowels occurred because the “oi” and “ow” spelling pattern lent itself to use of phonological recoding. Though she did not recognise these two spelling patterns as digraphs, when she sounded them out and blended, she produced the correct vowel sound. In addition to these clinically significant gains in nonword reading accuracy, her scores on the TOWRE-2 PDE suggested a trend for improved nonword reading efficiency where there was a 95% probability that the gains in raw scores were due to the intervention and not to testing error.

There was a trend for increased word reading efficiency (TOWRE-2 SWE) with a 95% probability that the change in raw score was due to the intervention. While this was not reflected in a clinically significant change in text reading

accuracy (Neale), her reading comprehension increased in percentile rank from below average to average with a five month gain in reading age, and her rate of text reading slowed (percentile rank changed from average to below average). This slower rate of reading is consistent with the increased attention to decoding accuracy that was demonstrated on the dependent variable: as her accuracy increased she attempted fewer items.

These results suggest that despite having weaknesses in seven of the eleven pre-intervention language, phonological processing and intellectual skill areas, P3 made significant gains in nonword reading on the dependent variable, and clinically significant gains on standardised tests of nonword reading, and reading comprehension. While there was a trend for increased word reading efficiency, there were minimal gains in text reading accuracy, and no change in nonword spelling.

Participant 4

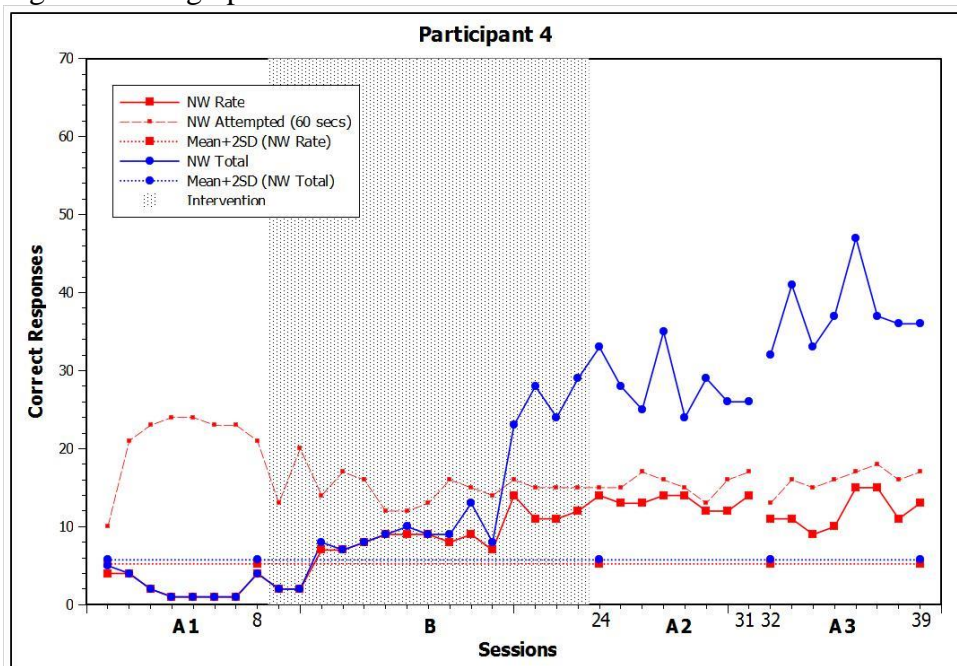
Decoding Intervention modules completed

Participant 4 (P4) was randomised to the A¹-B-A²-C-A³ intervention regime (decoding-first): Decoding Intervention followed by the Language Intervention. Table 11 shows that P4 reached criterion for 3-letter items in session six, and did not progress past 4-letter items reaching criterion for 4-letter items in session fifteen.

Nonword reading rate and accuracy

The graphed responses for participant 4 (P4) are depicted in Figure 45.

Figure 45: P4 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs; NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate and NW Total, consistent with the SPC definition of stability. There was a trend for decreasing accuracy. The NW Total scores mirrored NW Rate indicating that pre-intervention this child was unable to accurately decode 3-letter words even if there was no time limit.

Phase B: After the second intervention session scores increased (i.e., the level of response increased) for NW Total and NW Rate, and the trend was for increasing accuracy. For the first eleven intervention sessions the slope for NW Total mirrored

NW Rate, and following this, the slope for NW Total was more pronounced than for NW Rate, indicating that NW Total continued to improve with a levelling out of gains in NW Rate.

Phase A²: The level for NW Total and NW Rate remained constant and there was no slope or trend, indicating that the gains were maintained immediately following intervention.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A³: There was a slight decrease in level for NW Rate and an increase for NW Total suggesting that two months following the intervention this child became a little slower, but continued to increase in accuracy of decoding.

Visual inspection of NW Attempted compared to NW Rate indicated that prior to intervention there was a large gap between the number of attempted items and the number of correct responses in 60 seconds. As accuracy increased (between the seventh and eleventh intervention sessions), he attempted fewer items (NW Attempted slope decreased), suggesting that he took longer on each item. From 12th intervention session there was a close match of NW Attempted to NW Rate indicating that during intervention and thereafter this participant was correct on most attempted items in 60 seconds. During A¹ (see Table 12) the mean NW Attempted was 21.1 (SD 4.6) and NW Rate was 2.3 (SD 1.5) which demonstrates that P4 attempted up to 4-letter items but was inaccurate at the 2- and 3-letter level. This compares to A² and A³ with the mean NW Attempted score of 15.5 (SD 1.3) and 16.0 (SD 1.5), and NW Rate 13.3 (SD 0.9) and 11.9 (SD 2.2) respectively, which shows that he was accurate on most of the 2- and 3-letter items attempted in 60 seconds in the post-intervention baseline phases. In contrast, while the NW Total mirrored the NW Rate scores for A¹, during and following Decoding intervention NW Total scores ranged from 30 to 45, indicating that he accurately decoded 4- and 5-letter items.

2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. From the third intervention session all data points were above the 2SD band for both measures. This was sustained throughout A² and A³ indicating that the significant intervention effect immediately following intervention was maintained two months later.

Effect size

Table 13 indicates that the effect size for P4 from A¹ to A² (pre- post-intervention) was 7.39 for NW Rate, and 15.36 for NW Total, compared to -1.55 NW Rate and 2.33 for NW Total from A² to A³. The overall effect size (A¹ to A³) was 6.47 for NW Rate and 20.77 for NW Total. Thus, for NW Rate and NW Total, the pre- post-intervention effect sizes (A¹ to A² and A¹ to A³) were substantially greater than the post-intervention baselines phase (A² to A³) where minimal change was demonstrated.

Speed of motor response

Table 14 indicates that P4's S-Plate mean response time for the three baseline phases was 0.9 seconds (SD 0.5) for A¹, 1.0 seconds (SD 0.5) for A², 1.2 seconds (SD 0.6) for A³, and 0.7 seconds (SD 0.5) for the decoding intervention phase (B). These results demonstrate that P4's speed of motor response ranged from 0.7 to 1.2 seconds with SDs of 0.5 to 0.6, suggesting that there was minimal change from A¹ to A³. This is confirmed by the graphed responses depicted in Figure 1, which shows that, similar to the other participants in the decoding-first condition, his mean response time was reasonably constant across all phases, with slightly longer response times during A³ of less than one second.

Pre- post- intervention assessments

Table 15 indicates that P4 made clinically significant gains in two subtests of nonword reading accuracy on the PhAT-2: one targeted area (VC from 62 to 91, severe to average range), and one non-targeted areas (Consonant Digraphs from <72 to 84, severe to below average); and the Total score increased from 69 to 82 (severe to below average). Decoding of all vowel spelling patterns (Vowel Digraphs, R-Vowels, CVCe, and Diphthongs) remained in the severely delayed range. There were three clinically significant changes on the TOWRE-2: the standard score for nonword reading efficiency increased from 58 to 78 (very poor to poor); and there was a 95% probability that the increased nonword reading efficiency raw score (from zero to 11), and the increased raw score in word reading efficiency (from 17 to 25) was due to the intervention. There were minimal gains in text reading skills with a trend for increasing accuracy (reading age gain of five months over the three month period), a slowed rate of reading (percentile rank descriptor from below average to very low), with no change in reading comprehension.

Table 16 indicates that P4 made gains in nonword spelling responses: prior to intervention he omitted 31.8% and legally spelled 51.4% of phonemes in the target items, while following intervention he omitted 14.1% (17.7% fewer) and legally spelled 63.8% (12.4% more).

Pre-intervention profile

Table 17 indicates that six of the nine pre-intervention profile scores were more than 1SD below the mean. All language areas (CELF-4) were below average (Core Language 73, Receptive Language 82, Expressive Language 76). Two of the three scores on the intellectual assessment (WPPSI-III, which had been administered by a psychologist prior to Study 2), were more than 1SD below the mean (Full Scale 83, Verbal Comprehension 77), with Perceptual Reasoning in the average range (score of 86). One of the three phonological processing scores on the CTOPP-2 was below average (Phonological Memory 79), with average scores for Phonological Awareness (97), and Rapid Naming (103).

Clinical Observations

P4 was keen to accompany the researcher to the sessions and was cooperative throughout. A prominent characteristic of this child's response to intervention was his difficulty in verbal production of consonant blends, especially in the final position. Due to his very poor phonological recoding skills prior to intervention, he remained at the 3-letter level for the first seven intervention sessions. Once he progressed to 4-letter strings (between the seventh and tenth intervention session), the clinical notes describe motor programming difficulties and perseveration on verbal production of final blends. Strategies were used to strengthen his articulatory skills in production of final blends. For example, after phonologically recoding a 4-letter sequence (such as /b-u-l-t/, the child was encouraged to blend the first three sounds and then add the final sound (e.g., /bul-t/). By the 13th session improvement in phonological recoding and blending of final consonant blends was documented.

Summary and interpretation

These results indicate that prior to intervention, P4 presented with below average skills in six of the nine assessed areas, with his lowest scores in phonological memory, receptive language, perceptual reasoning, and processing speed. He was a very cooperative child, but had difficulty with articulatory production of complex consonant blends. During the pre-intervention baseline, P4 made errors at the 2- and 3-letter level on the dependent variable (Assessment NW Lists), and on most

sessions scored zero or one correct response. Standardised reading assessments revealed that he scored more than 2SD below the mean on word and nonword reading efficiency (TOWRE-2), and nonword reading accuracy (PhAT-2 Total Score). His decoding accuracy profile (PhAT-2) showed that he was more than 2SD below the mean in all areas - targeted (VC, CVC, Consonant Blends) and non-targeted (Consonant Digraphs and all vowel spelling patterns). His text reading scores (Neale) for accuracy and rate were in the very low range, with comprehension in the below average range.

P4 demonstrated a significant response to intervention on the dependent variables following the second intervention session, and his scores remained above the 2SD band thereafter. Following the eleventh session (when he had mastered verbal production of final consonant blends), his NW Total score dramatically increased. Following the two month break for language therapy, further gains (that were not due to increased skill on the motor component of the task, the S-Plate) had been made, indicating that he was accurately decoding up to the 5-letter level. The comparison of the number of correct items compared to the attempted items in 60 seconds indicated that, prior to intervention, P4 attempted a large number of items, but was predominantly inaccurate. As he began to master phonological recoding (around the sixth intervention session), he attempted fewer items, but the proportion of correct items increased so that by the twelfth intervention session he accurately decoding most attempted items in 60 seconds.

His improved scores on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading, with gains in one targeted area of nonword reading accuracy on the PhAT-2 (VC from 62 to 91, severe to average range), and one non-targeted area (Consonant Digraphs, from <73 to 84, severe to below average). Though there was no generalisation to any of the vowel spelling patterns, his overall score for nonword reading accuracy increased from severe to below average range. Gains were also made in nonword reading efficiency (TOWRE-2), with a clinically significant gain in the standard score from very poor to poor, and a 95% probability that the raw score change from zero to 11 was due to the intervention.

There was a trend for clinically significant gains in word reading efficiency (TOWRE-2) with a 95% probability that the change in raw score from 17 to 25 was due to the intervention, and text reading accuracy (Neale) with a gain of five months

in reading age over the three month period. Though there was no change in reading comprehension scores, the reading rate percentile rank changed from below average to very low, suggesting that as he began paying closer attention to the words in an attempt to increase accuracy his reading rate slowed. The gains in nonword spelling (18% fewer phonemes omitted and 12% more phonemes spelled legally) may have been due to his increased ability to articulate each phoneme (and therefore spell more phonemes) following the Decoding Intervention.

These results suggest that though this child was below average in six out of the nine language, phonological processing, and intellectual skill areas, he made significant gains in nonword reading accuracy, with clinically significant gains in nonword reading efficiency, trends for improved word reading efficiency and text reading accuracy, and gains in nonword spelling.

Participant 5

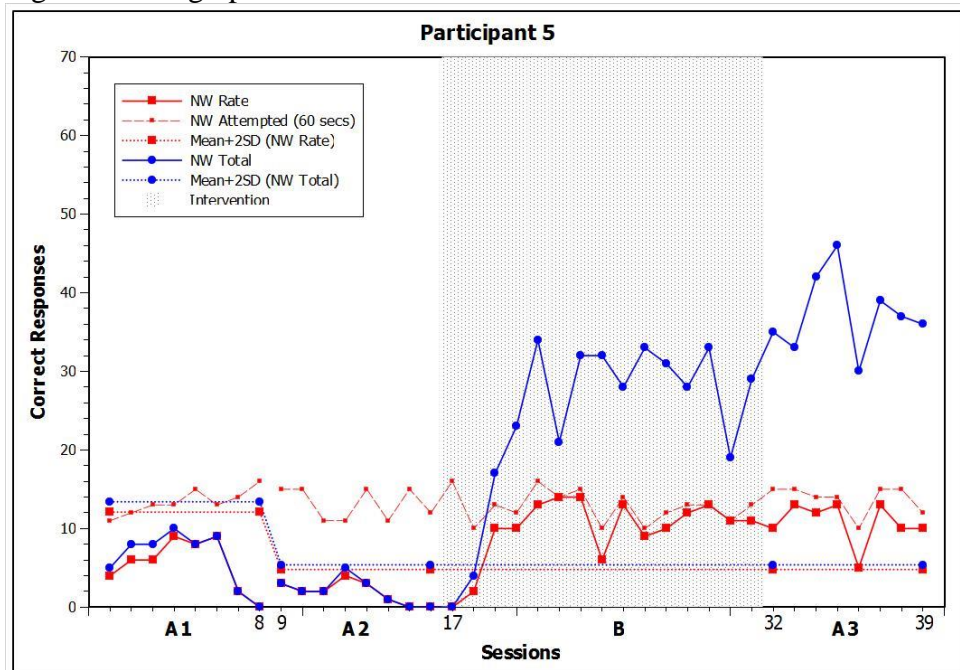
Decoding Intervention modules completed

Participant 5 (P5) was randomised to the A¹-C-A²-B-A³ intervention regime (language-first): Language Intervention followed by the Decoding Intervention. Table 11 shows that P5 reached criterion for 3-letter items in session four. Though she remained at the 4-letter level for nine intervention sessions, she did not reach criterion for this level.

Nonword reading rate and accuracy

The graphed responses for participant 5 (P5) are depicted in Figure 46.

Figure 46: P5 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs; NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate and NW Total, consistent with the SPC definition of stability. There was a trend for decreasing accuracy in the final two sessions of the first baseline.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A²: Scores (i.e., the level of response) for NW Total and NW Rate were lower than A¹. A stable baseline was achieved, consistent with the SPC definition of stability, as all data points were below the 2SD band that was calculated for A². No slope or trend was demonstrated.

Phase B: After the second intervention session the level of response increased for NW Total and NW Rate, and the trend was for increasing accuracy. The slope for NW Total was more pronounced than NW Rate indicating that NW Total continued to improve with a levelling out of NW Rate.

Phase A³: Apart from one outlier (fifth session in A³), the NW Rate level remained constant. The NW Total level increased for the first five sessions (trend for increasing accuracy) and then decreased to the level attained during the intervention phase. This suggests that the gains made during the intervention were maintained immediately following intervention.

Visual inspection of NW Attempted compared to NW Rate indicated that while the number of attempted items remained constant across all phases, the proportion of correct responses increased during the intervention phase, and following the third intervention session most attempted items were correct. Though the pattern of this child's accuracy of response was unexpected (i.e., dropped in the second pre-intervention baseline following language intervention), the gap between number of attempted to number correct items was smaller during and following intervention compared to either of the pre-intervention baseline phases. Table 12 shows that during the two pre-intervention baseline phases (A¹ and A²), the mean NW Attempted scores were 13.4 (SD 1.6) and 13.1 (SD 2.0) and NW Rate were 5.5 (SD 3.3) and 1.9 (SD 1.5) respectively. This demonstrates that prior to intervention P5 attempted up to 4- letters items, was inaccurate at the 2- and 3-letter level during A¹, and became increasingly inaccurate during A². This compares to the post-intervention baseline (A³) where the mean NW Attempted score was 13.8 (SD 1.8) and the NW Rate score was 10.8 (SD 2.7), which shows that she was accurate on most of the 2- and 3-letter items attempted in 60 seconds in the post-intervention baseline phase. In contrast, while the NW Total mirrored the NW Rate scores during the pre-intervention baseline phases (A¹ and A²), following Decoding intervention NW Total scores ranged from 30 to 45, indicating that she accurately decoded 4- and 5-letter items.

2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. On this graph a revised 2SD band was drawn to reflect the decreased scores in NW Rate and NW Total accuracy scores during A². From the third intervention session all data points were above the revised 2SD band for both measures. Apart from one outlier NW Rate score (fifth A³ session), this was sustained throughout out A³ indicating that the significant intervention effect immediately following intervention was maintained two months later. Additionally, if the 2SD band from A¹ is extended across all phases (a more conservative approach), her scores still achieved significance on both measures (by the third session for NW Total, and the fifth for NW Rate).

Effect size

Table 13 indicates that the effect size for P5 from A¹ to A² (pre-intervention) was -1.10 for NW Rate and -1.10 for NW Total, compared to 6.09 for NW Rate and 20.85 for NW Total from A² to A³. The overall effect size (A¹ to A³) was 1.59 for NW Rate and 8.67 for NW Total. Thus, for NW Rate and NW Total, the pre- post-intervention effect sizes (A² to A³ and A¹ to A³) were substantially greater than the post-intervention baselines phase (A¹ to A²) where a negative change was demonstrated (reduced skills).

Speed of motor response

Table 14 indicates that P5's S-Plate mean response time for the three baseline phases was 1.1 seconds (SD 0.5) for A¹, 1.2 seconds (SD 0.6) for A², 1.1 seconds (SD 0.5) for A³, and 1.4 seconds (SD 1.1) for the decoding intervention phase (B). These results demonstrate that P5's speed of motor response ranged from 1.1 to 1.4 seconds with SDs of 0.5 to 1.1, suggesting that there was minimal change from A¹ to A³. The graphed mean response times depicted in Figure 2 suggested that this child's response times varied within each phase (consistent with the large SD during the Decoding Intervention phase).

Pre- post- intervention assessments

Table 15 indicates that P5 made clinically significant gains in three subtests of nonword reading accuracy on the PhAT-2, all of which were targeted areas: VC from 74 to 100 (moderate to average range), CVC from 86 to 108 (low average to average), Consonant Blends from 85 to 107, (mild delay to average), and her Total Score increased from 79 to 88 (mild delay to average). Prior to intervention she was

in the average range for Consonant Digraphs and remained at that level post-intervention. Decoding of all vowel spelling patterns (Vowel Digraphs, R-Vowels, CVCe and Diphthongs) remained in the severely delayed range. There were three clinically significant changes on the TOWRE-2. Nonword reading efficiency changed from severe to mildly delayed (62 to 84), and there was a 95% probability that the change in raw score from zero to 13 was due to the intervention. While there was no clinically significant change in the standard score for word reading efficiency, there was a 95% probability that the change in raw score from 23 to 33 was due to the intervention. There were no clinically significant changes in accuracy, comprehension or rate of text reading skills.

Table 16 indicates that there were changes in P5's nonword spelling skills: prior to intervention she omitted 9% and legally spelled 76.3% of phonemes in the target items and following intervention she omitted 3.4% (6% fewer), and legally spelled 82.4% (6% more).

Pre-intervention profile

Table 17 indicates that seven of the 11 pre-intervention profile scores were more than 1SD below the mean. All language areas (CELF-4) were below average (Core Language 79, Receptive Language 68, Expressive Language 80). Two of the five scores on the intellectual assessment (WISC-IV) were more than 1SD below the mean (Full Scale 82, Processing Speed 85), with Verbal Comprehension (score of 87), Perceptual Reasoning (86), and Working Memory (86) all in the average range. Two of the three phonological processing scores on the CTOPP-2 were below average (Phonological Memory 76 and Rapid Naming 85), with average scores for Phonological Awareness (100).

Clinical Observations

P5, though being easily distracted, was a cooperative child who was always keen to accompany the researcher to the intervention sessions. A prominent feature of her response to intervention was the drop in NW Rate scores across the first two pre-intervention baseline sessions. For the first six baseline sessions her accuracy scores ranged from three to six correct (out of about 12 attempted items), but following this her accuracy scores ranged from zero to three. The clinical notes document that during the first six baseline sessions she attempted to phonologically recode and blend, but that following the sixth session she did not continue to perform blending, even though the researcher initially provided prompts, such as “now, join

the sounds together”. Due to the standardised nature of the Assessment NW Lists, these prompts were discontinued. Her distractible nature possibly contributed to the variability in her mean response times on the S-Plate: she tended to stop half way through an S-Plate and comment about things of interest to her, for example, “we’ve just got five new puppies at home” – a topic that was difficult to ignore.

Summary and interpretation

These results indicate that prior to intervention, P5 presented with delays in seven of the 11 pre-intervention language, phonological processing, and intellectual skill areas, with her lowest scores in receptive language, phonological memory, and overall language. During the two pre-intervention baseline phases, P5 inaccurately decoded 2- and 3-letter items on the dependent variable (Assessment NW Lists). Standardised reading assessments revealed that she scored more than 2SD below the mean for nonword reading efficiency, and more than 1SD below on word reading efficiency (TOWRE-2) and nonword reading accuracy (PhAT-2). Her decoding accuracy profile (PhAT-2) shows that she was in the low average range for one targeted area (CVC), below average for the two remaining targeted areas (VC and Consonant Blends), but in the average range for a non-targeted area (Consonant Digraphs). Her decoding of all vowel spelling patterns was in the severe range with zero raw scores in all areas. Her text reading scores (Neale) were in the very low range for accuracy and rate of reading, and in the below average range for comprehension.

P5 demonstrated a significant response to intervention on both measures of the dependent variable (NW Rate and NW Total) following the second intervention session. Her gains were maintained following intervention and were not due to increased skills in the motor component of the task. The comparison of number of correct responses compared to attempted items indicated that P5 attempted about the same number of items across all phases: prior to intervention (A^1 and A^2) she accurately decoded less than half of the attempted items (which were 2- and 3-letter items), but that after the fourth intervention session her accuracy increased so that most attempted items were correct.

Her improved scores on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading. Her nonword accuracy scores (PhAT-2) increased in all three of the targeted areas (VC, CVC, Consonant Blends), with no generalisation to decoding of vowel spelling patterns. Interestingly,

prior to intervention, she was in the average range for one non-targeted area (Consonant Digraphs). In addition to these gains in nonword reading accuracy, she made clinically significant gains in nonword reading efficiency (TOWRE-2 PDE), with her standard scores changing from very poor to poor, and a 95% probability that the gain in raw score was due to the intervention. Though there was a trend for clinically significant gains in word reading efficiency, there were no changes in text reading skills (where her scores were very low for accuracy and rate, and below average for comprehension), and only notional changes in nonword spelling.

These results suggest that though P5 was below average in seven of the eleven pre-intervention profile areas (with a notable severe receptive language delay, and significant phonological memory impairment in the presence of average phonological awareness), her response to intervention was positive. She made significant gains in nonword reading accuracy on the dependent variable, clinically significant gains in standardised tests of nonword reading accuracy and efficiency, with minimal changes in word and text reading skills, and nonword spelling. It is possible that while her average phonological awareness enabled her to master phonological recoding, her reduced phonological memory may have contributed to blending errors in decoding, and difficulty holding a sequence of phonemes in memory to support the encoding process for nonword spelling. Additionally, her language delays may have reduced her ability to access semantic and syntactic information to support word and text reading accuracy.

Participant 6

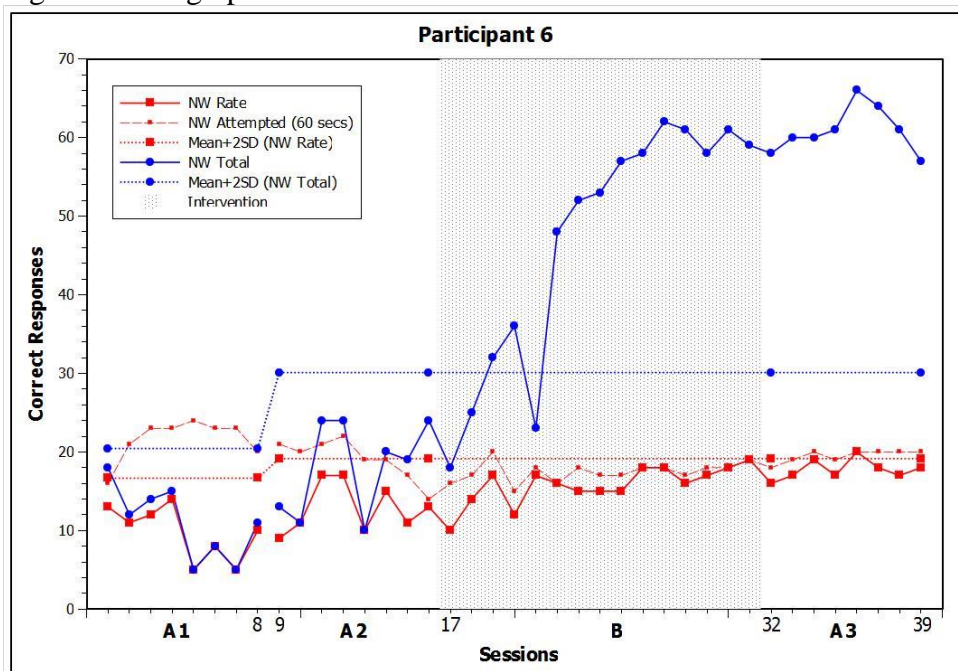
Decoding Intervention modules completed

Participant 6 (P6) was randomised to the A¹-C-A²-B-A³ intervention regime (language-first): Language Intervention followed by the Decoding Intervention. Table 11 shows that P6 reached criterion for 3-letter items in session two, 4-letter items in session four, 5-letter items in session eight, and 6-letter items in session 15.

Nonword reading rate and accuracy

The graphed responses for participant 6 (P6) are depicted in Figure 47.

Figure 47: P6 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs); NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate and NW Total, consistent with the SPC definition of stability. There was a trend for decreasing accuracy.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A²: There was a slight increase in the level of response for NW Rate and NW Total compared to the previous pre-intervention baseline (A¹). A stable baseline was achieved, consistent with the SPC definition of stability, as all data

points were below the 2SD band that was calculated for A². No slope or trend was demonstrated.

Phase B: Following the second intervention session there was an increase in level of response for NW Total with a steep slope and a trend for increasing accuracy. Though the variability of response was reduced after the fifth intervention session for NW Rate, there was no change in level of response. This indicates that P6 made substantial gains in NW Total and minimal gains in NW Rate.

Phase A³: The level of response remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains in NW Total and the relatively unchanged level for NW Rate were maintained.

Visual inspection of NW Attempted compared to NW Rate indicated that in the first pre-intervention baseline phase (A¹) there was a large gap between the number of attempted and number of correct items in 60 seconds (indicating inaccuracy on most attempted items), and that in the second pre-intervention phase (A²) the gap narrowed signifying an increase in decoding skill prior to intervention. Following the ninth intervention session the gap became marginal indicating that most attempted items were correct. Table 12 shows that during the two pre-intervention baseline phases (A¹ and A²), the mean NW Attempted scores were 21.6 (SD 2.6) and 19.1 (SD 2.6) and NW Rate were 9.8 (SD 3.5) and 12.9 (SD 3.1) respectively. This demonstrates that prior to intervention P6 attempted up to 4- letters items, was inaccurate at the 2- and 3-letter level during A¹, and became slightly more accurate during A². This compares to the post-intervention baseline (A³) where the mean NW Attempted score was 19.5 (SD 0.8) and the NW Rate score was 17.8 (SD 1.3), which shows that he was accurate on most of the 2- and 3-letter items attempted in 60 seconds in the post-intervention baseline phase. In contrast, while the NW Total mirrored the NW Rate scores during the first pre-intervention baseline phase (A¹), and showed a trend for higher level for NW Total compared to NW Rate in the second pre-intervention baseline (A²), following Decoding Intervention NW Total scores improved dramatically, ranging from 55 to 65, indicating that he accurately decoded 5- and 6-letter items.

2SD band method

Though a significant effect of intervention was demonstrated for NW Total, this child did not reach significance for NW Rate. On this graph a revised 2SD band was drawn to reflect the increased scores in NW Rate and NW Total accuracy scores

during A². A significant intervention effect was demonstrated for NW Total following the second intervention session, and following the fifth intervention session all NW Total data points were above the revised 2SD band, indicating that his gains were maintained during and following intervention. The NW Rate scores remained predominantly below the 2SD band during the Decoding Intervention phase and in the post-intervention baseline (A³). These results indicate that though this child demonstrated a significant intervention effect for nonword reading accuracy, any gains in rate of nonword reading did not reach significance.

Effect size

Table 13 indicates that the effect size for P6 from A¹ to A² (pre-intervention) was 0.90 for NW Rate and 1.51 for NW Total, compared to 1.55 for NW Rate and 7.14 for NW Total from A² to A³. The overall effect size (A¹ to A³) was 2.32 for NW Rate and 10.57 for NW Total. Thus, for NW Rate and NW Total, the pre- post-intervention effect sizes (A² to A³ and A¹ to A³) were greater than the post-intervention baselines phase (A¹ to A²).

Speed of motor response

Table 14 indicates that P6's S-Plate mean response time for the three baseline phases was 0.8 seconds (SD 0.2) for A¹, 0.9 seconds (SD 0.5) for A², 1.0 seconds (SD 0.3) for A³, and 1.0 seconds (SD 0.2) for the decoding intervention phase (B). These results demonstrate that P6's speed of motor response ranged from 0.8 to 1.0 seconds with SDs of 0.2 to 0.5, suggesting that there was minimal change from A¹ to A³. This is reflected the graphed mean response times (Figure 2) which shows that this child's mean response was constant throughout Study 2.

Pre- post- intervention assessments

Table 15 indicates that P6 made clinically significant gains in one of the targeted areas in nonword reading accuracy on the PhAT-2 (Consonant Blends from 85 to 102, mild delay to average), and the PhAT-2 total score increased from 83 to 86 (below average to average). The other two targeted areas (VC and CVC) and non-targeted area (Consonant Digraphs) were in the average range prior to intervention and remained at the same level. While there was a slight gain in one of the vowel spelling patterns (Vowel Digraphs from 66 to 72, severe to moderate severe delay), scores in all other vowel spelling patterns (R-Vowels, CVCe, Diphthongs) remained static. There were no clinically significant gains in any of the vowel spelling patterns (Vowel Digraphs, R-Vowels, CVCe and Diphthongs). Clinically significant gains

were demonstrated on the TOWRE-2. The standard score for nonword reading efficiency increased from poor to below average with a 95% probability that the gains in raw scores from 12 to 19 were due to the intervention. The standard score for word reading efficiency increased from very poor to poor with an 85% probability that the raw score gain from 26 to 32 was due to the intervention. There were no clinically significant changes in accuracy, comprehension or rate of text reading skills.

Table 16 indicates that prior to intervention P6 omitted 7.3% and legally spelled 85.3% of phonemes in the target nonwords, and following Decoding Intervention he omitted 4% (3.3% fewer), and legally spelled 93.2% (7.9% more).

Pre-intervention profile

Table 17 indicates that P6's pre-intervention profile scores were mostly in the average range. Two of the three language areas (CELF-4) were average (Core Language 90, Expressive Language 91), with a mild delay in Receptive Language (84). All subtests on the intellectual assessment (WISC-IV) were in the average range (Full Scale 100, Verbal Comprehension 99, Perceptual Reasoning 100, Working Memory 94, Processing Speed 106). One of the three phonological processing scores on the CTOPP-2 was below average (Phonological Memory 85), with average scores for Phonological Awareness (94) and Rapid Naming (97).

Clinical Observations

P6 was quietly enthusiastic in his attendance at all intervention sessions. His responses were very consistent, and his measured approach to all tasks contributed to a slow decoding style. He became very skilled at decoding: though he continued to make errors, he often reached the end of the Assessment NW Lists in the third baseline, an achievement that gave him great satisfaction.

Summary and interpretation

These results indicate that prior to intervention P6 presented with average skills in all but two of the eleven profile areas with mild weaknesses in receptive language and phonological memory. He was an enthusiastic boy with a cautious approach to all tasks. During the first pre-intervention baseline (A¹), P6 inaccurately decoded items at the 2- and 3-letter level on the dependent variable (Assessment NW Lists). During the second baseline (A²) a slight increase in decoding accuracy was demonstrated (though there was no increasing trend across the baseline sessions). Pre-intervention standardised reading assessments revealed that he scored more than

2SD below the mean for word and nonword reading efficiency (TOWRE-2), and nonword reading accuracy (PhAT-2 Total score). His decoding accuracy profile (PhAT-2) showed that he was in the average range for two of the three targeted areas (VC, CVC) and one non-targeted area (Consonant Digraphs), but below average for the remaining targeted area (Consonant Blends), and all other areas (Vowel Digraphs, R-Vowels, CVCe, Diphthongs). His text reading scores (Neale) were below average for accuracy, average for comprehension and very low for rate.

P6 demonstrated a significant response to intervention on the dependent variable for NW Total, and he continued to improve to a level which indicated accurate decoding of 6-letter items. His NW Rate score failed to reach significance, a finding that is consistent with the very low scores on the other timed nonword reading test – the TOWRE-2 (despite scoring in the average range for three nonword accuracy subtests on the PhAT-2), and the generally cautious approach to all reading tasks that was noted in the clinical observations. This lack of progress in NW Rate was not due to changes in the motor component of the task as this remained constant through all phases. The comparison of the number of correct compared to attempted items showed that initially there was a large gap, indicating that he attempted many items with a low percentage correct. The gap was reduced prior to intervention in the second baseline, which suggested that his accuracy had increased over the two month Language Intervention period. However, following the ninth intervention session the gap became negligible indicating that most attempted items were correct.

His improved scores on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading. He made clinically significant gains in only one targeted area of nonword reading accuracy on the PhAT-2 (Consonant Blends from 85 to 107, below average to average), as prior to intervention the other two targeted areas (VC and CVC) were in the average range and remained unchanged. While there was one clinically significant change in vowel decoding (Vowel Digraphs from 66 to 72, severe to moderately severe), there were no changes in the remaining vowel spelling patterns (R-Vowels, CVCe, Diphthongs). In addition, he made clinically significant changes in nonword reading efficiency (TOWRE-2) where the standard score changed from poor to below average, and there was a 85% probability that the change in raw score from 26 to 32 was due to the intervention.

Clinically significant changes were also demonstrated in word reading efficiency (TOWRE-2), with a change in standard score from 69 to 74 (very poor to poor) and a 95% probability that the raw score change from 12 to 19 was due to the intervention. No clinically significant changes occurred in text reading accuracy (below average), comprehension (average) or rate of reading (very low); and there was a notional change of about 3% fewer phonemes omitted in nonword spelling with a greater number of legally spelled phonemes (nearly 8%) following Decoding Intervention.

These results suggest that though this child's pre-intervention profiles of language, intellectual and phonological processing skills were mostly in the average range (with mild delays in receptive language and phonological memory), he presented with delays in word and nonword reading efficiency, nonword reading accuracy, and below average text reading accuracy. Following the Decoding Intervention he demonstrated significant gains in decoding accuracy in a previously delayed targeted area (Consonant Blends), with an indication of generalisation to some vowel spelling patterns. Additionally, there was evidence for increased efficiency in word and nonword reading (though this was not demonstrated in changes in text reading rate), and slight changes in the expected direction in nonword spelling. His relatively strong language profile most likely supported his reading comprehension skills (as he was able to access semantic and syntactic knowledge), which remained in the average range in the presence of below average accuracy (due to his continuing delays in vowel digraph knowledge).

Participant 7

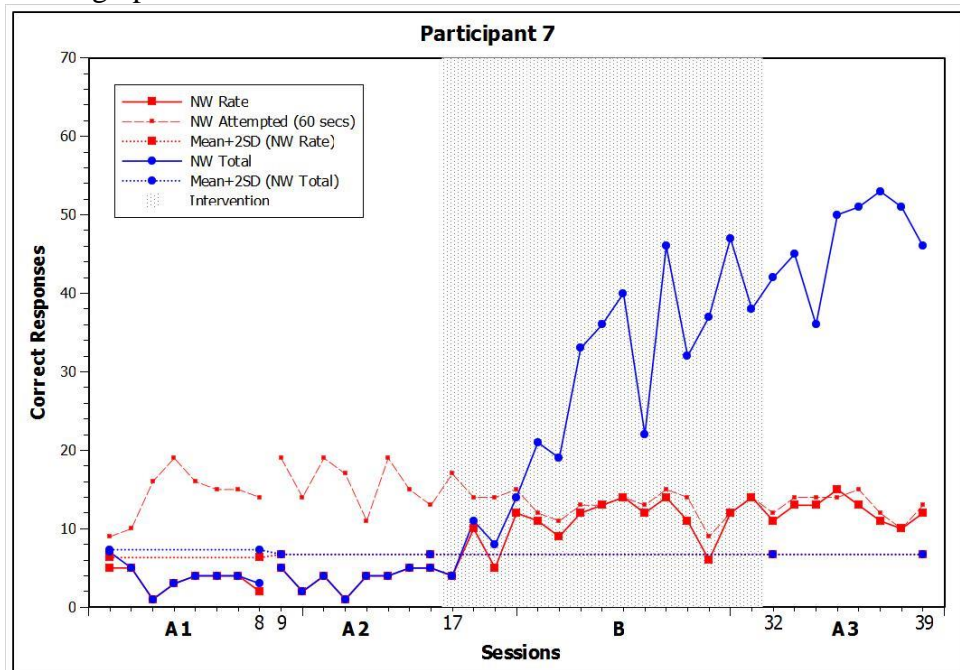
Decoding Intervention modules completed

Participant 7 (P7) was randomised to the A¹-C-A²-B-A³ intervention regime (language-first): Language Intervention followed by the Decoding Intervention. Table 11 shows that P7 reached criterion for 3-letter items in session four, 4-letter items in session eight, and though she spent seven sessions focusing on 5-letter items she did not reach criterion by the last Decoding Intervention session.

Nonword reading rate and accuracy

The graphed responses for participant 7 (P7) are depicted in Figure 48.

Figure 48: P7 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs; NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate and NW Total, consistent with the SPC definition of stability. There was no trend as scores were variable.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A²: There was no change in scores (i.e., the level of accuracy) for NW Rate or NW Total compared to the previous pre-intervention baseline (A¹). A stable

baseline was achieved, as all data points were below the 2SD band that was calculated for A². No slope or trend was demonstrated.

Phase B: After the third intervention session there was an increase in level of response for NW Total and NW Rate with a trend for increasing accuracy. The slope for NW Total was more pronounced than for NW Rate indicating that NW Total continued to improve with a levelling out of gains in NW Rate.

Phase A³: The level of response remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains in NW Total and the relatively unchanged level for NW Rate were maintained.

Visual inspection of NW Attempted compared to NW Rate indicated that in the first pre-intervention baseline phase (A¹) there was a large gap between the number attempted and the number of correct responses in 60 seconds (indicating inaccuracy on most attempted items). This pattern was also observed in the second pre-intervention baseline (A²), indicating that there had been no change in decoding accuracy prior to intervention (following Language Intervention). Following the fifth intervention session the gap between attempted and correct items narrowed and became negligible after the seventh intervention sessions signifying that most attempted items in 60 seconds were accurately decoded. Table 12 shows that during the two pre-intervention baseline phases (A¹ and A²), the mean NW Attempted scores were 14.3 (SD 3.3) and 15.9 (SD 3.1) and NW Rate were 3.5 (SD 1.4) and 3.8 (SD 1.5) respectively. This demonstrates that prior to intervention P7 attempted up to 3- and 4- letters items, but was predominantly inaccurate. This compares to the post-intervention baseline (A³) where the mean NW Attempted score was 13.0 (SD 1.5) and the NW Rate score was 12.3 (SD 1.6), which shows that she was accurate on most of the 2- and 3-letter items attempted in 60 seconds in the post-intervention baseline phase. In contrast, while the NW Total and NW Rate scores were mostly equal during the two pre-intervention baseline phases (A¹ and A²), following Decoding intervention NW Total scores improved dramatically, ranging from 35 to 50, indicating that she accurately decoded 4- and 5-letter items.

2SD band method

A significant effect of intervention was demonstrated for both NW Rate and NW Total. On this graph a revised 2SD band was drawn to reflect the NW Rate and NW Total scores during A², but as there was no change in either measure the 2SD band remained unchanged. Following the first intervention session all data points

were above the 2SD band for NW Total, and from the third intervention session for NW Rate, apart from one outlier at the 13th intervention session. The significant intervention effect was maintained following intervention during the third baseline phase as all data points were above the 2SD band for both measures.

Effect size

Table 13 indicates that the effect size for P7 from A¹ to A² (pre-intervention) was 0.18 for NW Rate and -0.07 for NW Total, compared to 5.71 for NW Rate and 28.90 for NW Total from A² to A³. The overall effect size (A¹ to A³) was 6.19 for NW Rate and 24.83 for NW Total. Thus, for NW Rate and NW Total, the pre- post-intervention effect sizes (A² to A³ and A¹ to A³) were greater than the post-intervention baselines phase (A¹ to A²).

Speed of motor response

Table 14 indicates that P7's S-Plate mean response time for the three baseline phases was 1.0 seconds (SD 0.8) for A¹, 1.3 seconds (SD 1.4) for A², 1.5 seconds (SD 1.2) for A³, and 2.2 seconds (SD 1.8) for the decoding intervention phase (B). These results demonstrate that P7's speed of motor response for the baseline phases ranged from 1.0 to 1.5 seconds with SDs of 0.8 to 1.4, and her speed of motor response during the intervention phase was slightly slower with a mean of 2.2 (SD 1.8). The graphed mean response times depicted in Figure 2 suggested that this child's mean response times varied within each phase (consistent with the large SDs during each phase).

Pre- post- intervention assessments

Table 15 indicates that P7 made clinically significant gains in two of the three targeted areas in nonword reading accuracy on the PhAT-2 (VC from 77 to 103, moderate delay to average, Consonant Blends from 69 to 114, severe to high average). The PhAT-2 Total Score increased from 68 to 81 (severe to mild delay), and the gains were generalised to one non-targeted area (Consonant Digraphs), where the score increased from 67 to 104 (severe delay to average range). The remaining targeted area (CVC) was in the average range prior to intervention, and increased from 89 to 112, low to high average. Decoding of all vowel spelling patterns remained in the severely delayed range. While clinically significant gains were demonstrated on nonword reading efficiency (standard score increased from very poor to poor, with a 95% probability that the gains in raw scores from 4 to 12 were due to the intervention), no gains were made on word reading efficiency

(TOWRE-2). Clinically significant gains were demonstrated in all areas of text reading (Neale). The percentile rank score for accuracy improved from very low to below average and the reading age score increased five months over the three month period. The percentile rank score for comprehension improved from below average to average and the reading age increased five months. The percentile rank for rate decreased from below average to very low and there was a seven month decrease in reading age, indicating that P7's closer attention to reading accuracy was reflected in a slower rate of reading.

Table 16 indicates that prior to intervention, P7 omitted 18.1% and legally spelled 59.9% of phonemes in target items, and that following Decoding Intervention she omitted 12.5% (6% fewer), and legally spelled 71.6% (11.7% more).

Pre-intervention profile

Table 17 indicates that five of the eleven pre-intervention profile scores were more than 1SD below the mean. All language scores (CELF-4) were below average (Core Language 81, Receptive Language 74, Expressive Language 78). All intellectual subtests on the WISC-IV were in the average range (Full Scale 92, Verbal Comprehension 87, Perceptual Reasoning 98, Working Memory 99, Processing Speed 97). Two of the three phonological processing skills were below average on the CTOPP-2 (Phonological Awareness 85, Phonological Memory 82), with scores in the average range for Rapid Naming (88).

Clinical Observations

P7 was enthusiastic about being involved in the intervention sessions and happily accompanied the researcher on each occasion. The clinical notes document frequent instances of challenging behaviour which were characterised as avoidance of tasks that were difficult for her, and a need to be in control. For example, when presented with items to decode, she sometimes decided not to look at the items and to guess, and when asked to write words to dictation in the nonword spelling task, she sometimes produced cursive writing which was difficult to decipher. To feel in control, she often stated which activity she would do first, or part way through an activity she sometimes specified how many more items she was going to complete. While strategies such as positive comments about her progress and gentle encouragement were successful in increasing compliance, sometimes her behaviours impacted on timed tasks, such as the S-Plate response times.

Summary and interpretation

These results indicate that P7 presented with average intellectual skills, significant delays in all language areas, mild weaknesses in two of the phonological processing areas (Phonological Awareness and Phonological Memory), and frequent instances of challenging behaviour. During the pre-intervention baseline, P7 attempted a large number of items on the dependent variable (Assessment NW Lists) and was predominantly inaccurate. No change in decoding level following the Language Intervention was demonstrated, indicating that her skill level had not changed. Standardised reading assessments revealed that prior to intervention she scored more than 2SD below the mean for word and nonword reading efficiency (TOWRE-2), and nonword reading accuracy (PhAT-2 Total Score). Her decoding profile (PhAT-2) showed that she was average in one targeted area (CVC), but delayed in the remaining two targeted areas (VC and Consonant Blends), and severely delayed in all other areas (Consonant Digraphs and all vowel spelling patterns - Vowel Digraphs, R-Vowels, CVCe, and Diphthongs). Her text reading scores (Neale) were in the very low range for accuracy and below average for comprehension and rate.

P7 demonstrated a significant response to intervention on the dependent variable following the first intervention session for NW Total and the third session for NW Rate. Apart from one NW Rate outlier (where clinical notes document behaviour difficulties), her scores for both measures remained above the 2SD band, and her NW Total scores indicate accurate decoding of 5-letter items. These gains were maintained following intervention and were not due to increased skill in the motor component of the task. The comparison of number of attempted to number of correct items indicated that prior to intervention she attempted a large number and was predominantly inaccurate. As her accuracy increased she attempted fewer items, and after the fifth intervention session there was a close match of attempted to correct items, showing that most attempted items were correct.

Her improved scores on the dependent variable were reflected in clinically significant gains on standardised tests of nonword reading. Her nonword reading accuracy scores (PhAT-2) increased in two of the targeted areas (VC from 77 to 103, moderate delay to average; Consonant Blends from 69 to 114, severe to high average), and the third targeted area (CVC) which was in the average range prior to intervention demonstrated a non-clinically significant gain from 89 to 112 (average

to high average). While these gains were generalised to a clinically significant gain in one non-targeted area (Consonant Digraphs from 67 to 104, severe delay to average), all other non-targeted areas (all vowel spelling patterns) remained in the severely delayed range. Examination of her responses indicated that prior to intervention P7 had mastered letter-sound knowledge of consonant digraphs as her errors were due to inaccurate decoding of the short vowel (e.g., pronouncing *thamp* as /thap/), but that she had not mastered orthographic knowledge of any of the vowel spelling patterns. Hence her increased use of phonological recoding supported generalisation to items with consonant digraphs and not vowel spelling patterns. Clinically significant gains were made in nonword reading efficiency (TOWRE-2) with the standard score improving from very poor to poor and a 95% probability that the change in raw score from 4 to 12 was due to the intervention.

While no gains were demonstrated in word reading efficiency (TOWRE-2), clinically significant gains occurred in most text reading scores (Neale). Her reading accuracy percentile rank score increased from very low to below average with a reading age gain of five months over the three month period. Her reading comprehension percentile rank increased from below average to average with a reading age gain of five months, and her reading age rate decreased seven months. This suggests that her increased attention to accuracy of reading (and hence increased comprehension) was reflected in a slower rate. Her changes in nonword spelling were consistent with an increased attention to each phoneme in an item with 6% fewer phonemes omitted and 11.7% more phonemes legally spelled following Decoding Intervention.

These results suggest that though this child presented with delays in all language areas, weaknesses in phonological processing, and behaviour difficulties (which were possibly related to her reading failure), she made significant gains in nonword reading accuracy and efficiency, with trends for generalisation to accuracy, comprehension and rate of text reading.

Participant 8

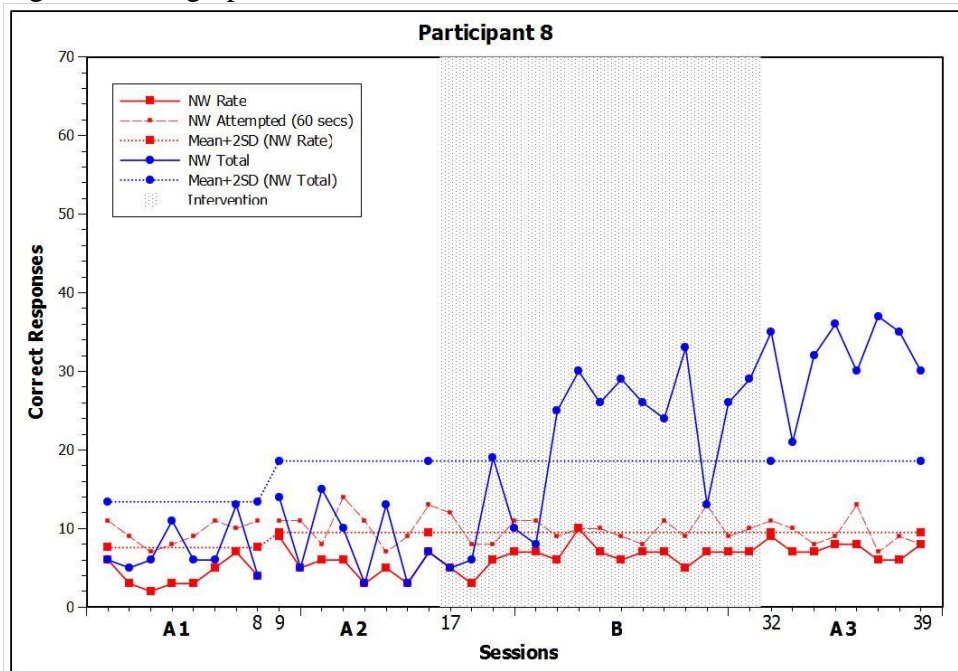
Decoding Intervention modules completed

Participant 8 (P8) was randomised to the A¹-C-A²-B-A³ intervention regime (language-first): Language Intervention followed by the Decoding Intervention. Table 11 shows that P8 reached criterion for 3-letter items in session five. He was presented with 4-letter items from session six to eight, experienced difficulty at this level, and was returned to 3-letter items in session nine and ten to consolidate skills. Following this he spent five sessions on 4-letter items and reached criterion for 4-letter items in session 15.

Nonword reading rate and accuracy

The graphed responses for participant 8 (P8) are depicted in Figure 49.

Figure 49: P8 graphed Assessment NW List



Note: NW Rate = correct responses in 60 secs; NW Attempted = number of nonwords attempted in 60 secs; NW Total = number of nonwords correct; Mean+2SD (NW Rate) = 2SD band for NW Rate; Mean+2SD(NW Total) = 2SD band for NW Total

Visual inspection

Phase A¹: A stable baseline was achieved for NW Rate and NW Total as all data points were below 2SD for NW Rate and NW Total, consistent with the SPC definition of stability. There were no trends as scores were variable.

Phase C: The dependent variable was not administered during the 15 Language Intervention sessions hence no data points are graphed.

Phase A²: There was a slight increase in level for NW Rate and NW Total compared to the previous pre-intervention baseline (A¹). A stable baseline was achieved, as all data points were below the 2SD band that was calculated for A². No slope or trend was demonstrated as scores remained variable.

Phase B: After the fifth intervention session there was an increase in scores (i.e., in level of response) for NW Total with a gentle slope indicating a trend for increasing accuracy. There was minimal change in level with no slope or trend for NW Rate. This indicates that P8 made gains in NW Total with no gains in NW Rate.

Phase A³: The level of response remained constant and there was no slope or trend for NW Rate or NW Total indicating that the gains in NW Total and the relatively unchanged level for NW Rate were maintained.

Visual inspection of NW Attempted compared to NW Rate indicated that the number of attempted items in 60 seconds remained constant throughout all phases. The gap between attempted and correct items was slightly greater in the two pre-intervention baseline phases (A¹ and A²) with a narrowing towards the end of the intervention and extending into the post-intervention phase. This suggests that P8 was a slow decoder (attempting about 10 items in 60 seconds), and that his accuracy in 60 seconds only slightly improved. Table 12 shows that during the two pre-intervention baseline phases (A¹ and A²), the mean NW Attempted scores were 9.5 (SD 1.5) and 10.5 (SD 2.4) and NW Rate were 4.1 (SD 1.7) and 5.5 (SD 2.0) respectively. This demonstrates that prior to intervention P8 attempted up to 3- letters items in 60 seconds, and was inaccurate at the 2- and 3-letter level during both pre-intervention baseline phases (A¹ and A²). This compares with the post-intervention baseline (A³) where there was a slight increase in accuracy compared to attempted items: the mean NW Attempted score was 9.4 (SD 1.9) and the NW Rate score was 7.4 (SD 1.1). This indicates that though he remained inaccurate at the 3-letter level his overall decoding accuracy in 60 seconds improved in the post-intervention baseline phase. In contrast, NW Total demonstrated greater gains during and following intervention (where scores ranged from 25 to 35) compared to the two pre-intervention baselines (scores between two and 12), indicating that post-intervention he accurately decoded 4- and some 5-letter items.

2SD band method

Though a significant effect of intervention was demonstrated for NW Total, this child failed to reach significance for NW Rate. On this graph, a revised 2SD

band was drawn to reflect the slight increase in NW Rate and NW Total scores during A². A significant intervention effect was demonstrated for NW Total following the fifth intervention session as all but one data point (13th intervention session) fell above the 2SD band, indicating that his gains were maintained during and following intervention. The NW Rate scores remained below the 2SD band during the intervention phase and in the post-intervention baseline (A³), indicating that this child was unable to achieve significant increases in the rate of decoding accuracy.

Effect size

Table 13 indicates that the effect size for P8 from A¹ to A² (pre-intervention) was 0.80 for NW Rate and 0.52 for NW Total, compared to 0.94 for NW Rate and 4.72 for NW Total from A² to A³ (post-intervention). The overall effect size (A¹ to A³) was 1.88 for NW Rate and 7.93 for NW Total. Thus, for NW Total, the pre-post-intervention effect sizes (A² to A³ and A¹ to A³) were greater than the pre-intervention baselines phase (A¹ to A²), with a much small pre- post-intervention effect size difference for NW Rate.

Speed of motor response

Table 14 indicates that P8's S-Plate mean response time for the three baseline phases was 1.1 seconds (SD 0.6) for A¹, 1.3 seconds (SD 1.7) for A², 1.4 seconds (SD 1.1) for A³, and 1.5 seconds (SD 1.2) for the decoding intervention phase (B). These results demonstrate that P8's speed of motor response ranged from 1.1 to 1.5 seconds with SDs of 0.6 to 1.7, suggesting that there was minimal change from A¹ to A³. The graphed mean response times depicted in Figure 2 suggested that this child's mean response times varied, particularly during A², B and A³, consistent with the large SDs observed these phases.

Pre- post- intervention assessments

Table 15 indicates that P8 made clinically significant gains in all targeted areas in nonword reading accuracy on the PhAT-2 (VC from 63 to 103, severe to average; CVC from 74 to 97, moderate delay to average; Consonant Blends from 73 to 99, moderate delay to average), with generalisation to one non-targeted area (Consonant Digraphs, from 80 to 103, mild delay to average). The PhAT-2 total score increased from <64 to 71 (severe to moderate severe delay). No gains were demonstrated in any of the vowel spelling patterns (Vowel Digraphs, R-Vowels, CVCe, and Diphthongs) which remained in the severely delayed range. While there

was no change in the standard scores for word and nonword reading efficiency (TOWRE-2), there was an 85% probability that the raw score change in nonword reading efficiency was due to the intervention. Trends for gains in text reading (Neale) were demonstrated. The percentile rank descriptor for accuracy increased from very low to below average, the reading age for comprehension increased five months over the three month period, and the reading age for rate decreased six months, suggesting that his increased attention to reading accuracy resulted in a slowed reading rate.

Table 16 shows that prior to intervention, P8 omitted 22% and legally spelled 69.5% phonemes in the target items, and following Decoding Intervention he omitted 15.9% (6.1% fewer) and legally spelled 67.6% (1.9% fewer).

Pre-intervention profile

Table 17 indicates that eight of the eleven pre-intervention profile scores were more than 1SD below the mean. All of the language areas (CELF-4) were below average (Core Language 79, Receptive Language 84, Expressive Language 76), as were three of the intellectual skill areas on the WISC-IV (Full Scale 80, Working Memory 80, Processing Speed 78), with scores in the average range for Verbal Comprehension (89) and Perceptual Reasoning (88). Two of the three phonological processing scores on the CTOPP-2 were below average (Phonological Memory 82, Rapid Naming 70), with an average score for Phonological Awareness (88).

Clinical Observations

P8 was cooperative during the intervention sessions, though at times he presented as fatigued and easily distracted, requiring positive comments and encouragement to complete tasks. This distractibility sometimes affected time tasks, such as the S-Plate. His teacher reported that this child had an unpredictable timetable at home and was often up late in the evening, resulting in frequent absences from school, instances of reluctance to complete tasks, and difficulty complying with classroom expectations. A prominent feature of this child's response to intervention was his severe difficulties with accurate retrieval of the sounds of letters (consistent with his score in the severe range on the Rapid Naming subtest), and difficulty blending sounds (consistent with his below average scores in Processing Speed and Phonological Memory). He was slow in decoding all items, usually attempting each item numbers of times, and demonstrating frequent instances of perseveration where

his decoding attempts were a repetition of a previous item. For example, when decoding *isps*, his multiple attempts included /z/ /z-s/ /z/ /i-s/ /i-s-p-s/ /sti/ /ips/, thus demonstrating difficulty with retrieval of letter-sound knowledge and blending.

Summary and interpretation

These results indicate that prior to intervention, P8 presented with delays in most language, intellectual and phonological processing skill areas (with the most significant delays in Rapid Naming, Expressive Language, and Processing Speed), accompanied by reported reduced compliance classroom tasks. During the pre-intervention baseline (A¹), P8 inaccurately decoded 2- and 3- letter items on the dependent variable (Assessment NW Lists). Slight gains were demonstrated during the second pre-intervention baseline (A²), suggesting that over the two month period for Language Intervention, the level of decoding accuracy had marginally increased, though variability was a key feature of this child's NW Total score. Pre-intervention standardised reading assessments revealed that he scored more than 2SD below the mean for word and nonword reading efficiency (TOWRE-2), and nonword reading accuracy (PhAT-2 Total Score). His decoding accuracy profile (PhAT-2) showed that he was in the moderately severe or severe range for the three targeted areas (VC, CVC, Consonant Blends), and in the mildly delayed range for one non-targeted area (Consonant Digraphs), with severe delays in all vowel spelling patterns (Vowel Digraphs, R-Vowels, CVCe, and Diphthongs). His text reading score (Neale) was very low for accuracy and rate, and below average for comprehension.

P8 demonstrated a significant response to intervention on the dependent variable for NW Total following the fifth intervention session, and he continued to improve to a level which indicated accurate decoding of 4- and 5-letter strings. His NW Rate score failed to reach significance, most likely due to his significant delays in retrieval of letter-sound knowledge and blending (consistent with his low scores in Rapid Naming, Processing Speed and Phonological Memory). His responses on the NW Total and NW Rate measures were not due to changes in the motor component of the task as, though variable, this remained at a similar level through all phases. The comparison of number correct to attempted items in 60 seconds showed that this child attempted a consistent number of items across all phases, with about 50% correct during pre-intervention phases. Though the gap decreased during and following intervention, he continued to have problems decoding 3- and 4-letter

strings in the timed measure, consistent with the observed difficulty with rapid retrieval and perseverative attempts.

His improved scores on the dependent variable were reflected in clinically significant gains in all targeted areas on standardised tests of nonword reading accuracy on the PhAT-2 (VC, CVC and Consonant Blends, where scores changed from severe and moderately severe range to the average range), with generalisation to one non-targeted area (Consonant Digraphs). No changes were observed for the remaining non-targeted areas (vowel spelling patterns) which remained in the severe range. Examination of his responses indicated that prior to intervention, he had mastered letter-sound knowledge of consonant digraphs as his errors on the Consonant Digraph subtest were due to errors on the short vowel (e.g., pronouncing *thamp* as /thump/), and perseveration (e.g., following the previous item, pronouncing *nuch* as /fumpt/). However, he had not mastered orthographic knowledge for vowel spelling patterns. Hence his increased use of phonological recoding following the Decoding Intervention supported generalisation to those items that contained previously mastered orthographic patterns. In addition to gains in nonword reading accuracy, there were trends for improved nonword reading efficiency on the TOWRE-2 with an 85% probability that the change in raw score from 4 to 9 was due to the intervention.

P8 demonstrated a clinically significant gain in text reading accuracy (Neale), with a change in percentile rank descriptor from very low to below average. There was a trend for increased reading comprehension (with a reading age gain of five months over the three month period) with a slower rate of reading (more than a six month reduction of reading age). No change in word reading efficiency was demonstrated, consistent with his minimal change in NW Rate – the timed measure of the dependent variable. Though he omitted about 6% fewer phonemes in nonword spelling, there was no change in the number of phonemes legally spelled.

These results suggest that though this child presented with delays in most of the pre-intervention profiles of language, intellectual and phonological processing, his decoding accuracy for all targeted areas increased from moderate or severely delayed to well into the average range. While these gains were not generalised to increases in any of the timed measures (most likely due to his significant impairments in Rapid Naming and Processing Speed), there was a trend for improvement in text reading accuracy.

Discussion

The results of the SSRD analyses reveal individual differences, particularly with respect to pattern of response, and the information from the pre-intervention profiles and clinical observations. This section provides a discussion of the SSRD results for each of the three research questions, and draws links between the individual and the group results. This is followed by general conclusions about how the overall findings may inform subsequent investigation and intervention for this population.

Question 1

The hypothesis relating to the first research question was that the single component Tier 3 intervention (the Decoding Intervention) developed for this research, would significantly improve the nonword reading ability of Year 2 children with word reading impairment who had demonstrated inadequate response to previous Tier 2 interventions. Within the SSRD framework this was examined via analyses of two measures of the dependent variable: NW Rate (number of accurately decoded items in 60 seconds), and NW Total (total number of accurately decoded items) assessed by researcher-developed Assessment NW Lists. The analyses involved visual inspection of the graphed responses (within phase characteristics of stability and trend, and between phase changes in level, trend and slope), an analysis of the response time on the motor component of the task (Speed of Motor Response), and two statistical analyses - the 2SD band method (Portney & Watkins, 2009; Rubin, 2010) and a calculation of effect size (Beeson & Robey, 2006).

Visual inspection

This section discusses the visual analyses of NW Rate and NW Total during each phase (pre-intervention baselines, intervention, and post-intervention baselines), followed by the NW Attempted/NW Rate comparison across all phases.

Visual inspection of the NW Rate and NW Total graphed responses revealed that all participants achieved a stable pre-intervention baseline (A^1 for the decoding-first, and A^2 for the language-first condition) as defined by Statistical Process Control (SPC: Portney & Watkins, 2009), with no trends for increasing accuracy. This indicates that an accurate reflection of pre-intervention decoding levels was

obtained and that prior to intervention there was no trend for improvement in decoding levels. The language-first participants (those who completed the Language Intervention followed by the Decoding Intervention) completed two pre-intervention baselines. This enabled examination of any changes that may have occurred during the Language Intervention condition (which controlled for the effects of individual time spent with the researcher), and the possible effects of the baseline task, that is, that the baseline task itself did not lead to improvement in decoding. The results showed that of the four children in the language-first condition, two (P6 and P8) demonstrated a slight increase in level of accuracy in the second pre-intervention baseline, one (P5) had decreased in level, and the fourth child (P7) demonstrated no change.

During the Decoding Intervention (Phase B), the NW Total score increased in level for all participants. This indicates that using this untimed measure, all participants (including the two children in the language-first condition who had made slight gains in their second pre-intervention baseline), demonstrated an increase in nonword reading accuracy compared to their pre-intervention baseline. While the trend was for increasing accuracy for all participants, the slope varied between participants. Four participants, two in the decoding-first (P1 and P3), and two in the language-first condition (P6 and P7) demonstrated a pattern that suggests a gradual increase in decoding skill for the first five to six decoding intervention sessions, followed by a steep slope, reaching a level which indicated accurate decoding at the 5- or 6-letter level. This suggests that it took about five to six sessions for these participants to master certain aspects of phonological recoding, and that once mastered, they were able to consistently apply that skill to complex letter strings. In contrast, two participants (P2 in the decoding-first and P8 in language-first condition) demonstrated a gradual NW Total slope with variability (that remained a feature throughout), and finally reached a stage indicating accuracy at the 4-letter (P8) and 5-letter (P2) level, that is, their progress was less consistent and they reached a lower level of accuracy. While this may suggest similar patterns of response for these two individuals (and therefore similar intervention needs), the information from the pre-intervention profiles and clinical notes reveal very different clinical profiles. P2 presented with close to average scores on all pre-intervention language, intellectual and phonological assessments but with severe “b/d” confusion which contributed to her variability of decoding accuracy, whereas P8’s pre-

intervention profile of significantly delayed scores in Rapid Naming and Processing Speed were the most likely factors influencing his variable response and lower level of final achievement in decoding accuracy. The remaining two participants (P4 in the decoding-first, and P5 in language-first condition) reached similar final accuracy levels (at the 4-letter level), but their slope of response was quite different. P5 demonstrated a steep slope after the second intervention session, whereas P4 responded with a gradual slope for the first 11 intervention sessions followed by a steep slope, possibly explained by his initial difficulty with verbal production of final consonant blends (documented in the clinical notes), which impacted on accurate decoding of 4- and 5- letter strings with final consonant blends.

The visual analysis of the NW Rate score (number correct in 60 seconds) during the Decoding Intervention phase demonstrated that all participants increased in level of response with a trend for increasing accuracy that was generally consistent with the NW Total score, that is, the increases in level of NW Rate and NW Total occurred at about the same time, and the child who demonstrated the lowest gain in NW Total (P8) also demonstrated minimal gains in NW Rate. Though the slope for NW Rate was much less pronounced than for NW Total for all participants, (a feature that occurred because there is a limit to the number of items a child could attempt in 60 seconds), most children demonstrated a gradual increase in nonword decoding rate. This is consistent with the findings of Pullen et al. (2005) who conducted an SSRD study to examine whether gains in decoding accuracy (as measured by a NW Rate dependent variable) occur immediately or over time. They concluded that the gradual emergence of decoding accuracy occurs because decoding involves the skilful coordination of several component skills – blending, association of letter with sounds, and pronouncing words.

During the post-intervention baseline phases (A³ for the language-first, A² and A³ for the decoding-first condition), all participants maintained the level of response that was achieved during intervention for NW Total and NW Rate. This indicates that language-first participants maintained the gains in decoding rate and accuracy immediately following intervention, and that the decoding-first participants also maintained gains following the two month gap for language therapy.

The comparison of NW Attempted to NW Rate provided additional information about decoding patterns which are graphically displayed in the individual analyses, and documented in Table 12. It involved a calculation of the

mean number of attempted items in 60 seconds (NW Attempted) compared to the mean number of correct items in 60 seconds (NW Rate). The first observation is that while most participants demonstrated a large gap between attempted and correct items in the pre-intervention baselines (A^1 for the decoding-first, A^1 and A^2 for the language-first condition), two participants (P2 and P8) had a narrower gap between attempted and correct items. This quantifies the visual observation that prior to intervention most participants attempted a large number of items and were predominantly incorrect, but these two participants (with different pre-intervention profiles, as discussed previously) demonstrated a much slower decoding style. Secondly, most participants attempted about the same number of items across each of their baselines (a range of about nine to 20 items). This means there was a limit to the NW Rate score which is consistent with the observation that the NW Rate slope flattened compared to the NW Total slope. Third, it supported the visual observation that two participants in the language-first condition (P6 and P8) demonstrated slight gains in decoding accuracy following the Language Intervention. That is, while each participant in the language-first condition attempted a similar number of items in both pre-intervention baselines, P6 and P8 improved by a mean of 3.1 and 1.4 respectively, compared to P5 whose score decreased by 3.6 and P7 whose score remained the same (with a small increase of 0.3).

Speed of motor response

The S-Plate measured the speed of response on the motor component of the iPad intervention tasks. The analysis of the mean response times and standard deviations across each phase showed that the response times remained at a similar level for all participants. Examination of the graphed response suggests two patterns. The first is that the mean response times for the decoding-first participants appear to have slowed by about half a second during the two post-intervention baseline phases. It is possible that, as these sessions had no Decoding Intervention module (i.e., less demanding), participants may have become more easily distracted and more likely to start a conversation during a task that only had a physical requirement. The second observation is that the graphed responses for the language-first participants appear to be more variable compared to the decoding-first participants. However, closer examination reveals that two participants (P5 and P6) displayed a pattern that was similar to those of the decoding-first pattern, and that P7 and P8 were much more variable: possibly explained by the P7's behaviour difficulties, and P8's fatigue and

distractibility. These results suggested that the response times on the motor component of the task either slightly slowed, remained constant, or were variable. Therefore, it was concluded that there were no changes in response times that could account for the increased scores that occurred on the timed measure of the dependent variable (NW Rate).

2SD band method

The 2SD band method (Portney & Watkins, 2009) determined whether the changes from pre-intervention baseline to intervention that were observed in the visual analyses were significant. It was found that all participants reached significance for NW Total, and six of the eight for NW Rate. This result suggests that the Decoding Intervention which was closely matched to the decoding level of each child (i.e., prior to intervention all participants made errors on 2-letter items), resulted in significant gains in decoding accuracy for all participants. The NW Rate analysis revealed that two participants failed to make gains in rate of reading. This finding is consistent with other research (Buckingham et al., 2012; Denton et al., 2013; National Reading Panel, 2000; Torgesen, 2001) which has found reading fluency to be relatively resistant to intervention. However, the SSRD used in this research provides additional information regarding the differing intervention needs of the two participants who did not make gains in reading fluency: P2 presented with severe “b/d” confusion with a pre-intervention profile of average or close to average scores in language, intellectual and phonological processing, while P8 demonstrated moderate language delays, and significant delays in Rapid Naming and Processing Speed.

Effect size

The effect size calculation (Beeson & Robey, 2006) displayed in Table 13, enabled further investigation of the individual differences in response to intervention for these eight participants. Three effect sizes were calculated for each participant: A^1 to A^2 represented effect sizes of pre-post intervention for the decoding-first, and the two pre-intervention baselines for the language-first participants (changes that may have occurred with the passage of time); A^2 to A^3 were the effect sizes for pre-post intervention for the language-first, and the two post-intervention baselines for the decoding-first participants (changes that may have occurred two months after intervention); and A^1 to A^3 were the overall effect sizes for all participants from pre-to post intervention.

Regarding the NW Total score, while all participants demonstrated a larger pre-post effect size (ranging from 4.98 to 27.79) compared to either the two month post-intervention (decoding-first, from -0.12 to 0.67), or the delayed start to intervention (language-first, from -0.07 to 1.51), there were difference in the magnitude of the pre-post intervention effect size between participants. Whereas most pre-post intervention effect sizes were between 10.00 and 20.00, those for P2 (4.98), and P8 (4.72) were much lower, which indicates that these two children demonstrated relatively less gain in nonword reading accuracy.

The NW Rate pre- post-intervention effect sizes for the six participants who demonstrated a significant intervention effect, ranged from 2.46 to 12.02 compared to the two month post-intervention effect sizes (decoding-first, from -0.54 to 0.16) and those for the delayed start to intervention (language-first, from -1.10 to 0.90). This compares with the pre-post intervention effect sizes for the two participants who did not demonstrate a significant intervention effect: P6 with a pre- post-intervention effect size of 1.55 and P8 with 0.94. Further examination of the effect size calculation also revealed that though P2 demonstrated a significant intervention effect on the 2SD band analysis, her effect size was low compared to the other participants.

The effect size calculations discussed above quantified the results of visual inspection of the graphs. It showed that three participants made comparatively less gains: P2 and P8 on nonword reading accuracy (NW Total), and P2, P6, and P8 on nonword reading rate (NW Rate). The SSRD analyses, which also examined pre-intervention profiles and clinical observations, provided additional information which adds insight into these individual differences in response to intervention. This will be elaborated upon in the discussion of the Question 3 results.

Linking SSRD and group results

The SSRD analyses discussed above, and group analyses (presented in Chapter 6) both demonstrate strong support for hypothesis 1, that is, that this Tier 3 decoding intervention resulted in significant gains in nonword reading assessed by the Assessment NW Lists.

The group analyses, using the GLMM (an ANOVA procedure that accommodates the requirements for normality, homogeneity of variance, sphericity, and independence of observations), found that the Decoding Intervention resulted in significant increases in the dependent variables assessed by NW Rate (the number of

nonwords read correctly in 60 seconds) and NW Total (the total number of nonwords read correctly) for both groups. Furthermore, neither group demonstrated a significant change in NW Rate or NW Total following the comparison condition (Language Intervention). This indicates that the decoding-first participants maintained skills two months following the Decoding Intervention, and the language-first participants made no significant changes following Language Intervention. Given that the mean time for the Decoding Intervention in Study 2 (seven minutes per session) was less than other studies with a similar focus (14 to 30 minutes per session), it was concluded that the Decoding Intervention developed for this research resulted in highly significant ($p < .001$) outcomes with greater efficiency.

The SSRD analyses provided additional detail about the individual differences in responses to intervention that were not apparent in the group analysis. The visual inspection demonstrated that while all participants increased in level of response following the intervention, there were differences in pattern and level of response. The 2SD band analyses added to this information by revealing that all participants made significant gains on NW Total but only six for NW Rate. In addition to this, the effect size calculation and the comparison of NW Attempted to NW Rate quantified the differences in response between participants, in particular for the two participants (P6 and P8) who did not make significant gains in rate of nonword reading, and the third (P2) who presented with initial variability in response and lower overall gains.

The data from the SSRD analyses provides details regarding individual responses to intervention that may contribute to the discussion of the extent to which the gains on the dependent variable were generalised to the other standardised reading assessments that were administered to answer the second research question.

Question 2

The second research question examined whether the Decoding Intervention would result in improved scores on standardised tests of nonword reading accuracy, word and nonword reading efficiency, text reading, reading comprehension, and a detailed examination of nonword spelling skills in Year 2 children with word reading impairment. Thus this question examines the extent to which improved nonword reading skills, measured by the dependent variable, would generalise to other measures of reading and spelling. It was hypothesised that gains would be observed

in some, but not all, areas. Firstly, while the single component intervention enabled unambiguous analysis of the intervention effect in a controlled research environment, it did not involve activities to support use of phonological recoding during text reading. Secondly, the intervention matched the decoding level of each participant, therefore targeting items with 1:1 letter-sound correspondence. It was possible that participants may have required support to generalise decoding skills to text reading, and specific teaching of consonant and vowel digraphs to enable generalisation to a wider range of spelling patterns – a goal that was not part of this first stage intervention.

The results of the SSRD analyses indicated that most participants made clinically significant gains on standardised tests of nonword reading accuracy and nonword reading fluency, fewer gains on word reading fluency, trends for improved text reading accuracy and comprehension, and some changes in nonword spelling consistent with improved phonological recoding skills (i.e., increased attention to all letters in an item). Each of these areas will now be discussed by highlighting how the SSRD results augment the group analyses.

Nonword reading accuracy was assessed by eight subtests of the PhAT-2: three targeted areas (VC, CVC, Consonant Blends) and five non-targeted areas (Consonant Digraphs, Vowel Digraphs, R-Vowels, CVCe, and Diphthongs); resulting in a PhAT-2 Total score which included all eight subtests. It was found that two participants (P5 and P8) made gains on all three targeted areas, four participants (P1, P2, P3, P7) on two targeted areas, and two participants made gains on only one targeted area (P4 and P6). The large majority of these clinically significant gains (14 of 16), represented improvement from below average into the average range, the remaining two being a low to high average gain. Additionally, seven of the eight participants made clinically significant gains in their PhAT-2 Total score. Generalisation to one non-targeted area (Consonant Digraphs) was demonstrated by six participants (P1, P2, P3, P4, P7, P8), while the other two participants (P5 and P6) were in the average range for this area prior to intervention. Examination of pre-intervention participant responses on this subtest indicated that in each case, orthographic knowledge of the consonant digraphs was demonstrated, as the pre-intervention errors were related to other skill deficits, such as inaccurate decoding of the short vowel or problems blending the sounds. Hence, their increased proficiency with phonological recoding as a result of this intervention enabled generalisation on

this subtest. In contrast, none of the participants demonstrated pre-intervention orthographic knowledge of vowel spelling patterns resulting in a lack of generalisation to the four vowel subtests. While the group analysis (discussed in Chapter 6) found statistically significant gains in only two areas (VC and PhAT-2 Total), the SSRD analysis reveals a number of other clinically significant gains made by individual participants. Thus the SSRD analyses are often able to “provide more ‘real world’ insight and understanding of individual responses than data from group studies” (Portney & Watkins, 2009, p. 268).

The SSRD analysis of nonword reading fluency (assessed by the TOWRE-2 PDE) found that four participants made clinically significant changes on their standard scores: two (P4 and P7) improved from very poor to poor, and two (P5 and P6) from very poor to below average. Using the raw score interpretation (Torgesen et al., 2012) there was a 95% probability that the gains were due to the Decoding Intervention for five participants (P3, P4, P5, P6, P7), an 85% probability for one (P8), and 70% probability for one (P1). These observations are consistent with the group analysis which found a significant intervention effect on nonword reading fluency for both groups. This suggests that generalisation occurred from targeted to non-targeted areas, as the TOWRE-2 PDE involved items with a range of spelling patterns.

Trends for improvements in word reading fluency (TOWRE-2 SWE) as a result of the Decoding Intervention were demonstrated using the SSRD analysis. Though only one participant made a clinically significant gain in standard score increases (P6, from very poor to poor), five participants demonstrated a trend for clinically significant gains using the interpretation of raw score changes (Torgesen et al., 2012): there was a 95% probability for three participants (P3, P4, and P5), an 85% probability for P6, and a less convincing 60% probability for P8. While the group analysis found no significant intervention effect (as both groups made significant gains in a similar pattern, from T2 to T3, and T1 to T3), the results of the SSRD analysis highlighted the nature of the variability between participants, that is, it suggested that some generalisation to word reading efficiency may have occurred as trends were present for two participants in the decoding-first and three in the language-first condition.

Generalisation to text reading, comprehension and rate were examined using the Neale Analysis of Reading Ability 3rd edition (Neale). The SSRD analysis for

reading accuracy found that three participants (P1, P7, and P8) made clinically significant changes in their percentile rank descriptors, and four (P1, P2, P4, and P7) made reading age gains using the “a priori learning criterion” described by McCandliss et al. (2003). Using these analyses for reading comprehension, four participants (P1, P2, P3, and P7), made clinically significant gains in percentile rank descriptors, and the same four participants as well as P8 made reading age gains. The results for the reading rate analysis suggest marginal changes to a slower reading rate: P3 and P4 made a clinically significant change in percentile rank descriptor and P7 and P8 using the reading age change analysis. Though these analyses can only be considered as trends, they provided additional insight into the individual differences in responses to intervention, that is, that some generalisation to text reading accuracy and comprehension may have occurred and that there was a tendency for participants to slow their reading rate in an effort to increase accuracy.

The SSRD analysis of nonword spelling (using the SSS procedure) examined pre- post-intervention changes in two measures: the percentage of phonemes omitted and the percentage legally spelled. The expected pattern was that compared to pre-intervention responses there would be fewer phonemes omitted and more phonemes legally spelled following the Decoding Intervention. This analysis revealed that one participant (P4: the child who, prior to intervention, had oral motor programming difficulty producing consonant blends) made greater than 10% gains on both measures, two (P5 and P7) made greater than 5% gains on both measures, and two made greater than 5% gain on one measure (P6 on phonemes legally spelled, and P8 on phonemes omitted). One child (P1) made slight gains in the expected direction, and two remained static (P2 and P3). While the SSS procedure does not provide normed referenced scores, this analysis suggests that there may have been trends for improved nonword spelling for some participants following the Decoding Intervention. These results are consistent with Buckingham et al. (2012) who found less pronounced gains in spelling skills compared to measures of nonword and word reading. It suggests that spelling skills may need to be specifically targeted within a reading intervention programme or that longer periods of intervention are needed for improvements in decoding skills to transfer to spelling.

The discussion of the SSRD analyses relating to Question 2 demonstrates that, like the group analyses, the second hypothesis was partially supported, that is, that the gains in nonword reading demonstrated on the dependent variable were

reflected in significant gains on some standardised assessments of reading (nonword reading accuracy and efficiency), with minimal gains on other measures (word reading efficiency, text reading, reading comprehension, rate of reading, and nonword spelling). However, it was also found that, compared to the group analyses, the SSRD analyses provided additional information about individual response to intervention. While the group analysis demonstrated a significant intervention effect on two standardised measures of nonword reading accuracy (VC and Total score on the PhAT-2), the SSRD analyses revealed that all participants made clinically significant gains in the other targeted areas (CVC, Consonant Blends), and six generalised to one non-targeted area (Consonant Digraphs). Additionally, the SSRD analyses found clinically significant changes (or a high probability that gains in raw scores were due to the intervention) in other areas for which no intervention effect was demonstrated in the group analyses (word reading efficiency, text reading accuracy and comprehension). These individual differences in responses to intervention that were revealed using the SSRD analyses have the potential to inform further investigation into interventions for this population who have been shown to have a high proportion of non-responders.

Question 3

The third research question investigated whether pre-intervention scores on measures of language, intellectual, and phonological processing skills would influence the outcome measures of word and nonword reading, text reading, reading comprehension, and spelling. Similar to Study 1, the SSRD analysis involved a comparison of the number of pre-intervention scores that fell below 1SD (Table 7) to the magnitude of gain in outcome measures. This was determined by examination of the effect size calculation on the dependent variable (Table 13), a calculation of the number of clinically significant gains demonstrated for each participant (Table 15), and the examination of changes in nonword spelling skills (Table 16). While the results on the small sample of three children in Study 1 suggested that the child with the greatest number of pre-intervention profile scores that fell more than 1SD below the mean (i.e., below average) made the least number of clinically significant gains, the Study 2 analysis reveals a more complex relationship between pre-intervention profile and response to intervention.

Most participants in Study 2 had six to seven pre-intervention profile areas that were below average (with a range from two to eight). The three participants with the smallest effect sizes on the dependent variables (P2, P6, and P8), included the two children with the strongest pre-intervention profiles (P2 with three, and P6 with two areas below average) and the child with the weakest pre-intervention profile (P8 with eight areas below average). The SSRD analysis (which includes visual inspection of the graphed responses, clinical observation, and pre-intervention profiles) enables interpretation of this outcome. P2 demonstrated severe “b/d” confusion and a slow decoding style (resulting in variability of decoding accuracy); P6 was characterised by a slow and cautious decoding style who began intervention at a higher level than the other participants (hence less gains on timed measures and lower overall effect size); and P8 demonstrated significant Rapid Naming and Processing Speed impairments (contributing to multiple attempts on each item due to effortful retrieval of letter-sound knowledge). Thus the relatively smaller effect size on the dependent variables for these three participants was due to a range of individual factors.

With regard to the standardised outcome measures of nonword reading accuracy (PhAT-2), word and nonword reading efficiency (TOWRE-2), text reading accuracy, reading comprehension, and rate of reading (Neale), regardless of the number of pre-intervention profile weaknesses, most participants demonstrated about seven clinically significant changes (range from six to ten). Additionally, the three participants who made the most number of gains (P3 and P8 with ten, P1 with nine clinically significant gains) had the weakest pre-intervention profiles (P8 with eight, P1 with seven, and P3 with six areas below average).

Though there were minimal changes in nonword spelling skills, examination of the influence of pre-intervention profiles on nonword spelling responses also suggests that a range of individual factors were involved. For example, the child who demonstrated the most convincing gains in nonword spelling (P4, with over 10% gains on both measures) had one of the weakest pre-intervention profiles (with six areas in the below average range). He was also the child who had significant difficulty with oral production of consonant blends, hence his gains in nonword spelling were likely due to his increased ability to verbally produce each sound. This informal analysis suggested no obvious relationship between pre-intervention profile and response to intervention. For example, of the two children with the strongest pre-

intervention profiles, one remained static (P2), and the other (P6) made a 5% gain in one of the nonword spelling measures; and the child with the weakest pre-intervention profile (P8), similar to P6 made a 5% gain in one of the measures. An additional observation of the responses on the nonword spelling measures showed that, for all participants, the pre-intervention phonemes omitted scores were higher than phonemes legally spelled, in other words, though participants were able to represent most phonemes (mean phonemes omitted = 14.5) they had more difficulty legally spelling phonemes (mean phonemes legally spelled = 71.6). This is consistent with the observation that most participants scored in the average range for phonemic awareness (hence they were able to identify each sound in an item), but had delays in orthographic knowledge (as has been demonstrated in the SSRD analysis of decoding accuracy).

Though Study 2 involved a small number of participants, the SSRD analysis of the influence of pre-intervention profiles of language, phonological processing, and intellectual skills on responses to intervention highlighted that a range of individual participant factors were involved. It suggests that this relationship is a complex one with no clearly predictive pre-intervention patterns, and further suggests that reading interventions for this population need to be specifically targeted to the individual needs of each child.

Conclusions

The results of the SSRD analyses discussed in this chapter augmented the group analyses presented in Chapter 6 by providing additional information about the individual patterns of response on the dependent variable, the extent of clinically significant gains on the standardised reading assessments, and the complex nature of the influence of the pre-intervention profiles on responses to intervention. While both the group and the SSRD analyses demonstrated highly significant gains on the dependent variables, the SSRD analyses revealed differences in the graphed responses (e.g., slope and variability) which provide insight into individual skill deficiencies which are likely to impact on response to intervention. In evaluating generalisation of nonword reading to other standardised measures of reading, the group analyses (which showed significant gains only on nonword reading efficiency and two measures of nonword reading accuracy) combined with examination of

clinically significant gains in the SSRD analysis suggested more extensive gains in decoding accuracy and trends for improved scores on measures of word reading. Finally, the SSRD examination of the predictors of response to intervention illuminated the individual variability that existed between the participants. A major limitation to this study is the small number of participants. Nevertheless, the outcomes of the group and SSRD analyses suggests that these children who required Tier 3 intervention made significant gains in nonword reading with trends for generalisation to word reading skills, and additionally, that they represent a diverse group in which the variables that impact on response to intervention may be specific to each child.

CHAPTER 8: DISCUSSION AND CONCLUSIONS

“The current emphasis on evidence-based instructional practices and materials is dependent on the development of a research base that goes beyond what works with most struggling readers to address instruction for students with persistent reading difficulties and disabilities who have not responded well to currently identified evidenced-based approaches. Doing “more of the same” in smaller groups or for a longer period of time will likely work for some students, but others will need a different approach to reading instruction, perhaps going beyond currently understood ‘best practices’.” (Denton et al., 2013, p. 645)

The programme of research discussed in this thesis designed, developed and evaluated the effectiveness of a reading intervention for children with persistent reading impairment, by investigating three research questions:

1. Does an intervention that targets phonological recoding and orthographic processing increase nonword reading skills in Year 2 children with persistent word reading impairment?
2. Does an intervention that targets phonological recoding and orthographic processing result in gains on standardized measures of a range of reading related skills (nonword reading accuracy, word and nonword reading efficiency, text reading, and reading comprehension) and spelling, in Year 2 children with persistent word reading impairment?
3. Do pre-intervention scores on language, intellectual, and phonological processing skills influence outcome measures of nonword reading, text reading, reading comprehension, and nonword spelling?

This chapter discusses the findings of this research within the context of theoretical models of reading and existing research reviewed in Chapters 1 and 2, by firstly reviewing the rationale. This is followed by a discussion of the outcomes of each stage of the research:

- Stage 1: Design of the Decoding Intervention
- Stage 2: Trial of the Decoding Intervention - Study 1

- Stage 3: Evaluation of the Decoding Intervention - Study 2 (which investigated the three research hypotheses and included additional analyses examining the research design)

Finally, the limitations, and future directions and overall conclusions will be considered.

Research Rationale

The literature review presented in this thesis identified word reading skills as a key aspect of early reading development. Consistent with the simple view of reading (Gough & Tunmer, 1986; Ouellette & Beers, 2010) and the evidence demonstrating the importance of early mastery of accurate word reading, that is, that it predicts later reading skill (Botting et al., 2006; García & Cain, 2014; Sparks et al., 2014) but is delayed in most children with reading impairment (Catts et al., 2003; Torppa et al., 2007), the intervention procedure developed for this thesis focused on word reading skills.

This was followed by a discussion of research investigating reading interventions which highlighted three issues. The first issue was that though interventions targeting phonemic awareness and the alphabetic principle combined with a range of other research validated skills (e.g., sight word development, text reading using decodable books, comprehension strategies) demonstrate significant positive results at Tier 1 (Department of Education, 2005; National Reading Panel, 2000) and Tier 2 (Gillon, 2000, 2002; Hempenstall, 2008; Ryder et al., 2008), a substantial number of nonresponders have been reported in studies investigating Tier 2 interventions (Buckingham et al., 2012; Hatcher et al., 2006; Wheldall & Beaman, 1999). Additionally, only a few studies have examined Tier 3 reading interventions, and these report similar levels of nonresponders (Denton et al., 2013; Torgesen, 2001). Hence the first goal of the research in this thesis was to investigate Tier 3 reading interventions.

The remaining issues relate to this consistent finding of a sizable number of children who fail to demonstrate an adequate response to reading interventions. In order to address this lack of response to intervention, further evidence regarding the individual profiles of children with persistent reading delay, and the impact of each intervention component on word reading skills is required, as this would allow

formulation of a specific mix of intervention components matching the individual needs of the child. To date, studies that have investigated predictor skills for successful response to Tier 3 reading interventions (Denton et al., 2013; Torgesen, 2001) have used group analyses. While these studies found that language skills (phonological processing and receptive language) were the most consistent predictors, it is possible that group analyses may fail to expose the nature of individual variation that has been reported in this group of children (Denton et al., 2013). Thus the second goal of the research in this thesis was to examine pre-intervention profiles of language, phonological processing, and intellectual skills using a research design (a single subject research design, SSRD) that would highlight individual characteristics that may contribute to the variability in responsiveness that has been reported in the literature.

The third issue was that most intervention studies (Buckingham et al., 2012; Denton et al., 2013; Lane et al., 2009; McCandliss et al., 2003; Pullen et al., 2005; Ritter et al., 2013) have involved a range of elements, which means that researchers have been unable to isolate which element was responsible for the reported gains. Without this knowledge, selection of intervention components to match a child's specific needs has not been possible. Therefore, to enable an unambiguous evaluation of the effect of an intervention on a range of reading measures, the third goal of this research was to develop a single component intervention (the Decoding Intervention), the design of which occurred in the first stage of this programme of research.

Stage 1: Design of the Decoding Intervention

The Decoding Intervention developed for this research was based on evidence regarding the goal, the strategy, and the structure. The goal (improving use of the grapheme-phoneme rules to decode words) is consistent with Ehri's theory of learning to read (Ehri, 2005). The participants in Study 1 and Study 2 were at the partial alphabetic phase: they had mastered knowledge of the names and sounds of letters but were unable to pay attention to all letters to decode words. Thus the Decoding Intervention aimed to teach skills to achieve mastery of the full alphabetic phase which supports expansion of the child's orthographic knowledge and progression to the consolidated phase of early word reading.

The strategy (targeting phonological recoding and orthographic processing) is supported by evidence demonstrating that phonological recoding plays a key role in the establishment of orthographic representations (Bowey & Muller, 2005; Cunningham et al., 2002; Kyte & Johnson, 2006; Nation et al., 2007; Share, 1995, 1999), and that orthographic processing plays a unique and significant role in the establishment of early reading skills (Badian, 2001; Cunningham et al., 2001) with its role increasing from Grades 1 to 3 (Deacon et al., 2012). Within the Decoding Intervention the strong focus on nonword reading is based on evidence that shows nonword reading to be a strong predictor of later reading outcomes (Good et al., 2008; Hudson et al., 2012) but that most children with reading disorders have delayed nonword reading skills (Castles & Coltheart, 1993b; Herrmann et al., 2006).

Finally, the structure of the Decoding Intervention (a) presented items without story context, as it has been shown that the effectiveness of phonological recoding in supporting orthographic learning is not influenced by context (Cunningham, 2006; Nation et al., 2007), (b) organised items according to orthotactic probability, consistent with evidence showing that children (typically developing and those at risk for reading delay) form MORs more efficiently with items of high orthotactic probability (Apel et al., 2006; Wolter & Apel, 2010), and (c) targeted items with 1:1 letter-sound correspondence as it has been shown that children of this age (seven to nine years) with word reading delays have not mastered accurate decoding of 3- and 4-letter words (McCandliss et al., 2003). The Decoding Intervention therefore matched the decoding skill level of the participants: a feature that was designed to optimise participant progress, as prior orthographic knowledge has been found to predict orthographic learning (Cunningham et al., 2002).

The iPad delivery of the Decoding Intervention provided a motivating activity for participants which was portable and enabled standardised presentation of intervention materials. The trial of this newly developed intervention in Study 1, as discussed in the next section, was consistent with the first phase of research that aims to evaluate new interventions (Beeson & Robey, 2006).

Stage 2: Trial of the Decoding Intervention - Study 1

The aims of Study 1 were to gather preliminary evidence about the three research questions and to trial the function and implementation procedures of the

Decoding Intervention. Three children in their third year of school (aged 7 – 8 years) who satisfied the selection criteria (typically developing with persistent reading delay despite previous reading intervention) participated in a single subject research design (SSRD) with three phases ($A^1 - B - A^2$).

The first research question investigated whether this single component intervention targeting phonological recoding and orthographic processing would increase nonword reading skills. The results of the SSRD analyses revealed that all participants demonstrated statistically significant gains in nonword reading on the dependent variable (researcher-developed Assessment NW Lists) which were maintained during the post-intervention baseline, and were not due to increased speed of motor response. The results of this direct replication across three participants suggested that the Decoding Intervention resulted in significant gains in use of grapheme-phoneme rules to decode unknown words (nonwords), a crucial factor for later reading success (Good et al., 2008; Hudson et al., 2012). However, it was possible that some of the demonstrated improvements in nonword reading may have been due to the extra individual time spent with each participant, hence the need for the second study (stage 3, discussed in the next section) undertaken in this programme of research.

The second research question for Study 1 aimed to gather preliminary evidence about (a) the impact of improved nonword reading on standardised assessments of a range of reading skills, and (b) the influence of pre-intervention language, intellectual, and phonological processing skills on the reading outcome measures. It was found that all participants made clinically significant gains on standardised measures of nonword reading accuracy in the targeted areas (VC, CVC, and Consonant Blends), and in a non-targeted area where prior orthographic knowledge had been demonstrated (Consonant Digraphs). This suggests that the Decoding Intervention was successful in teaching accurate phonological recoding (being able to sound out and blend) and orthographic processing (attending to the spelling constraints of English), but that these children had significant delays in orthographic knowledge, specifically, that they had not established orthographic knowledge of vowel digraphs. Delays in orthographic knowledge of vowel digraphs is consistent with the additional finding that the improved nonword reading skills following the Decoding Intervention did not result in clinically significant gains in measures of word and text reading skills, as those tasks require knowledge of vowel

digraph spelling patterns. Examination of the influence of pre-intervention profiles on the standardised reading outcome measures suggested that the main factor was the number of pre-intervention scores that were below average, that is, children with the greatest number of pre-intervention skills below average may demonstrate fewer clinically significant gains following intervention. However, due to the small number of participants in this study, the results regarding generalisation to standardised tests of reading and the influence of pre-intervention profiles on response to intervention were preliminary, as the main goal of Study 1 was to trial this newly developed intervention.

The final goal of Study 1 - trialling the Decoding Intervention materials and procedures, resulted in minor modifications to the screen display, the procedure, and the configuration of WordDriver. The screen was modified to reduce distraction (removal of dials that provided feedback about accuracy of response). Interestingly, it was the participant with significantly impaired processing speed and rapid naming who became distracted by this visual feedback. As this cognitive profile is likely to occur in many other children requiring Tier 3 reading intervention, it was decided to reduce this form of visual feedback, as it impacted on the timed tasks such as nonword reading rate – one of the dependent variable measures. Two procedures were modified: one to allow participants to generate their own sentence to demonstrate the meaning of words (instead of the researcher providing a scripted sentence) thus increasing saliency and engagement; and the second was a change in the role of the L-Plate from a demonstration of phonological recoding to one of specific teaching. Finally, the WordDriver configuration was modified to prevent the chance presentation of a series of words (for which the child may have an established orthographic representation), as this would result in the child progressing through the D-Plate with minimal use of grapheme-phoneme rules. This modification ensured that each participant (a) completed at least 20 trials (using phonological recoding to decode a novel item, i.e., a nonword) per session, and (b) was successful at decoding items across the full range of orthotactic probability values by the time they had reached the criterion (90% accuracy) at each level (2-, 3-, 4-, 5- and 6-letter levels).

The goals of Study 1 were therefore achieved. The Decoding Intervention was trialled on a small number of children, satisfying the requirements of the first phase in the evaluation of new interventions (Beeson & Robey, 2006). The preliminary results suggested that the intervention was effective in improving

nonword reading as measured by the dependent variable and standardised assessments. The minor modifications which were made within the first few sessions resulted in an intervention with improved functionality and increased engagement for participants, thus ready for evaluation in Study 2.

Stage 3: Evaluation of the Decoding Intervention - Study 2

The design of Study 2 provided systematic replication in the investigation of the Decoding Intervention – the second stage in the evaluation of clinical outcomes (Portney & Watkins, 2009), gathered evidence regarding the three research questions, and performed additional analyses to examine aspects regarding a number of design features in the Decoding Intervention. It employed a more complex SSRD compared to Study 1, allowing for statistical analyses at the group level as well as examination of individual response to intervention. After a brief discussion of the research design, this section discusses the results relating to the three research questions and the additional analyses.

Research design

A number of features were incorporated into the research design of Study 2 to respond to the limitations revealed in Study 1 and to increase the strength of the SSRD method. First, eight participants from three schools were involved, thus incorporating a larger number of children from different teaching environments. Second, the SSRD design ($A^1-B-A^2-C-A^3$) involved a comparison condition (Language Intervention) which did not include any reading material. This meant that there were two forms of control: the pre-treatment baseline phase (a feature of SSRDs) provided information about a “no treatment” or control condition for each participant, and the Language Intervention controlled for the effect of additional individual therapy time. Third, the eight participants were randomly assigned to one of two groups in a cross-over design: Group 1 completed $A^1-B-A^2-C-A^3$, and Group 2 completed $A^1-C-A^2-B-A^3$ (Figure 1, Chapter 6). This enabled a comparison of treatment versus no treatment, and an examination of maintenance over an extended follow up period. Finally, each of the baseline phases involved the same number of

sessions (eight), enabling use of statistical analyses to compare changes in performance between baseline measures.

These features resulted in an SSRD of the highest level of evidence (Logan et al., 2008; Tate et al., 2008), and represented a more controlled and robust design compared to the SSRD conducted by Pullen et al. (2005) – an SSRD with similar goals to Study 2, where all participants were from one school, there were only two phases (A-B), and they had fewer baseline measures (one to three). Additionally, the SSRD employed in Study 2 enabled statistical analyses of results at the group level, as well as individual analyses appropriate to SSRD, as discussed in the next section.

Question 1

The hypothesis relating to the first research question was that the Decoding Intervention would result in significant and positive effects on the ability to decode nonwords with 1:1 letter sound correspondence as measured by researcher-developed nonword lists. This was strongly supported by the group and individual analyses of the responses on the two measures (NW Rate and NW Total) of the dependent variable.

Using a GLMM (Generalised Linear Mixed Model), the group analyses revealed that the Decoding Intervention resulted in significant gains in both NW Rate and NW Total for both groups, with neither group demonstrating a significant change in either measure following the comparison Language Intervention condition. The results of the SSRD analyses (visual inspection of the graphed responses, 2SD band method, clinical observations, and an effect size calculation) also showed significant gains on both measures, and provided additional information about variability in participant response. Using the 2SD band method, all participants made significant gains in NW Total, and six of the eight in NW Rate. Examination of the graphed responses combined with the clinical observations highlighted variability in response patterns. While the pattern for four participants was characterised by a slow increase in accuracy and rate for the first six sessions followed by a steeper slope (signifying gradual mastery of phonological recoding), the remaining four produced variable patterns of response, such as day to day inconsistency (due to severe “b/d” confusion, and severely impaired rapid naming skills) and very slow increase in skill development (due to motor programming difficulties in articulation of consonant

blends). The effect size calculation quantified the results of visual inspection of the graphs, showing that the data for these participants (those with day-to-day variability, and the child with motor programming difficulties) demonstrated smaller effect sizes compared to the other participants.

Though other studies have targeted similar goals and used researcher-developed nonword lists as an outcome measure (Lane et al., 2009; Pullen et al., 2005), the findings of Study 2 are most appropriately compared to those of McCandliss et al. (2003) as it employed comparable research procedures: random assignment to intervention and control groups, an individual intervention targeting decoding (manipulative letters activity), and use of researcher-developed nonword lists combined with standardised word reading measures to evaluate effectiveness. Noteworthy differences between Study 2 and the McCandliss et al. (2003) study are that Study 2 used an SSRD design with group and individual analyses (compared to a group design), involved a single component intervention targeting items with 1:1 letter sound correspondence (compared to one using two tasks which included consonant and vowel digraphs), involved children with lower reading skills, and employed a more comprehensive measure of nonword reading (39 separate Assessment NW Lists compared to the same list of 128 words which were related to the intervention material). As the group analyses in both studies resulted in significant gains in nonword reading, it suggests that though the Decoding Intervention in Study 2 involved one component, it achieved the goal of significantly improving nonword reading for children with severe and persistent reading delay. The success of the Decoding Intervention lends support to the results of Pullen and Lane (2014) who found that of the three components in their multi-component reading intervention (specific decoding using manipulative letters, oral language, and support in use of decoding during book reading), the key ingredient was the activity focusing on word decoding, which was analogous to the single component used in the Decoding Intervention.

In addition to the group analyses, the results of the SSRD analyses in Study 2 provided insights into the variability in responses to intervention in this population, as there was a range of patterns in the graphed responses. Unlike the SSRD conducted by Pullen et al. (2005), which concluded that the decoding skill (measured by NW Rate) gradually emerged for all nine participants, in Study 2 half of the participants produced varying patterns. This difference in outcomes may be due to

the timing of the administration of the dependent variable. In Study 2 the dependent variable was administered prior to, rather than after therapy as was done in the Pullen et al. (2005) study. Therefore, the Study 2 measures may represent a truer assessment of skill mastery (and variability) as they were not influenced by the practice afforded by the therapy immediately prior. Secondly, the Study 2 participants were more impaired than those in the Pullen et al. (2005) study: Study 2 involved students requiring Tier 3 intervention whose scores on standardised tests of nonword reading were on average below the 4th percentile compared to the participants in the Pullen et al. (2005) study who required Tier 2 intervention and scored below the 20th percentile on a nonword spelling test. The final insight into the variability that was revealed in the Study 2 SSRD analyses was that while all participants made significant gains in NW Total, two did not reach significance for NW Rate. This indicates that one quarter of the Study 2 participants did not make significant gains in nonword reading fluency, a result that is consistent with other Tier 3 studies that have demonstrated reading fluency to be more resistant to intervention (Denton et al., 2013; Torgesen, 2001).

One final issue when discussing the significance of the gains made by the participants in Study 2 is the nature of the target items. Other studies with a similar specific focus on decoding (McCandliss et al., 2003; Pullen & Lane, 2014; Pullen et al., 2005) trained participants using items that included consonant and vowel digraphs. In response to research demonstrating the strong predictive value of nonword decoding (Hudson et al., 2012; Johnston, McGeown, & Moxon, 2014), and that children who are failing to master early reading skills are unable to successfully decode 3- and 4-letter words (McCandliss et al., 2003), items with 1:1 letter sound correspondence were targeted in the Decoding Intervention, as this enabled delivery of an intervention that matched the skill level of these children who had already failed to respond to previous reading interventions.

In summary, the analyses of the two measures of dependent variable in Study 2 indicated that, though there was variability in pattern of response, the first hypothesis was supported. The Study 2 participants demonstrated significant gains in nonword reading as measured by researcher-developed nonword lists. It suggested that all participants had mastered a key foundation skill (phonological recoding) enabling efficient use of the non-lexical route (Coltheart, 2006) and transition from the partial alphabetic to the full alphabetic stage of reading (Ehri, 2005): a

requirement for emergence to the consolidated phase which supports development of a large bank of established sight words.

Question 2

The hypothesis addressing the second research question was that the Decoding Intervention would result in gains in some of the reading related skills as measured by standardised assessments of nonword reading accuracy, word and nonword reading efficiency, text reading and comprehension, and a detailed assessment of nonword spelling. The results of the group and individual analyses partially supported this hypothesis.

The group analyses revealed that the Decoding Intervention resulted in significant gains in standardised measures of nonword reading efficiency and accuracy, but no significant gains on the standardised assessments of word reading efficiency, text reading accuracy, reading comprehension, nor the number of phonemes omitted or legally spelled in nonword spelling. The SSRD analyses provided additional detailed information about the nature of the gains in all areas - nonword reading accuracy, nonword reading fluency, word and text reading skills, and spelling.

First, with respect to nonword reading accuracy, the results of the SSRD analysis indicated that following the Decoding Intervention, all participants made clinically significant gains in at least one of the three targeted areas, with six of the eight participants making gains in two or three targeted areas. Additionally, 14 of the 16 clinically significant gains represented movement from below average to scores in the average range. This indicates that all participants demonstrated clinically significant gains in mastery of the process of phonological recoding. While six of the eight participants generalised to a non-targeted area (items with consonant digraphs), no generalisation to vowel digraphs was demonstrated: a result that was likely due to lack of pre-intervention orthographic pattern knowledge for vowel digraphs. Second, the SSRD analyses of nonword reading fluency reflected the group analyses by revealing that four participants made clinically significant gains on standard score results, and for six participants there was greater than an 85% probability that gains in raw scores were due to the intervention. This result suggests that a degree of generalisation may have occurred, as the nonword reading fluency assessment

included items that contained consonant and vowel digraphs. Third, while the group analyses revealed no significant gains in word reading fluency or text reading accuracy and comprehension, the SSRD analyses suggested trends for improved skills: there was greater than an 85% probability that the raw score gains on word reading fluency for four participants were due to the intervention, and half the participants demonstrated trends for improved scores on text reading accuracy and comprehension as measured by changes in percentile rank descriptors and the a priori learning criterion. Finally, though the results of the group and SSRD analyses of spelling showed minimal changes in nonword spelling skills, examination of individual responses highlighted gains in nonword spelling for some children, particularly in the ability to include a greater number of phonemes in spelling responses. However, overall, these results were consistent with previous studies which have found spelling to be less responsive than word reading measures to reading interventions (Buckingham et al., 2012).

The results of Study 2 may be considered within the context of two studies that had similar goals and involved children in the same age range - McCandliss et al. (2003) and Pullen & Lane (2014). Though these studies are both Tier 2 interventions, they comprised fewer components (compared to many other Tier 2 and Tier 3 studies), and used similar reading outcome measures. Pullen and Lane (2014) examined the active ingredient in a two-component intervention (decoding and book reading) that targeted sight word development and decoding of 3-letter items with 1:1 letter sound correspondence. Similar to Study 2, participants demonstrated significant gains on a standardised measure of nonword reading accuracy. However, though significant gains were demonstrated on researcher-developed measures of sight words (irregular words) and 3-letter word reading, no standardised measure of word reading was used. Hence it was not possible to determine whether their decoding intervention (which was found to be the active ingredient) resulted in gains on standardised measures of word reading. The McCandliss et al. (2003) study also investigated a two-component intervention (decoding and sentence reading components), but included a standardised outcome measure. Similar to Study 2, the results demonstrated significant gains on researcher-developed nonword lists and a standardised measure of nonword reading, but no significant gains on a standardised measure of word reading. While the lack of gains in word reading may have been due to the nature of the word reading test (i.e., that the test items contained irregular

words which were not targeted in the intervention), as discussed in Chapter 6, it was also possible that the participants in this study failed to develop sufficient orthographic knowledge to support generalisation to word reading, that is, as the target items were real words, participants may have developed sight words for the items and therefore not benefited from the decoding activity to teach orthographic knowledge.

To illustrate this point, the assessments used in Study 2 provided data which lend support to this explanation, that is, that delays in orthographic knowledge of vowel digraphs may have prevented generalisation of increased decoding skill to standardised measures of word reading. One of the outcome measures in Study 2 involved a detailed pre- post-intervention assessment of nonword reading accuracy using a standardised test – the PhAT-2 (Robertson & Salter, 2007). This test comprises eight subtests, thus assessing the orthographic knowledge that is required to decode a range of word forms: VC, CVC, Consonant Blends, Consonant Digraphs, R-Vowels, CVCe, and Vowel Diphthongs. The SSRD analysis of clinically significant gains and examination of the error patterns on this test revealed that prior to intervention all participants had mastered orthographic knowledge of consonants, short vowels, and consonant digraphs, but no participant demonstrated orthographic knowledge of vowel spelling patterns. For example, prior to intervention *faim* was often pronounced as /fam/, *sead* as /sad/; and following intervention (once the process of phonological recoding had been mastered), attempts at these items revealed mastery of phonological recoding but lack of orthographic knowledge - *faim* was recoded as /f-a-i-m, fam/ and *sead* as /s-e-a-d, sad/, and so on. Therefore, the increased skill in use of phonological recoding following the Decoding Intervention did not translate to accurate decoding of items with vowel digraphs.

This discussion suggests that one likely explanation for the lack of generalisation to standardised measures of word reading in Study 2, and possibly the McCandliss et al. (2003) study, was related to delays in orthographic knowledge, particularly for vowel digraphs. Within the paradigm of Ehri's phase model (Ehri, 2005), children in the early stages of learning to read (full alphabetic phase) need to have knowledge of the grapheme-phoneme rules for at least the common spelling patterns in order to perform accurate phonological recoding of an item. In the case of a word, after a few exposures this results in the formation of MORs (Share, 1995), which, according to connectionist theories of word reading (Plaut, 2005), allows

links between existing phonological and semantic representations to form a sight word. Thus, a delay in orthographic knowledge for vowel digraphs prevents the first stage in this process - formation of accurate MORs.

There are three other reasons that may explain the limited gains on standardised measures of word reading in Study 2. The first relates to the nature of the standardised measure of word reading – the Test of Word Reading Efficiency-2 (Torgesen et al., 2012), which is a timed test. It is possible that an untimed test may have revealed gains in word reading for these participants, particularly as the results of the SSRD analyses suggested trends for gains on this test (i.e., a greater than an 85% probability that the increased raw scores for four participants was due to the intervention). When this is combined with the results of the 2SD band analyses of the graphed responses on the dependent variable (showing that two participants failed to make significant gains in rate of nonword reading), it suggests that similar to other studies (Buckingham et al., 2012; Denton et al., 2013; Torgesen, 2001), word reading fluency is an area that is resistant to remediation: a factor that may have influenced outcomes on a timed measure of word reading.

A second possible explanation for the lack of significant gains in word reading scores relates to the amount of time it may take for improved decoding skills to generalise to word reading. Consistent with connectionist theories (Plaut, 2005; Seidenberg & McClelland, 1989), it has been shown that nonword reading and orthographic processing are stronger predictors of word reading (regular and irregular) than measures of vocabulary knowledge (Johnston et al., 2014; Wang et al., 2013). This suggests that the gains in nonword reading following the Decoding Intervention should generalise to improved word reading skills. However, it has been demonstrated (Apel et al., 2012; Wolter & Apel, 2010) that children at risk of literacy delay (those with language impairment or from low socio-economic groups) are less efficient at developing MORs. This implies that the Study 2 participants, though making significant gains in phonological recoding (a skill that supports orthographic learning), may also have impairments and/or inefficiencies in the ability to form MORs. Hence, it may take longer for improved nonword reading skills to be reflected in gains on measures of word reading skills for this population, that is, providing intervention over a longer period of time, or increasing the amount of time devoted to the Decoding Intervention within each session.

A final possible reason for the limited gains in word reading scores in Study 2 relates to the goals and methodology of this programme of research. Study 2 aimed to investigate a single component intervention as this would enable an unambiguous evaluation of the impact of the Decoding Intervention and provide evidence about a specific component which is often included in many multi-component reading interventions. As such, participants did not receive any extra support to apply decoding strategies (phonological recoding) during classroom text reading activities. It is possible that the additional strategy of supporting use of accurate phonological recoding during text reading may have enhanced generalisation to word reading skills. Nevertheless, this combination (decoding plus text reading) was used in two previous studies (Lane et al., 2009; Pullen & Lane, 2014), both of which concluded that the decoding activity was the key component.

This discussion reveals that the hypothesis addressing the second research question was partially supported. The results of the group and SSRD analyses revealed that the Decoding Intervention resulted in significant gains on measures of nonword reading for all participants, while the SSRD analyses highlighting trends for improved word reading efficiency, text reading, and reading comprehension. Drawing on research that (a) identified specific decoding activities as the active ingredient in multi-component reading interventions (Lane et al., 2009; Pullen & Lane, 2014), and (b) concluded that children with persistent reading impairment may require a different approach, that is, they may not benefit from more intensive Tier 2 interventions (Denton et al., 2013), these results suggest that the single component Decoding Intervention may be an effective component within reading interventions for this population of children. The Decoding Intervention was successful in teaching a skill (phonological recoding) which has been shown to be a requirement for efficient development of MORs – a central aspect in the development of word reading skills. Possible reasons for the lack of generalisation to word and text reading skills (i.e., delays in orthographic knowledge and MOR formation, use of a timed reading measure, and the focus on a single component intervention) were suggested, and will be further discussed when outlining future directions.

Question 3

The hypothesis in relation to the third research question was that participant response to intervention would be influenced by pre-intervention language and phonological processing skills. This was based on previous research (Denton et al., 2013; Nelson, Benner, & Gonzalez, 2003; Torgesen, 2001) that employed statistical analyses of group data to determine predictors of response to intervention. Of the pre-intervention measures used in Study 2, the results of these studies suggested that measures of phonological processing (specifically rapid naming and phonological awareness) and receptive language were more strongly related to treatment effectiveness than measures of intellectual skills. Due to the risk of Type 1 and Type 2 errors in the statistical analyses of group data in Study 2 (with a small number of participants and large number of measures), an SSRD analysis (which compared the number of below average pre-intervention scores with the magnitude of gain) was used to examine the third research question. The results suggested a complex relationship between pre-intervention language, intellectual, and phonological processing skills and response to intervention.

Firstly, contrary to the preliminary conclusions in Study 1, the SSRD analysis in Study 2 suggested that overall severity of pre-intervention profile (as measured by the number of below average language, intellectual, and phonological processing areas) may not predict response to intervention. For example, the three participants with the smallest effect size on the dependent variable included the two children with the strongest and the child with the weakest pre-intervention profiles. Closer examination using clinical observation and visual inspection of graphs, revealed that these results were due to individual factors, for example, severe “b/d” confusion and slow decoding style (in the contradictory presence of above averages scores on measures of processing speed and average score for rapid naming).

Secondly, specific weaknesses in receptive language did not seem to predict participant gains on the dependent variable nor on the standardised assessments. The only child with a receptive language score in the average range (seven of the eight participants scored below average) demonstrated the second lowest effect size on the dependent variable (NW Total), and made the second lowest number of clinically significant gains on the standardised assessments. Conversely, the child with the lowest receptive language score achieved the third highest effect size on the

dependent variable (NW Total), and, along with another child, the second highest number of clinically significant gains.

Third, when considering the influence of phonological processing skills on response to intervention, six of the eight participants scored in the average range for phonological awareness and rapid naming, but all participants were in the below average range for phonological memory. Hence, there was no clear pattern that phonological awareness and rapid naming were factors that influenced response to intervention.

In summary, the results of this SSRD analyses did not support the third hypothesis – that pre-intervention phonological awareness and language skills would influence response to intervention. Though Study 2 involved a small number of participants, these results suggested that children with persistent reading delay present with individual and complex needs: a factor that may explain the variability in responsiveness that has been reported in previous studies (Denton et al., 2013; Torgesen, 2001). It suggests that interventions for this population may need to be targeted to the specific needs of each child, and focus on key areas that have been shown to be the active ingredient in reading interventions.

Additional analyses

Three additional analyses were completed to examine various aspects relating to the design of the newly developed Decoding Intervention. These included the Decoding Error Pattern analysis, the Orthotactic-Phonotactic Decoding Accuracy analysis, and the Mean Intervention Time analysis.

The Decoding Error Pattern analysis aimed to justify use of items with 1:1 letter-sound correspondence in the Decoding Intervention, and to replicate the results of McCandliss et al. (2003) who found that children with reading delay (aged 7 – 10 years) had not mastered decoding of 3- and 4-letter nonwords. The responses on the pre-intervention Assessment NW Lists were scored for decoding accuracy at each letter position and analysed at the group level. The results indicated that when decoding 3-letter items, the Study 2 participants demonstrated greater accuracy on the first letter, followed by the final letter and then the vowel. For items with consonant blends, the second letter of an initial blend and the first of the final blend were least accurate. These results were consistent with those of McCandliss et al.

(2003) and indicated that the Study 2 participants were at the partial alphabetic phase of reading (Ehri, 2005), that is, they had not mastered accurate phonological recoding of items with 1:1 letter sound correspondence. Based on research (Hudson et al., 2012) that has demonstrated that automaticity in sub-lexical skills (such as decoding fluency) predicts text reading fluency, and that children need to “become automatic in oral blending of sounds, individual letter sounds, and larger letter patterns in order to be successful decoders” (Hudson et al., 2012, p. 501), it suggests that the goal of establishing accurate decoding of items with 1:1 letter sound correspondence was an appropriate target for the Study 2 participants, particularly as these students remained deficient in this skill despite previous reading interventions.

The second additional analysis, the Orthotactic-Phonotactic Decoding Accuracy analysis, was a preliminary investigation examining whether use of orthotactic probability in the organisation of the items in the Decoding Intervention was beneficial. In all Decoding Intervention modules participants were initially presented with items of high orthotactic probability (easier items), leading to items with low orthotactic probability (harder items). This design feature was based on evidence that formation of MORs in the early stages of reading acquisition (for typically developing and those at risk of reading delay) is more efficient with items of high orthotactic probability (Apel, 2009, 2010; Apel et al., 2012). This analysis examined responses, at the group level, on the pre-intervention Assessment NW Lists to determine if accuracy was higher on items with high orthotactic probability. The results suggested a trend, which was more pronounced for 3-letter compared to 4-letter items, for higher accuracy on items with high orthotactic probability. These results provided preliminary evidence suggesting that the organisation of items using orthotactic probability was successful in presenting participants with a progression from easier to harder items in the early stages of their mastery of phonological recoding, that is, at the 3-letter level. Additionally, it was a key aspect in the programming of the D-Plate, where the PEST procedure was employed to automatically present easier or harder items in response to decoding accuracy.

The third additional analysis, the Mean Intervention Time analysis, aimed to examine the efficiency of the Decoding Intervention. It compared the time taken to complete the Decoding Intervention with analogous decoding tasks that were described in other multi-component interventions (Buckingham et al., 2012; Denton et al., 2013; Lane et al., 2009; McCandliss et al., 2003; Pullen et al., 2005; Ryder et

al., 2008; Torgesen, 2001). The results indicated that the mean intervention time of the specific decoding tasks in the Decoding Intervention: a mean of seven minutes within each 20 minute session (two hours in total) was substantially shorter than most of the multi-component interventions (e.g., 30 minutes per session, 10 hours in total for those studies with similar goals to Study 2). The computerised nature of the iPad-delivered material in Study 2 is likely to be a contributing factor to the economy of time, as the tasks were immediately available at the level required for an individual child.

These three additional analyses provided data that supported design aspects of the Decoding Intervention. The results indicated that the intervention target (items with 1:1 letter-sound correspondence) was appropriate to the skill level of participants, thus optimising an outcome where each child would demonstrate a significant response to intervention. Secondly, the preliminary evidence that was gained regarding use of orthotactic probability in the organisation of items within each module of the Decoding Intervention suggested that this feature was successful in delivering items based on ease of decoding. Finally, the efficiency of the Decoding Intervention was demonstrated: a feature that may be of considerable value when designing interventions for children who require intense and targeted interventions.

Limitations

The research presented in this thesis has a number of limitations. The first limitation relates to the measures of word reading that were employed. Firstly, a timed measure (word reading efficiency) was used to evaluate changes in word reading skills. This may have been less sensitive to gains in word reading, particularly as word and text reading fluency have been shown to be resistant to intervention (Buckingham et al., 2012; Torgesen, 2001). Secondly, inclusion of word reading measures that comprised separate assessments of regular and irregular word reading would have enabled categorisation into subtypes of word reading disability according to the dual-route model (Coltheart, 2005). This type of data may have been useful when examining reasons for differential responses to intervention.

The second limitation was that it may have been useful to have systematically gathered information regarding the type of previous reading interventions. Recent research (McGeown & Medford, 2014) has suggested that method of reading

instruction (e.g., a focus on phonemic awareness and alphabet knowledge versus a method that teaches whole word reading strategies, or use of context to predict words) may influence children's reading strategies, and therefore the cognitive and reading related skills that predict word reading development. McGeown and Medford (2014) conducted a longitudinal study to examine predictor skills for word reading development involving children who received initial reading instruction focusing on phonological recoding. They found that letter-sound knowledge, short term memory span, and phoneme awareness were the strongest predictors of early word reading, with vocabulary not reaching significance as a predictor of word reading. However, the outcomes of previous research (Wagner et al., 1997) with a similar research design involving children who had been taught with a language-based approach, found that the predictors of reading outcome for participants included measures of phonological awareness and language. These results are consistent with the proposition that if initial reading instruction focuses on use of language skills (e.g., teaching children to use context cues to support word reading) rather than decoding, the predictors of word reading may more likely be pre-intervention measures of language skills. Therefore, inclusion of information about method of previous reading intervention may provide valuable insights into the effectiveness of the Decoding Intervention for different groups of children.

A third limitation was that the researcher developed and investigated the effectiveness of the Decoding Intervention, so a number of strategies were employed to limit the risk of researcher bias. Firstly, the research design in Study 1 and Study 2 incorporated use of an independent speech pathologist (blind to the goals of the research and not familiar with the participants) to perform the administration of all post-intervention standardised assessments. Second, sound recordings were made of all verbal responses on the dependent variables, thus allowing for independent verification of data analyses. Third, all scoring procedures (e.g., calculation of standard scores) were cross-checked by a colleague. Nevertheless, future studies should involve independent researchers.

A final limitation to the research in this thesis relates to the research design. Use of a SSRD with small numbers, while appropriate to the goals of the current research, does not provide data which supports more conclusive evidence regarding the effectiveness of the Decoding Intervention on the development of word reading skills for this population. Though the research design permitted some positive

features (such as use of complete standardised assessments of language, intellectual, and phonological processing skills, and individual examination of participant response to intervention), larger scale studies are required to gather evidence at the next level of investigation of clinical outcomes – clinical replication, where the intervention is field tested in a range of clinical settings.

Future Directions

The preceding discussion about the results of each of the research stages in this thesis points to a number of directions for further research. These include adjustments to the intervention materials, variations in the research design, and exploration of hypotheses generated from this research.

In regard to the intervention materials, the first, and most important, is an extension of the targets to include consonant and vowel digraphs. Consistent with Ehri's phase model (Ehri, 2005), and the evidence depicting the developmental progression of skills contributing to reading fluency (Hudson et al., 2012), children with persistent reading impairment need to progress from mastery of accurate phonological recoding of items with 1:1 letter-sound correspondence to items that include larger units (e.g., rimes, syllables, morphemes and whole words). Additionally, the phonological recoding theory (Share, 1995) proposes that mastery of accurate phonological recoding for items with 1:1 letter-sound correspondence is sufficient to kick start the self-teaching mechanism which allows orthographic knowledge to become increasingly lexicalised. However, in this population of children who have not mastered orthographic knowledge of larger units despite previous reading intervention, perhaps due to their decreased ability to form MORs as demonstrated in previous studies (Apel et al., 2012; Wolter & Apel, 2010), specific teaching of vowel digraphs may be necessary. Use of the phonological recoding strategy employed in the Decoding Intervention to expand orthographic knowledge is supported by research (Johnston et al., 2014) demonstrating that irregular word reading was better predicted by nonword reading and orthographic processing than measures of vocabulary and reading frequency. These results suggest that the Decoding Intervention, which teaches use of phonological recoding to decode unfamiliar words (nonwords) has the potential to facilitate growth of orthographic knowledge to include vowel digraphs. Future studies would therefore

extend the Decoding Intervention to include more levels that target, in a systematic manner, firstly consonant and vowel digraphs, and later, larger units of syllables and morphemes.

The second consideration in the design of the intervention materials for future studies relates to the Assessment NW Lists and Assessment NW Spelling Lists. First, the number of items in the Assessment NW Lists (the dependent variable) could be decreased. These were constructed to ensure that participants would not be able to read all items in less than one minute (as NW Rate measures the number of correct responses in one minute). Though researcher pilot testing revealed that 70 items were required for a competent reader, the results of Study 1 and Study 2 indicated that no participant read more than 20 items in one minute. Therefore, future studies could involve shorter Assessment NW Lists. Second, very rare spelling patterns could be avoided, and morphological complexity could be controlled. For example, the structure of the lists could start with single morpheme items progressing to items with more than one morpheme.

The third factor which would be considered in future studies is the inclusion of additional reading and spelling measures. These would include an untimed standardised word reading measure, a test that separately examines accuracy of regular and irregular word reading - thus examining the two processes described in the dual-route model (Coltheart, 2006), and a measure of real word spelling. These outcome measures would provide information about (a) the nature of the word reading impairment prior to intervention, (b) the effectiveness of the Decoding Intervention on word reading accuracy (as opposed to word reading efficiency as was measured in Study 1 and Study 2), (c) the impact of the Decoding Intervention on regular and irregular word reading, thus determining whether increased phonological recoding of vowel digraphs had a differential impact on regular versus irregular word reading, and (d) the influence of any gains in orthographic knowledge and MOR development on spelling and morphological knowledge.

There are a number of adjustments to the research design that could be considered in future studies investigating the Decoding Intervention. Firstly, future studies with a larger number of participants would increase the strength of evidence regarding the effectiveness of the Decoding Intervention. Larger group designs mean that individual analyses using an SSRD, as was done in Study 1 and Study 2, may not be feasible. However, the main conclusion regarding response to intervention

following the SSRD analyses in Study 2 was that children with persistent word reading delay present with differing pre-intervention profiles of language, intellectual, and phonological processing skills. Nevertheless, each of the participants in Study 1 and Study 2 demonstrated significant gains in the targeted skills regardless of their pre-intervention profile. This suggests that the Decoding Intervention procedure (which matches intervention targets to the skill level of the child, and each child's progression through the materials is dependent on their success at reaching criterion on each level) may result in significant gains for all children in future group design studies.

Secondly, future studies should involve different people delivering the Decoding Intervention. This would include other speech pathologists, teachers, and integration aides. As the Decoding Intervention is computer-supported (delivered as an iPad web app), standardised delivery is possible along with automatic recording of response accuracy. Further developments to the iPad app could also allow independent over-the-web delivery. In this scenario, students who live in remote locations may be able to access the app and, with guidance from a clinician, complete the Decoding Intervention at a level that matches their intervention needs.

Thirdly, an examination of dose rate needs to be considered. Study 2 targeted a key foundation skill for word reading (phonological recoding) demonstrating significant gains following a mean of seven minutes per session over 15 sessions. Future studies could investigate (a) the impact of shorter Assessment NW Lists which would allow for more time spent on the decoding modules (L-, P-, and D-Plates), and (b) the time required to master each phase of word reading development: phonological recoding (targeted in Study 2), orthographic knowledge for consonant digraphs, followed by orthographic knowledge of each of the vowel spelling patterns.

The last factor related to research design, is that future studies should consider ways to document the teaching methods that have been used prior to intervention. The possibility that the nature of a child's previous reading intervention may influence their response to the Decoding Intervention suggests that including information about previous reading interventions may add to the research base regarding selection of the Decoding Intervention for particular groups of children.

A final issue for future development of the Decoding Intervention regards consideration of its role within reading interventions for children with persistent reading delay. It has been proposed (Compton, Miller, Elleman, & Steacy, 2014) that

interventions focusing on context-independent methods via a self-teaching process (as is used in the Decoding Intervention) fail to promote the inductive learning mechanisms that occur in typical reading development. However, based on the evidence presented in the literature review and the results of Study 2, the proposition in this thesis is that children with persistent reading impairment have not demonstrated efficient use of inductive mechanisms to gain the orthographic knowledge that is required for development of word reading skills; and furthermore, that focused teaching of key skills (phonological recoding and orthographic processing) as part of a reading intervention has the potential to boost word reading skills. Consistent with the conclusions of Denton et al. (2013), the evidence in this thesis suggests that some children may demonstrate stronger responses to intervention when specific skills are targeted using a focused and intense approach.

Conclusions

This programme of research aimed to add to the evidence-base for Tier 3 reading interventions by addressing the three issues that were highlighted in the literature review: few studies have examined Tier 3 reading interventions, a large proportion of children demonstrate an inadequate response to intervention, and to date, there has not been an evidence base regarding the specific role of each component in multi-component interventions. The outcomes of this research augment the existing evidence-base in a number of areas.

Firstly, a single component Tier 3 reading intervention (the Decoding Intervention) was developed enabling an unambiguous examination of its impact on a range of reading and spelling skill areas. It focused on developing key skills (phonological recoding and orthographic processing) for word reading, as word reading predicts later reading success but is deficient in most children with reading delay. The notable features of the Decoding Intervention are that it delivers efficient (seven minutes per session), explicit, and intense instruction, with automatic recording of response time and calculation of percentage accuracy of response. It is designed to match the decoding skill of each participant, and, as it is delivered on an iPad, it is portable, replicable, and motivating for children.

Secondly, the evaluation of the Decoding Intervention found that it resulted in significant gains in nonword reading skills for all participants. Thus, all

participants demonstrated an adequate response to intervention, indicating that it was successful in establishing accurate phonological recoding: a skill that supports further development of orthographic knowledge. This suggests that the Decoding Intervention, following further investigation, has the potential to be a valuable contribution to reading interventions for this population of children.

The third contribution was the manner in which the SSRD was used to, (a) perform systematic replication, and (b) explore factors that may contribute to a lack of response to intervention, that is, the influence of participant pre-intervention profiles of language, phonological processing, and intellectual skills on response to intervention. In performing the systematic replication, the SSRD employed in this research was consistent with the highest level of evidence in SSRDs (random assignment to an alternating-treatment crossed design, replication across more than three participants, use of an equal number of data points in each baseline that was greater than the minimum of three, and a blind assessor for post-intervention outcome measures). In the examination of the influence of pre-intervention profiles on response to intervention, the SSRD enabled administration of complete assessments, instead of selected subtests (which is usually the case in larger group designs). Though this research involved small numbers, the close examination of participant profiles highlighted three areas of insight. Firstly, it suggested that children with persistent reading disorders present with a complex mix of language, phonological processing, and intellectual skills, possibly explaining the variable responsiveness that has been reported in the literature. Secondly, as all participants demonstrated an adequate response to intervention in both Study 1 and Study 2 regardless of pre-intervention profile, it suggested that the targeted and specific nature of the Decoding Intervention may result in adequate responses to intervention in other children requiring Tier 3 intervention. Third, examination of individual pre-intervention decoding skill revealed that the lack of generalisation to measures of word reading was likely due to severe delays in orthographic knowledge, specifically for vowel digraphs.

In conclusion, the outcomes of the research in this thesis suggest that the Decoding Intervention has the potential to be an efficient evidence-based component of reading interventions for children with severe and persistent reading delay. Additionally, it highlights the need for further investigation incorporating targets to extend orthographic knowledge and delivered within clinical settings.

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APPENDIX A: N-WATCH EMAIL CORRESPONDENCE**Email to Colin Davis 20th October 2011**

Dear Colin,

I am a PhD student, supervised by Dr Suze Leitao and Dr Mara Blossfelds at Curtin University, <http://www.curtin.edu.au/>

I've been recommended N-Watch by colleagues at Macquarie University, and really appreciate your efforts in making this great tool. However, we believe we've uncovered some errors, and would like your comments.

My research is an intervention study targeting orthographic processing in children with word identification impairment. I am designing and evaluating a computer delivered intervention that will use thousands of single syllable real and nonwords that have 1:1 letter sound correspondence. I'm a speech pathologist and am fortunate to have the support of my husband Rob, a computer programmer, in the design of the computer delivered materials. We have a background of working together to produce computer programs for speech pathologists, www.elr.com.au.

Rob is writing Perl scripts to rank my real and nonwords according to orthotactic as well as phonotactic probabilities. I'm using N-Watch to produce the probability lists for real words, but as N-Watch doesn't produce phonotactic probabilities for nonwords, we are planning to use the output from the ARC nonword database and analyse that using the rules and frequency tables of N-Watch. Rob is using several files from your N-Watch package (eg bf3.txt, and bpf3.txt) as "lookup" tables for these scripts. In testing these scripts he is comparing various outputs with those produced by neighbourhoodwatch.exe, and we have found inconsistencies with some of the N-Watch outputs.

The first inconsistency relates to the N-Watch CV_P (phonological structure) reporting of the /u/ sound (as in "bug"). In words such as "tub, bug, won, ton, one", the CV_P is reported as CCC (sic). The CV_O values (orthographic structure) are

correct, eg "tub" CVC, "won" CVC, "one" VCV, "ton" CVC. This error with the CV_P reporting of the /u/ sound also occurs in all 4 letter words (eg "bust" CCCC, "bunk" CCCC), and some of the multi-syllabic words we looked at, eg "button" CCCC, "butter" CCCVC, compared with "better" which was correct, CVCVC (if the /r/ final is pronounced).

The second inconsistency is to do with the rule for computing the biphone mean frequencies (for type and token: BPF_TP, and BPF_TK). There is no worked example in the N-Watch article (Davis, 2005), so we assumed that it would follow the same pattern as for bigram mean frequency, ie extract all biphones, look up each one in turn in the relevant position (in the appropriate bpf file), sum these values and divide by the number of biphones in that letter string. Here are some detailed examples of what we have found.

3 letter real words (single syllable with 1:1 letter sound correspondence):

For bigram frequencies, BF_TP (bigram frequency mean type), and BF_TK (bigram frequency mean token): The rule we used is as described in your article, and matches N-Watch output values for all 3 letter real words we tried.

- For example "cat"
- Using BF3.txt, "ca" in the 1st position was 8 for type, 2442.96 for token. "at" in the second position was 13 for type, 597.13 for token.
- Summing and dividing by 2 gives a BF_TP of 10.5 (21/2), and BF_TK of 1520.04 (3040.9/2). Both match the N-Watch values

We repeated this on about 300 three letter words, and the results were identical to N-Watch.

We then applied this rule to get BPF_TP (biphone frequency mean type), and BPF_TK (biphone frequency mean token)

- Continuing with the example "cat". Using DISC.PRON /k{t/, and the bpf3.txt file
- the biphone frequency for k{ in the first position is 9 for type, and 2290.72 for token
- the biphone frequency for {t in the second position is 14 for type and 12620.98 for token

- Summing and dividing by 2 gives a BPF_TP of 11.5 ($23/2$), and a BPF_TK of 7455.85 ($14911.70/2$). Both of these values also match N-Watch.

We repeated this with hundreds of 3 letter real words that had a CV_P pattern of CVC or CCC with the /u/ sound, and they matched N-Watch.

But, for all of the 3 letter real words that had a CV_P pattern of VCC (eg elk, elf, apt), or CCV (dry, fro, ply, ski), our value did not match N-Watch. However, we found that if we calculated those words using only the 1st biphone and dividing that by 2, most matched N-Watch.

- For example, with "apt", DISC.PRON /{pt/ and bpf3.txt
- the biphone frequency for {p in the first position is 3 for type, and 39.67 for token
- dividing these by 2, we get 1.5 for BPF_TP, and 19.83 for BPF_TK. These match N-Watch values

4 letter real words (single syllable with 1:1 letter sound correspondence):

We used the same rule to calculate BF_TP (bigram frequency mean type), and BF_TK (bigram frequency mean token). For about 320 words, our value matched the N-Watch values.

But using the analogous rule to calculate BPF_TP and BPF_TK (splitting on phoneme pairs, and using the BPF4.txt file), none matched N-Watch values. However, if we just used the 1st biphone and the next VC biphone the outcomes do match N-Watch values (eg "dent" 1st and 2nd biphones, "drab" 1st and 3rd biphones)

- For example "dent", DISC.PRON /dEnt/
- the biphone frequency for dE in the first position is 16 for type, 208.44 for token
- the biphone frequency for En in the second position is 43 for type, and 3089.17 for token
- Summing these and dividing by 3, the BPF_TP is 19.67 ($59/3$), and the BPF_TK is 1099.2 ($3297.6/3$). Both of these values match N-Watch.

Our conclusion is that we have correctly implemented your N-Watch rule for the bigram mean frequency for 3 and 4 letter words. And that an analogous rule for biphone mean frequency outputs the same values as N-Watch for 3 letter words

with CVC phonological structure (or CCC with the /u/ vowel sound). But such a rule (using all position specific biphones) does not work with any 4 letter word, or 3 letter words with CCV or VCC phonological structures (CV_P). A few provisional calculations suggest that similar inconsistencies occur with longer words, eg "string".

So, our question is, are we correct in using a rule based on total number and position of the biphones in a letter string to calculate the biphone frequencies, as is done with the bigrams, or is there a different algorithm for computing biphone mean frequencies?

Thank you very much, and look forward to your comments. I have copied this to my two supervisors, Dr Suze Leitao and Dr Mara Blosfelds.

Toni
(Antonette Seiler)

Email from Colin Davis 26th October 2011

Hi Toni,

Yes, you're right about the CV_P. The code I used searched through a list of consonants, but it wasn't a case-specific search, so it confuses the vowel "V" with the consonant "v". I vaguely remember someone else pointing out this bug some years back.

Re the biphone frequency measures, I'm not sure what the problem is there, but it sounds like you've investigated this very thoroughly and have identified another bug. Sorry!

Good luck with your PhD research,

Best,
Colin

Email reply to Colin Davis 26th October 2011

Hi Colin,

Many thanks for this. Its Rob here - Toni's away for a couple of days.

I guess the main thing she wants confirmed is that the intended algorithm for calculation of biphone mean frequency is that it would follow the same pattern as for bigram mean frequency:

ie extract ALL biphones in the string DISC_PRON value, look up each one in turn in the relevant position in the appropriate bpf file, sum all these corresponding values and divide by the number of biphones in that letter string.

Cheers

Rob Seiler

APPENDIX B: SENTENCE REINFORCEMENT

Word	Sentence
act	I am in the school play and I have to act like a teacher.
ad	I will put an ad in the paper to sell my bike.
am	I am going swimming today.
amps	Amps is the measurement of electricity.
an	I saw an elephant at the circus.
and	My favourite sandwich is cheese and pickles.
ant	The small ant can give you a nasty sting.
ants	Ants are very small insects that live in the ground.
at	I play with lots of kids at school.
bad	I got upset when I heard the bad news about the flood.
bag	I hung my school bag on the hook.
bags	I will put all my shopping bags in the car.
ban	At school there is a ban on using swear words.
band	The rock band played loud music all night long.
bands	There were about 40 bands playing at the music festival.
banks	The banks on main street all close at 4pm.
bat	A cricket bat has a narrow handle and a flat end to hit the ball.
bats	We went in to the cave to see where the bats lived.
bed	We have to go to bed at about 8 o'clock.
beds	There were five beds in the large bedroom.
beg	Some poor people beg for food or money.
belt	I made my own leather belt.
belts	He made belts out of leather.
bend	Some people find it hard to bend over and touch their toes.
bends	The road bends around to the right and then goes up the hill.
bent	The wind was so strong it bent the trees over.
best	This is the best meal I've ever had.
bet	The man bet \$2 that his horse would win the race.
bid	At the auction the woman bid for the expensive carpet.
big	The boy dragged the big suitcase behind him.
bin	The children knew they had to put all the rubbish in the bin.
bit	I bit my lip when I was eating my sandwich.
bits	The biscuit broke into lots of small bits.
bland	The food was very bland without salt and pepper.
blank	There was nothing on the paper. It was blank.
bled	The deep cut in my arm bled for quite a while.
blend	I stirred the cake mixture to blend in the nuts and sultanas.
blink	The dirt in my eye made me blink.
blobs	She put big blobs of paint all over the page.
blond	My friend has very blond hair and blue eyes.
blot	There was a big ink blot right in the middle of the page.
blots	There were lots of ink blots on the page.
blunt	The knife was so blunt I couldn't cut the apple.
bob	When it's calm the boats bob up and down on the water.
bog	The animal got stuck in the muddy bog.
bond	There has been a close bond between them ever since he saved her from drowning.

bran	Some breakfast cereals have extra bran added to them.
brand	This is not my usual brand of shampoo.
brat	The child was called a brat because she often did naughty things.
bred	Our dog is a pure bred collie.
brink	She was standing right on the brink of the cliff.
brisk	They went for a brisk walk in the morning.
bud	I took a photo of the beautiful rose bud.
buds	In the spring the apple trees have lots of buds.
bug	The little child was frightened of the bug that was crawling on the leaf.
bugs	There were lots of bugs eating the leaves on the fruit trees.
bulb	Dad put a new light bulb in the kitchen because the other one broke.
bulbs	We planted tulip bulbs in the garden.
bulk	It's cheaper to buy meat in bulk but that means you have a lot of meat.
bump	When I rode over the bump I fell off my bike.
bumps	We drove over lots of bumps on the dirt road.
bun	I bought a cream bun at the bakery shop.
bunks	On camp we all slept in bunks.
bus	We go to school on the bus every morning.
bust	They used a big hammer to bust up the old footpath.
but	I wanted to swim in the ocean but I wasn't allowed to.
cab	We caught a cab to get to the airport.
camp	Our visitors had to camp outside in tents.
camp	There were 4 school camps on the island.
can	I enjoyed the cold can of fruit juice.
cap	It was a sunny day so I wore a cap on my head.
caps	The whole team wore the same colour caps on their heads.
cat	My cat loves warm milk.
cats	We've got 3 pet cats.
cent	I only had one cent left in my purse.
cents	My sandwich only cost 90 cents.
clam	I saw a big clam on the bottom of the ocean.
clamp	I had to clamp the two pieces of wood together until the glue dried.
clamps	The clamps were too tight so I loosened them.
clan	A Clan is like a large family or group of people who share the same ideas.
clank	I heard the clank of the buckets as they started to milk the cows.
clap	When I clap my hands together I want you to all stand up.
clink	I heard a clink when we I dropped the ice cube into my glass.
clip	I kept all the pages together with a paper clip.
clips	She wore clips in her hair.
clog	When the cars all leave the footie at the same time they will clog the roads up.
clogs	All the rubbish clogs up the pipes when it rains.
clot	The man had a blood clot removed from his brain.
club	I wanted to join the football club.
clubs	I belong to 3 sports clubs.
clump	There was a clump of grass growing in the middle of the road.
clumps	The paddock had a few clumps of trees in one corner.
clunk	He shut the car door with a clunk.
cob	We had corn on the cob at dinner time.

cop	The man was stopped by a cop because he was speeding.
cost	That car will cost a lot of money.
costs	It costs a lot of money to build a house.
cot	My baby sister sleeps in a cot.
crabs	We walked along the beach collecting small crabs.
cram	I had to cram all my books into one box.
cramp	I got a cramp in my leg after I ran the long race.
crank	He was a bit of a strange person and people thought he was a crank.
crept	We crept out of the room so we wouldn't wake the baby.
crest	She surfed right up on the crest of the wave.
crib	The baby slept in a crib.
crimp	I want to crimp my hair with those special crimping irons.
crisp	The potato chips were nice and crisp.
crisps	I ate the whole packet of crisps.
crop	This year's crop of potatoes was big because we had lots of rain at the right time.
crops	All of the vegetable crops grew well this year because we had lots of rain.
crust	Could you cut the crust off my sandwich please?
crusts	She cut the crusts off all of her sandwiches.
cult	Their son ran away from home and joined a religious cult.
cup	I need a cup of sugar for this cake recipe.
cups	I dropped all the cups when I tripped over the stone.
cut	I cut my finger on the sharp knife.
cuts	That sharp knife cuts meat really well.
dad	My dad took us all for a swim in the river.
dam	The huge dam burst because of all the rainfall.
damp	My clothes were damp because I was sweating so much.
den	The young lion was sleeping in lion den.
dens	Lions' dens are usually very hard to find.
dent	The ball hit our car and made a little dent in the door.
desk	I sit at my desk to do my homework.
desks	We all sat at our desks to write the essay.
did	The oldest brother did all the hard work.
dig	My dog likes to dig a hole and bury his bone.
digs	Our dog digs a hole to bury his bones.
dim	The small child liked to keep a dim light on during the night.
dip	I had to dip my dirty shirt into the bleach.
dips	The road dips down to the river and then goes up the hill on the other side.
disc	I put the music disc into my computer.
disk	The dog's name was engraved on a little disc that was on his collar.
dog	My dog is trained to do many tricks.
dogs	A pack of dogs ran through the park.
dot	The child painted a big red dot in the middle of the page.
dots	Her dress was blue with white dots.
drab	I feel a bit drab when the weather is cold and rainy.
drag	It was hard to drag the heavy box up the hill.
drags	He often drags his chair instead of picking it up to move it.
drank	She was so thirsty she drank the whole bottle of water.

drift	We didn't notice that our boat had begun to drift out to sea.
drink	On a hot day I drink about 3 litres of water.
drinks	We all had cold drinks after our long walk.
drip	The tap will drip if you don't turn it off properly.
drop	Be careful not to drop those dishes.
drops	The temperature drops to below zero in the winter.
drug	The doctor gave me a pain killing drug when I broke my arm.
drum	I could hear the beat of a drum somewhere in the jungle.
drums	My sister plays drums in the rock band.
drunk	I had drunk so much coffee I couldn't get to sleep.
dud	The fireworks display was a dud because lots of them didn't go off.
dug	I dug up an old box in the garden.
dump	We took all our rubbish to the dump.
dumps	There were about 3 rubbish dumps on the edge of the city.
dusk	At dusk, when the sun was setting, all the bats came out of the cave.
dust	The furniture was covered in dust and cobwebs.
end	At the end of the year we play lots of games at school.
ends	Our property ends at the river.
fact	It is a fact that the sun rises in the east and sets in the west.
facts	We are getting all the facts before we make our decision.
fan	The fan made me feel cool even though it was quite hot.
fat	The bear stores fat during the winter when he doesn't eat.
fats	The unhealthy food was full of oil and fats.
fed	We fed the kitten milk in a bottle.
felt	I felt very happy when I won the race.
fend	The young lions had to fend for themselves when their parents were killed.
film	We loved watching the film about African wildlife.
films	I really like watching detective films.
fin	I saw the big fin of a shark when I was fishing.
finds	He finds it easier to run a marathon than a 100m sprint race.
fist	He punched his fist through the glass window.
fists	She was so angry she clenched her fists and shouted at him.
fits	Your jacket fits me really well.
flag	We didn't swim at the beach because the red flag was flying.
flags	The flags were all flying when our team won the contest.
flank	Sometimes a jockey whips the horse on the flank to make the horse run faster.
flap	The pelican has to run and flap its wings in order to fly.
flaps	The tiny bird flaps its wings while it sucks nectar from the flower.
flat	I had to change the wheel on my car because I had a flat tyre.
flats	We caught crabs on the mud flats at the beach.
fled	The fox fled from the dogs that were chasing it.
flint	Ancient man used sharp flint tools as knives and in spears.
flip	When one side is cooked flip over the pancake to cook the other side.
flips	The sail boat sometimes flips over if the wind is too strong.
flog	In the olden days the captain was told to flog the men if they didn't work well.
flop	I tried to bake a sponge cake but it was a flop.
flops	His hair is so long it flops into his eyes.

fog	The fog was so thick I could hardly see.
fogs	It's hard to see where you're driving if there is heavy fog.
fond	She smiled when she thought of the fond memories of her childhood.
frank	I'll be frank and tell you exactly what I think.
frisk	The airport staff had to frisk all the passengers to see if they had dangerous items.
frog	I got a fright when the frog jumped onto the window.
frogs	There are lots of frogs in the shallow parts of the river.
from	The special box came all the way from China.
frond	The long thin leaf of a fern or a palm is called a frond.
fronds	Ferns and palms have long leaves that are called fronds.
frost	We sometimes get frost early in the morning during the winter.
fun	The children are having fun playing on the swings.
fund	The school has set up a special fund to buy the new equipment.
gap	The explosion made a big gap in the wall.
gaps	She has small gaps between her front teeth.
gas	Mum likes our gas stove.
get	Could you get me those books over there please?
gets	It gets very wet here in the summer time.
gift	We bought a gift for our teacher to thank her for helping us.
gifts	She got many gifts on her birthday.
gig	The band played a gig on New Year's Eve.
glad	I'm glad you were able to come to my party.
gland	The gland on the side of my neck was sore and swollen.
glands	I had a bad cold and the glands in my neck were sore.
glint	She was smiling and had a glint in her eye when she told the funny story.
glints	The diamond ring glints when it's in the sun.
glut	There was a glut in the wheat harvest so some had to be thrown away.
gob	A gob is a schoolyard name for mouth.
god	Many people believe in a god.
gods	Many ancient tribes believed in many gods.
golf	My mum and dad play golf every weekend.
got	I finally got around to painting the windows.
grab	I had to grab her arm to stop her running on the road.
grabs	In the movie the man grabs the child's arm to stop her running on the road.
gram	I only needed one gram of salt.
grams	I need 500 grams of flour for the cake.
grand	The actor made a grand entrance onto the stage.
grant	They won a grant of \$25,000 to build an extra room onto the school.
grid	We put a grid across the hole to stop people falling in.
grim	We had the grim task of burying the dead animals after the fire.
grin	I thought everything had gone well because he had a big grin on his face.
grins	She grins every time she thinks about the funny thing that happened at school.
grip	He held on to the boat with a very strong grip.
grips	That new type of tyre grips really well onto the road.

grist	Grist is used in a saying. I might as well learn Japanese, it's all grist to the mill when it comes to getting a job.
grit	After the floods there was a lot of dirt and grit on the road.
grub	A grub looks like a short fat worm.
grubs	There were lots of grubs eating the vegetable rubbish.
grunt	The pigs grunt happily as they eat their food.
grunts	The pig grunts if anyone goes near him.
gulf	A gulf is a large area of water with land on 3 sides of it.
gulp	We were in a hurry so we had to gulp our food down.
gun	It is not legal to have a gun in the house without a gun licence.
guns	The soldiers could hear guns firing in the distance.
gut	Dad had to gut the fish before we could eat it.
had	When I broke my leg I had to leave the hockey team.
ham	I had a sandwich with ham, cheese and tomato.
hand	The children were told to put up their hand if they had a question.
hands	I had blisters on both hands from raking the leaves.
hat	Every child had to wear a hat during the sports day.
hats	We all wear hats when we go outside.
held	The little girl held her baby sister very carefully.
helm	A helm is the wheel that controls which way a ship or boat will go.
help	My dad said he would help me with my homework.
helps	It really helps if you listen to me reading each night.
hem	My dress was too short so I let down the hem.
hen	Our hen lays one egg every day.
hens	The hens were sitting on a dozen eggs.
him	I gave him a book for his birthday present.
hint	She gave her friend a hint about what she wanted for her birthday present.
hip	The old lady broke her hip when she fell.
hips	My gran fell and broke both her hips.
hit	I hit the cricket ball over the fence.
hits	He usually hits the ball so high it goes over the fence.
hop	We all had to hop on one leg.
hot	Today is so hot I think we'll go for a swim.
hub	The tyre goes around the hub of the wheel.
hug	Mum gave me a big hug when I came home from school camp.
hum	The boy liked to hum his favourite song as he worked.
humps	There are lots of speed humps on that road.
hunks	We put big hunks of bread on the plate.
hunt	Some animals hunt for their food at night time.
husk	I took the husk off the outside of the corn and then boiled the corn in water.
hut	We stayed in an old hut at the seaside.
if	If I am sick I will stay home from school.
in	My dog jumped in the water.
ink	My pen has run out of ink.
it	It was fun to play with the kids at the party.
jam	I like strawberry jam on my toast.
jest	His suggestion was not jest. He was very serious about it.
jet	I could see the jet flying high up in the sky.

jets	Jets cannot land at this small airport.
job	I got a job during the school holidays to earn extra money.
jobs	When she finished school she got two part time jobs.
jot	I had to jot down some notes to help me remember the instructions.
jug	I put the fresh milk into the jug.
jump	She wanted to run and jump into the water.
jumps	Our cat always jumps up on to the furniture.
just	I'll just finish my homework and then I can go out and play.
kept	My grandmother kept all her old photos in a special box.
kid	The kid next door broke my bike.
kids	The kids were playing outside all day.
kilt	A kilt is a skirt worn by Scottish men and boys.
kilts	The Scottish men all wore kilts for the march.
kinds	There were all kinds of birds in the cage.
kit	We have a first aid kit in our boat.
lad	The lad next door helped us put up the fence.
lads	The man said that the young boy was a nice lad.
lag	Walk a bit faster so you don't lag behind us.
lamp	The street lamp was broken so I couldn't read the name of the street.
lamps	The street lamps were all off after the cyclone.
land	This sort of land is no good for growing vegetables.
lands	The tribal dances were confusing to visitors from other lands.
lap	The dog jumped up onto my lap.
led	We led the horses to water.
left	The boy wrote with his left hand.
leg	I broke my leg when I was learning skate boarding.
legs	My legs were very sore after I ran the cross country race.
lend	I will lend you \$10 but you need to pay it back to me.
lens	My camera has a zoom lens.
lent	I lent my bicycle to me friend for the weekend.
let	Our parents let us drive the car in our paddock.
lets	Mum lets us go to town by ourselves.
lid	I broke the lid on our washing machine.
lift	We got the lift up to the 10th floor of the big building.
lifts	He lifts those heavy boxes with a machine.
lilt	He's got a lovely Irish lilt in his voice.
limp	He walked with a limp because he had a broken leg.
links	That bridge links the north shore to the main part of the city.
lip	It really hurt when I bit my lip.
lips	My lips get very dry in cold windy weather.
list	I took a list to the shop so I wouldn't forget anything.
lists	The lists of children's names were kept by the principal of each school.
lit	We lit the fire with a burning stick.
lofts	The lofts in all of those houses were changed into small apartments.
log	We crashed into a big log as we drove around the corner.
logs	There were logs across the road so we had to stop.
lost	I lost my purse at the football match.
lot	There were a lot of birds in the sky.
lots	I bought lots of lollies.
lump	A big lump of coal fell off the truck.

lumps	You don't want lumps in the sauce so make sure you mix it well.
lust	The old lady was very energetic and had a lust for life.
mad	She gets mad when you wake her up too early.
man	He listened carefully to the wise old man.
map	We got out the map to see where she lived.
maps	We bought lots of maps so we would know where to go on our holiday.
mat	We have a mat at our front door.
mats	The mats got very dirty because we wiped our muddy boots on them.
melt	My ice cream will melt if I go outside in the sun.
melts	Ice melts very quickly in hot weather.
men	The men have been working on the road for weeks.
mend	I need to mend the hole in my sock.
met	I met my cousin for the first time last weekend.
mid	He stopped mid-way through the race.
midst	In the midst of all the kids I could see the clown doing his tricks.
milk	I like to have milk in my tea.
milks	She usually milks the cow early in the morning.
mint	I chopped up the mint to make a sauce for the roast lamb dinner.
mist	There was a lot of mist this morning but it had gone by lunchtime.
mob	A mob of angry people marched down the street.
mop	I like to mop the floor after I have swept it.
mops	I put all the floor mops in the laundry.
mud	The horse pulled the cart out of the mud.
mug	I like a big mug of coffee in the morning.
mugs	I gave my sister 6 new coffee mugs for her birthday.
mum	My mum turns 40 this weekend.
mumps	When I was 12 I got very sick with mumps.
mums	All of the mums watched the football game on the TV.
must	We must not leave our bags on the floor.
nest	There was a baby bird in the nest.
nests	The birds' nests were high up in the tree.
net	I caught the big fish with a fishing net.
nets	We were not allowed to use nets to catch fish.
nil	We lost the game, 7 to nil, or 7 to zero.
nip	Can you nip down the shop and get me some milk?
nod	She gave me a nod and I knew I could come in.
not	The boy was not interested in the story.
nun	She is a nun and she teaches at the catholic school.
nuns	The nuns were praying in the church.
nut	I put a cashew nut in the middle of each chocolate.
nuts	I chopped the nuts for the cake.
on	Mum put my birthday cake on the table.
pact	The two countries signed a pact so they could buy goods from each other.
pad	Footballers sometimes wear a knee pad for protection.
pal	He was my best pal at school.
pan	I cooked the sausages in the frying pan.
pants	His mum fixed the rip in his pants.
pat	I bent down to pat the little puppy.
pats	She pats her little puppy when he does the right thing.

peg	He took off his coat and hung it on the peg.
pen	I like to write with my favourite pen.
pens	We were allowed to use special pens to do the art work.
pep	Our teacher gave us a pep talk before the game.
pest	Cane toads are a pest because they poison lots of wild animals.
pests	The farmer tried to get rid of all the pests but it was difficult.
pet	We just got a white rabbit for a pet.
pig	The meat from a pig is called pork, bacon or ham.
pin	I hurt my finger with the sharp pin.
pit	They dug a deep pit to lay the water pipes.
plan	The plan is that we will all go to the beach and then to the movies.
plank	We put a plank of wood across the stream so we could get across to the other side.
planks	We used planks of wood to cross the ditch.
plans	Our holiday plans had to change because of the flood.
plant	I bought a new plant for the garden.
plants	The plants grew very quickly after the rain.
plod	Even though it was windy and rainy we had to plod on 'til we got to the cottage.
plop	The stone fell into the water with a plop.
plot	The movie had a very simple plot that all the children could understand.
plots	The law says we can't build large houses on small plots of land.
plug	I had to plug in my mobile phone so I could recharge it.
plugs	The electricity plugs all had to be replaced.
plum	I ate the juicy ripe plum.
plump	We really enjoyed the plump juicy grapes on the hot day.
plums	We picked all the plums off the tree.
plus	Does anyone know the answer to 6 plus 10?
pond	We saw lots of baby fish in the pond.
ponds	There were goldfish and ducks in the ponds.
pop	Could you pop the pizza into the oven?
pops	The popcorn pops quickly in the microwave oven.
pot	I put the pot of boiling water on the stove.
pots	We grew lots of herbs in pots.
pram	She put the baby in the pram.
prams	It was hard to get the prams up on to the train.
prank	My friend played a funny prank on his teacher.
prep	The young children were in grade prep, the first year of school.
print	The name of the book was written in large print at the top of the page.
prints	He wanted 10 prints of that particular photo.
prod	The teacher had to prod her in the back to get her attention.
prompt	She is always prompt to help her friends.
prop	I had to prop my bike up against the wall.
props	We made all the props for the play.
pub	The workers went to the pub for lunch.
pump	It was hard to pump up the flat tyre on our car.
pumps	He pumps up the tyre with a very old bicycle pump.
pun	A pun is the funny use of a word that has a couple of different meanings.

pup	Our dog had one male pup and the rest were female.
puts	She always puts her eggs in the fridge.
rag	I wiped the grease off my bike with an old rag.
rags	I keep all the old rags in the cupboard in the bathroom.
ramp	I pushed the wheelchair up the ramp into the shop.
ran	The children ran as fast they as could in the race.
rat	There was a big rat in our shed.
rats	I think there are rats in the roof of our house.
red	Mum made me a red dress for the dance.
reds	She uses a lot of reds and pinks in her paintings.
rent	I pay a higher rent because my room is bigger.
rest	I needed to have a rest after I ran the long race.
rid	I used a special cream to get rid of the sores on my arm.
rig	My dad works on an oil rig.
rim	The rim of the cup was chipped and broken.
rip	There was a rip in his pants so he couldn't wear them.
risk	There's a high risk of another accident happening in this fog.
risks	I hate taking risks so I decided not to climb the mountain.
rob	The thieves were planning to rob the bank.
rod	I took my new fishing rod on our holiday at the seaside.
romp	The children love to romp around on the green grass.
rub	Your pet cat wants to rub itself up against my leg.
rug	My dog loves lying on the rug in front of the fire.
rum	Rum is an alcoholic drink made out of cane sugar.
rump	His favourite meal was grilled rump steak and potato chips.
run	I can run a kilometer in 5 minutes.
rust	There was a lot of rust on the old bike.
sad	It was sad to hear the news about the damage done by the cyclone.
sand	We made sand castles on the beach.
sands	The desert sands shifted each day with the strong wind.
sat	We all sat in a circle to play the game.
scalp	I could feel blood on my scalp after I hit my head.
scan	He had to have a scan to see if his leg bone was broken.
scant	Scant means not very much. I paid scant attention to the instructions.
scram	Get out of here! Go on, scram!
scrap	Every scrap of food was eaten by the pigs.
scraps	All of the kitchen scraps go into that white bucket.
script	The young boy wrote the script for the school play.
scrub	I had to scrub the floor to get the oil mark off.
scrum	The football players took a long time to get the ball out of the scrum.
scum	There was a layer of smelly scum on the top of the water.
self	Losing the race affected his self-esteem.
send	I will send your presents early to make sure you get them on time.
sends	She sends her best wishes to all of you.
sent	I put the letter in an envelope and sent it to my sister.
set	Lightening set fire to the trees in the forest.
sets	She sets aside time for her exercise every day.
silk	The dress was made of beautiful silk material.
silt	After the flood the river was full of silt.
sin	I think it's a sin to waste food.

sinks	That boat sinks because it wasn't made properly.
sit	We're trying to train our dog to sit.
sits	He usually sits outside to have his breakfast.
skid	If you're not careful your car will skid on the ice that's covering the road.
skim	I'll use a spoon to skim the cream off the top of the milk.
skimp	I was told not to skimp on the gravy but to put it all over the meat.
skin	My skin got very sunburned.
skins	The potato skins were fed to the pigs.
skip	She watched her little granddaughter skip down the path,
skips	She skips all the way to school every day.
slab	He ate a whole slab of chocolate.
slabs	There were 3 concrete slabs under the house.
slam	Please don't slam the door.
slant	The tower had a definite slant to the right.
slap	He won the race and I gave him a friendly slap on the back.
slept	We slept in sleeping bags in the tent.
slim	She was a slim girl with blonde hair.
slink	I tried to slink out of the room so no one would see me.
slip	That child might slip on the wet floor.
slips	She slips on the ice every time she tries to ice skate.
slog	Even though it's raining we'll have to slog on for another few hours.
slop	Walk carefully or the water will slop out of the bucket.
slops	The animals were fed the slops that were thrown out of the kitchen.
slot	You put the CD in the slot and then press the play button.
slots	The shelf has slots for 100 CDs.
slug	The slug was slowly creeping up the tree.
slugs	The slugs ate all of my lettuce plants.
slum	This house would be a real slum if I wasn't here to clean it.
slump	The value of the house will slump next year so we probably won't try and sell it.
smelt	On the hot day the rubbish tip smelt really bad.
smog	As we flew into the airport we could see the smog hanging over the city.
smug	She did win the race but I wish she wasn't so smug about it.
snag	The anchor was caught in a snag at the bottom of the river.
snap	We had a cold snap in the middle of summer.
snaps	That ruler snaps very easily if you bend it too much.
snob	He came from an expensive school and was a bit of a snob about it.
sob	She broke her favourite doll so she'll probably sob for hours.
sod	He's won again. The lucky sod.
soft	I lay down on the soft mattress and went to sleep.
sold	We sold our house last year.
span	He has a very short attention span and finds it hard to finish his work.
spank	The workers are not allowed to spank the children if they do the wrong thing.
spat	I spat the grape seeds onto the plate.
specs	That type of door was in the specs for the building.
sped	The train sped along at over 200 kilometers an hour.
spelt	My name was spelt the wrong way.

spend	I plan to spend all my pocket money on new games.
spent	I spent \$10 on my lunch.
spilt	I spilt milk all over the floor.
spin	Spiders are able to spin a very fine web.
spins	The wheel spins faster and faster as it rolls down the hill.
spit	I like watermelon but I have to spit out the seeds.
splint	The doctor put a splint on my broken leg.
split	He split the wood with a special axe.
splits	The carrot splits in two very easily when it is fresh.
spot	He had a spot of grease on his new pants.
spots	There were spots of oil all over the floor.
sprig	I decorated the food with a sprig of parsley.
sprint	We had to sprint to catch the bus.
squint	The sun was shining straight in her eyes which made her squint.
stab	The hunter used a spear to stab the wild animal.
stag	A stag is an adult male deer.
stamp	I put a stamp on the envelope and posted it yesterday.
stamps	I bought stamps at the Post Office.
stand	Please don't stand so close to the edge of that cliff.
stands	Granny says if she stands for a long time her ankles hurt.
stank	After the fire the house stank of smoke.
stem	The plant has tiny leaves on the stem.
stems	There were small leaves growing up the stems of the flowers.
step	Be careful not to step in the mud.
steps	There were 20 steps up to the 1st floor.
stilts	I learned to walk on stilts when I was very young.
stink	Those rotten vegetables stink.
stint	I did a short stint as a life saver.
stop	The police tried to stop the thief.
stops	The rain usually stops once the wind changes direction.
strand	She tucked a loose strand of hair behind her ears.
strap	I put a strap around my suitcase so that it would stay shut.
strict	My teacher is very strict but it means we get our work done.
strip	He had to strip the bark off the logs.
strut	The rooster seemed to strut around to impress the hens.
stud	He hammered the nail into the stud in the wall.
studs	That amazing horse was bred in one of the horse studs in the valley.
stump	It was very hard to dig the tree stump out of the ground.
stumps	We had to get rid of all the tree stumps from the paddock.
stunt	Lack of water will stunt the growth of the trees.
sub	Sub is short for submarine, a boat that goes under water.
sum	She was given a huge sum of money from her parents.
sun	On very hot days we should keep out of the sun.
swam	We all swam across the river.
swept	The houses were swept away in the terrible flood.
swift	The police took swift action against the thieves.
swifts	Swifts build their nests high up on the cliff.
swim	It was dangerous to swim across the flooded river.
swims	She swims across the channel every year.
tact	He never had much tact and people didn't like the way he talked.

tag	I cut the tag off my T shirt because it was annoying me.
tan	Some people get a tan when they sit in the sun for a long time.
tanks	All of the water tanks were full after the heavy rain.
tap	Turn off the tap so you don't waste water.
taps	Turn off the taps and don't waste water.
tempt	They tried to tempt me to buy the car by offering me a new TV.
ten	I got ten of those questions right.
tend	We tend to get our rain in the winter time.
tents	They put up their tents well away from the water.
test	We are having a spelling test tomorrow.
tests	At the end of the course we had to do lots of tests to see if we were good enough.
tilt	Please don't tilt your chair backwards. It might break.
tin	We had a tin of baked beans for lunch.
tip	Don't tip your chair back like that or you'll fall.
tips	Have you got any tips for how to pass the exam?
tom	A male cat is called a tom.
top	She waited for me at the top of the stairs.
tops	There were flags on the tops of most of the buildings.
tot	Small children are sometimes called tiny tots.
tract	They are building new houses on an improved tract of land near the river.
tram	The child was excited to have a ride on the tram.
tramp	The sheep will tramp down the grass if they are left there too long.
trap	The fox got its foot caught in the trap.
traps	They were not allowed to put fish traps in the river.
trek	The group of men went for a long trek through forests and over mountains.
trend	The new trend is to shave all your hair off.
trim	You need a hair trim before you go to the formal dinner.
trip	The bus trip from Melbourne to Sydney takes about 15 hours.
trips	We had 3 trips overseas last year.
trot	I made my horse trot across the yard.
trump	In our game of cards last night I played a trump and won the game.
trunk	My grandmother kept all her photos in an old trunk.
trunks	There was a strange mark on all of the tree trunks.
trust	I trust you to do the right thing.
tug	I will have to tug hard at this rock to move it.
tut	You're late again - tut tut!
twig	The bird made its nest on a twig high up in the tree.
twigs	We picked up all the twigs that had fallen under the tree.
twin	My friend has a twin sister.
twins	We have four children, two sets of twins.
twist	I can't twist my head around because I have a sore neck.
twists	The path twists and turns for over 2 kilometers.
twit	I felt like a twit when I dropped the glass vase.
up	The cat climbed up the tree.
us	The teacher told us to talk quietly.
van	We hired a big van to move our furniture.
vat	The rain water drains into this big vat.

vent	The vent in the wall allowed fresh air to get into the room.
vest	She always wore a woollen vest in the winter time.
vests	Our woollen vests kept us very warm.
vet	Our dog was sick so we took our dog to the vet.
vets	I need to take my sick dog to one of the vets in town.
wag	The dog was so sick he could hardly wag his tail.
web	We watched the spider spin a web between the grass stems.
webs	There were lots of spider webs in the tree.
wed	My sister eventually wed after a very long engagement.
weld	It takes a long time to learn how to weld two pipes together.
went	We all went swimming this afternoon.
west	The sun sets in the west.
wet	You have to drive carefully when the roads are wet.
wig	I had to wear a white wig on my head for the school play.
win	I hope we win the football game next weekend.
wind	The wind blew most of the apples off the tree.
winds	The weather forecast warned of winds of up to 60-miles-an-hour today.
wins	Whoever wins the race will get the trophy.
wit	He was a clever man with lots of wit.
wits	I was scared out of my wits.
yes	If your mum says yes then we can all go to the zoo.
yet	I haven't finished my homework yet so I can't go outside.
zest	I used the zest of a lemon in the pudding.
zinc	Lean, iron, copper and zinc are all metals.
zip	I broke the zip on my jacket.

APPENDIX C: WORDDRIVER ITEMS

L-Plate Items

2-letter	3-letter	4-letter	5-letter	6-letter
oc	cat	pram	slump	blusts
on	mat	bram	smump	brusts
un	lat	gram	blump	grusts
up	lal	grag	blunt	crusts
us	lan	grat	blund	crufts
	lap	grab	blend	crults
	lip	grib	blond	crulps
	lup	grob	bland	cralps
	lep	grub	creld	crelps
	cup	bomp	drums	glopts
	das	spin	calts	skofts
	and	rats	drems	scrand

P-Plate Items

2-letter	3-letter	4-letter	5-letter	6-letter
sa	leg	flap	strap	blints
da	reg	slap	srap	crints
ad	heg	stap	splap	prints
ap	seg	spap	scrap	plints
am	feg	smap	scapt	slints
av	peg	snap	stapt	smints
at	pef	snat	stand	snints
an	pet	snag	stant	drints
in	pes	snas	stamp	drinds
ic	ped	sans	stals	drisks
if	pen	sand	staps	drisps
it	pan	sant	steps	drists
ot	pon	sent	stips	drosts
ga	pin	sint	stops	drusts
zi	pun	sont	stups	drests
	pig	sunt	stump	drasts
	pum	slot	stemp	twists
	hom	drup	stimp	crolts
	gas	rest	tofts	flomps
	han	empt	melts	grelts
	fot	lump	plost	mempts
	hig	dist	tresk	plisks
	bus	crut	clump	scompt
	ant	milk	flags	

D-Plate Items for 3-letter level

Item number							
1-39		40-78		79-117		118-155	
end	ans	yet	heb	bit	gos	cob	jom
had	cas	hem	hef	sit	gol	gig	wob
but	fas	get	hez	bat	res	act	nig
not	pas	dim	alm	den	ven	cop	rop
wag	wap	net	alk	bed	cen	rum	rus
him	wav	ban	alf	big	dap	mob	von
cut	sut	ran	alc	pat	wes	pop	zod
hat	dut	tan	gan	dam	kes	rug	vod
gut	lut	met	ont	red	dak	rub	lin
hut	yut	van	ons	rat	ves	mop	jol
tut	wut	let	fet	pup	ces	tap	joc
nut	fon	bet	tet	run	zes	rag	som
mad	fod	wet	ket	pub	fap	gap	ast
hit	hab	jet	zet	lit	ols	pal	ruv
ham	hal	vet	fim	bin	olt	dog	sus
fog	fom	did	pim	wed	usk	sum	pav
hip	fof	rim	ses	sun	bon	fin	dom
sad	hif	cap	nim	sin	puv	tin	sug
tot	hiv	cab	cak	bob	fam	sub	cuv
hot	yod	map	cav	wit	bip	win	ict
got	yop	sat	nen	vat	fep	tag	sud
dad	non	yes	dit	pit	fev	dug	nin
nod	nop	bid	yed	gun	jat	tip	gud
bad	nof	men	sez	kit	fek	dud	tav
lad	dis	top	hon	job	yat	nil	gak
lot	bot	dig	tob	log	bic	rip	zil
pad	rad	hop	ats	fun	jop	mum	hus
jot	tad	tom	tog	nun	jun	hum	fub
dot	jad	lid	sav	sod	ent	mug	vam
cot	het	god	fid	sob	ust	hug	tib
pot	mot	gob	tid	bag	usp	hub	vip
bun	bis	rid	gop	bog	dob	jam	kev
can	lis	kid	pid	lag	bam	web	hud
bug	tis	dip	vid	wig	dop	nip	vab
bud	wis	mid	gid	rig	bab	mud	wol
man	nis	ten	diz	beg	pev	zip	tum
hen	san	fed	yep	pep	peb	tug	jup
set	ald	led	yek	rod	bal	jug	val
fan	hev	fat	gom	rob	vig		

D-Plate Items for 4-letter level

Item number							
1-59		60-118		119-176		177-234	
wits	blat	drop	saft	vets	yalk	jets	twak
flat	clat	tact	lelf	tips	julf	plug	crec
brat	crat	trot	selk	span	goft	grit	plup
spat	quat	pond	solt	scan	kesk	plum	skal
west	wilk	tend	solk	caps	sulp	twin	bref
from	wilm	crop	glis	gods	slad	blot	dwak
wins	wiln	lent	swom	bred	juft	slop	plun
hand	lits	prop	snis	nets	fets	stag	spal
best	wict	mats	drol	lets	swad	spot	twag
must	wids	self	dend	glad	cens	stab	blus
lost	hant	mend	trol	plod	pift	clot	fums
weld	gren	romp	homs	sets	jals	bugs	ploc
list	frod	film	nond	pots	kolk	guns	stoz
just	dren	melt	delk	tops	gogs	jobs	grap
cost	tast	rent	tald	pens	grad	grip	zods
went	plen	mops	lolt	sped	blod	nuns	yevs
fits	trom	silt	vond	legs	fegs	bump	ists
vest	brom	silk	frun	jump	jums	dips	kuns
bust	tust	dent	basp	fled	cles	dump	vops
dust	pust	kilt	mogs	bled	snol	drip	zefs
nest	fest	camp	balp	kids	kisc	pump	fubs
rust	frol	hens	timp	risk	hict	club	blug
lust	frof	dots	lasp	taps	seps	stud	plec
frog	fros	lots	pasp	snob	snos	tram	prit
sits	nust	cent	calc	fogs	fulk	buds	plig
fist	jost	lamp	zelt	disk	wocs	trap	plib
test	hamp	lips	beps	bulk	stal	trip	pliv
hits	dest	soft	walf	prep	fulf	grim	slud
bits	halc	maps	pamp	trek	dept	rump	stiv
mist	beld	beds	zelf	cult	kect	slug	rum
pest	frem	grid	golk	step	blon	slum	slup
hats	hads	cats	nans	reds	sevs	drag	dras
jest	frid	bats	trid	disc	pids	flip	glub
zest	lild	plan	tolt	grin	gulk	glut	sluv
bend	sald	golf	nilm	digs	gips	flog	flob
band	bist	skid	prid	plop	vigs	drab	kags
belt	cavs	fund	brid	stop	lulf	spit	slof
lilt	yist	stem	ciln	gulf	tral	slip	spog
land	belp	lens	yilm	pops	zict	cram	vogs
bent	lond	husk	vins	plot	duts	trim	gump
held	sask	clan	dalp	kept	demp	slog	lums
webs	snom	dusk	smid	rags	dems	twit	glun
bond	wevs	damp	mulp	gulp	lulp	clip	twop
help	gond	lads	yiln	plus	plel	skip	prip
prod	malk	dogs	folf	slam	nulp	clog	clos
helm	malf	pats	lund	flag	flas	ends	spus
tilt	frep	logs	busp	skin	prin	slim	flib
limp	frel	fats	nusk	clam	stek	drug	rumf
fond	stom	ramp	rusp	clap	gabs	cups	jeds
mint	yont	ants	swem	gets	yisc	drum	brus
fend	yand	left	feft	cuts	flav	skim	brab
lend	nend	dens	gwem	swam	opts	crib	ompt
lift	slom	hunt	dwem	gaps	glam	amps	wups
send	fral	mugs	fols	slab	plut	swim	gliz
pact	clom	gift	ralm	flop	plil	twig	zeks
vent	zavs	bran	nalp	hips	yems	smug	dwef
felt	yomp	desk	valk	bulb	cref	scum	scup
fact	dris	bags	seft	nuts	Plud	smog	Dweb
hint	besk	mums	fisc				

D-Plate Items for 5-letter level

Item number							
1-33		34-66		67-98		99-130	
stint	stind	hands	blasp	spots	sunds	desks	wunts
grins	dreld	grips	grece	flops	frips	vests	celks
print	prald	fists	bliin	drift	fregs	clubs	velks
flint	smind	blots	rints	tents	grugs	split	scask
glint	dwald	sends	tonds	frogs	probs	camp	yemps
spins	stond	bands	stris	crisp	plobs	plugs	sprap
stunt	womps	strip	flasp	risks	relds	swims	hilms
twins	spult	spent	sliit	frisk	mipts	flips	kolts
crest	clulk	spend	treim	grubs	lalms	scalp	dweks
skins	gwins	midst	glalt	slops	gists	bumps	cuets
strut	flult	sands	grimp	crimp	swals	slept	glusk
frost	bulk	belts	nonds	blobs	crigs	hump	skaks
grist	trilt	trips	ploms	drags	vonts	plump	bimps
grunt	skult	clamp	bleds	slabs	nasts	slips	smimp
studs	stalc	films	glaks	lifts	nesks	mumps	cimps
grand	plict	pants	walds	spelt	slof	lumps	snalf
frond	greds	slots	siin	tests	dwend	spring	spumf
trend	dwulb	drops	scilt	lofts	dompt	jumps	zimps
stems	brist	scant	brek	clips	gisks	pumps	demps
gland	stisk	flaps	befts	cramp	prapt	dumps	slevs
plans	trods	props	cleks	gifts	clecs	slugs	gwolt
trust	stref	crops	trimp	plums	gweds	tempt	scags
brand	glont	traps	homps	cents	plelf	bulbs	snisk
bends	stusk	grabs	selds	facts	bopts	swept	dupps
costs	dwict	prams	drocs	crabs	snats	swift	wulps
flats	presk	brisk	sonst	trump	telms	skips	twemp
lands	slals	twist	fants	pests	twacs	scram	scisk
crust	brois	clogs	pralm	lamps	clift	snaps	gwops
tract	drots	crept	pralc	kilts	selps	twigs	swocs
spilt	swost	milks	holts	specs	swols	scrum	lulfs
ponds	smilt	lists	munds	helps	junts	scrub	skubs
grams	plilm	nepts	frect	smelt	refts	skimp	dulbs
plots	crols	tramp	brimp				

D-Plate Items for 6-letter level

Item number							
1-30		31-60		61-90		91-120	
sprint	strend	clinds	grifts	splons	sprefs	scralm	frasps
splint	sprins	stamps	clonts	glalks	blintz	dwolts	drufts
strond	strent	scrypt	crands	glends	slofts	splals	dwefts
squint	strelt	scrulf	brasts	sprevs	brimps	clamps	scusks
strund	strels	glands	pralds	stolfs	spects	drelks	snects
strict	strelp	slinds	bripts	prasks	grasks	flufts	spalbs
sprend	strost	splits	scrant	plasp	briscs	brems	clisks
strand	bempts	troks	frols	crisps	smintz	plusps	skalks
gropts	propts	plelts	splunt	splust	glafst	slamps	smucts
strots	spreld	glonts	stemp	bralbs	blalps	dwalks	crusks
stands	strulf	spilts	flalds	splots	stulfs	swifts	slemps
stroms	streft	sponts	prisks	clalbs	sprags	clusks	scravs
strolf	strims	stusps	fripts	plelds	clefts	swafts	skipts
strulp	bronts	brilks	grefts	splulk	splulp	skufts	swufts
stonts	strib	script	cempts	brufts	clolds	swucts	dwonds
stilts	brants	prompt	slosts	frelts	bructs	gwonds	swelds
sprelm	spront	scrogs	clalks	brekts	scruct	glisks	snelds
sprelp	sprict	folts	splelm	blalms	fralms	glempt	blompt
scints	stists	splelk	skinds	drilms	flults	twemps	smisks
stunds	bralts	stilms	cracts	scilds	scufts	scruff	sprusp
plents	brists	yempts	trafts	flects	blunds	snalms	trulps
frilts	frents	clelts	spists	cracks	glests	clisks	splalc
glints	snopts	stelps	snilts	scruds	plamps	felps	snasks
scrics	scrids	gralps	gwinds	splisp	treps	gwemps	flusps
crintz	drilts	plunds	frests	slipts	splags	splusp	skalbs
glalts	bompts	stumps	scrols	scraps	breps	gwolds	prulbs
stifts	cronds	scromp	swunts	prusks	swosts	twusps	dwilns
fronds	crist	spruts	sprog	trusks	scracs	splocs	splavs
strusk	straft	brofls	felts	frelks	blids	splabs	splolk
grunts	gwints	frects	slonds	dwests	skults	clumps	splaft

APPENDIX D: ASSESSMENT NW LISTS

Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
ib	ip	oa	vi	om	ek
wa	ob	ed	ez	ac	ii
vos	zad	nas	nos	noz	voc
dat	toz	hos	med	ots	mav
qoz	vec	nez	lod	mek	hoz
mun	olf	lem	ait	fak	bap
ciq	rab	vop	teb	beb	zon
qua	vil	sos	mup	vaq	doz
kaa	vaq	wep	fiv	cea	kef
vav	nug	riv	lum	wum	ics
vud	kak	dez	int	jeb	evs
niz	vof	vem	niv	kac	iic
zek	ubs	uft	cez	iif	ums
spen	fost	fren	rost	savs	drom
helt	dand	tant	lins	wems	liln
nind	zand	pron	qom	voms	velk
sof	celd	dwom	bint	scom	scis
filn	calt	munt	frib	croq	friv
siln	celp	lalk	nomp	laf	miln
plid	vilt	colk	libs	yilk	stid
qask	crid	alid	viln	daik	dods
cund	dusp	kund	hefs	vins	snod
valt	iulk	rols	hebs	mesk	sult
snon	teft	cimp	vefs	faft	zons
fipt	zens	spes	keft	kisk	fips
sept	dled	ceft	neds	tect	alts
pulk	twal	nevs	qwal	hias	dulk
noft	snet	visc	aral	snel	dapt
drev	clin	drec	blaq	wulp	qapt
prez	zaft	dwap	kaft	flus	pref
ploz	clel	snez	qlot	stoa	dwav
plef	slek	vulb	clek	stim	stol
clum	bups	zept	eops	ieas	dwet
brap	qwt	yipt	qlof	grud	peds
blib	slea	twus	kuds	druv	skol
qlic	emps	scol	prut	snut	glez
skos	skob	qwub	isks	skoz	brug
zevs	smef	qwef	smic	twec	smab
flald	brald	steld	brold	qlild	trint
frulp	frulf	tront	plulb	crulf	frics
scres	qwulp	brilm	drilm	drilk	trand
trats	trals	stoft	qlads	truns	spond
qralp	prens	dwest	frots	flilt	plist
flalf	snunt	spads	dands	plaps	smuns
frims	dlalc	pends	plaft	belms	plamp
snist	prelf	twilm	dwand	broas	prelp
creas	bolds	slolt	fisps	smols	dwuns
qlamp	sprin	qlaft	nefts	pript	bemps
iilds	tweds	tolts	smeks	vilds	selms
awesk	tifts	vompt	masps	racts	dalts
slep	zomps	bults	bafts	zalks	slelt
lults	spefs	splev	swask	splec	spleb
spods	fects	plubs	splak	lufts	scalk
qlelp	jesks	bamps	vesks	splis	jipts
solfs	fluqs	himps	yasps	twums	semp
sluct	dwips	alugs	nusps	scups	swups
swogs	twegs	skift	fulfs	scrud	scroc
strids	strecs	scrins	tropts	strons	screl
trents	blopts	stists	scris	sprild	screts
drintz	plasts	screcs	dronds	scrugs	twints
iompts	struft	plends	rompts	stisks	stilns
slolts	snonts	dralds	brilns	stulks	spintz
spalds	scrift	sposts	crilns	splets	qlilts
spract	skilts	spribs	blofts	aremps	premp
blefts	scraks	dwintz	flalbs	sprans	spelds
scalms	brusks	awests	smonds	splads	snunds
twipts	spleks	spraps	plimps	skefts	smucts
splams	blelks	spilms	dwufts	dwofts	awucts
slimps	swusks	dwalms	scumps	qwemtp	splums
skelks	slulps	qlelms	sculfs	skolk	dwasp

Set 7	Set 8	Set 9	Set 10	Set 11	Set 12
aa	ut	ud	vo	fu	vo
ep	ec	ak	uv	pu	uq
hib	tas	voz	nad	foz	wat
sen	mal	wid	uts	sep	zim
yef	yeq	mec	qoq	lon	neb
lek	loz	biv	ked	ied	sif
rud	rup	boz	tem	cuq	soq
hup	qav	tal	uct	soz	poq
wec	kem	kel	wev	roz	zeq
muv	pif	vup	poz	pof	wus
vic	vib	ipt	yab	vos	moz
voz	vel	vef	zec	cep	elp
ulf	kav	isc	isp	umf	iiv
welf	trat	hald	dast	qost	wibs
habs	tavs	fant	wemp	soms	haps
vind	frek	cald	vavs	comp	cron
qrof	smis	qwis	frit	prot	qros
bros	proc	crof	frif	broq	velt
caks	cals	palk	rilk	qilm	zont
zent	fims	fimp	kins	talf	ijlk
zilm	snid	jans	nens	zacs	tisk
tias	ralk	nask	wats	qims	qusk
ialt	hols	fots	iasp	iult	wusp
cred	vons	zalf	flad	nals	datz
iens	flod	wapt	ialc	vemp	zalc
snoc	twes	nemp	drep	blal	skes
smed	peft	qwod	daas	dult	scod
crek	nisp	dids	rems	wult	bisp
qibs	funs	treb	blas	dreb	tref
qwap	crev	flot	mevs	prec	crez
stip	stos	ceps	ploq	sneb	stav
clit	flum	nulb	fups	flun	stua
drac	qwet	zaqs	nuqs	cluv	traq
dwil	dwot	grum	trib	drut	dumf
skam	slig	crim	bliv	crav	prac
dwol	crub	omps	umps	skub	twol
snup	snum	spac	swic	swof	brum
qwug	sciv	scib	twun	qwup	sciz
smild	stold	slild	clold	blad	qreld
club	clost	prulb	cruk	stids	drulf
qwulb	stoms	spost	prilt	slict	brilk
trets	grims	qrelt	stogs	skics	fresk
vends	frels	qralf	frols	qlunt	treps
trept	traln	clolt	flalm	flalc	nands
drasp	cralt	alols	plapt	blaqs	brams
frolf	brebs	qlend	frask	fremq	crelf
trums	qwist	braps	pomps	drevs	snuns
bloft	fluts	ripts	rolks	qlids	fompt
rimps	zilds	snend	slems	ionts	cacts
tisks	spums	tasps	nalks	scacs	slomp
kalks	scret	smusk	delms	smamp	dilks
falps	splez	vofts	pipts	plups	snels
slelm	kompt	snoms	fleqs	kipts	slusk
ilns	blibs	cesks	splud	famps	nufts
glecs	slebs	twoms	sweps	snalp	hulps
femps	dwaps	slubs	dulps	pusps	swolk
snect	biscs	wempt	scrim	scroq	rulfs
strets	sprind	scrond	streds	street	scrend
prolts	splund	arents	arilts	brolts	slopts
smopts	scrons	strabs	stilds	hompts	sprics
prolks	brolks	plintz	alents	snants	qompts
clends	flacts	sprast	clalks	plusts	prafts
felts	scribs	splect	slelts	smonts	smands
premps	sprift	stulfs	twintz	swends	clasks
qlalms	scipts	qresks	swasts	cralbs	snasts
snests	scramp	crelks	blifts	swefts	flasps
splimp	plilms	prusps	splift	clompt	twafps
clolfs	blomps	snucts	smolds	smelds	slusks
smemps	smolks	flimps	culks	swisks	snimps
flulps	skesks	skusps	spulfs	twiscs	smiscs

Set 13	Set 14	Set 15	Set 16	Set 17	Set 18
ol	iv	os	na	io	va
co	ev	ia	um	ub	ab
ras	fol	yoo	yof	vom	hin
sef	sem	vis	alt	als	tol
dal	div	veb	vev	dav	nev
zat	fef	yun	liq	leb	lof
tez	isk	bez	mon	zop	ioz
qam	rav	min	vin	suv	moa
wos	qip	iea	coz	keb	kep
jal	ilt	nup	ilm	yus	wuq
qiz	iav	viv	iev	vib	viz
yic	eds	ceb	cem	kal	unt
uns	zif	ulp	omp	ulb	yif
dwat	vost	arom	blen	fron	pren
samp	salp	wect	belm	pavs	salm
stis	teld	deld	qint	gris	malc
cint	twom	aroz	aroc	smom	lans
prob	frud	croz	dact	telp	brob
palt	dald	hesk	iusp	lalt	pelk
bolf	lalm	heft	zilk	rilm	voms
iilm	wolk	zels	clid	niln	tals
dobs	dwan	sesk	tusp	wund	lusk
vasp	laft	jalk	valt	caas	nons
pred	bims	suts	vamp	nalc	tibs
zals	kalc	kals	snop	lefs	kaks
roas	snof	febs	iumf	snoz	femp
smod	nisk	sebs	dict	dwal	dwod
nulk	slon	nids	meps	nisc	plas
trev	fulb	vulf	zisc	blap	kulf
qwak	twon	spop	blap	fler	creq
plob	snea	scal	stob	luns	slet
drap	fluv	gras	ceds	skel	slub
floz	twet	dups	ariv	alud	cebs
zoqs	flef	grun	gruq	grup	qlip
slib	qups	jemp	swus	slec	zobs
alef	ulps	isps	prub	qumf	briv
brup	swif	dwub	twut	pevs	skoq
tweb	awiv	dwum	smup	dwud	scia
crild	grint	treld	slald	flild	grald
plulf	prulk	brulf	fruit	brulb	crulb
steks	dwulp	qwulf	awulk	sland	stens
qrolt	drods	honds	smunt	creds	stril
flofs	crans	clend	aralc	splut	tralt
yinds	smits	flalk	fliln	qliit	dwast
alots	swand	aliin	clock	qwont	wasts
zends	crelm	swuns	prelm	blops	sciln
plocs	skist	blems	blets	grups	trusk
praps	vants	pelds	sasts	scals	malms
lopts	snids	dwans	qlolf	blims	skent
spemp	twods	zents	nalts	softs	bacts
climp	blect	dwuts	speqs	walbs	drups
melps	rults	scasp	musks	fasps	kisks
slelk	splad	nusks	splid	qweks	jopts
nucts	splam	twalc	jects	flisp	kefts
smeft	busps	spriz	sprum	flibs	iasps
zamps	nulps	jisps	twavs	nolfs	tusps
swuft	scump	awups	dwept	tulbs	scrop
strins	strelk	strits	stalts	stants	strelm
spints	stends	scrost	frinds	strals	flants
splelf	bompts	stufts	dralts	grols	frofts
aracts	twents	flasts	sprulf	dwopts	alinds
prusts	skents	brects	promps	scrust	scremp
snintz	frefts	plects	grilms	trults	scolts
blalps	scrals	qlafts	qwands	fralps	clunds
fralbs	scucts	clifts	sprals	plilks	drelts
pramps	flipts	qlolds	spemps	scrask	plusks
twufts	sploms	smufts	twufts	snolds	clerks
qwufst	felks	dwelds	bilins	qlemps	splups
qwalms	dwemps	sculps	dwempt	snemps	swalbs
drumps	dwisps	swolks	spulbs	qwusps	sculbs

Set 19	Set 20	Set 21	Set 22	Set 23	Set 24
um	ac	ud	ut	oa	ib
os	io	na	co	ua	ol
vad	vol	wal	vot	bup	hiz
cac	seb	van	vim	sev	mim
hof	mef	mez	mem	nep	daq
kun	fac	lev	lez	feb	fav
bep	vob	bol	miq	zob	ziq
sof	zin	dus	lif	qac	dup
mub	fic	wem	kez	fud	rof
lub	iub	nam	wub	fuv	pib
ept	zol	qic	mof	dep	nuv
zac	zev	voc	cev	nav	zof
ams	ift	ims	yiv	wuv	vuv
slen	welm	cren	sken	fris	sten
weps	dont	wefs	mald	lant	favs
malm	lelt	cacs	sild	tont	spom
homp	spis	woms	selp	crot	vint
brof	frub	selm	vint	proz	nild
jomp	bons	kelm	rold	kilm	joms
qrem	falp	komp	zomp	famp	bebs
zald	dasp	holt	spid	biln	wolt
sims	luct	husp	blem	nund	tols
polk	mens	nusp	bran	zask	dunt
jolf	cims	mumf	toft	zams	zamp
fefs	mids	vems	zolf	kolf	wabs
trep	kisp	mets	jups	feds	wobs
defs	arek	brep	fevs	mefs	levs
dulp	clon	iisk	visk	vids	nult
mebs	drez	iisp	crin	sepe	keps
vias	vuts	swas	wuts	clep	dulb
vods	slus	qwac	clet	alop	veks
ifts	huds	ipts	jefs	smep	vips
drav	tras	clun	iept	snil	awel
nump	quds	cloz	pumf	trif	triv
blif	bliz	twip	wuds	bliq	trud
smol	qlev	skas	brif	qleb	jeps
spav	skun	swud	skea	crun	swib
dwif	qwib	scic	jevs	qwif	dwiv
qlald	trald	plald	brind	drald	troid
dwins	plulk	brulb	drulb	smult	bluit
dwulf	qrols	clons	slest	stolt	grads
smond	spund	preds	trem	dwics	drust
blask	londs	qalk	plalc	stefs	prels
qlods	smans	scont	sints	traf	iinds
dwont	trisc	clolf	trevs	qilm	plids
twiln	kends	awand	bromp	scilm	prelk
spoils	vonts	bluts	bript	spalt	qloms
qompt	nolds	selts	spret	flets	polks
telks	solts	pofts	speps	celds	vasts
frums	spelm	fleit	spelk	melms	snols
cliqs	blept	vusts	zists	smums	kusts
spapt	skols	pilns	welms	brump	fusks
vafts	lucts	crubs	scalp	slemp	gafts
tisps	spuct	prump	polfs	qlelf	vimps
skalc	hempt	tolfs	slisp	snalk	snalm
vulps	flumf	awaps	qlibs	snisp	hulbs
pempt	dwect	scrof	scobs	scrol	qwept
stopts	strics	stront	striqs	scrent	strist
brosts	pompts	arosts	stalps	flopts	trosts
frintz	scalts	scrilt	prolds	clents	scriqs
vompts	splost	nempts	arolks	tompts	awopt
trompt	skinds	drilds	bralks	spieim	delts
brults	splant	spolts	scract	snunts	trofts
skands	dromps	stulbs	swilts	tralbs	dwands
snonds	presks	swists	frasks	scufts	twalds
spempt	spilks	scracs	swolts	spolec	spalms
qlelds	cliins	blucts	grusps	twilds	scilns
twalms	swalps	awipts	dramps	flusks	dwucts
skisks	bilms	qilps	skasks	skalbs	skusks
skilms	smulks	dwelps	skasps	smompt	awisps

Set 25	Set 26	Set 27	Set 28	Set 29	Set 30
va	ip	ev	vo	vi	ii
ed	ab	ek	ec	uv	aa
jas	zot	foc	ris	ind	fis
cal	toc	sal	zan	aim	sab
des	mev	qoc	vez	nef	mep
siz	lom	iit	vit	fec	aas
bef	esk	paq	tef	bem	bav
tam	qub	wom	rez	wea	vil
rol	tus	kek	dea	kom	vip
piv	kiz	kuq	iln	riz	yum
dem	aib	wud	zos	nal	zab
zeb	uds	zel	zal	elt	zep
oms	viz	oqs	ziv	cef	ulk
wint	crom	snen	tist	stat	swen
fres	weks	lont	wavs	salk	sams
onts	vavs	flom	velf	blom	tilm
moft	dwis	jond	mads	brop	nelm
telf	melf	cild	proa	crob	zeld
zend	nact	vont	bect	susp	kont
vomp	qolt	zoms	bems	zelp	trem
bols	swid	kald	toif	fusk	pold
zins	cusk	veft	slem	caft	simp
cran	kift	tesk	ares	vsp	himp
vops	vods	nolf	sman	kalo	valo
vals	misc	drad	vebs	nefs	valc
tocs	nebs	kias	fems	lemp	lebs
awed	tret	pult	twod	poft	cisk
plaa	futt	usts	plab	rulp	daps
pral	kulp	slin	iops	cral	zisp
devs	preb	creb	quft	zias	pulb
dwac	cuns	twac	noas	plos	awav
pums	dums	bipt	arus	wulb	slil
spof	drim	bloa	ruds	hups	zeas
yabs	unds	smit	dwop	qwil	trig
ilns	blic	slev	drun	slab	qubs
wubs	qlea	yups	briz	sput	priv
skec	skoc	skuv	prun	cruv	snun
smum	twea	qwum	dwig	twup	olks
stins	brint	blild	drind	brild	drint
frict	frulk	prulp	clulf	druk	prulf
smost	stral	crilt	trund	clals	stran
smant	brids	smont	stobs	swest	plilt
grect	stevs	stram	plits	flait	drets
flilk	flots	skund	smons	truts	arias
pralt	druds	creps	alalf	draks	wends
frasp	pleks	spacs	drecs	snits	crelk
smots	qosts	qwits	lelts	iunds	dolds
mofts	gruft	domps	polts	frift	lelms
fraqs	flomp	floft	aluds	sprek	alolk
skeds	smavs	spusp	spelp	dasks	ralms
dwacs	dilts	nopts	snuts	jalts	smapt
fults	lulks	spamp	drucl	iolks	basps
scalm	hemps	nults	zompt	self	iisks
kafts	blubs	qlelm	zilns	flisk	zefts
jalps	spruq	sprif	sprib	qlips	sprub
skops	twops	swolf	visps	swisc	valbs
scroz	dwups	scrus	scrob	qwift	scrun
scrint	strunt	strost	sprond	strint	strilt
screct	trilts	dronts	strans	lompts	stusts
strusp	spinds	screds	frists	stipts	scrots
scands	crends	practs	swants	hempts	crifts
tromps	crokls	trecls	brompt	dripts	flunts
spusts	specls	blalks	clofts	scosts	spremp
scrans	flusts	scalks	spromp	sprimp	alofls
tresks	spufts	scrocs	clilds	skists	spold
gramps	spraks	awalds	clolks	scrasp	skosts
twofts	snilks	silks	dresks	spramp	smafcs
spimps	smilks	awelds	sousps	twempt	dwafcs
tweks	awilks	smisps	spleft	alesks	smempt
drulps	flumps	snusps	twelms	snelos	dwusps

Set 31	Set 32	Set 33	Set 34	Set 35	Set 36
ep	ob	wa	iv	ou	ia
ak	om	ub	vo	ez	fu
vas	nol	kas	yad	vas	wab
ets	iis	caq	bim	sim	cim
siq	dif	nem	bes	vem	gof
lef	fal	vit	zit	ved	lec
jof	rin	pab	lil	yiq	tev
fum	com	zoq	fup	iap	fiq
wef	nus	wib	tiv	ros	kec
nud	huv	wup	kib	lus	piz
iec	zib	dev	tuv	miv	iep
val	veb	zem	zoz	juv	zic
ist	zez	kuv	ump	iiz	ost
smat	hans	tren	clen	sost	hest
hend	bant	wegs	hapt	lilm	sasp
plis	tron	velp	mals	mots	iavs
nint	womp	rild	lald	zant	brot
broc	frug	frut	broz	melk	fria
pilt	befs	noms	dilt	mels	dans
talp	tams	pent	zilt	bemp	volt
holk	kacs	mulk	bots	mult	vald
yund	dalm	cuct	galp	qund	qimp
nalf	smem	nams	boft	fict	polt
kalf	inds	snes	nolk	baps	taft
veds	veft	sulb	zaks	sict	pabs
fult	nems	iubs	iats	seas	swes
reas	rept	kets	tulk	dwed	risp
visp	qipt	zisk	kefs	spon	vult
wulf	brin	treq	trez	plet	jaft
kems	prea	qlas	pobs	vebs	qlaq
trit	clus	twav	slsl	culb	iect
crit	plev	plea	flup	ests	plez
blos	skop	aric	ariz	clup	smet
cuds	brip	prak	blim	smop	flim
trup	swip	slez	lups	trum	slef
qwol	spim	zebs	yubs	skiv	qlia
skeb	skez	vumf	skev	scub	kumf
twez	dwuq	dwiz	twoq	twob	ulks
quild	brel	grol	drol	clild	plild
plulp	bruik	frest	brost	clulp	drulb
stavs	stels	frilt	prast	flont	flond
flons	clust	crek	freds	awics	sinds
splen	qlact	flust	prans	grept	stumf
tralk	flalp	smals	zinds	smist	flols
aramp	sluns	qlalm	qlalp	skond	cluds
traqs	mosts	twilk	crelp	scilk	plens
qwuns	malks	cints	rintz	lelks	freks
helks	frevs	halks	hests	blomp	hasks
vefts	drusk	awend	fents	tilks	scods
swuts	dalks	relts	truft	malps	falms
hults	vintz	tunts	zasks	smaft	wusts
spleq	blebs	splem	crups	smeps	zelts
twask	slusp	prubs	blups	ructs	spuqs
qwask	vipts	slect	smift	qllek	flisc
smuct	snalc	twusp	zalps	scril	kalps
ialbs	kulps	alips	hisps	snocs	scrup
dwift	fempt	scibs	sulbs	skelp	qlumf
splind	bropts	strelf	streqs	strent	strens
prilts	cronts	sprelk	prosts	grolts	trofts
plalds	clands	swints	screqs	stucts	sprids
sorept	clalds	spreps	scrast	plaks	blonts
bromps	solics	swinds	splids	slacts	flots
twands	prilms	sprust	trilms	stulps	fralks
clulfs	scrolt	crunds	alonds	brasks	alists
sprolt	slolds	brasps	awintz	criscs	plamps
spruds	drempt	splods	sprocs	spleas	blids
spluds	blelds	skalks	spesks	blufts	freps
snufts	drusks	cleps	awafcs	qlamps	slesks
frulks	slusps	snalbs	swelks	drusps	bleps
qwasps	swusps	qlulks	snolfs	spluft	qwelps

Set 37	Set 38	Set 39	Set 40	Set 41	Set 42
ii	ak	aa	co	fu	ib
na	ez	uv	vi	ob	wa
bub	und	nom	zas	ond	vos
mab	fes	sid	nid	zis	dat
ild	dac	tes	meb	cid	qoz
lun	dod	lel	jod	olk	mun
bof	tep	pob	bev	pez	cia
ect	roa	aup	ral	rem	qua
zaa	fif	wez	woc	vom	kaa
yub	tud	zam	yuq	jus	vav
iez	aif	zak	vif	iud	vud
ids	vez	vek	vec	zoc	niz
emp	zav	ciz	vav	zef	zek
twen	awat	flen	sust	qat	spen
sal	wecs	somp	domp	lilk	helt
frin	bron	dold	kavs	dron	nind
relt	drof	qwom	twis	hild	sof
sabs	fric	relp	dolk	iint	filn
yelm	dacs	rilt	fask	jend	silm
drem	fams	walm	hilm	jelp	plid
rask	plem	vans	rolt	jald	qask
ral	clem	guct	qalf	fusp	cund
oaks	namp	rimp	qalm	bunt	valt
bres	blad	zalp	bimp	hif	snon
papt	volf	aict	misp	rads	fiot
skad	clcd	lems	flal	arep	sept
trel	crep	smad	zads	swod	pulk
remp	plep	rulf	yefs	alds	noft
vaft	yulp	duft	flep	alks	drev
zets	clav	meks	prev	kemp	prez
plip	snec	hibs	snev	kecs	ploz
clol	flua	kulb	spol	stut	plef
aria	bloz	arif	bubs	alil	clum
luds	triz	twek	smot	qwop	brap
lubs	vuds	skap	prav	clim	blib
spak	qlec	brib	skaq	lumf	qlic
brud	smub	spuv	swiv	wumf	skos
twew	qwud	qwiz	twoc	dwib	zevs
snild	prild	trind	clald	stald	flald
clast	crulp	drost	frulb	grond	frulp
briln	frast	crast	brits	dwulk	scres
twest	slans	spren	spont	trens	trats
qalm	skost	crels	slund	ronds	qralp
pleds	clags	twund	flilm	flams	flalf
lilds	clalk	snust	dwilt	talds	frims
frolk	snant	flot	fruds	hunds	snist
nilds	tunds	molks	smuds	trusp	creas
macts	qlapt	helts	rilns	qolts	qlamp
slets	jelds	mafts	brabs	smens	iilds
talps	frusk	twuds	spelf	cafts	awesk
splef	fafts	pleft	kumps	scalt	slep
cintz	prups	mults	twens	swasp	lults
mucts	yisks	scalf	calbs	sneks	spoqs
yilns	fruft	jafts	zafts	twalp	qlelp
spruv	spriv	sprip	qleqs	bulps	solfs
scron	qlipt	snisc	iusps	aweps	sluct
swefs	snept	dwaft	scros	skuqs	swoqs
struqs	scrint	propts	splins	strind	strids
strolt	prents	scrist	clints	crinds	trents
splict	slands	skints	stravs	drents	drintz
stempt	stemp	spresk	slasts	flonts	iompts
trilns	scruts	aromps	stesks	splulf	slots
clalps	sproqs	profls	qrolfs	crefts	spalds
arempt	sprols	fruits	spraas	scrops	spract
clipts	scrolk	blasks	skends	smalds	blefts
smofts	skults	swults	solalf	dwalds	scalms
sprask	spracs	clomps	swalks	skests	twipts
snelds	dwipts	smalms	scolks	qwilds	spalms
bolfs	swasks	splefs	dwilks	films	slimps
swilms	twimps	smomps	smelps	twulks	skelks

APPENDIX E: ASSESSMENT NW SPELLING LISTS

Study 2

Baseline A ¹		Baseline A ²		Baseline A ³	
List 1	List 2	List 1	List 2	List 1	List 2
fes	nom	dod	tes	toz	zad
dac	sid	tep	lel	olf	yec
gif	zak	rog	pob	vil	rab
vez	vek	fif	gup	nug	yag
zav	ciz	tud	wez	vof	ubs
gwat	flen	bron	dold	fric	relp
wecs	somp	dacs	rilt	plem	yans
glec	brib	clem	guct	blad	zalp
smub	spuv	volf	gict	crep	rulf
gwud	gwiz	plep	duft	flug	kulb
prild	trind	frast	crast	slans	spren
crulp	drost	skost	crels	clags	twund
spriv	srip	jelds	mafts	frusk	twuds
glipt	snisc	fafts	pleft	prups	mults
snept	dwaft	yisks	scalf	fruft	jafts
scrind	scrist	slands	spresk	blopts	strecs
prents	skints	stemp	gromps	struft	plasts
scruts	smalms	scrolk	prolfs	scrift	snonts
sprogs	splefs	skults	frults	scraks	skilts
sprols	smomps	dwipts	blasks	spleks	blelks

APPENDIX F1: SCHOOL LETTERS OF CONSENT

Letter to Principals for Study 1 and Study 2



School of Psychology and Speech Pathology

(date)

Antonette Seiler (Toni)

PhD student

580 Nicholson Sarsfield Rd

Sarsfield

VIC 3875

Dear Principal,

The effectiveness of a computer-supported intervention for children with decoding impairment

My name is Toni Seiler. I am a speech pathologist who has worked with school age children in East Gippsland for many years, and am currently enrolled as a PhD student with Curtin University. As part of my PhD I am conducting research involving children in Year 2. My supervisors for this project are Dr Suze Leitao and Dr Mara Blosfelds from Curtin University in Western Australia. The research will take place here in Bairnsdale, Victoria, and I am inviting local schools to participate.

My area of research focuses on developing an intervention for children with reading impairment, in particular, for their problems with word decoding. There are a number of ways that children read words (eg sight words, getting clues from context, and decoding). Decoding involves looking at each letter, saying the sound for the letters and blending those sounds to read the word. While it is important that children use a range of strategies to read words, developing accurate decoding is a key skill as this enables children (and adults) to read unfamiliar words. Most children with reading difficulties have specific problems in this area, and if this problem persists it impacts on their reading development, particularly in later years.

I am recruiting participants who will be in Year 2 in 2012, who have had previous reading intervention but have persisting word decoding problems, and who have no oral language, cognitive, developmental or sensory impairments.

What does participation in the research project involve?

This research consists of two studies. Study 1 will involve three participants and will occur in the first term of 2012. This will be followed by Study 2 with ten participants in terms 2 and 3 of 2012. All assessment and intervention sessions will occur at the school after discussion with school staff about times and locations.

I would like to invite your school to participate in Study 1 (first term 2012), and Study 2 (second and third terms 2012). This would involve the following steps:

Study 1: February – April 2012

- a) Selection of 3 participants
 - I will meet with you and your staff toward the end of this year (2011), to explain the research and answer any questions you may have.
 - School staff will identify those children in Year 2 in 2012, with persisting word decoding problems. These children will have received a previous intervention for their reading problems, and have no previously identified oral language, cognitive, developmental or sensory impairments.
 - I will deliver a set of information packages to you as principal of the school. Each package describes the research in plain English and contains a consent form, a letter for the child written in Easy English (with picture support), and a stamped addressed envelope. An example package is attached.
 - You, as principal, will provide an information package to the parents/carers of the identified children.
 - The parents/carers will return the consent forms to me. I will contact each parent/carer, discuss any questions they may have, and advise them of the next step.
 - After discussion with school staff I will assess the children to determine if they meet the requirements for Study 1.

- I will discontinue the selection process once I have 3 children who fit the criteria for Study 1.
- b) Pilot intervention
- Each child will receive 3 sessions per week for about 8 weeks during term 1.
 - A report summarizing each child's assessment results and progress will be prepared. Following parent/carer consent this will be provided to the school.

Study 2: April – September 2012

- a) Selection of eight participants
- The same procedure for Study 1 described above will be used to select eight participants for the second study.
- b) Intervention
- Each child will receive 3 sessions per week for about 16 weeks during term 2 and 3.
 - A report summarizing each child's assessment results, progress, and impact on text reading, reading comprehension and spelling, will be prepared. Following parent/carer consent this will be provided to the school.

After completion of the research a presentation describing the outcomes of the research will be provided to staff and parent/carers.

What will happen to the information collected, and is privacy and confidentiality assured?

When data are collected from the children, identifying details will be removed and a code will be given. The list of these codes will be stored in a locked cupboard in my office in Bairnsdale, with a copy at Curtin University. These codes can only be accessed by me and my supervisors (Dr Suze Leitao and Dr Mara Blosfelds). Electronic backup will also occur to increase security. The data will be stored for a minimum period of 5 years, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

The data are stored in this way so that if a participant decides to withdraw I can re-identify the child's data file and destroy it.

The identity of the children and the school will not be disclosed at any time, except in circumstances that require reporting under the Department of Education and Training Child Protection policy, or where the research team is legally required to disclose that information. Participant privacy and the confidentiality of information disclosed by participants, is assured at all other times.

What are the benefits of this research for the child's education and the school?

If your school participates, the results of the language and literacy tests will be provided to each parent/carer and, following parent/carer consent, to the school. They may be used in programme planning for that child.

This research will evaluate a new computer-supported intervention. It is based on similar research which has demonstrated improvements in decoding skills and in reading. It is therefore expected that the child's ability to decode words will improve.

If the results of this research indicate that the intervention produces significant improvement in word decoding skills, the school will be offered use of the program following training sessions for school staff provided by me.

The results of this study will be used to inform teaching and clinical decision making, improve outcomes for children who have difficulty learning how to read words, and add to the evidence base for effective practice for teachers and speech pathologists.

Are there any risks associated with participation?

There are no risks associated with participation. The tasks focus on a specific skill (decoding) that is necessary in developing word reading skills. The activities will be presented on an iPad and will be enjoyable and motivating for the children.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?

Under the Working with Children (Criminal Record Checking) Act 2004, people undertaking research that involves contact with children must undergo a

Working with Children Check. I have attached evidence of my current Working With Children Check.

Is this research approved?

The research has been approved by the Curtin University Human Research Ethics Committee (HR #####). If needed, verification of approval can be obtained either by writing to the Curtin University HREC, c/- Office of Research & Development, Curtin University of Technology, GPO Box U1987 Perth 6845 or by phoning (08) 9266 2784 or by emailing hrec@curtin.edu.au. The research has also met the policy requirements of the Department of Education and Early Childhood Development as indicated in the letter attached.

Who do I contact if I wish to discuss the project further?

Please ring me if you have any questions about the project. I can be contacted on (03) 5156 8309 or by email: antonette.seiler@postgrad.curtin.edu.au. Alternatively you may wish to speak with my supervisor, Dr Suze Leitão who works at Curtin on a Monday/ Wednesday/Thursday and can be contacted on 08 9266 7620 or S.Leitao@Curtin.edu.au. If you wish to speak with an independent person about the conduct of the project, please contact Curtin HREC on (08) 9266 2784..



Toni Seiler (Antonette)	Dr Suze Leitão	Dr Mara Blossfelds
Speech Pathologist	Speech Pathologist	Supervisor, Lecturer
PhD Student	Supervisor, Senior Lecturer	Curtin University
Curtin University	Curtin University	



Human Communication Science

School of

Psychology

**The effectiveness of a computer-supported intervention for children with
decoding impairment**

Principal Consent Form for Study 1 and Study 2, 2012

- I have read and understood this information letter and any risks of this project, as described within it.
- Any questions I may have had have been answered to my satisfaction.
- I am willing for this school to be involved in the research project, as described.
- I understand that participation in the project is entirely voluntary.
- I understand that this school may withdraw its participation at any time without consequence.
- I understand that the results of this research may be published in a journal, provided that the participants or school are not identified in any way.
- I understand that this school will be provided with a copy of the research findings upon completion of the project.

Name of School (please print): _____

Name of School Principal (please print): _____

Signature: _____

Date: ____/____/____

Letter to Principals for Study 2**School of Psychology and Speech Pathology****(date)****Antonette Seiler (Toni)**

PhD student

580 Nicholson Sarsfield Rd

Sarsfield

VIC 3875

Dear Principal,

The effectiveness of a computer-supported intervention for children with decoding impairment

My name is Toni Seiler. I am a speech pathologist who has worked with school age children in East Gippsland for many years, and am currently enrolled as a PhD student with Curtin University. As part of my PhD I am conducting research involving children in Year 2. My supervisors for this project are Dr Suze Leitao and Dr Mara Blosfelds from Curtin University in Western Australia. The research will take place here in Bairnsdale, Victoria, and I am inviting local schools to participate.

My area of research focuses on developing an intervention for children with reading impairment, in particular, for their problems with word decoding. There are a number of ways that children read words (eg sight words, getting clues from context, and decoding). Decoding involves looking at each letter, saying the sound for the letters and blending those sounds to read the word. While it is important that children use a range of strategies to read words, developing accurate decoding is a key skill as this enables children (and adults) to read unfamiliar words. Most children with reading difficulties have specific problems in this area, and if this problem persists it impacts on their reading development, particularly in later years.

I am recruiting participants who will be in Year 2 in 2012, who have had previous reading intervention but have persisting word decoding problems, and who have no oral language, cognitive, developmental or sensory impairments.

What does participation in the research project involve?

This research consists of two studies. Study 1 will involve three participants and will occur in the first term of 2012. This will be followed by Study 2 with ten participants in terms 2 and 3 of 2012. All assessment and intervention sessions will occur at the school after discussion with school staff about times and locations.

I would like to invite your school to participate in Study 2 (second and third terms 2012). This would involve the following steps:

Study 2: April – September 2012

- a) Selection of eight participants (April 2012)
 - I will meet with you and your staff early in first term 2012 to explain the research and answer any questions you may have.
 - School staff will identify those children in Year 2 in 2012, with persisting word decoding problems. These children will have received a previous intervention for their reading problems, and have no previously identified oral language, cognitive, developmental or sensory impairments.
 - I will deliver a set of information packages to you as principal of the school. Each package describes the research in plain English and contains a consent form, a letter for the child written in Easy English (with picture support), and a stamped addressed envelope. An example package is attached.
 - You, as principal, will provide an information package to the parents/carers of the identified children.
 - The parents/carers will return the consent forms to me. I will contact each parent/carer, discuss any questions they may have, and advise them of the next step.
 - After discussion with school staff I will assess the children to determine if they meet the requirements for Study 1.

- I will discontinue the selection process once I have eight children who fit the criteria for Study 2.
- b) Intervention
- Each child will receive 3 sessions per week for about 16 weeks during term 2 and 3.
 - A report summarizing each child's assessment results, progress, and impact on text reading, reading comprehension and spelling, will be prepared. Following parent/carer consent this will be provided to the school.

After completion of the research a presentation describing the outcomes of the research will be provided to staff and parent/carers.

What will happen to the information collected, and is privacy and confidentiality assured?

When data are collected from the children, identifying details will be removed and a code will be given. The list of these codes will be stored in a locked cupboard in my office in Bairnsdale, with a copy at Curtin University. These codes can only be accessed by me and my supervisors (Dr Suze Leitao and Dr Mara Blosfelds). Electronic backup will also occur to increase security. The data will be stored for a minimum period of 5 years, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

The data are stored in this way so that if a participant decides to withdraw I can re-identify the child's data file and destroy it.

The identity of the children and the school will not be disclosed at any time, except in circumstances that require reporting under the Department of Education and Training Child Protection policy, or where the research team is legally required to disclose that information. Participant privacy and the confidentiality of information disclosed by participants, is assured at all other times.

What are the benefits of this research for the child's education and the school?

If your school participates, the results of the language and literacy tests will be provided to each parent/carer and, following parent/carer consent, to the school. They may be used in programme planning for that child.

This research will evaluate a new computer-supported intervention. It is based on similar research which has demonstrated improvements in decoding skills and in reading. It is therefore expected that the child's ability to decode words will improve.

If the results of this research indicate that the intervention produces significant improvement in word decoding skills, the school will be offered use of the program following training sessions for school staff provided by me.

The results of this study will be used to inform teaching and clinical decision making, improve outcomes for children who have difficulty learning how to read words, and add to the evidence base for effective practice for teachers and speech pathologists.

Are there any risks associated with participation?

There are no risks associated with participation. The tasks focus on a specific skill (decoding) that is necessary in developing word reading skills. The activities will be presented on an iPad and will be enjoyable and motivating for the children.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?

Under the Working with Children (Criminal Record Checking) Act 2004, people undertaking research that involves contact with children must undergo a Working with Children Check. I have attached evidence of my current Working With Children Check.

Is this research approved?

The research has been approved by the Curtin University Human Research Ethics Committee (HR #####). If needed, verification of approval can be obtained

either by writing to the Curtin University HREC, c/- Office of Research & Development, Curtin University of Technology, GPO Box U1987 Perth 6845 or by phoning (08) 9266 2784 or by emailing hrec@curtin.edu.au. The research has also met the policy requirements of the Department of Education and Early Childhood Development as indicated in the letter attached.

Who do I contact if I wish to discuss the project further?

Please ring me if you have any questions about the project. I can be contacted on (03) 5156 8309 or by email: antonette.seiler@postgrad.curtin.edu.au. Alternatively you may wish to speak with my supervisor, Dr Suze Leitão who works at Curtin on a Monday/ Wednesday/Thursday and can be contacted on 08 9266 7620 or S.Leitao@Curtin.edu.au. If you wish to speak with an independent person about the conduct of the project, please contact Curtin HREC on (08) 9266 2784.



Toni Seiler (Antonette)
Speech Pathologist
PhD Student
Curtin University

Dr Suze Leitão
Speech Pathologist
Supervisor, Senior Lecturer
Curtin University

Dr Mara Blosfelds
Supervisor, Lecturer
Curtin University



Human Communication Science
School of
Psychology

**The effectiveness of a computer-supported intervention for children with
decoding impairment**

Principal Consent Form Study 2, 2012

- I have read and understood this information letter and any risks of this project, as described within it.
- Any questions I may have had have been answered to my satisfaction.
- I am willing for this school to be involved in the research project, as described.
- I understand that participation in the project is entirely voluntary.
- I understand that this school may withdraw its participation at any time without consequence.
- I understand that the results of this research may be published in a journal, provided that the participants or school are not identified in any way.
- I understand that this school will be provided with a copy of the research findings upon completion of the project.

Name of School (please print): _____

Name of School Principal (please print): _____

Signature: _____

Date: ____/____/____

APPENDIX F2: PARENT LETTERS OF CONSENT

Parent letter Study 1 and Study 2



School of Psychology and Speech Pathology

(date)

Antonette Seiler (Toni)

PhD student

580 Nicholson Sarsfield Rd

Sarsfield

VIC 3875

Dear Parent/Carer

The effectiveness of a computer-supported intervention for children with decoding impairment

My name is Toni Seiler. I am a speech pathologist who has worked with school age children for many years. I have a special interest in children who have reading difficulties, in particular, problems with decoding words. Decoding, or being able to *sound out* words, is one of the important ways that children read words (word identification), and most children with reading difficulties have problems in this area.

As part of my PhD I am developing a new computer-supported intervention for children who are having difficulties with decoding and reading words. The first part of my project (Study 1) will develop the intervention and pilot it on a small group of children. The second phase (Study 2) will use this new intervention with a larger number of children to determine if the intervention significantly improves decoding skills and if, as a result of this, other areas are improved, such as phonological awareness, reading, reading comprehension and spelling. So, my aim is to work with children who have difficulties reading words, and provide them with an intensive intervention to start the process of recovery.

My supervisors for this project are Dr Suze Leitao and Dr Mara Blosfelds from Curtin University in Western Australia. The project itself will take place here in Bairnsdale, Victoria.

What does participation in the research project involve?

I am inviting your child to take part in one of the Studies. Study 1 will occur during term 1 of 2012, and Study 2 during term 2 and 3. You have received this letter from your child's school because the principal has identified him/her as having ongoing reading difficulties after receiving an intervention such as reading recovery.

If you choose to take part, I will first assess your child's reading, language and nonverbal skills, to see if their scores fit the requirements for Study 1 of the research. This testing should take about 45 minutes and I will provide you with a report on your child's skills. If your child is selected for Study 1 they will be seen three times per week for about 8 weeks during term 1. If your child is not selected for Study 2, they may be selected for Study 2 where they will be seen three times per week during term 2 and 3.

I will be visiting your child's school to carry out all testing and intervention sessions in a familiar environment for your child.

Does my child have to take part?

No. Participation in this research project is entirely voluntary. If you do not want your child to take part in the project, or your child does not wish to take part, then they do not have to. You should make this decision freely and I will respect your decision.

I have included a letter for you to discuss the project with your child. If you are happy for your child to participate in my research then please talk through this letter with them and have your child indicate that he/she is happy to take part in the project.

What if either of us was to change our mind?

I need to know by the end of February 2012 if you decide to participate in my project. Once you and your child have decided to participate, either of you can change your mind at any time. Information collected from your child will be held confidentially for a minimum 5-year storage period, however you may decide to

withdraw your child from the study at any time during this period. If you decide to withdraw your child from the study then all contributions made to the project will be destroyed unless explicitly agreed to by you.

If the project has already been published at the time you and your child decide to withdraw, your child's contribution that was used in reporting the project can not be removed from the publication.

Your decision about whether to participate in this research or not will not affect your family's relationship with your child's teacher or school.

What will happen to the information collected, and is privacy and confidentiality assured?

When data is collected from your child his/her name and identifying details will be removed and a code will be given. The list of these codes will be stored in a locked cupboard in my office in Bairnsdale, with a copy at Curtin University. These codes can only be accessed by me and my supervisors (Dr Suze Leitao and Dr Mara Blosfelds). Electronic backup will also occur to increase security. The data will be stored for a minimum period of 5 years, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

The data is stored in this way so that if you decide to participate in the project, and then withdraw I can re-identify your child's data and destroy it.

Your child's identity and the identity of the school will not be disclosed at any time, except in circumstances that require reporting under the Department of Education and Training Child Protection policy, or where the research team is legally required to disclose that information. Participant privacy, and the confidentiality of information disclosed by participants, is assured at all other times.

What are the benefits of this research for my child's education?

If you give permission, the results of the language and literacy tests will be provided to your child's school for use in programme planning and a summary of your child's performance can also be provided to you.

This new intervention method is based on similar research which has demonstrated improvement in decoding skills. It is expected that your child's decoding and word reading skills will be improved.

The results of this study will be used to inform teaching and clinical decision making, improve outcomes for children who have difficulty learning how to read words, and add to the evidence base for effective practice for teachers and speech pathologists.

Are there any risks associated with participation?

There are no risks associated with participation. The tasks focus on a specific skill that is necessary in developing word reading skills (decoding). They will be presented on an iPad, and will be enjoyable and motivating for the children.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?

Under the Working with Children (Criminal Record Checking) Act 2004, people undertaking research that involves contact with children must undergo a Working with Children Check. I have provided the Principal of your child's school with evidence of my current Working With Children Check.

Is this research approved?

The research has been approved by the Curtin University Human Research Ethics Committee (HR #####). If needed, verification of approval can be obtained either by writing to the Curtin University HREC c/- Office of Research & Development, Curtin University of Technology, GPO Box U1987 Perth 6845 or by phoning 9266 2784 or by emailing hrec@curtin.edu.au. The research has also met the policy requirements of the Department of Education and Early Childhood Development as indicated in the letter attached.

Who do I contact if I wish to discuss the project further?

Please ring me if you have any questions about the project. I can be contacted on 5156 8309 or by email: antonette.seiler@postgrad.curtin.edu.au. Alternatively you may wish to speak with my supervisor, Dr Suze Leitão who also works at Curtin on a Monday/Wednesday/Thursday and can be contacted on 08 9266 7620 or S.Leitao@Curtin.edu.au. If you wish to speak with an independent person about the conduct of the project, please contact Curtin HREC.

How does my child become involved?

Please ensure that you:

- discuss what it means to take part in the project with your child before you both make a decision; and
- take up my invitation to ask any questions you may have about the project.
- Once all questions have been answered to your satisfaction, and you and your child are both willing for him/her to become involved, please complete the **Consent Form** on the following page, and return it to me in the stamped addressed envelope by the **end of February 2012**.

This project information letter is for you to keep.



Toni Seiler (Antonette)
Speech Pathologist
PhD Student
Curtin University

Dr Suze Leitão
Speech Pathologist
Supervisor, Senior Lecturer
Curtin University

Dr Mara Blosfelds
Supervisor, Lecturer
Curtin University



Human Communication Science
School of Psychology

The effectiveness of a computer-supported intervention for children with decoding impairment

Parent Consent Form Study 1 and Study 2

- I have read this document, or have had this document explained to me in a language I understand, and I understand the aims, procedures, and risks of this project, as described within it.
- For any questions I may have had, I have taken up the invitation to ask those questions, and I am satisfied with the answers I received.
- I am willing for my child to become involved in the research project, as described.
- I have discussed with my child what it means to participate in this project, and he/she has indicated a willingness to take part.
- I understand that both my child and I are free to withdraw that participation at any time within 5 years of project completion, without affecting the family's relationship with my child's teacher or my child's school.
- I give my permission for the contribution that my child makes to this research to be used in conference talks and published in a journal, provided that my child or the school is not identified in any way.
- I understand that a summary of findings from the research will be made available to me and my child upon its completion.

Please also tick boxes to give consent for the following:

I give permission for my child's speech and language assessment data to be released to his/her school.

I would like to be provided with a summary report with my child's results.

Name of Child and date of birth (printed): _____

Name of Parent/Carer (printed): _____

Signature of Parent: _____

Date: / /

Contact address (to post results if required):

Contact telephone number: _____

Language spoken at home: _____

Please circle yes or no for the following questions:

Has your child ever had a hearing impairment? Yes No

Has your child ever been diagnosed with a language impairment? Yes No

Has your child ever been diagnosed with an intellectual impairment? Yes No

Has your child ever been diagnosed with developmental delay? Yes No

Has your child ever had a head injury? Yes No

Parent letter Study 2



School of Psychology and Speech Pathology
(date)

Antonette Seiler (Toni)

PhD student
580 Nicholson Sarsfield Rd
Sarsfield
VIC 3875

Dear Parent/Carer

**The effectiveness of a computer-supported intervention for children with
decoding impairment**

My name is Toni Seiler. I am a speech pathologist who has worked with school age children for many years. I have a special interest in children who have reading difficulties, in particular, problems with decoding words. Decoding, or being able to *sound out* words, is one of the important ways that children read words (word identification), and most children with reading difficulties have problems in this area.

As part of my PhD I am developing a new computer-supported intervention for children who are having difficulties with decoding and reading words. The first part of my project (Study 1) will develop the intervention and pilot it on a small group of children. The second phase (Study 2) will use this new intervention with a larger number of children to determine if the intervention significantly improves decoding skills and if, as a result of this, other areas are improved, such as phonological awareness, reading, reading comprehension and spelling. So, my aim is to work with children who have difficulties reading words, and provide them with an intensive intervention to start the process of recovery.

My supervisors for this project are Dr Suze Leitao and Dr Mara Blosfelds from Curtin University in Western Australia. The project itself will take place here in Bairnsdale, Victoria.

What does participation in the research project involve?

I am inviting your child to take part in the second phase of my research project (Study 2) during second and third term of 2012. You have received this letter from your child's school because the principal has identified him/her as having ongoing reading difficulties after receiving an intervention such as reading recovery.

If you choose to take part in the study, I will first assess your child's reading, language and nonverbal skills, to see if their scores fit the requirements for Study 2 of the research. This testing should take about 45 minutes and I will provide you with a report on your child's skills. If your child is selected for Study 2 they will be seen three times per week for 2 terms.

I will be visiting your child's school to carry out all testing and intervention sessions in a familiar environment for your child.

Does my child have to take part?

No. Participation in this research project is entirely voluntary. If you do not want your child to take part in the project, or your child does not wish to take part, then they do not have to. You should make this decision freely and I will respect your decision.

I have included a letter for you to discuss the project with your child. If you are happy for your child to participate in my research then please talk through this letter with them and have your child indicate that he/she is happy to take part in the project.

What if either of us was to change our mind?

I need to know by the end of March 2012 if you decide to participate in my project. Once you and your child have decided to participate, either of you can change your mind at any time. Information collected from your child will be held confidentially for a minimum 5-year storage period, however you may decide to withdraw your child from the study at any time during this period. If you decide to

withdraw your child from the study then all contributions made to the project will be destroyed unless explicitly agreed to by you.

If the project has already been published at the time you and your child decide to withdraw, your child's contribution that was used in reporting the project can not be removed from the publication.

Your decision about whether to participate in this research or not will not affect your family's relationship with your child's teacher or school.

What will happen to the information collected, and is privacy and confidentiality assured?

When data is collected from your child his/her name and identifying details will be removed and a code will be given. The list of these codes will be stored in a locked cupboard in my office in Bairnsdale, with a copy at Curtin University. These codes can only be accessed by me and my supervisors (Dr Suze Leitao and Dr Mara Blosfelds). Electronic backup will also occur to increase security. The data will be stored for a minimum period of 5 years, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

The data is stored in this way so that if you decide to participate in the project, and then withdraw I can re-identify your child's data and destroy it.

Your child's identity and the identity of the school will not be disclosed at any time, except in circumstances that require reporting under the Department of Education and Training Child Protection policy, or where the research team is legally required to disclose that information. Participant privacy, and the confidentiality of information disclosed by participants, is assured at all other times.

What are the benefits of this research for my child's education?

If you give permission, the results of the language and literacy tests will be provided to your child's school for use in programme planning and a summary of your child's performance can also be provided to you.

This new intervention method is based on similar research which has demonstrated improvement in decoding skills. It is expected that your child's decoding and word reading skills will be improved.

The results of this study will be used to inform teaching and clinical decision making, improve outcomes for children who have difficulty learning how to read

words, and add to the evidence base for effective practice for teachers and speech pathologists.

Are there any risks associated with participation?

There are no risks associated with participation. The tasks focus on a specific skill that is necessary in developing word reading skills (decoding). They will be presented on an iPad, and will be enjoyable and motivating for the children.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?

Under the Working with Children (Criminal Record Checking) Act 2004, people undertaking research that involves contact with children must undergo a Working with Children Check. I have provided the Principal of your child's school with evidence of my current Working With Children Check.

Is this research approved?

The research has been approved by the Curtin University Human Research Ethics Committee (HR #####). If needed, verification of approval can be obtained either by writing to the Curtin University HREC c/- Office of Research & Development, Curtin University of Technology, GPO Box U1987 Perth 6845 or by phoning 9266 2784 or by emailing hrec@curtin.edu.au. The research has also met the policy requirements of the Department of Education and Early Childhood Development as indicated in the letter attached.

Who do I contact if I wish to discuss the project further?

Please ring me if you have any questions about the project. I can be contacted on 5156 8309 or by email: antonette.seiler@postgrad.curtin.edu.au. Alternatively you may wish to speak with my supervisor, Dr Suze Leitão who also works at Curtin on a Monday/Wednesday/Thursday and can be contacted on 08 9266 7620 or S.Leitao@Curtin.edu.au. If you wish to speak with an independent person about the conduct of the project, please contact Curtin HREC.

How does my child become involved?

Please ensure that you:

- discuss what it means to take part in the project with your child before you both make a decision; and
- take up my invitation to ask any questions you may have about the project.
- Once all questions have been answered to your satisfaction, and you and your child are both willing for him/her to become involved, please complete the **Consent Form** on the following page, and return it to me in the stamped addressed envelope by the **end of March 2012**.

This project information letter is for you to keep.



Toni Seiler (Antonette)
Speech Pathologist
PhD Student
Curtin University

Dr Suze Leitão
Speech Pathologist
Supervisor, Senior Lecturer
Curtin University

Dr Mara Blosfelds
Supervisor, Lecturer
Curtin University



Human Communication Science

School of

Psychology

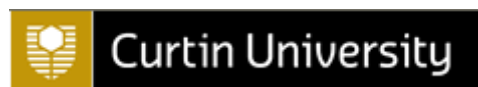
**The effectiveness of a computer-supported intervention for children with
decoding impairment**

Parent Consent Form Study 2, 2012

- I have read this document, or have had this document explained to me in a language I understand, and I understand the aims, procedures, and risks of this project, as described within it.
- For any questions I may have had, I have taken up the invitation to ask those questions, and I am satisfied with the answers I received.
- I am willing for my child to become involved in the research project, as described.
- I have discussed with my child what it means to participate in this project, and he/she has indicated a willingness to take part.
- I understand that both my child and I are free to withdraw that participation at any time within 5 years of project completion, without affecting the family's relationship with my child's teacher or my child's school.
- I give my permission for the contribution that my child makes to this research to be used in conference talks and published in a journal, provided that my child or the school is not identified in any way.
- I understand that a summary of findings from the research will be made available to me and my child upon its completion.

Please also tick boxes to give consent for the following:

APPENDIX F3: PARTICIPANT LETTER



Human Communication Science
School of
Psychology

Hello,



My name is Toni Seiler. I am a speech pathologist.
I am working out ways to help you get better at reading words.



Would you like to be part of my project next year?

I would see you 3 times a week.



I will come to your school, and we would work together in a quiet room in your school. Each sessions will be about 20 minutes.



We would do activities on an iPad.

- Some days we will work with words.
- And other days we will do activities where you talk about pictures.

You can talk to your parents/carers about this. You can ask them questions. And then, let them know if you would like to do these activities with me.

Toni Seiler

APPENDIX F4: PLAIN ENGLISH RESEARCH DESCRIPTION

School of Psychology and Speech Pathology

1st November 2011**Description of research for school staff and families****“The effectiveness of a computer-supported intervention for children with word decoding impairment”**Overview

This research aims to develop a computer-supported intervention for children who have difficulty reading words (word identification impairment). It will involve two studies in 2012. During the first study, the new intervention will be developed and piloted with 3 children. The second study will evaluate the effectiveness of the intervention on word reading and other literacy areas such as phonological awareness, text reading, reading comprehension and spelling.

Background information

About 35% of children have reading skills below the expected level, and most of these children have impaired word reading skills. There are a number of ways to read a word, for example as a ‘sight’ word, using context, knowing a similar looking word, and decoding. While it is important to use a range of strategies, decoding skills play a key role in developing automatic and fluent reading. Decoding involves looking at each letter in the word, sounding out the word and blending the sounds to read the word. This skill enables a reader to work out unfamiliar words, especially when the subject matter is new, as is the case when children are required to read new information independently. Accurate word reading is important. It is the first process in reading and therefore forms the basis of reading comprehension. Most children

who have problems with word reading continue to have reading difficulties throughout their school and adult years, so it is important to intervene when they are still young.

Over the past 20 years, most interventions have focused on improving phonological and phonemic awareness, that is, increasing the child's awareness of sounds in words, breaking words into sounds and blending sounds to make words. However, in most of these interventions about 25% of children do not make significant improvement.

More recent research has highlighted the importance of a focus on decoding skills. These involve looking at the letters (the orthography), sounding out and accurately blending sounds to read words (phonological recoding), and becoming more automatic in recognition of bigger word chunks (part and whole word "maps"). Training these skills may lead to improvements in all children with impaired word reading.

Aims of this research

The aim of this research is to:

- Develop an intervention that focuses on decoding (increasing the child's ability to process letters and letter patterns; orthographic processing). The intervention will be presented on computers (iPad) as this will enable a greater number of practice words at each session, will be motivating for the children, and will be easier for other researchers to repeat.
- Trial the intervention on a small number of children first, so that the procedures can be fine-tuned.
- Evaluate how effective the intervention is at increasing the child's ability to accurately decode unfamiliar words.

- And finally, to see if improvements in decoding also result in improved text reading, reading comprehension and spelling.

Method

There will be two studies during 2012.

Study 1 in 1st term will pilot the intervention with 3 children.

Study 2 during 2nd and 3rd term will evaluate the intervention with eight children.

Approval for this research was granted from the Human Research Ethics Committee Curtin University on 7th Sept 2011 (approval number HR 111/2011), and from the Department of Education and Early Childhood Development on 24th Oct 2011 (application number 2011_001308). The two studies will proceed as follows:

- The principals at each school will be invited to have their school participate. Staff will be provided with information, and the opportunity to meet with me to discuss the research.
- Staff will identify children to the principal if they meet the following criteria: in Year 2 during 2012, have received previous intervention for reading, but have continuing word reading problems. These children will have no other language, intellectual or developmental disorders.
- The principal will provide the parent/carers of these children with an information package that invites the family to consider having their child participate in the research.
- Parent/carers will return the consent form to me, and I will phone to discuss the next steps and answer any questions.
- I will assess each child at the school so that I can select the children who meet the requirements for each study.
- The children who are selected will receive a therapy session, three times per week. For Study 1 this will occur in term 1, and for Study 2 in terms 2 and 3 (2012).
- A report summarising the results of the assessments will be provided to the parent/carers of each child, and with parent/carer permission, to the school.

- At completion of the research, a presentation will be offered to staff, families and interested people.
- If this study shows that the intervention is effective, the school will be offered use of the program with staff training provided by me.

I am very happy to be contacted to discuss any aspect of this research.

A handwritten signature in cursive script that reads "Toni Seiler".

Toni Seiler (Antonette)

Address: 580 Nicholson Sarsfield Rd, Sarsfield, VIC 3875

Phone: 03 5156 8309

Email: antonette.seiler@postgrad.curtin.edu.au

APPENDIX G: CURTIN UNIVERSITY ETHICS APPROVAL



Memorandum

To	Dr Suze Leitao, School of Psychology and Speech Pathology
From	A/Prof Stephan Millett, Chair, Human Research Ethics Committee
Subject	Protocol Approval HR 111/2011
Date	7 September 2011
Copy	Antonette Seiler, School of Psychology and Speech Pathology Dr Mara Blossfelds, School of Psychology and Speech Pathology Graduate Studies Officer, Faculty of Health Sciences

Office of Research and Development

Human Research Ethics Committee

TELEPHONE 9266 2784

FACSIMILE 9266 3793

EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Committee (HREC) for the project titled "*The effectiveness of a computer-supported intervention for children with word decoding impairment*". Your application has been reviewed by the HREC and is **approved**.

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 111/2011**. Please quote this number in any future correspondence.
- Approval of this project is for a period of twelve months **06-09-2011 to 06-09-2012**. To renew this approval a completed Form B (attached) must be submitted before the expiry date **06-09-2012**.
- If you are a Higher Degree by Research student, data collection must not begin before your Application for Candidacy is approved by your Faculty Graduate Studies Committee.
- The following standard statement **must be** included in the information sheet to participants:

This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number HR 111/2011). The Committee is comprised of members of the public, academics, lawyers, doctors and pastoral carers. Its main role is to protect participants. If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845 or by telephoning 9266 2784 or by emailing hrec@curtin.edu.au.

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **FORM B** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development:

When the project has finished, or

- If at any time during the twelve months changes/amendments occur, or
- If a serious or unexpected adverse event occurs, or
- 14 days prior to the expiry date if renewal is required.
- An application for renewal may be made with a Form B three years running, after which a new application form (Form A), providing comprehensive details, must be submitted.

Yours sincerely,

Associate Professor Stephan Millett
Chair Human Research Ethics Committee

**APPENDIX H: VICTORIAN DEPARTMENT OF EDUCATION ETHICS
APPROVAL**



**Department of Education and
Early Childhood Development**

Office for Policy, Research and Innovation

2 Treasury Place
East Melbourne, Victoria 3002
Telephone: +61 3 9637 2000
DX 210083
GPO Box 4367
Melbourne, Victoria 3001

2011_001308

Mrs Antonette Seiler
580 Nicholson Sarsfield Road
BAIRNSDALE 3875

Dear Mrs Seiler

Thank you for your application of 12 September 2011 in which you request permission to conduct research in Victorian government schools and/or early childhood settings titled *The effectiveness of a computer-supported intervention targeting orthographic processing for children with impaired word identification*.

I am pleased to advise that on the basis of the information you have provided your research proposal is approved in principle subject to the conditions detailed below.

1. The research is conducted in accordance with the final documentation you provided to the Department of Education and Early Childhood Development.
2. Separate approval for the research needs to be sought from school principals and/or centre directors and this is to be supported by the DEECD approved documentation and the letter of approval from a relevant and formally constituted Human Research Ethics Committee.
3. The project is commenced within 12 months of this approval letter and any extensions or variations to your study, including those requested by an ethics committee must be submitted to the Department of Education and Early Childhood Development for its consideration before you proceed.
4. As a matter of courtesy, you advise the relevant Regional Director of the schools or early childhood settings that you intend to approach. An outline of your research and a copy of this letter should be provided to the Regional Director.
5. You acknowledge the support of the Department of Education and Early Childhood Development in any publications arising from the research.
6. The Research Agreement conditions, which include the reporting requirements at the conclusion of your study, are upheld. A reminder will be sent for reports not submitted by the study's indicative completion date.
7. If DEECD has commissioned you to undertake this research, the responsible Branch/Division will need to approve any material you provide for publication on the Department's Research Register.

I wish you well with your research study. Should you have further enquiries on this matter, please contact Kathleen Nolan, Research Officer, Education Policy and Research, by telephone on (03) 9637 3244 or by email at nolan.kathleen.j@edumail.vic.gov.au.

Yours sincerely

A handwritten signature in black ink that reads "Elizabeth Hartnell-Young". The signature is written in a cursive style with a large initial 'E'.

Dr Elizabeth Hartnell-Young
Group Manager
Education Policy and Research

24/10/2011

enc

**APPENDIX I: REPORT FOR THE VICTORIAN DEPARTMENT OF
EDUCATION**

Research in Schools: Final Report

1st June 2015

Project ID number: 2011_001308

Research Title: The effectiveness of a computer-supported intervention targeting phonological recoding and orthographic processing for children with impaired word identification

Author/s Antonette Seiler (Toni)

Contact details: Phone: 03 5156 8309
Email: antonette.seiler@postgrad.curtin.edu.au

Contact details to be published:
On completion of the thesis contact details and a link to the thesis will be provided.

Research abstract:

This programme of research designed, developed, trialled, and evaluated a reading intervention targeting phonological recoding and orthographic processing for children with persistent word reading impairment. Eight otherwise typically developing Year 2 participants with reading delay despite previous intervention, were randomly assigned to two groups in a single subject multiple-treatment cross-over design study. The results of group and individual analyses indicated that all participants made significant gains in decoding skills (measured by researcher-developed and standardised assessments of nonword reading) with trends for gains in measures of word reading.

Summary/Discussion of Findings:

This report summarises the research that was undertaken for a PhD thesis which investigated an iPad-delivered reading intervention for children with persistent reading delay. The research was conducted in three stages. The first stage involved the development of an evidence-based intervention (Decoding Intervention) which focused on word reading skills and targeted phonological recoding and orthographic

processing within individual 1:1 sessions. The intervention targets were matched to the skill level of each child and involved items (words and nonwords) with 1:1 letter sound correspondence, starting with 2-letter and progressing to 6-letter items. The second stage trialled the intervention on a small number of children (see Seiler, Leitão, & Blosfelds, 2013 for details) and the third stage used a robust single subject design to address the three research questions:

Does the Decoding Intervention (1) increase nonword reading skills; (2) result in gains on standardized measures of a range of reading related skills (nonword reading accuracy, word and nonword reading efficiency, text reading, and reading comprehension) and spelling; and (3) do pre-intervention scores on language, intellectual and phonological processing skills influence the outcome measures of nonword reading, text reading, reading comprehension and nonword spelling?

The participants were eight typically developing Year 2 children with persistent reading impairment despite receiving previous reading intervention (e.g., Reading Recovery). After measuring baseline performance, half of the children received the Decoding intervention (15 sessions) first, followed by a Language intervention (which did not target reading; also 15 sessions), while the other children received the Decoding intervention *after* the Language intervention.

The results demonstrated strong support for the hypothesis relating to the first research question. Both groups made significant gains in nonword reading following the Decoding Intervention. Furthermore, the cross-over design showed that skills were maintained two months following the Decoding Intervention for the group who received this treatment first. The individual analyses showed that all participants demonstrated significant gains in nonword reading even though there were differences in the number of sessions it took to master accurate phonological recoding. These results indicate that the single component Decoding Intervention was successful in teaching skills which support progression from the partial alphabetic to the full alphabetic phase of reading development.

Partial support for the second research question was demonstrated. The group analyses showed that both groups made significant gains on standardised measures of nonword reading accuracy and efficiency, with no gains on measures of word reading efficiency, text reading and comprehension, or nonword spelling. The individual analyses augmented the group analyses by revealing that five of the eight participants made clinically significant gains on measures of word reading efficiency,

and four on measures of text reading accuracy and comprehension, suggesting that generalisation to word reading skills may have occurred for some children.

Examination of pre-intervention decoding errors suggested that delays in orthographic knowledge may have reduced generalisation to word reading, that is, prior to intervention, all participants had mastered letter-sound knowledge for consonants and short vowel letters but none had mastered letter-sound knowledge of vowel spelling patterns (such as “ea, ow, ai). This means that though the Decoding Intervention resulted in significant gains in use of phonological recoding (decoding skills) for all children, participants were unable to apply this skill to the wide range of spelling patterns that exist in measures of word and text reading.

The individual analyses related to the third research question concluded that the relationship between pre-intervention profiles and responses to intervention was a complex one. For example, a weak response to intervention (i.e., comparatively small effect sizes) occurred in children with strong pre-intervention profiles (but with significant “b/d” confusion, or a slow decoding style) as well as a child with significant delays in all profile areas. It suggests that reading interventions for this population need to be specifically targeted to the individual needs of each child.

Additional analyses indicated that, compared to other interventions targeting decoding skills, the Decoding Intervention achieved significant results in a comparatively shorter time frame: two hours in total (approximately seven minutes per session) for the Decoding Intervention compared to about 12 hours in total for other Tier 3 interventions (Denton et al., 2013; Torgesen, 2001).

Generalisability and significance for the settings in your study or for the Victoria Government Department of Education and Early Childhood:

The findings of the research in this thesis have a number of **implications** for the Victorian Government Department of Education and Early Childhood Education, and for the design of interventions for children with persistent reading impairment in general. Firstly, the results suggest that the Decoding Intervention has the potential to boost foundation skills that are required for accurate sight word development and text reading fluency. Secondly, the efficiency and iPad delivery of the Decoding Intervention means that (a) it may be incorporated into a child’s intervention program with minimal disruption to the classroom routine, (b) it is a motivating activity for children, and (c) the computerised recording of response accuracy and

automated presentation of materials enables fidelity in delivery. Third, this intervention has the potential to be effective for all children with decoding impairment, as irrespective of pre-intervention profile, as all participants demonstrated a significant response to intervention. Finally, as it was a single component intervention (which resulted in unambiguous improvement in specific reading skills), following in-depth assessment, this intervention may be used selectively to match the specific needs of the child.

This research project suggests that the Decoding Intervention could be an efficient evidence-based intervention that targets an essential foundation reading skill (decoding) for children with severe and persistent reading delay. Future investigations are needed to examine (a) the effectiveness of the Decoding Intervention in teaching orthographic knowledge of vowel spelling patterns, and (b) delivery within more realistic settings, that is, with larger numbers and delivered by trained school support staff.

Acknowledgements

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Publications and conference presentations:

- Seiler, T., Leitão, S., & Blosfelds, M. (2013). *The effectiveness of a computer-supported intervention targeting orthographic processing and phonological recoding for children with impaired word identification*. *Journal of Clinical Practice in Speech-Language Pathology*, 15(1), 13-18.
- Speech Pathology Australia Conference 2013: Seiler, T., Leitão, S., & Blosfelds, M. (2013). *The effectiveness of a computer-supported intervention targeting orthographic processing and phonological recoding for children with impaired word identification: A preliminary study*.
- Royal College of Speech Language Therapists Conference 2014 (UK): Seiler, T., Leitão, S., & Blosfelds, M. (2014). *The effectiveness of an iPad-delivered*

intervention targeting phonological recoding and orthographic processing for children with persistent word reading impairment.

- ARC Reading and Spelling Conference 2015 (Macquarie University). Seiler, T., Leitão, S., & Blosfelds, M. *The effectiveness of an intervention targeting phonological recoding and orthographic processing for children with persistent word reading impairment.*

APPENDIX J: PROCEDURES MANUAL

Introduction

This manual describes the procedures for the iPad-delivered intervention which was designed, developed, trialled, and evaluated in the programme of research for this thesis. The research involved two studies: Study 1 trialled the Decoding Intervention, and Study 2 evaluated the intervention. The procedures outlined in this manual relate to those used in Study 2 (i.e., they incorporate the modifications made after Study 1).

The computer program, *WordDriver*, manages six components of the iPad-delivered intervention materials. These components include:

- The management module: the Loader Page
- Three intervention modules: the L-Plate, P-Plate, and D-Plate
- Two assessment modules: T-Plate, and S-Plate

Procedures

The procedures cover:

- The first session: using the Loader Page, and introducing the child to the research
- The T-Plate
- The S-Plate
- L-Plate
- P-Plate
- D-Plate

The first session

The aim of the first session is to introduce the child to the research, and to complete the first Assessment NW List (Test Drive).

Using the Loader Page

Each participant and the researcher were assigned a “number plate” which refers to their unique identifier (e.g., AMS-001). To select each module the researcher:

- Selects the appropriate number plate which loads the current settings for that participant (or for demonstration purposes the researcher selects their own number plate).
- Selects the module (e.g., T-Plate, S-Plate, P-Plate etc.).
 - For all sessions, the T-Plate is selected first. Delivery of each of the 39 Assessment NW Lists is programmed to occur automatically.
 - To load the Decoding Intervention modules, first select the module (L-Plate, P-Plate, D-Plate), then the level (2-letter, 3-letter etc.).
- For all modules the participant touches their number plate to load the selected module.

Introducing the participant to the research

The child is seated at a table with the iPad placed on the table in front of the child. The researcher sits beside the child.

Researcher: *“Hello [name]. My name is [name]. We’re going to do some activities that will help you get better at reading words. I will see you three times each week for about 20 minutes. For the next couple of weeks we will do two activities.”*

Show the Loader Page.

Researcher: *“This is the page where I choose activities. It’s a bit like what happens when people are learning to drive a car. First they do a Test Drive (point to the T-Plate), then they get their L-Plate (point to L-Plate), then their P-Plate (point to P Plate), and then their Full Licence: it’s called the D-Plate which stands for Driver” (point to D-Plate symbol). The other activity we will do is a bit like a speed test. It’s called the S-Plate.”*

Point to the S-Plate.

T-Plate Procedure (Assessment NW List)

During the T-Plate the child reads as many non-words as quickly and accurately as they can. The child is told to stop after 60 seconds if they have made

six errors in eight consecutive items, or after they have made six errors in eight consecutive items.

During the first session the researcher demonstrates the T-Plate (using a T-Plate loaded with the researcher's number plate). Thereafter, the T-Plate module is presented without the need for demonstration.

Researcher: *"I'll show you how to do a T-Plate. I touch my number plate"*.

The researcher touches the number plate button, and the T-Plate appears on the screen.

Researcher: *"Here is the windscreen, and this sign will show you different non-words that I want you to read. Non-words are like real words but they are made up words. They don't have any meaning. You have to look at each letter to work out how to read and say each made up word. Here is the Go button. You touch the Go button, read the word out loud, and press Go again for the next made up word. You will read these made up words as fast as you can, but try to read them carefully so you get as many right as you can. I will tell you when to stop. I'll show you what I mean"*.

The researcher demonstrates how to touch the Go button and read each item in the T-Plate modelling how to sound out some of the words.

The researcher selects the participant's number plate and the T-Plate module.

Researcher: *"So, this is your number plate. Today we are going to do your first T-Plate. Over the next 2 weeks we'll do about eight of these T-Plates, and then you'll be ready to get your L-Plate, then your P-Plate, and then your D-Plate."*

Point to each of the icons depicting L-, P-, and D-Plates.

Researcher: *"Now you can do your first T-Plate. Touch the Go button to see each made up word. Read them carefully and as fast as you can. I will tell you when to stop"*.

The child touches the Go button and reads each item. The researcher marks correct/incorrect on the Assessment NW List response form. The child is told to stop once one minute has elapsed (if they have already made six errors in eight items), or after they have made six errors in eight items.

S-Plate Procedure

The S-Plate measures the motor response time of the task. No words or nonwords are presented. After touching the Go button, the child waits for the road sign to turn black and then touches the Go button as quickly as possible to turn the sign back to white.

Researcher: *“In the S-Plate there are no words or made up words to read. After you touch the Go button, you will see the white road sign. As soon as the road sign turns black, you need to touch the Go button as quickly as possible to turn the road sign white again.”*

The child touches the Go button to start the S-Plate. After 20 trials “all done” appears on the road sign signifying completion of the S-Plate.

L-Plate Procedure

The aim of the L-Plate is to teach phonological recoding using a controlled sequence of items: for the first few items the first letter changes, then for the next few the final letter changes and then the middle letter changes, and for the last few items all letters change.

The researcher holds the iPad in front of the child. The child would have just completed a T-Plate.

Researcher: *“Well done. Now you’re ready to do your L-Plate”.*

The researcher loads the appropriate L-Plate for the participant using the Loader Page. The researcher touches the number plate to load the module.

Researcher: *“This looks just like the T-Plate, but this time I will show you how to sound out the words and the “made up” words. If it’s a real word I will tell you a sentence so you know the meaning of the word. Then I will put the real words into the Book and the “made up” words into the Bin. For the L-Plate, you watch, and I will show you how to sound out each item.”*

The researcher completes the L-Plate. At each level (2-, 3-, 4-, 5-, and 6-letter items), the researcher demonstrates incorrect responses: one third to the first level of help, one third to the second level of help, and one third to the third level of help.

a) First level of help

The researcher touches the Go button

Researcher: *“c-a-t, cap”*. *“That’s not quite correct. I’ll touch the Help button”*

The researcher touches the Help button for the first level of help. The computer provides a visual cue of left to right processing by sequentially highlighting each letter.

Researcher: *“c-a-t, cat. Cat is a real word. My cat likes to drink milk. It’s a real word. It goes in the book. I’ll touch the Book button”*.

The researcher touches the Book button, and the word flies into the Book.

The researcher touches Go button for the next item.

b) Second level of help

Researcher: *“m-a-t”*. *See how the first letter has changed.*

The researcher responds with incorrect responses on two attempts to initiate the second level of help.

Researcher: *“m-a-t, map, that’s not quite right. I’ll touch the Help button.*

The researcher touches the Help button. The computer provides the first level of help - left to right visual highlighting of each letter.

The researcher responds with an incorrect response to initiate the second level of help.

Researcher: *“m-a-t, lap”, that’s not quite right. I’ll touch the Help button again.*

The researcher touches the Help button. The computer provides the second level of help: the sound of each letter which is synchronised with the visual left to right highlighting of each letter. Thus the child sees and hears a demonstration of how to sound out an item.

The researcher responds with the correct response.

Researcher: *“m-a-t, mat. Mat is a real word. We got out the map to see where she lives. It goes in the book. I’ll touch the Book button”*.

The researcher touches the Book button, and the word flies into the Book.

The researcher touches the Go button for the next item.

c) Third level of help

Researcher: *“l-a-t”*. *See how the first letter has changed.*

The researcher responds with incorrect responses on three attempts to initiate the third level of help.

Researcher: *“l-a-t, lap, that’s not quite right. I’ll touch the Help button.*

The researcher touches the Help button. The computer provides the first level of help - left to right visual highlighting of each letter.

The researcher responds with an incorrect response to initiate the second level of help.

Researcher: *“l-a-t, lut”, That’s not quite right. I’ll touch the Help button again.*

The researcher touches the Help button. The computer provides the second level of help: the sound of each letter which is synchronised with the visual left to right highlighting of each letter.

The researcher responds with another incorrect response.

Researcher: *“l-a-t, mat. That’s not quite right. I’ll touch the Help button again.*

The researcher touches the Help button. The third level of Help requires the researcher to perform phonological recoding and blending, while touching each letter.

Researcher: *“l-a-t, lat. That’s correct. Lat is not a real word. It has not meaning. It goes in the bin.*

The researcher touches the Bin button, and the word flies into the Bin. At the completion of the L-Plate “All done” is displayed on the road sign.

P-Plate procedure

At each of the levels (2-, 3-, 4-, 5-, and 6-letter), the P-Plate is completed by the child after the child has observed the L-Plate. The aim of the P-Plate is to provide the child with practice at independent phonological recoding of letter strings that are arranged similarly to the L-Plate, that is, the first letter changes for the first few items, the last letter changes for the next few items, and the middle letter (vowel) changes for the next few. For the last few items all letters change, preparing the child for the D-Plate. This encourages the child to pay attention to each letter position. The child decodes 25 letter strings, and must reach 90% accuracy to proceed to the D-Plate.

The child holds the iPad.

Researcher: *“OK. Now you are ready for your P-Plate at level X”*.

The researcher loads the appropriate P-Plate using the Loader Page.

Researcher: *“This works just like the L-Plate that I just showed you. Touch the Go button and you will see a real word or a made up word. Sound out each letter and then read the word out loud. I will tell you if you have read it correctly.”*

Child touches the Go button to display a real word or non-word.

Researcher provides feedback as follows:

- a) Real word correctly decoded

Researcher: *“That’s correct”*

The researcher touches the Correct button.

Researcher: *“[word] is a real word. For example, [sentence illustrating meaning of the word]. It goes in the book. You can touch the Book button”*.

Child touches the Book Button. The real word flies into the Book.

- b) Non-word correctly decoded:

Researcher: *“That’s correct”*

The researcher touches the Correct button.

Researcher: *“[nonword] is a made up word. It has not meaning. It goes in the Bin. You can touch the Bin button”*.

Child touches the Bin button. The nonword flies into the Bin.

c) Word or nonword incorrectly decoded

The procedures outlined in the L-Plate are followed except in each case the child touches the Book or Bin button.

D-Plate procedure

At each of the levels (2-, 3-, 4-, 5-, and 6-letter), the D-Plate is completed by the child after the child has completed the P-Plate. The aim of the D-Plate is to achieve mastery of decoding at each level. The child is presented with at least 20 trials which require decoding of a nonword item. After achieving 90% accuracy on the D-Plate the child progresses to the next level. The procedure is as for the P-Plate described above with one exception: if the child accurately reads an item without use of phonological recoding, this response is accepted.

APPENDIX K: STUDY 1 CLINICALLY SIGNIFICANT CHANGES

Tests	P1		P2		P3	
	Pre	Post	Pre	Post	Pre	Post
TOWRE-2: standard score (average range 90-110)						
SWE	91	92	79	76	78	87*
PDE	76	91*	66	67	69	76*
PhAT-2 Decoding: standard score (normal range 86 – 115)						
VC	84	114*	87	93	87	112
CVC	97	112	75	108*	75	114*
Cons Dig	87	100	<73	73	73	100*
Cons Blend	81	103*	<77	77	<77	90*
Vowel Dig	<85	85	<78	<78	<78	<78
R Vowels	<85	<85	<81	<81	<81	<81
CVCe	<86	<86	<80	<80	<80	80
Diphthongs	<88	88	<82	<82	<82	82
Total Score	82	94*	73	78	77	88*
Neale Analysis: percentile rank (reading age)						
Accuracy	6(6:0)	10(6:3)	4(<6:0)	10(6:3)	4(<6:0)	11(6:4)
Comp	12(6:7)	15(6:9)	1(<6:0)	10(6:3)	10(6:3)	15(6:9)
Rate	21(6:10)	9(6:1)	8(6:0)	11(6:4)	16(6:8)	13(6:5)

Note. SWE = Sight Word Efficiency; PDE = Phonemic Decoding Efficiency; VC = Vowel Consonant; CVC = Consonant Vowel Consonant; Cons Dig – Consonant Digraph; Cons Blend = Consonant Blends; Comp = Comprehension; * clinically significant positive change

APPENDIX L: STUDY 2 CLINICALLY SIGNIFICANT CHANGES

	P1		P2		P3		P4		P5		P6		P7		P8	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TOWRE-2																
SWE SS	76	74	66	56	74	77	66	70	80	81	69	74*	69	69	55	55
PDE SS	79	81	79	75	73	78	58	78*	62	84*	75	85*	66	79*	60	68
SWE raw	27	29	17	12	29	42* ⁹⁵	17	25* ⁹⁵	23	33* ⁹⁵	26	32* ⁸⁵	23	23	21	25* ⁶⁰
PDE raw	9	13* ⁷⁰	9	9	8	14* ⁹⁵	0	11* ⁹⁵	0	13* ⁹⁵	12	19* ⁹⁵	4	12* ⁹⁵	4	9* ⁸⁵
PhAT-2 Decoding: standard score (normal range 86 – 115)																
VC	84	111*	81	111*	70	103*	62	91*	74	100*	111	111	77	103*	63	103*
CVC	89	114*	64	108*	98	105	69	70	86	108*	112	112	89	112	74	97*
Cons Dig	78	112*	82	95*	<64	104*	<73	84*	100	104	98	111	67	104*	80	103*
Cons Blend	99	109	102	104	<67	108*	<77	<69	85	107*	85	102*	69	114*	73	99*
V Dig	<74	<74	<78	<74	<66	<66	<78	79	<78	<78	66	72*	<74	<66	<65	<65
RVowels	<75	<75	<81	<75	<69	<69	<81	<75	<81	<81	79	74	<75	<69	<63	<63
CVCe	<75	<75	<80	<75	<71	<71	<80	75	<80	<80	76	<71	<75	<71	<64	<64
Diphthongs	<78	<78	<82	<78	<74	93*	<82	78	<82	<82	79	79	<78	<74	<65	<65
Total Score	75	88*	77	83	<64	83*	69	82*	79	88*	83	86*	68	81*	<64	71*
Neale Analysis: percentile rank (PR)/reading age (RA)																
Accuracy PR	10	18*	4	5	15	20	8	10	17	14	18	21	7	17*	4	14*
Accuracy RA	6:4	6:11*	<6	6:5*	6:9	7:0	6:1	6:6*	6:8	6:7	6:10	7:1	6:5	6:10*	6:4	6:7
Comp PR	10	24*	7	12*	19	24*	11	13	15	15	52	53	20	42*	13	22
Comp RA	6:3	7:4*	6:2	6:6*	6:11	7:4*	6:5	6:8	6:10	6:9	8:1	8:0	7:2	7:7*	6:8	7:1*:
Rate PR	10	5	6	4	27	20*	16	9*	15	21	13	10	20	11	9	5
Rate RA	6:3	6:3	<6	6:1	7:2	6:11	6:6	6:5	6:9	6:10	6:5	6:3	6:11	6:4*	6:6	<6*

Note: SWE = Sight Word Efficiency; PDE = Phonemic Decoding Efficiency; VC = Vowel Consonant; CVC = Consonant Vowel Consonant; Cons Blend = Consonant Blend; Cons Dig = Consonant Digraphs; Comp = Comprehension “*” = clinically significant gain; “*nn” = probability that the difference is not due to error

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APPENDIX N: SEILER, LEITÃO, & BLOSFELDS (2013)

Computer-assisted assessment and intervention



The effectiveness of a computer-supported intervention targeting orthographic processing and phonological recoding for children with impaired word identification

A preliminary study

Toni Seiler, Suze Leitão and Mara Blosfelds

This study investigated the effectiveness of a computer-supported intervention targeting orthographic processing and phonological recoding for word identification skills. Participants were three children (aged 7–8 years) with persistent word identification impairment. A single subject design with three phases was used, comprising a total of 31 sessions (8 baseline, 15 intervention, and a further 8 baseline) over 10 weeks. Results indicated a significant treatment effect based on measures of rate and accuracy of nonword reading measured at the start of every session. In addition, all participants made clinically significant gains in accuracy of nonword reading from pre- to post-intervention, and demonstrated mixed results with word and nonword reading efficiency.

About 8% of Australian children in year 2 do not meet the minimum National Benchmarks for Reading (Rowe, 2005). Given that this stage at school represents the beginning of the transition from learning to read to reading to learn, and that most children with early reading problems continue to have reading delays at the secondary school level (Kamhi, 2009), the development of effective interventions in the early years is a priority. Reading is a complex activity that involves a range of language skills (Bishop & Snowling, 2004). Coltheart (2006) suggests that in order to understand the reading process, the skills that underlie reading need to be understood first. Accurate word reading is considered to be a key skill in learning to read. Furthermore, poor performance on word identification has been found to predict later reading difficulties (Botting, Simkin, & Conti-Ramsden, 2006).

Theories underlying reading and word identification

The dual route model (Coltheart, 2006) proposes that there are two processes or routes involved in skilled reading aloud. The lexical route accesses a store of previously identified written words, referred to as mental orthographic representations (MORs), while the nonlexical route uses letter–sound relationships to decode unfamiliar words. Most children with significant reading problems demonstrate

difficulty with the skills involved in the nonlexical route, that is, phonological recoding, the act of sounding out and blending to read the word or nonword (Herrmann, Matyas, & Pratt, 2006). There is strong evidence that phonological recoding plays a key role in the development of MORs (Cunningham, 2006; Cunningham, Perry, Stanovich, & Share, 2002; Share, 1999). Moreover, when phonological recoding is compromised, MOR development is also reduced (Kyte & Johnson, 2006), suggesting that the establishment of orthographic representations of written words is dependent on the degree and accuracy of phonological recoding. Other factors that influence MOR development include the provision of repetition (Nation, Angell, & Castles, 2007) and presentation of words of similar types (Goswami, Ziegler, Dalton, & Schneider, 2003). However, presentation of words in context has not been found to influence MOR development (Cunningham, 2006).

Recent research has shown that orthographic processing, the ability to acquire, store, and use MORs and orthographic pattern knowledge (Apel, 2011), also makes a unique and significant contribution to the development of word identification (Cunningham, Perry, & Stanovich, 2001) and predicts later word reading and comprehension skills (Badian, 2001). However, the relationship between orthographic processing skills and reading is a complex one. Apel (2009) found that preschool children without phonological recoding skills still developed MORs and were sensitive to the orthotactic probability of words (frequency with which a word's graphemes and bigraphs appear in English), thus supporting the independent contribution of orthographic processing skills. More recently, Deacon, Benere and Castles (2012) evaluated the direction of the relationship between orthographic processing and reading in a longitudinal study of children from grade 1 to 3. While their results indicated that reading skills predicted orthographic processing skills and supported the role played by phonological recoding, they concluded that the reverse could also be true: that orthographic processing plays a role in determining reading success.

Intervention for word identification disorders

Over the past 20 years, the focus of many reading intervention studies has been phonemic awareness because these skills have been identified as predictors of reading development (Bishop & Snowling, 2004), having significant positive effects on word identification skills (Torgerson, Brooks, & Hall, 2006). However, there is

KEYWORDS
COMPUTER-SUPPORTED INTERVENTION
ORTHOGRAPHIC PROCESSING
PHONOLOGICAL RECODING
READING DIFFICULTIES
TREATMENT EFFECTIVENESS

THIS ARTICLE HAS BEEN PEER-REVIEWED



Toni Seiler (top), Suze Leitão (centre) and Mara Blosfelds

increasing evidence of the need to also focus on orthographic processing. A meta-analysis conducted for the National Reading Panel in the United States (Ehri et al., 2001) indicated that although there was strong evidence for interventions focusing on phonemic awareness, there was a smaller effect size for students with reading impairment compared to at-risk or typically developing students. This suggests that interventions for students with reading difficulties need to focus on other areas in addition to phonemic awareness.

Earlier studies that examined orthographic processing in reading interventions found significant gains in nonword reading (McCandliss, Beck, Sandak, & Perfetti, 2003; Pullen, Lane, Lloyd, Nowak, & Ryals, 2005). These studies used a manipulative letters activity combined with other text-based tasks (repeated reading and sentence reading, respectively). Similar to other research focusing on phonemic awareness (Hatcher et al., 2006; Wheldall & Beaman, 1999), there was a range of improvement. While the researchers were unable to isolate which of the tasks produced the gains, a subsequent evaluation of Pullen et al. (2005) found that the orthographic processing task was the crucial element of the intervention (Lane, Pullen, Hudson, & Konold, 2009). This highlights the need to consider intervention programs that target the development of orthographic representations.

Computer-supported learning

Many aspects of the general curriculum, including the teaching of reading, are supported by computers. Though it has been found that the use of computers alone does not make a significant difference to learning outcomes (Torgerson & Zhu, 2003) or respond to learner needs (Moridis & Economidis, 2008), there are many advantages to computer-supported interventions (e.g., systematic delivery, integrated data collection and analysis, and increased motivation for children). These advantages can be used to address factors shown to influence the development of orthographic representations such as repetition and systematic presentation of words.

This research designed a computer-supported intervention based on the evidence demonstrating accurate phonological recoding to be an effective strategy for reading words using the nonlexical route (Coltheart, 2006). The intervention was designed to target both orthographic processing (by presenting items based on their orthotactic probability and encouraging attention to each letter in the stimulus) and phonological recoding (by providing corrective feedback about decoding accuracy). Computer delivery on an iPad also enables seamless presentation of more than 3000 items (words and nonwords) with automatic adjustment of difficulty level in response to errors, and allows collection of on-line data for later analysis.

Research aims

To assess the effectiveness of the computer-supported intervention designed for this research, the following research questions were posed:

1. Is a computer-supported intervention that targets orthographic processing and phonological recoding effective in increasing nonword reading skills in year 2 children with persistent word identification impairment?
2. Are the improvements in nonword reading as measured within the program, reflected in standardised tests of nonword reading accuracy and real and nonword reading efficiency?

Method

Study design

This study used a single subject research design with three phases. The first phase (A1), involved eight sessions where the child's nonword (NW) reading skills were assessed to establish a pre-intervention baseline. In the second phase (B) the child received 15 intervention sessions, followed by the third phase (A2) where the NW reading skills were assessed post-intervention. Standardised assessment of word and nonword reading was also administered during the pre- and post-intervention baseline sessions.

Participants

Three year 2 children (aged 7–8 years) participated in this study. Teachers from a Victorian government school were asked to identify children they considered to have typically developing oral language and intellectual skills, and who continued to have problems with word reading despite previously completing reading intervention programs (such as Reading Recovery). The participants were thus representative of those children reported in previous studies who make minimal response to current interventions. The inclusion criteria were therefore as follows:

- a score of more than 1 standard deviation (*SD*) below the mean on the Phonemic Decoding Efficiency subtest of the Test of Word Reading Efficiency 2: TOWRE 2 (Torgesen, Wagner, & Rashotte, 2012);
- a Core Language Score within 1.25 *SD* of the mean on the Clinical Evaluation of Language Fundamentals 4 (Semel, Wiig, & Secord, 2003);
- no developmental or sensory impairment, as screened using a parent questionnaire (Claessen, Leitão, & Barrett, 2010);
- hearing and vision in the normal range (school nurse screening);
- intellectual skills in the average range using the Wechsler Intelligence Scale for Children IV Full Scale Score (Wechsler, 2003);
- letter sound knowledge in the average range using the Grapheme subtest of the Phonological Awareness Test 2 (Robertson & Salter, 2007).

Approval for this research was granted by the Curtin University Human Research Ethics Committee and the Victorian Department of Education. Procedures complied with confidentiality guidelines and both caregivers and participants provided informed consent to participate. Participant details are presented in Table 1.

Table 1. Scores on standardised tests for selection (CELF 4, WISC IV)

Tests	Participant 1	Participant 2	Participant 3
CELF 4 (normal range 86–115)			
Core language score	100	96	82
Receptive language score	111	72	84
Expressive language score	102	102	86
WISC IV (normal range 86–115)			
Full scale	96	81	89
Verbal comprehension	102	96	93
Perceptual reasoning	92	90	100
Working memory	91	80	86
Processing speed	100	70	88

Design of the computer-supported intervention materials

Two computer-supported programs were developed for this research: the Assessment NW Lists, and the intervention activity targeting accurate phonological recoding of words and nonwords. Both were presented to all participants on an iPad, using graphics relating to the metaphor of learning to drive a car (Figure 1).



Figure 1. iPad screen graphic of intervention activity

The items were letter strings with 1:1 letter sound correspondence, thus presenting letter strings of similar type (Goswami et al., 2003). The Assessment NW Lists used nonwords and the intervention activity, both words and nonwords. The letter strings were presented with an increasing level of difficulty, starting with 2-letter strings and progressing through to 6-letter strings. Additionally, within each level the letter strings were ordered from those with high (easy) and progressing to those with low (harder) orthotactic probability. Each of the Assessment NW Lists required for the 31 sessions was constructed to be of equal difficulty by use of a systematic allocation of nonwords according to their orthotactic probability value. The MRC Psycholinguistic Database (Coltheart, 1981) was the source for the real words and the ARC Database (Rastle, Harrington, & Coltheart, 2002) for the nonwords. The orthotactic probability values of both words and nonwords were calculated using the N-Watch method (Davis, 2005), which enables users to obtain a broad range of statistics (e.g., word frequency, orthotactic and phonotactic probability).

An iPad was used to present the stimuli in a systematic manner and record the child's responses, but unlike many other programs, the interactive role of the researcher was central to provide reinforcement and feedback regarding reading accuracy.

Measures

The primary measures of intervention effectiveness were nonword reading rate (NW rate: the number of nonwords read out loud in 1 minute) and the total number of nonwords read correctly (NW total: the number correctly read to a ceiling of 6 out of 8 errors), from 31 experimenter-developed nonword lists each containing 70 letter strings – the Assessment NW Lists. These measures were taken at the beginning of every session (baseline and intervention). Nonword reading measures the child's ability to use orthographic processing and phonological recoding to decode unfamiliar words, and strongly predicts reading development (Badian, 2001).

Additional measures of intervention effectiveness were standardised measures of word and nonword reading administered by the researcher prior to the intervention, and by a speech pathologist unfamiliar with the children and blind to research aims during the post-intervention baseline sessions. These included the Test of Word Reading Efficiency 2 (TOWRE 2; Torgesen et al., 2012) and the Decoding subtests of the Phonological Awareness Test 2 (PhAT 2; Robertson & Salter, 2007).

Procedure

Each participant was involved in a total of 31 sessions of 15 to 20 minutes duration at their school. During the eight pre- and eight post-baseline sessions (A1 and A2), the Assessment NW List (referred to as *T Plate*) was administered. The child touched the *Go* button on the iPad and read out loud a nonword letter string. No feedback about accuracy was given and responses were recorded on a digital recorder for later analysis. This generated two scores, NW rate and NW total, and provided data for the starting level of each participant's intervention phase.

During the 15 intervention sessions, the child began the session with the *T Plate* and then completed the intervention task. After touching *Go* the child read out loud a randomly presented word or nonword, and was provided with verbal feedback from the researcher, who touched the *Correct* button for accurate phonological recoding and blending, or the *Help* button following inaccurate responses. The child then put real words in the *Book* and nonwords in the *Bin* by touching either graphic, and touched the *Go* button when they were ready to start the next trial.

Three levels of help were provided for inaccurate responses:

1. visual highlighting of each letter to prompt phonological recoding,
2. visual highlighting with auditory cues of how to sound out the word,
3. demonstration by the researcher of phonological recoding and blending to read the real or nonword.

To strengthen MOR development, the verbal feedback involved a scripted sentence for real words explaining the meaning of the word, and for nonwords a sentence explaining that it was not a word and thus had no meaning. At the completion of the intervention task, the program calculated percent correct responses.

The intervention involved three components: teaching (*L plate*), practising (*P plate*), and consolidating the skills of phonological recoding and blending to read letter strings (*D plate*). The *L plate* was the starting point at all levels (2-, 3-, 4-letter strings, etc.) where the researcher modelled and explained phonological recoding and blending. This was followed by the *P plate* (where the child practised phonological recoding and blending with a controlled set of words) and finally by the *D plate* (full driver's license). The *D plate* used a PEST algorithm, based upon that used by McArthur, Ellis, Atkinson, and Coltheart (2008) in which the computer program responds to the accuracy of the child's response. As errors are made the program presents increasingly easier letter strings (higher orthotactic probability). If the child's responses are accurate, the program presents letters strings of increasing difficulty (lower orthotactic probability). The child was required to reach 90% accuracy to move on to the next level.

Results

This intervention was tailored to match the skills of each participant. All participants began at 2-letter strings but

each reached different levels: P1 progressed to 4-letter strings, P2 to 3-letter strings, and P3 to 5-letter strings.

Nonword reading accuracy and rate

Effectiveness was examined through analysis of the primary measures, NW rate and NW total, using the 2 SD band method (Portney & Watkins, 2009). First, the variability during the baseline phase was established using the mean and standard deviation of data points within that phase. The 2 SD band was drawn on the baseline phase and extended into the intervention and post-intervention phases (Figure 2). If at least 2 consecutive data points in the intervention phase fall outside the 2 SD band, changes from the baseline are considered significant.

All participants scored more than six consecutive points above the 2 SD band for NW rate and NW total, and

remained above that level post-intervention, indicating that the intervention resulted in a significant and positive effect on nonword reading. Two participants (P1 and P2) took about eight intervention sessions to reach that point, while the third child (P3) began scoring above the 2 SD band by the second intervention session. Analyses of the responses revealed that during the first baseline, P1 and P2 were not using phonological recoding as a strategy at all (i.e., they made errors that were often not related to the target nonword), while P3 was already using phonological recoding but did not blend to read the letter string, or made errors on blending. All participants made greater gains in NW total compared to NW rate, indicating that they plateaued in speed of nonword reading, but continued to improve in accuracy.

Standardised assessment results

The pre- and post-intervention scores on the standardised tests assessing accuracy of nonword reading (Decoding subtests of the PhAT 2) and efficiency of real word and nonword reading (TOWRE 2) were calculated and are reported in Table 2.

The PhAT 2 Decoding assesses accuracy of nonword reading using eight subtests. All participants made clinically significant gains in one or more of the three areas targeted by this intervention (i.e., VC, CVC, Consonant blends). P1 moved from below average to normal range in two areas (VC: 84 to 114, Consonant blends: 81 to 103). P2 improved from moderate impairment to normal range in one area (CVC: 75 to 108), and P3 from moderate impairment to normal range in two areas (CVC: 75 to 114, Consonant blends: < 77 to 90). Two participants generalised skills to a non-targeted area, and made clinically significant gains in the Total score (overall decoding): Consonant digraphs (P1 from 87 to 100, P3 from 73 to 100), Total score (P1 from 82 to 94, P3 from 77 to 88).

The TOWRE 2 assesses efficiency of real word (sight word efficiency) and nonword (phonemic decoding efficiency) reading. Two participants made clinically significant gains in nonword reading efficiency: P1 moved from moderate impairment to normal range (76 to 91) and P3 from severe to moderate impairment (69 to 76). P2 did not demonstrate gains (from 66 to 67). Word reading efficiency improved for P3 (from moderate impairment to normal range, 78 to 87), and remained the same for P1 (in the normal range, from 91 to 92), and P2 (in the moderately impaired range, from 79 to 76).

Discussion

The results of this preliminary study indicate that the computer-supported intervention designed to target orthographic processing and phonological recoding was effective in increasing nonword reading skills as measured during the baseline periods and start of each intervention session, and the effects remained significant during the follow-up baseline phase. In addition, these gains were reflected in clinically significant changes in a number of the standardised subtests, most particularly in the measures of nonword reading. These outcomes provide support for the effectiveness of this approach that combined computer-supported delivery (allowing items to be engagingly presented with automatic adjustment of difficulty level) with feedback and explicit teaching from a therapist.

Performance on the standardised assessments may have been influenced by differences in the stimuli and scoring. The PhAT 2 Decoding subtest assesses accuracy of nonword reading at different levels (e.g., CV, CVC,

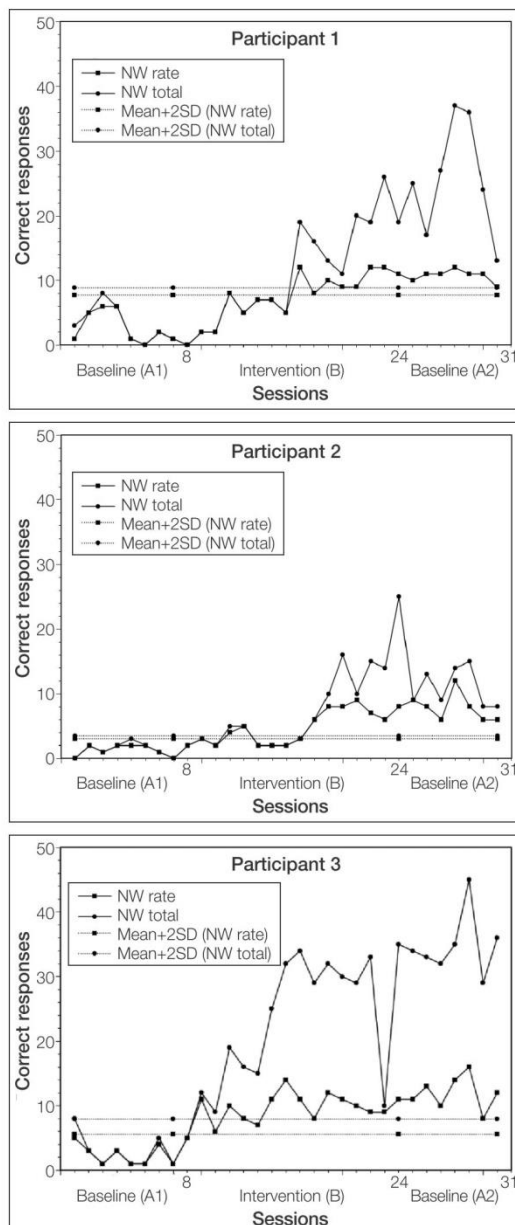


Figure 2. NW rate (correct responses in 1 min) and NW total (total number of correct responses) for participants 1, 2 and 3, showing the 2 SD band method of analysis

Table 2. Scores on pre- and post-intervention standardized tests (TOWRE 2, PhAT 2 Decoding)

Tests	Participant 1		Participant 2		Participant 3	
	Pre	Post	Pre	Post	Pre	Post
TOWRE 2 (normal range 86–115)						
Sight word efficiency	91	92	79	76	78	87
Phonemic decoding efficiency	76	91	66	67	69	76
PhAT 2 Decoding (normal range 86–115)						
Vowel consonant	84	114	87	93	87	112
Consonant vowel consonant	97	112	75	108	75	114
Consonant digraphs	87	100	<73	73	73	100
Consonant blends	81	103	<77	77	<77	90
Vowel digraphs	<85	85	<78	<78	<78	<78
R controlled vowels	<85	<85	<81	<81	<81	<81
Consonant vowel consonant-e	<86	<86	<80	<80	<80	80
Diphthongs	<88	88	<82	<82	<82	82
PhAT 2 Total score	82	94	73	78	77	88

Consonant blends) and is not timed. In contrast, the TOWRE 2 is timed, presents mixed stimuli (e.g., CVC, digraphs), and encourages the child to read quickly and skip items they cannot read. All children made clinically significant gains in accuracy of nonword reading (PhAT 2), but the pattern was less clear on the TOWRE 2 which may be explained by the task being timed and the inclusion of items which were not targeted in the intervention (digraphs).

The language and cognitive profiles of the participants may also have influenced their performance. The child who improved from below average to normal range in both accuracy and efficiency of nonword reading, P1, scored in the normal range on all language and cognitive measures. In contrast, P3, whose cognitive scores were average but language scores were mildly impaired, improved from moderate impairment to normal range in nonword accuracy and word reading efficiency, but remained below average in nonword efficiency. P2, despite having average core language and cognitive skills, had severe impairments in receptive language and processing speed. He made clinically significant gains on the targeted areas only, did not generalise skills, and when faced with the pressure of the timed test (TOWRE 2), his decreased processing speed resulted in him reverting to pre-intervention patterns of guessing, with no change in word and nonword reading efficiency.

This preliminary study designed, developed and provided evidence on the effectiveness of a computer-supported intervention task targeting word decoding skills. However, the small number of participants limits generalisation of the findings to other children with word identification difficulties, and the short duration of the maintenance period prevents investigation of the sustained effects of the intervention. A follow-up study is currently in progress to address these limitations, involving a larger number of participants over a period of 20 weeks. Results from that study will enable further understanding of the value of this computer-based intervention task in improving word identification among children with reading difficulties.

Conclusion

This paper reports on a computer-supported intervention targeting orthographic processing (through encouraging attention to letter-sound mapping) and phonological recoding (through the provision of corrective feedback as the child attempted to sound out and blend). The use of computer-supported delivery allowed the intervention to

provide a systematic focus on decoding skills starting at a level that matched the skills of each child. Prior to intervention, all children were unable to decode 2- and 3-letter strings; after intervention all had made gains in accurate phonological recoding (even those with severe impairments in some processing areas). The targets (letter strings of increasing length with 1:1 letter-sound correspondence) were appropriate to the needs of each participant and aimed to develop their MORs by increasing their ability to take note of each letter rather than guess based on the first letter. A strength of this intervention is that all children showed improvement even though they started with quite different language and cognitive ability profiles. These results provide additional evidence that orthographic processing is a key factor in improving word decoding skills, and highlight the value of using a computer to allow systematic delivery and integrated data collection.

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