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

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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.

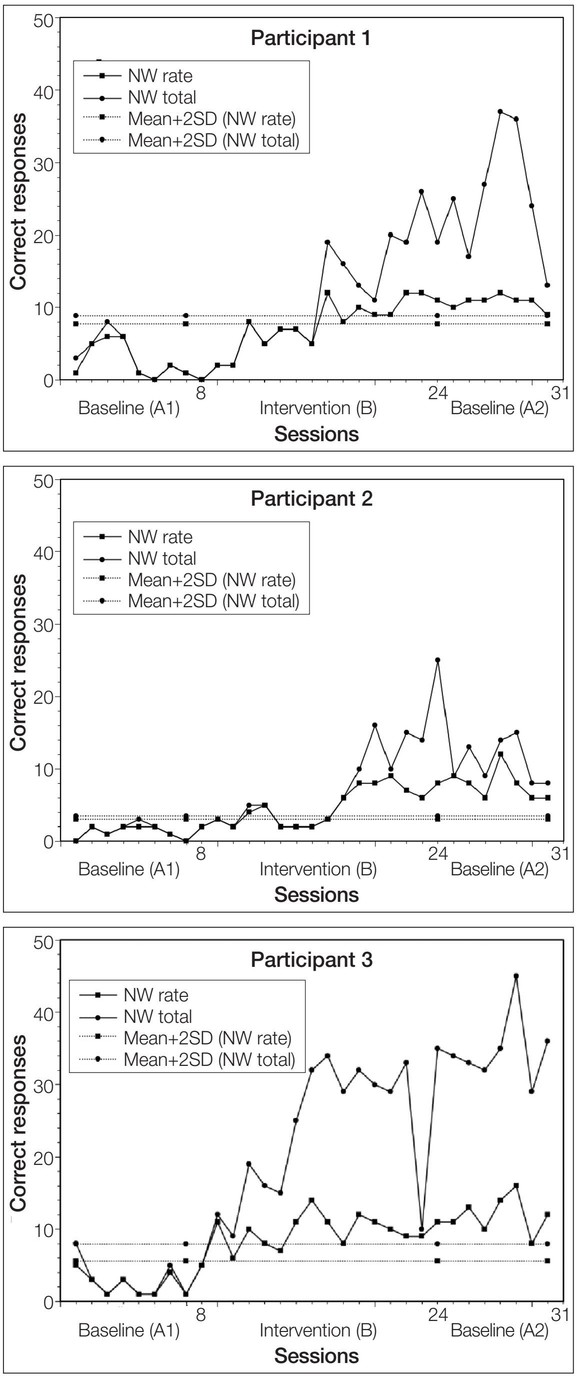

Figure 2. NW rate (correct responses in 1 min) and NW total (total number of correct responses) for participants 1, 2 and 3, showing the 2 SD band method of analysis

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,

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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