JLCD12388

<LRH>*Antonette Seiler* et al.

<RRH>*Evaluation of WordDriver-1*

Research Report

WordDriver-1: evaluating the efficacy of an app-supported decoding intervention for children with reading impairment

Antonette Seiler†, Suze Leitão† and Mara Blosfelds‡

†School of Occupational Therapy, Social Work and Speech Pathology, Curtin University, Perth, WA, Australia

‡School of Psychology, Curtin University, Perth, WA, Australia

(*Received May 2017; accepted March 2017*)

<FN>Address correspondence to: Antonette Seiler, PO Box 1456, Bairnsdale, VIC 3875, Australia; e-mail: Toni.Seiler@curtin.edu.au

Abstract

Background: Fluent word reading is a key characteristic of skilled reading, yet most children with reading disorders have impaired word-reading skills. Previous research has demonstrated that multi-component interventions targeting phonemic awareness and the alphabetic principle are effective for children with reading disorders. However, about 25% of children fail to respond to these interventions. While it has been difficult to isolate the active ingredient, the findings of some studies suggest that tasks targeting phonological recoding and orthographic processing are essential elements in improving decoding.

Aims: To develop and evaluate an intervention that specifically targets phonological recoding and orthographic processing (a decoding intervention) for children with persistent word-reading impairment.

Methods & Procedures: A single-subject crossover design with multiple treatments was used to examine the efficacy of the decoding intervention (15 × 20-min sessions) compared with a language intervention that controlled for individual therapy time. Eight children (aged 7:6–8:11 years) with persistent word-reading impairment were randomly assigned to one of two intervention sequences. The effect of the decoding intervention was evaluated by (1) changes in decoding accuracy measured by performance on researcher-developed non-word lists; and (2) generalization to other standardized measures of reading.

Outcomes & Results: The results showed that all participants demonstrated significant gains in non-word reading on researcher-developed non-word lists and standardized measures of non-word-reading accuracy and efficiency. Trends for improvement on standardized measures of word-reading efficiency, text-reading accuracy and reading comprehension were observed.

Conclusions & Implications: This decoding intervention significantly improved non-word decoding skills in all participants who had not responded to previous reading interventions. As such, it may be an efficient adjunct to the first stage of reading interventions for this population. The relative lack of generalization to other word-reading skills may have been due to the nature of the outcome measures, the short intervention time and/or additional delays in participant orthographic processing skills.

Keywords: computer-supported intervention, reading disorder, phonological recoding, decoding, orthographic processing, dyslexia.

<A>**What this paper adds**

This research addressed the need for evidence about key components of reading interventions for children with persistent reading disorders. A specifically targeted decoding intervention that enabled interpretation of its impact on reading skills was developed, evaluated and made freely available for future research and clinical use. Consistent with the findings [AQ1] of a recent 2017 review by Austin *et al.*, the results provide preliminary evidence that an intervention that specifically targeted phonological recoding and orthographic processing for children with persistent word-reading impairment resulted in significant gains in measures of non-word decoding, with trends for gains in word-reading skills.

<A>**Introduction**

A substantial number of children have difficulty learning to read. For example, the results of an international assessment of educational achievement of 15-year-old students conducted by the Programme for International Student Assessment (Wheater *et al.* 2014) showed that 17% of students in England performed at or below the low international benchmark for reading. Reading is a skill that allows a person to comprehend the meaning of written text: a skill which, according to the Simple View of Reading (Gough and Tunmer 1986), is a product of listening comprehension (i.e., oral language skills—the ability to interpret the meanings of words, sentences and discourse) and word recognition (the ability to read words accurately). Research supports the conclusion that there are broadly two forms of reading disorder: difficulties with word recognition and difficulties with comprehension (Snowling and Hulme 2012). The research focused on children with persistent word-recognition impairment.

Accurate, context-free word recognition has been shown to predict later language, reading comprehension and general knowledge in children from Grades 1–10 (Sparks *et al.* 2014). However, most children with a reading disorder have impaired word-recognition skills, with decoding (use of grapheme–phoneme translation to read words) being the main area of difficulty (Herrmann *et al.* 2006).

Theories of word recognition have focused on a number of aspects, including the processes involved in skilled word reading, developmental phases and mechanisms which support the establishment of word-reading skills. The dual-route model (Coltheart 2006) proposes that in skilled readers two different paths (routes) are used in context-free word recognition. The lexical route enables instant recognition of words. It accesses the mental lexicon that contains a large bank of sight words: words with well-established knowledge about the visual form (orthographic representations), pronunciation (phonological representations) and meaning (semantic representations). If the word is not represented in the mental lexicon, the non-lexical route (in which grapheme–phoneme rules are used to sound out and read the word) is engaged.

Ehri's phase theory (Ehri 2005) describes a progression through four phases in the acquisition of fluent word recognition. The first phase (*pre-alphabetic*) is characterized by whole-word context-dependent recognition of a small number of words. In the second phase (*partial alphabetic*), knowledge of letter names and sounds emerges but an inability to pay attention to all letters in the word prevents accurate word decoding. In the third phase (*full alphabetic*), mastery of grapheme–phoneme correspondences allows decoding of unfamiliar words; while in the final *consolidated* phase, expanded knowledge of grapheme–phoneme connections of larger units (rimes, syllables, morphemes, whole words) enables decoding of multi-syllabic words, thus supporting the development of an increased bank of sight words.

The phonological recoding theory (Share 1995) describes a self-teaching mechanism (phonological recoding) that allows the child to develop well-specific orthographic representations of words—an essential component of sight-word development. 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. It has been shown to play a key role in orthographic learning (e.g., Cunningham *et al.* 2002): a process in which the child acquires automatic recognition of printed letter strings.

Orthographic processing itself has also been shown to be a key skill in word-recognition development. It refers to the ability to acquire, store and use orthographic knowledge: orthographic representations, as well as knowledge of the positional and contextual constraints on how letters may be used in a given language (Apel 2011). Orthographic processing has been shown to make a unique and statistically significant contribution to word-recognition development (Cunningham 2006); however, children at risk of reading delay have significantly reduced orthographic processing skills (Apel *et al.* 2012). The results of these studies—showing that phonological recoding and orthographic processing are key skills that underpin the transition through the phases of word-recognition development, and that children with literacy impairment may need a specific focus on these skills—supported the development of our decoding intervention.

In recent years, interventions for children with reading impairment have followed the Response to Intervention model. This three-tiered approach aims to prevent and ameliorate reading disorders. In Tier 1, evidence-supported instruction is provided to all students. Tier 2 involves an individualized plan and explicit instruction for students who are at risk of reading disorders; while in Tier 3, in-depth assessment and intensive instruction is provided to the students who make less progress than expected with Tier 2 interventions (Denton *et al.* 2013, Austin *et al.* 2017).

The evidence supporting early reading instruction (Tier 1) targeting phonemic awareness combined with letter–sound knowledge is well established (National Reading Panel 2000). Though there is evidence that targeting these skills with greater intensity is effective for most students requiring Tier 2 interventions (e.g., Ritter *et al.* 2013), about 25% of students fail to respond (Buckingham *et al.* 2012). Fewer studies have examined Tier 3 reading interventions, but significant levels of non-response (Torgesen 2001) or highly variable responses (Denton *et al.* 2013) have been reported. Furthermore, most reading interventions involve a number of components (e.g., phonemic awareness, writing, sight-word reading, text reading, word study, shared reading), which means it has been difficult to isolate which component(s) have contributed to improvement in specific skill areas.

Targeted at the Tier 2 level, some studies (McCandliss *et al.* 2003, Pullen and Lane 2014) have investigated interventions for word-reading impairment with fewer components. McCandliss *et al.* (2003) evaluated a two-component intervention (20 × 50-min sessions) that comprised a manipulative letters activity (progressive minimal contrasts changing one letter at a time to teach grapheme–phoneme correspondences of consonants, short vowels and vowel digraphs), and a sentence-reading activity involving target words. Participants were 24 typically developing children at risk of reading delay (with poor decoding skills) in their second year of school who were randomly assigned to a treatment or control group. Intervention effectiveness was evaluated using pre-/post-intervention scores on researcher-developed non-word lists, and standardized assessments of phonemic awareness, word and non-word reading, and reading comprehension. The results showed that while the intervention group made significant gains in non-word reading (decoding), comprehension and phonemic awareness, about one-third of the children made nominal gains. Lack of an intervention effect on word-reading skills was attributed to the nature of the word-reading outcome measure: it contained irregular words that were not targeted in the intervention. Additional analyses of pre-intervention decoding responses revealed a consistent pattern of decoding errors on three- and four-letter words (consonant–vowel–consonant words and those with consonant blends), which suggests that some of these children may have required a stronger focus on decoding items with one-to-one letter–sound correspondence to enable transition from the pre-alphabetic to the alphabetic phase of word-reading development.

Pullen and Lane (2014), in addition to examining the effectiveness of a two-component intervention (30 × 20-min sessions using a manipulative letters decoding activity and a book-reading activity), also aimed to isolate the key component. Ninety-eight children at risk of reading difficulty (i.e., had scored below the 20th percentile on a measure of invented spelling) in the second year of school were assigned to three conditions: treatment (book reading plus decoding), comparison (book reading only) and control (business as usual). Treatment effectiveness was examined using pre-/post-intervention responses on researcher-developed measures of word and non-word decoding (three-letter items), sight-word reading and phonological awareness. The results indicated that the group that received the full intervention (book reading plus decoding) 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 the decoding task reached significance. These results suggested that the manipulative letters task (an orthographic processing activity) was the key component, and that decoding practise may result in improved sight-word reading. Furthermore, it was suggested that future research should include a fourth intervention group: one that received only the decoding task.

The results of these intervention studies suggest that a proportion of children who have delays in the early stages of word-reading development may benefit from intervention targets that match their existing orthographic knowledge, and that tasks which specifically focus on orthographic processing may be a key component within interventions. These findings, combined with the need to gather evidence about children requiring Tier 3 interventions, supported the development of the decoding intervention which specifically targeted phonological recoding to support orthographic processing.

A number of factors that have been shown to impact on orthographic learning were incorporated into the design of the decoding intervention. First, the child receives corrective feedback about decoding accuracy on target items which have been matched to their level of orthographic knowledge, as decoding accuracy and prior orthographic knowledge both predict orthographic learning (Cunningham *et al.* 2002). Second, based on research (Apel *et al.* 2012) showing that children at risk of literacy delay develop orthographic representations more efficiently with items of high orthotactic probability (the frequency with which a word's graphemes and bigraphs appear in English), the items (words and non-words) are organized according to their orthotactic probability. Third, target items are presented without context because, while context has been shown to increase decoding accuracy, the ability to use phonological recoding to support orthographic learning is not affected by context (Cunningham 2006). Fourth, the intervention provides high levels of repetition of the target skill (phonological recoding), as repetition has been shown to optimize learning of key skills (Carmichael and Hempenstall 2006) and the development of orthographic representations (Bowey and Muller 2005). Finally, all items had one-to-one letter–sound correspondence because (1) most young children with reading delay have not mastered accurate decoding of short three-letter CVC (consonant–vowel–consonant) words (McCandliss *et al.* 2003); and (2) it has been shown that presentation of items with a similar grain size (in this instance, requiring use of grapheme–phoneme correspondence so there is no switching of strategy to read items) optimizes word-reading performance for English readers (Goswami *et al.* 2003).

Using the five-phase model for clinical-outcome research outlined by Robey (2004), this study used a single-subject research design (SSRD) as a Phase III test of efficacy of the decoding intervention. Following Phase I clinical trials (which showed gains on standardized measures of non-word reading as a result of interventions targeting decoding skills), the Phase II pilot study was conducted: Seiler *et al.* (2013) developed and trialled the iPad-delivered decoding intervention to gather preliminary evidence about efficacy and to fine tune intervention protocols. Three participants in their third year of school (aged 7–8 years) with persistent word-reading impairment were involved in an SSRD with three phases: A (eight baseline sessions), B (15 decoding intervention sessions) and C (eight baseline sessions). The results showed significant gains in non-word reading for all participants on targeted areas with trends for generalization to non-targeted areas. The limitations of this study included (1) the small number of participants, (2) the short duration of the maintenance period and (3) the fact that it did not include randomization or intervention comparisons.

This Phase III study aimed to address these limitations by increasing the number of participants, adding three variations to the research design and employing randomized allocation of participants to treatment regime.

The research questions were:

- Does a decoding intervention that specifically targets phonological recoding and orthographic processing increase non-word-reading skills of children in their third year of school with persistent word-reading impairment?
- Does this intervention result in gains on standardized measures of a range of reading-related skills (non-word-reading accuracy, word and non-word-reading efficiency, text reading, and reading comprehension) in this group of children?

The first hypothesis was that this Tier 3-decoding intervention that matched the orthographic knowledge of each participant would significantly improve performance on measures of non-word reading. The second hypothesis was that the intervention would result in gains on some of the standardized reading outcome measures, as some of these measures included items that were not targeted in the intervention.

<A>**Materials and method**

<B>*Study design*

This study used a single-subject cross-over design (figure 1). There were two treatments: the decoding intervention and a language intervention that controlled for the effect of individual therapy time with the researcher. Treatment commenced with eight baseline sessions (A^1) in which pre-intervention measures were administered. Participants were then randomly allocated to receive either 15 decoding (B) or language intervention (C) sessions. The second baseline (A^2) reassessed performance on selected outcome measures over eight sessions. The intervention conditions were then swapped. Finally, all participants completed eight baseline sessions (A^3) in which post-intervention performance on the outcome measures was assessed.

<fig 1>

<B>*Participants*

Participants were three boys and five girls in their third year of school (aged 7–8 years). Ethical approval for the study was granted by the Curtin University Human Research Ethics Committee and the Victorian Department of Education, and caregivers provided informed consent. Teachers from three Victorian government schools were asked to identify monolingual children who had no known language or developmental delay, and who continued to have reading problems despite having received previous reading intervention—thus representing children requiring Tier 3 intervention.

Participants were selected if there were no sensory or developmental impairments on a school nurse screening and parent questionnaire; they were not considered to have an intellectual impairment as assessed by WISC-IV (Wechsler 2003); grapheme–phoneme knowledge for consonant and short-vowel letters were within 1 SD (standard deviation) on the Grapheme subtest of the Phonological Awareness Test 2: PhAT-2 (Robertson and Salter 2007); articulation skills were in the normal range on the RCH Articulation Survey (Atkin and Fisher 1996); and word-reading skills were more than 1 SD below mean on the Phonemic Decoding Efficiency and Sight Word Efficiency subtests of the Test of Word Reading Efficiency 2: TOWRE-2 (Torgesen *et al.* 2012). Table 1 provides participant performance on the selection measures. Apart from the RCH Articulation Survey, all scores are standard scores with a mean of 100 and SD of 15.

<tab 1>

Following selection, additional measures of pre-intervention oral language and phonological processing were administered to provide insight into individual responses to intervention, using the CELF-4 Australian (Wiig 2006) and the Comprehensive Test of Phonological Processing—2 (Torgesen *et al.* 2012). Although teachers had been asked to select children with no known language difficulties, a number of participants demonstrated receptive and/or expressive language skills below the average range, and all demonstrated difficulty with phonological memory (table 2).

<tab 2>

<B>*Outcome measures*

To assess the success of the intervention, two measures of non-word reading were collected using researcher-developed non-word lists. There were 39 lists: 24 for the baseline sessions and 15 for the decoding intervention. Each list contained 70 items with one-to-one grapheme–phoneme correspondence, starting with two- and progressing to six-letter items. The measures included NW Rate (number of non-words read correctly in 60 s) and NW Total (number of non-words accurately read to a ceiling of six errors in eight consecutive items). Researcher-developed measures were used because most standardized assessments lack the sensitivity to measure short-term growth in children at the early stages of word-reading development (Lane *et al.* 2009).

To answer the second research question, standardized tests of reading (word and non-word efficiency, non-word accuracy, text-reading accuracy, and reading comprehension) were administered prior to intervention by the researcher and after the decoding intervention by a speech–language therapist unfamiliar with the children and blind to the research aims. These included:

- Test of Word Reading Efficiency—2 (TOWRE-2) (Torgesen *et al.* 2012), which comprised two subtests: Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE). These differed from NW Rate by including items that were not one-to-one letter–sound correspondence.
- Decoding subtests of the Phonological Awareness Test—2 (PhAT-2) (Robertson and Salter 2007), which has eight subtests: Vowel–Consonant, Consonant–Vowel–Consonant, Consonant Digraphs, Consonant Blends, Vowel Digraphs, R-Controlled Vowels, CVCe, and Diphthongs.
- Neale Analysis of Reading Ability 3rd Edition (Neale 1999), which results in three scores: Reading Accuracy, Reading Comprehension and Reading Rate.

<B>*Materials*

All materials (the decoding intervention, the researcher-developed non-word lists and the language intervention) were delivered on an iPad. *WordDriver-1* (see www.worddriver.com for details) presented the materials for the decoding intervention, the researcher-developed non-word lists and a measure of motor learning—all using the analogy of learning to drive a car (figure 2).

<fig 2>

Using this analogy, during the decoding intervention the learner progresses through three stages (L-Plate—learner; P-Plate—practice; D-Plate—driver) in mastering accurate decoding of randomly presented items (words and non-words) at five levels of difficulty (two-, three-, four-, five- and six-letter items). At each level, the L- and P-Plate items are organized in a predetermined sequence—initially the first letter changes, then the last, then the middle and then all letters. This draws attention to each letter and enables specific teaching (in the case of the L-Plate) and practice (P-Plate) of phonological recoding. The D-Plate items are organized according to orthotactic probability and are presented adaptively in response to participant error: easier items (higher orthotactic probability) following an incorrect response and more difficult (lower orthotactic probability) following a correct response. The researcher-developed non-word lists are presented with the T-Plate (test) using a similar graphical interface, while the S-Plate (speed) measures changes in motor response to control for any increased rate in using the app. Apart from two-letter items, there was no repetition of items between or within the decoding intervention and the T-Plates.

The Language Intervention condition used the Extra Language Resources app (ELRSoftware, 2000; see www.elr.com.au/elr.htm) and was designed to target participant-specific language weaknesses which were identified in the pre-intervention language assessment. For example, a picture-based 'associations' task (figure 3) targets vocabulary knowledge (naming each picture), comprehension (detecting an association with another picture) and expressive language (using specific vocabulary to explain the association). 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.

<fig 3>

<B>*Procedure*

Each participant progressed through five phases (table 3) comprising 54 sessions of 15–20 min duration. The intervention was delivered by the researcher and took place three times per week over two school terms in a quiet location at the child's school.

<tab 3>

In the first phase (A^1), all participants completed eight sessions. During each session, a T-Plate was administered first, followed by the S-Plate, and one or more of the standardized outcome measures so that each session was completed within 20 min. On each T-Plate trial, the child touched the Go button, read out loud the non-word letter string and touched the Go button to view the next item. No feedback about accuracy of response was provided. The researcher stopped the child after 60 s if the child had reached the criterion (six errors in eight consecutive items); otherwise, the child was allowed to continue until the criterion was reached. On each S-Plate trial (20 in total) 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 response time (time between presentation of black sign and touching of the Go button) was automatically recorded. There were no significant changes in motor response over time, hence improved skill at using the iPad was ruled out as a contributing factor in changes in responses on the NW Rate measure.

During the second phase, four participants completed 15 decoding intervention sessions (B) while four did 15 language intervention sessions (C). Each decoding intervention session consisted of a T-Plate, an S-Plate and one or two of the decoding intervention modules: an L-, P- or D-Plate (figure 4 shows an example progression).

<fig 4>

During the decoding intervention all participants began at the level of two-letter strings as they had all made errors at this level on the pre-intervention assessments. The L-Plate was the starting point at all levels (two-, three-, four-letter strings etc.), followed by the P-Plate, and finally the D-Plate. While the L-Plate was used explicitly to teach phonological recoding (i.e., the researcher performed all of the actions with the iPad), during the P-Plate and D-Plate the child performed more of the actions. The child touched the Go button, and read out loud a randomly presented word or non-word. The researcher told the child whether it was a word or a non-word, and provided corrective feedback about accuracy of response (by touching the Correct or Help button following a correct and incorrect response respectively). There were three levels of help following an incorrect response: 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. To support sight word development, the meaning of real words was highlighted either by the researcher using that word in a scripted sentence or by allowing the child to use the word spontaneously in a sentence that related to their own experience. In the case of non-words, the researcher used a sentence explaining that the item 'was not a real word; it has no meaning'. The child then put the item in the Book or the Bin (for words or non-words respectively) by touching either graphic, and touched the Go button to start the next trial. A criterion of 90% accuracy was required on the P-Plate to move to the D-Plate (within each level), and on the D-Plate to progress to the next level (e.g., from three- to four-letter).

Each language intervention session comprised two oral language activities selected from the e*L*r app. The T-Plate was not administered during these sessions. While vocabulary development was targeted for all participants, an additional goal for participants with expressive language impairment was oral narrative skills. The vocabulary tasks included 'associations' (depicted previously), 'similarities and differences' (naming two pictures and explaining how they are similar and different), 'detecting odd one out' (naming four pictures, categorizing, identifying the one that is not in the category) and 'generating words in a given category' (the child sees three pictures, names the category and names other items within that category). The oral narrative task used a picture sequence depicting a short story: the child described the action in each picture and then retold the entire story. Thus, the language intervention condition, while providing therapy for an identified need for each child, formed a control for the effects of individual time spent with each child.

During Phase 3 (A^2) all participants completed eight Baseline 2 sessions which were identical to A^1 except that a speech–language therapist blind to the research aims and unfamiliar with the participants administered the outcome measures to those participants who were now in post-decoding intervention phase.

Phase 4 of the cross-over design entailed a swap of intervention conditions. The procedures for each intervention condition were identical to those described in Phase 2.

Finally, in Phase 5 (A^3) all participants completed eight Baseline 3 sessions. As this was post-intervention for all participants, the researcher presented the T-Plate and S-Plate, and the independent speech–language therapist administered the other standardized outcome measures.

<B>*Data analysis*

The first research question examined the effect of the decoding intervention on the two measures of the dependent variable using analyses appropriate for SSRDs: visual inspection of the graphed responses and statistical analyses. Visual inspection (Rubin 2010) involves examination 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 from baseline to intervention phase.

Three statistical analyses were used:

- Statistical process control (SPC) (Portney and Watkins 2009) determined if a stable baseline were 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.
- The 2 SD band method (Rubin 2010) assessed whether there was a statistically significant difference between baseline and decoding intervention phases. If at least two consecutive data points in the intervention phase fall outside the 2 SD band, changes from pre-intervention baselines are considered significant.
- A calculation of Cohen's *d* effect size appropriate for SSRDs (Beeson and Robey 2006) in which the level of performance from the first baseline (A^1) was compared with that of the second (A^2) and third (A^3) using the following calculation:

$d = (X_{A2} - X_{A1})/S_{A1}$

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. As no previous studies with similar goals and outcome measures (e.g., McCandliss *et al.* 2003) have reported effect sizes to provide an appropriate benchmark, the effect size in this study was used to interpret the response to intervention for each participant relative to the other participants.

The second research question examined any clinically significant changes that were made by each participant in the standardized reading outcome measures. A clinically significant gain was judged to occur when a standard score moved from one category to the next as defined in the specific test manual, for example, from *severe delay* to *moderate delay*. The TOWRE-2 also provides an interpretation of change in raw score using a percentage probability that the difference is due to the intervention.

<A>**Results**

<B>*Question 1*

<C>*Visual analyses*

The first research question examined the impact of the decoding intervention on non-word decoding of items with one-to-one letter–sound correspondence as measured by researcher-developed non-word lists, the T-Plates. The graphed scores for each participant are shown in figure 5. Participants 1–4 depict the decoding-first condition (A^1–B–A^2–C–A^3), while participants 5–8 depict the language-first condition (A^1–C–A^2–B–A^3). Each graph includes four measures: NW Rate (number correct in 60 s), NW Total (total number correct), and the 2 SD band lines for both NW Rate and NW Total.

<fig 5>

During the first pre-intervention baselines (A^1), the NW Total data show low and stable levels for five participants (P1, P3–P5, P7) and greater variation for three (P2, P6, P8). The NW Rate data show low and stable levels for seven participants (P1–P5, P7, P8) with variation in responses for P6. During the second pre-intervention baseline (for the language-first participants), two (P6 and P8) demonstrated a slight increase in level (i.e., increased accuracy), one (P5) a decreased in level, and one (P7) no change for NW Rate and NW Total.

During the decoding intervention (Phase B), while the NW Total scores increased in level with a trend for increased accuracy for all participants, the slope varied between participants. Five participants (P1, P3, P5–P7) showed a gradual increase for the first six sessions, followed by a steep slope; P4 showed a gradual slope for the first 11 sessions followed by a steep slope; and two participants (P2, P8) showed a slope with variability. The NW Rate data generally mirrored NW Total with increases in level and trend, but with a less pronounced slope: an expected outcome as there is a limit to the number of items that can be attempted in 60 s.

During the post-decoding intervention baselines all participants maintained the level of response for NW Total and NW Rate, and there was no change in trend or slope.

<B>*Statistical analyses*

The SPC analyses show that though the visual inspection suggests a degree of variation in pre-intervention baselines, all participants achieved stable pre-intervention baselines as all data points are below the 3 SD band for NW Rate and NW Total (satisfying the SPC requirement), and all but one data point are below the 2 SD band.

The 2 SD band method which is graphed for NW Rate and NW Total shows that all participants reached significance for NW Total with a range of 7–14 consecutive data points above the 2 SD band. Five participants (P1, P3–P5, P7) reached significance for NW Rate (a range of 5–13 consecutive data points above the 2 SD band); one (P2) barely reached significance (three consecutive data points above the 2 SD band); and two (P6 and P8) did not reach significance.

The Cohen's *d* effect size calculation (table 4) shows the magnitude of the treatment effect for each participant. First, the decoding-first participants made gains following the decoding intervention (A1–A2) but no further gains following the language intervention, and the language-first participants made no gains until completion of the decoding intervention. The second observation is that though there is considerable variation between participants, significant gains are associated with effect sizes over 4: the NW Rate effect sizes for participants who did not make significant gains (P6 and P8) or barely reached significance (P2) were below 4, and all participants who made significant gains achieved effect sizes greater than 4 for NW Rate and NW Total.

<tab 4>

<C>*Question 2*

The second research question examined the effect of the decoding intervention on standardized assessments of reading by examining the clinically significant changes for each participant on standardized measures of word and non-word reading (table 5).

<tab 5>

The TOWRE-2 PDE analyses showed that four participants made clinically significant gains on their standard scores, and seven made gains using the raw score interpretation (Torgesen *et al.* 2012). On the TOWRE-2 SWE, one participant made a clinically significant gain on their standard score, and five on the raw score interpretation.

The PhAT-2 Decoding analyses showed that two participants made gains on all three targeted areas (VC, CVC, C Bl), four participants on two targeted areas and two participants on one targeted area. Fourteen of the 16 clinically significant gains represented improvement from below average to the average range. Generalization to one non-targeted area (consonant digraphs) was demonstrated by six participants.

The results of the Neale showed that three participants made clinically significant changes in their percentile rank descriptors for reading accuracy, four for reading comprehension and there were no gains in reading rate.

<A>**Discussion**

This study designed, developed and evaluated a decoding intervention targeting phonological recoding and orthographic processing, on word and non-word reading, text-reading accuracy, and reading comprehension. Following a discussion of the two research questions, a brief examination of the relationship between pre-intervention participant profiles and response to intervention is offered, and finally the limitations and conclusions are discussed.

<B>*Question 1*

The first research question examined the impact of the decoding intervention on non-word decoding of items with one-to-one letter–sound correspondence measured by researcher-developed non-word lists. The results showed that all participants made gains in decoding accuracy, but fewer in rate of decoding—a measure of reading fluency. 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.

Second, while we found that the language-first participants made no gains following the language intervention, all participants made gains following the decoding intervention, and, for the decoding-first participants, the gains were maintained for 2 months following the decoding intervention. These results suggest a direct relationship between the decoding intervention and the significant gains in non-word reading.

Third, visual inspection of responses during the decoding intervention showed that there was a gradual improvement in decoding accuracy over time. This suggests that accurate phonological recoding takes time to develop, and that there is variation in how quickly individual children master this skill.

The outcomes of this research may be considered in the context of other studies (Pullen and Lane 2014, McCandliss *et al.* 2003) that targeted word-reading skills (specifically to support progression from the partial to the full alphabetic stage) and employed researcher-developed non-word lists as an outcome measure. While analyses conducted at the group level showed significant gains for the experimental groups, McCandliss *et al.* (2003) conducted an examination of individual responses to intervention and found that about one-third of participants only made nominal gains. A number of differences in this research may have contributed to the findings that all participants made significant gains in decoding. First, our intervention involved a task that specifically targeted phonological recoding and orthographic processing. These results support the findings of Pullen and Lane (2014) who suggested that a key component of successful intervention was a task targeting decoding skills. Second, the decoding intervention targeted items with one-to-one letter–sound correspondence to match more precisely the known decoding deficits of this population, a feature which may have enabled all participants to demonstrate a positive response to intervention. Two additional differences highlight the implications of these results: compared with the Tier 2 interventions of McCandliss *et al.* (2003) and Pullen and Lane (2014), our specifically targeted decoding intervention required less time; and the participants (who required Tier 3 intervention) were more severely impaired.

The results suggest that the decoding intervention was successful in delivering a time-efficient intervention targeting key skills which some children have difficulty mastering despite receiving Tier 2 reading interventions. These skills allow progression from the partial to the full alphabetic stage of reading development, and underpin sight word development (Cunningham 2006) and reading comprehension (Ehri 2005).

<B>*Question 2*

The second research question examined the effect of the decoding intervention on standardized assessments of reading. Most participants made clinically significant gains on standardized tests of non-word-reading accuracy and non-word reading fluency, fewer gains on word reading fluency, and we observed trends for improved text-reading accuracy and comprehension.

<B>*Non-word reading*

Regarding non-word-reading accuracy, all participants made clinically significant standard score gains in at least one of the three targeted areas, suggesting improvements in their mastery of the process of phonological recoding. While six of the eight participants also showed generalization to a non-targeted area (items with consonant digraphs), no generalization to vowel digraphs was demonstrated. Examination of individual responses on the non-word-reading assessment provides some insight. Before 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, before intervention, *faim* was often pronounced as /fam/, *sead* as /sad/; and following intervention, attempts at these items revealed mastery of phonological recoding but lack of orthographic knowledge, i.e., *faim* was recoded as /f-a-i-m, fam/ and *sead* as /s-e-a-d, sad/. Hence, it was possible that their severe delays in orthographic knowledge of vowel spelling patterns may have contributed to the observed lack of generalization.

The analyses of the results on the non-word reading fluency measure showed that half the participants made clinically significant standard score gains; and for six of the eight participants, there was a greater than 85% probability that gains in raw scores were due to the intervention. This result suggests that a degree of generalization may have occurred, as the non-word-reading fluency assessment included items that contained consonant and vowel digraphs.

These results suggest that the decoding intervention was successful in developing a key foundation skill (phonological recoding) that enables efficient use of the non-lexical route (Coltheart 2006) and transition from the partial alphabetic to the full alphabetic stage of reading (Ehri 2005). This progression supports the emergence of the consolidated phase which leads to the development of a large bank of established sight words.

<B>*Word and text reading*

The analyses of the standardized measures of word-reading efficiency and text reading suggested trends for improved skills in word reading and reading comprehension: There was a greater than

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. Consistent with previous research (Buckingham *et al.* 2012, Denton *et al.* 2013, National Reading Panel 2000, Torgesen 2001), there were no changes in reading fluency.

[AQ2] A number of factors may have impacted on generalization to measures of word reading in this study. First, the word-reading outcome measure is a timed assessment. Similar to Buckingham *et al.* (2012), who found significant gains in an untimed but not in a timed measure of word reading, the participants may have demonstrated gains on an untimed measure of word reading as NW Total significantly improved for all participants, but NW Rate did not.

Second, delays in orthographic knowledge of vowel digraphs may have prevented generalization to word reading. Within the paradigm of Ehri's phase model (Ehri 2005), children in the early stages of learning to read need to have knowledge of the grapheme–phoneme rules for at least the common spelling patterns in order to perform accurate phonological recoding. Hence, even though all participants mastered phonological recoding, it is possible that they were unable to use this skill accurately to decode items which included unknown graphemes.

Third, lack of significant gains in word reading may relate to impaired orthographic processing skills in this population. Apel *et al.* (2012) have shown that children at risk of literacy delay are less efficient at developing orthographic representations. Hence, though the participants made significant gains in phonological recoding, this population may take longer or require a greater dose to develop orthographic representations for words.

Finally, this study investigated a specifically targeted decoding intervention to enable an analysis of its effect on a range of outcome measures. As such, there was no additional support to use phonological recoding during text reading: students with persistent word-reading impairment are likely to benefit from encouragement to use decoding strategies during text reading. Additionally, research has shown that effective interventions require a multi-component approach (National Reading Panel 2000). Hence, while the decoding intervention was successful in building essential foundation decoding skills, generalization to other domains of reading would be likely with broader components.

<B>*Response to intervention*

The single-subject research design used in this research incorporated in-depth pre-intervention assessment using standardized assessments of oral language and phonological processing. Informal examination of the relationship between individual pre-intervention profiles and the number of clinically significant standard score gains on measures of non-word and word reading revealed three observations. First, consistent with previous studies (Denton *et al.* 2013, Torgesen 2001) that highlighted the importance of oral language and phonological processing skills, most of the participants had below-average scores on more than half the pre-intervention measures. However, irrespective of pre-intervention profile, all participants demonstrated clinically significant gains. Second, the lowest effect sizes occurred for the two children with the strongest and for a child with one of the weakest pre-intervention profiles, which suggests that there may be other factors that influence response to intervention. Third, within phonological processing, while two participants had below-average phonological awareness and a different two weaknesses in rapid naming, all participants were below average in phonological memory. These observations suggest that the role of phonological memory in the development of decoding and word reading needs further exploration, and that the relationship between pre-intervention profile, including oral language skills, and response to intervention is a complex one.

<B>*Limitations*

Limitations of this research include the small number of participants; the fact that the decoding intervention was delivered by the researcher; and use of a timed measure of word reading. Future research aims (1) to vary the research design (larger number of participants, different people delivering the decoding intervention); (2) to extend targets to include consonant and vowel digraphs; (3) to include additional untimed outcome measures; and (4) to examine dose rate, particularly for the subsequent stages which target orthographic learning of consonant and vowel digraphs.

<A>**Conclusions**

This research adds to the existing evidence for Tier 3 reading interventions. It developed and evaluated a decoding intervention that delivers explicit, intense and efficient intervention for children who have not mastered accurate the use of phonological recoding to support continued growth of orthographic learning. It evaluated the efficacy of this intervention using an SSRD of the highest level of evidence: eight participants from three schools (thus incorporating children from different teaching environments); a research design involving two forms of control (a ‘no treatment’ phase for each participant, and a comparison intervention to control for the effect of individual therapy time); random assignment of participants to intervention regime; and finally, each of the baseline phases involved the same number of sessions (enabling use of statistical analyses to compare changes in performance between baseline measures). The findings are consistent with previous research (Denton *et al.* 2013, Austin *et al.* 2017) showing significant gains following Tier 3 interventions. Additionally, the decoding intervention significantly increased the decoding skills for all participants: this suggests that it may form a useful component within Tier 3 reading interventions, particularly for those students with specific impairments in orthographic learning who may 'need a different approach to reading instruction, perhaps going beyond currently understood "best practices"' (Denton *et al.* 2013: 645). Finally, *WordDriver-1* is available free for replication, clinical use and further investigations (see www.worddriver.com).

<A>**Acknowledgements**

This paper forms part of the programme of research for the PhD completed by the first author at Curtin University (Australia). The authors extend special thanks to Dr Robert Kane for his assistance with the statistical analyses, and Dr Rob Seiler for his computer programming expertise. They thank the parents and children who participated in the study, and the school staff who were so enthusiastic about involvement in research that aims to help children with reading difficulty.
Declaration of interest: The authors report no conflicts of interest as the intervention developed for this research has been made freely available for future research and clinical use. The authors alone are responsible for the content and writing of the paper.

<<t/s Set names in caps and scaps as per usual style>>

<A>**References**

APEL, K., 2011, What is orthographic knowledge? *Language, Speech and Hearing Services in Schools*, **42**, 592–603.

APEL, K., THOMAS-TATE, S., WILSON-FOWLER, E. B. and BRIMO, D., 2012, Acquisition of initial mental graphemic representations by children at risk for literacy development. *Applied Psycholinguistics*, **33**, 365–391.

ATKIN, N. and FISHER, J., 1996, *Articulation Survey* (Melbourne, VIC: Royal Children's Hospital).

AUSTIN, C., R, VAUGHN, S. and MCCLELLAND, A., M., 2017, Intensive reading interventions for inadequate responders in grades K-3: a synthesis. *Learning Disability Quarterly*, **40**, 191–210.

BEESON, P. M. and ROBEY, R. R., 2006, Evaluating single-subject treatment research: lessons learned from the aphasia literature. *Neuropsychology Review*, **16**, 161–169.

BOWEY, J. A. and MULLER, D., 2005, Phonological recoding and rapid orthographic learning in third-graders' silent reading: a critical test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, **92**, 203–219.

BUCKINGHAM, J., WHELDALL, K. and BEAMAN, R., 2012, A randomised control trial of a Tier-2 small-group intervention ('MiniLit') for young struggling readers 1. *Australian Journal of Learning Difficulties*, **17**, 79–99.

CARMICHAEL, R. and HEMPENSTALL, K., 2006, Building upon sound foundations. *Australian Journal of Learning Disabilities*, **11**, 3–16.

COLTHEART, M., 2006, Dual route and connectionist models of reading: an overview. *London Review of Education*, **4**, 5–17.

CUNNINGHAM, A. E., 2006, Accounting for children's orthographic learning while reading text: do children self-teach? *Journal of Experimental Child Psychology*, **95**, 56–77.

CUNNINGHAM, A. E., PERRY, K. E., STANOVICH, K. E. and SHARE, D. L., 2002, Orthographic learning during reading: examining the role of self-teaching. *Journal of Experimental Child Psychology*, **82**, 185–199.

DENTON, C. A., TOLAR, T. D., FLETCHER, J. M., BARTH, A. E., VAUGHN, S. and FRANCIS, D. J., 2013, Effects of Tier 3 intervention for students with persistent reading difficulties and characteristics of inadequate responders. *Journal of Educational Psychology*, **105**, 633–648.

EHRI, L. C., 2005, Learning to read words: theory, findings, and issues. *Scientific Studies of Reading*, **9**, 167–188.

GOSWAMI, U., ZIEGLER, J. C., DALTON, L. and SCHNEIDER, W., 2003, Nonword reading across orthographies: how flexible is the choice of reading units? *Applied Psycholinguistics*, **24**, 235–247.

GOUGH, P. B. and TUNMER, W. E., 1986, Decoding, reading, and reading disability. *Remedial and Special Education*, **7**, 6–10.

HERRMANN, J. A., MATYAS, T. and PRATT, C., 2006, Meta-analysis of the nonword reading deficit in specific reading disorder. *Dyslexia*, **12**, 195–221.

LANE, H. B., PULLEN, P. C., HUDSON, R. F. and KONOLD, T. R., 2009, Identifying essential instructional components of literacy tutoring for struggling beginning readers. *Literacy Research and Instruction*, **48**, 277–297.

MCCANDLISS, B., BECK, I. L., SANDAK, R. and PERFETTI, C., 2003, Focusing attention on decoding for children with poor reading skills: design and preliminary tests of the word building intervention. *Scientific Studies of Reading*, **7**, 75–104.

[AQ3] NATIONAL READING PANEL, 2000, *Teaching Children to Read. An Evidence-Based Assessment of the Scientific Research Literature on Reading and Its Implications for Reading Instruction* (US National Institute of Child Health and Human Development).

[AQ4] NEALE, M. D., 1999, *Neale Analysis of Reading Ability 3rd Edn* (Melbourne, VIC: Australian Council for Educational Research).

PORTNEY, L. G. and WATKINS, M. P., 2009, *Foundations of Clinical Research*, 3rd edn (Upper Saddle River, NJ: Pearson Prentice-Hall).

PULLEN, P. C. and LANE, H. B., 2014, Teacher-directed decoding practice with manipulative letters and word reading skill development of struggling first grade students. *Exceptionality*, **22**, 1–16.

RITTER, M. J., PARK, J., SAXON, T. F. and COLSON, K. A., 2013, A phonologically based intervention for school-age children with language impairment: implications for reading achievement. *Journal of Literacy Research*, **45**, 356–385.

ROBERTSON, C. and SALTER, W., 2007, *The Phonological Awareness Test 2* (East Moline, IL: LinguiSystems).

ROBEY, R. R., 2004, A five-phase model for clinical-outcome research. *Journal of Communication Disorders*, **37**, 401–411.

[AQ5] RUBIN, A., 2010, *Statistics for Evidence-Based Practice and Evaluation*, 3rd edn (Linda Schreiber-Ganster).

SEILER, A. M., LEITÃO, S. and 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**, 13–18.

SHARE, D. L., 1995, Phonological recoding and self-teaching: sine qua non of reading acquisition. *Cognition*, **55**, 151–218.

SNOWLING, M. J. and HULME, C., 2012, Annual Research Review: The nature and classification of reading disorders—a commentary on proposals for DSM-5. *Journal of Child Psychology and Psychiatry*, **53**, 593–607.

SPARKS, R., PATTON, J. and MURDOCH, A., 2014, Early reading success and its relationship to reading achievement and reading volume: replication of '10 years later'. *Reading and Writing*, **27**, 189–211.

TORGESEN, J. K., 2001, Intensive remedial instruction for children with severe reading disabilities: Immediate and long-term outcomes from two instructional approaches. *Journal of Learning Disabilities*, **34**, 33–58.

TORGESEN, J. K., WAGNER, R. K. and RASHOTTE, C. A., 2012, *Test of Word Reading Efficiency: Second Edition* (Austin, TX: PRO-ED).

WECHSLER, D., 2003, *WISC-IV Australian* (Marrickville, NSW: Harcourt Assessment).

WHEATER, R., AGER, R., BURGE, B. and SIZMUR, J., 2014, *Achievement of 15-Year-Olds in England: PISA National Report (OECD Programme for International Student Assessment)* (Slough: Department for Education).

WIIG, E. H., 2006, *CELF 4 Australian* (Marrickville, NSW: Harcourt Assessment).

Table 1. Participant performance on selection measures

Tests	Participant (age, years;months)							
	P1 (8:0)	P2 (7:9)	P3 (8:5)	P4 (7:10)	P5 (7:6)	P6 (8:4)	P7 (8:1)	P8 (8:11)
WISC-IV FS	83	90	80	83	82	100	92	80
PhAT G-P	105	102	101	95	106	101	101	106
RCH Artic	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL
TOWRE PDE	79	79	73	58	62	75	66	60

TOWRE SWE	76	66	74	66	80	69	69	55

Note: FS, full-scale score; G-P, grapheme–phoneme composite score for consonants and short vowel letters; WNL, within normal limits; PDE, Phonemic Decoding Efficiency; SWE, Sight Word Efficiency.

Table 2. Standard scores on pre-intervention profile assessments

Tests	P1	P2	P3	P4	P5	P6	P7	P8
CELF-4								
Core language	75*	90	84*	73*	79*	90	81*	79*
Receptive language	84*	98	77*	82*	68*	84*	74*	84*
Expressive language	72*	91	86	76*	80*	91	78*	76*
CTOPP-2								
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*

Notes: CELF-4, Clinical Evaluation of Language Fundamentals—4; CTOPP-2, Comprehensive Test of Phonological Processing—2.

*Scores > 1 SD (standard deviation) below the mean.

Table 3. Phases, session type and session content

Phase	Number of sessions	Decoding first		Language first	
		Session type	Session content	Session type	Session content
1	8	Baseline 1 (A1)	T-Plate S-Plate Outcome measures	Baseline 1 (A1)	T-Plate S-Plate Outcome measures
2	15	Decoding (B)	T-Plate S-Plate L-, P-, D-Plates	Language (C)	2 × e*Lr* language activities
3	8	Baseline 2 (A2)	T-Plate S-Plate Outcome measures	Baseline 2 (A2)	T-Plate S-Plate Outcome measures
4	15	Language (C)	2 × e*Lr* language activities	Decoding (B)	T-Plate S-Plate L-, P-, D-Plates
5	8	Baseline 3 (A3)	T-Plate S-Plate	Baseline 3 (A3)	T-Plate S-Plate

			Outcome measures		Outcome measures

Table 4. Cohen's *d* effect size

	NW Rate								NW Total							
	P1	P2	P3	P4	P5	P6	P7	P8	P1	P2	P3	P4	P5	P6	P7	P8
A^1–A^2	12.0	2.5	5.4	7.4	–1.1	0.9	0.2	0.8	9.6	5.0	27.8	15.4	–1.1	1.5	–0.1	0.5
A^2–A^3	–0.5	–0.6	0.2	–1.6	6.1	1.6	5.7	0.9	0.7	–0.1	0.0	2.3	20.9	7.1	28.9	4.7

Note: A^n = baseline phase; shaded data = post-decoding.

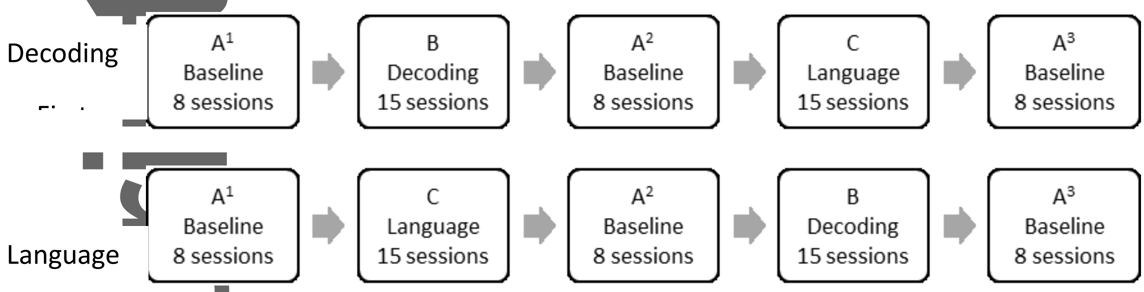
Table 5. Pre-/post-intervention standardized test scores

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 standard score (average range = 90–110)																
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 (average 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
Neale Analysis: percentile rank (PR)																
Acc	10	18*	4	5	15	20	8	10	17	14	18	21	7	17*	4	14*
Comp	10	24*	7	12*	19	24*	11	13	15	15	52	53	20	42*	13	22
Rate	10	5	6	4	27	20*	16	9*	15	21	13	10	20	11	9	5

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; Acc, accuracy; Comp, comprehension; * = clinically significant gain; *^{nn} = probability that the difference is not due to error.

Figure 1. Research design.



Participants

Figure 2. Screenshot of a decoding intervention module—the P-Plate.

Figure 3. Language intervention ‘associations’. An activity targeting vocabulary development: 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.

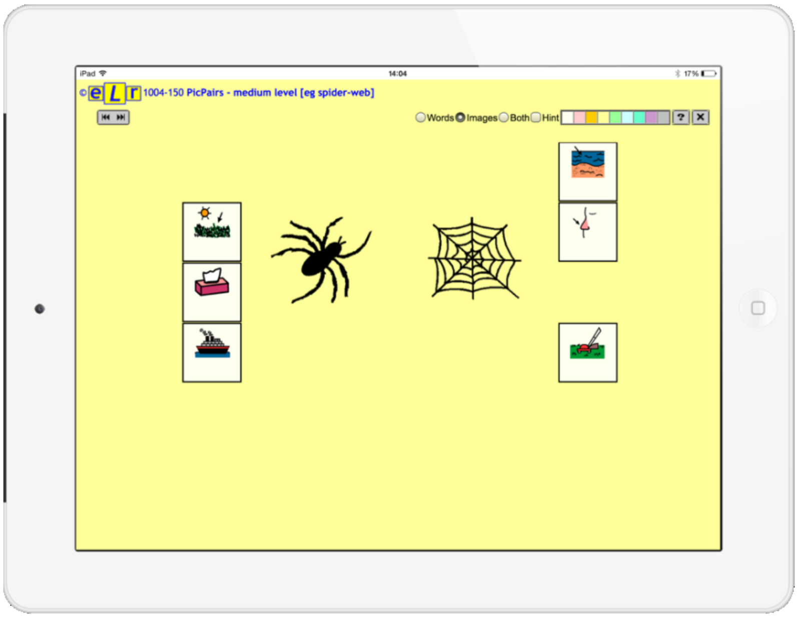


Figure 4. Example sequence of the 15 decoding intervention modules. T = T-Plate; S = S-Plate; L-2 = L-Plate two-letter level; P-2 = P-Plate two-letter level; D-3 = D-Plate three-letter level; L-4 = L-Plate four-letter level etc.

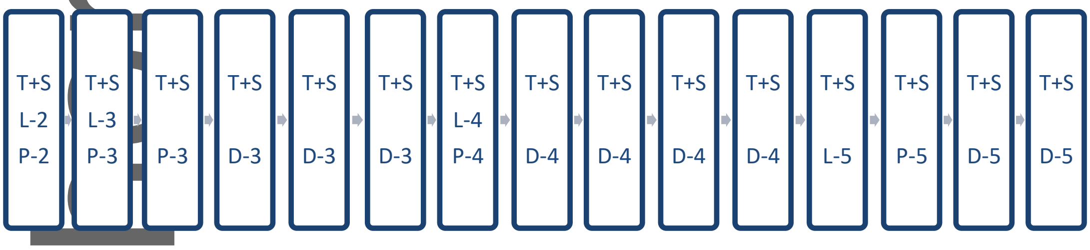
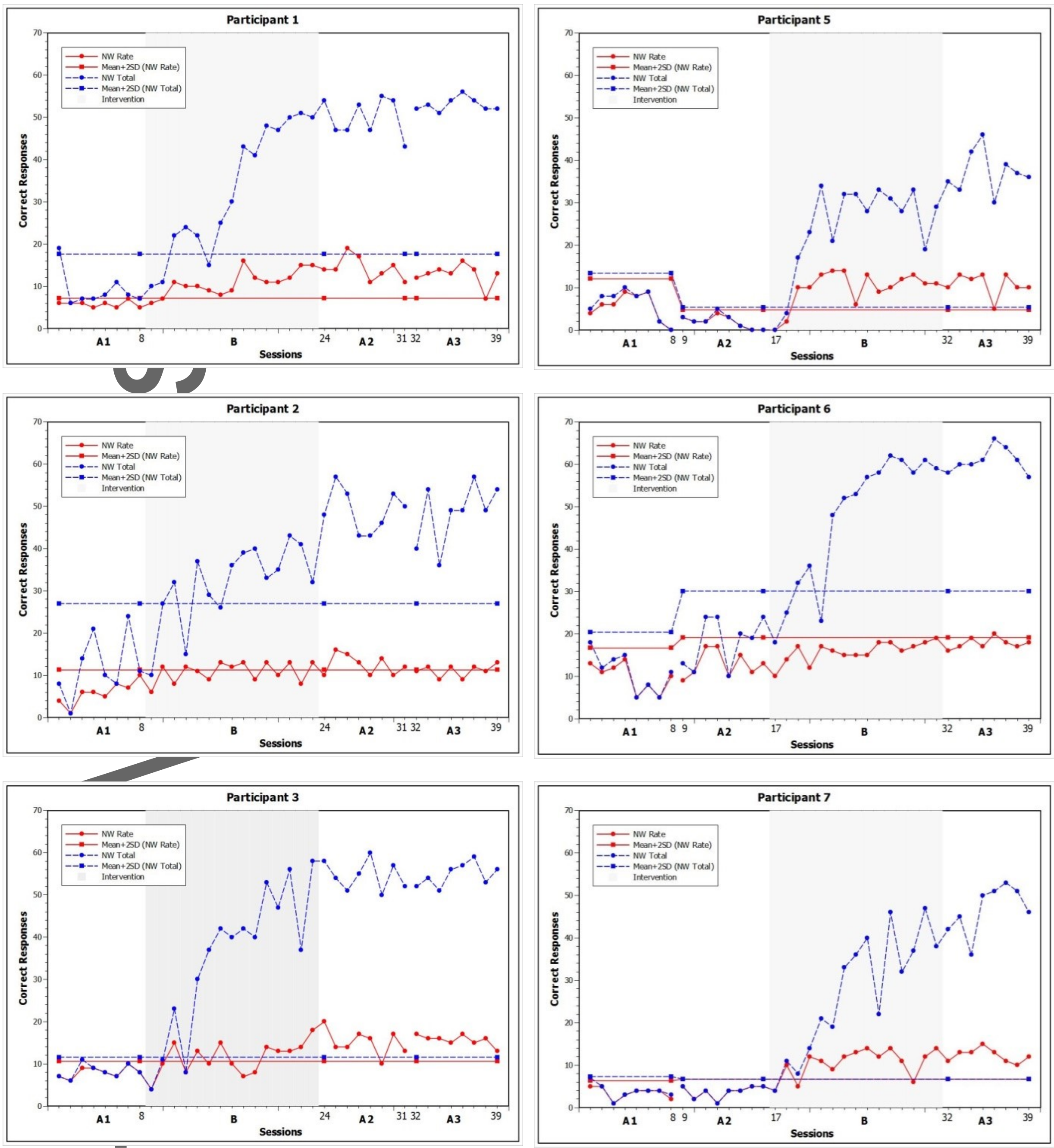
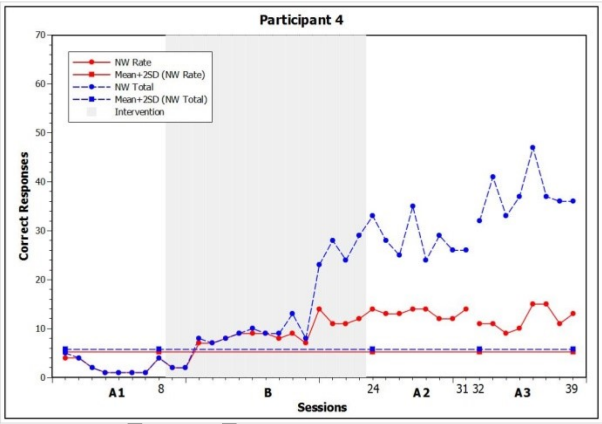
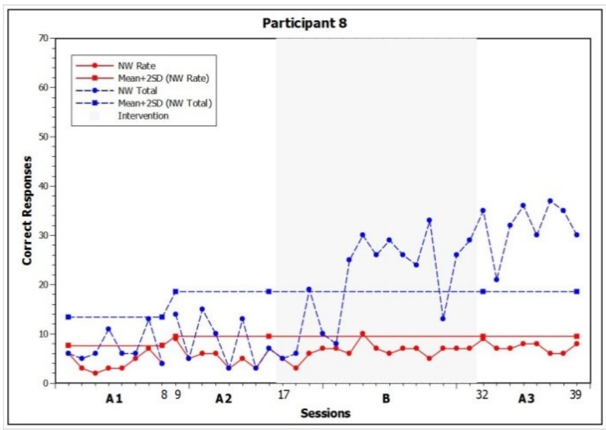


Figure 5. T-Plate scores for decoding-first (P1–4) and language-first (P4–6) participants. Shaded area = decoding intervention (B).




Participant 4
NW Rate
Mean+2SD (NW Rate)
NW Total
Mean+2SD (NW Total)
Intervention
Correct Responses
0
10
20
30
40
50
60
70
A1
8
B
24
A2
31
32
A3
39
Sessions


Participant 8
NW Rate
Mean+2SD (NW Rate)
NW Total
Mean+2SD (NW Total)
Intervention
Correct Responses
0
10
20
30
40
50
60
70
A1
8
9
A2
17
B
32
A3
39
Sessions