WordDriver-1: Development of an app designed to support a decoding intervention

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Abstract

Aims: This paper describes the development and availability of a single component decoding intervention, WordDriver-1.

Background: A focus on word reading skills is an essential component of early reading instruction and intervention. Multi-component interventions targeting phonemic awareness and the alphabetic principle have been shown to be effective for children with reading impairment. However about 25% of participants fail to respond and it has been difficult to determine the essential intervention component. Studies which have attempted to isolate the key component within multi-component interventions have concluded that tasks targeting phonological recoding and orthographic processing are a key element. Our research developed and investigated the effectiveness of a single component intervention for children with persistent word reading impairment which targeted phonological recoding and orthographic processing allowing unambiguous examination of its effect on word reading.

Method: WordDriver-1, an app with six modules, was developed. Three intervention modules present context-free items (words and nonwords with 1:1 grapheme-phoneme correspondence selected from the MRC and ARC databases) at five levels of difficulty (from 2- to 6-letters), while two testing modules present outcome measures. All items are presented from easiest to hardest according to orthotactic probability. Within each intervention module the items are automatically presented while the instructor plays a key role in providing corrective feedback about decoding accuracy. All activity within each module (e.g., presented items, response accuracy, response times) are logged for each user. An administrative module allows the instructor to select appropriate intervention and testing modules to match each child's decoding intervention needs.

Outcomes: Our research has developed and made available for other researchers, a single component reading intervention web app, WordDriver-1. It targets key skills in the early stages of reading acquisition which have been shown to be impaired in most children with reading impairment.

Conclusions & Implications: This intervention has the potential to be an efficient evidence-based component of reading interventions for children with severe and persistent reading delay, as initial evaluations (under review) suggest that 15 x 20 minutes sessions using WordDriver-1 resulted in significant gains in decoding skills for children (aged 7 – 8 years) who had not responded to previous reading interventions.

Keywords: Computer supported intervention, reading difficulties, phonological recoding, orthographic processing, dyslexia

What this paper adds.
This project makes available for further research a novel, single component reading intervention (an app called WordDriver-1) targeting key skills that are known to be (a) essential for development of word reading skills, (b) impaired in most children with reading difficulty, and (c) a key element within many multi-component reading interventions. WordDriver-1 allows an unambiguous examination of the impact of interventions which specifically target phonological recoding and orthographic processing for children with severe and persistent word reading impairment.

Introduction

This paper describes the development and availability of WordDriver-1: an app which is used to deliver an intervention targeting word reading impairment (the *decoding intervention*) for children with persistent reading disability. WordDriver-1 was developed, trialled, and evaluated (using an iPad) as part of a programme of research (Seiler, 2015, Seiler et al., 2013).

While Seiler et al. (under review) discuss the theoretical underpinnings and evaluation study of WordDriver-1, the focus of this paper is to describe its development. A summary of the rationale and design principles of the decoding intervention, and an overview of WordDriver-1 is presented. This is followed by a more detailed description of each module within the app, outlining for each one, the interface, organisation of stimuli, and a flow diagram depicting the programming logic. Finally, the data logging and a summary which includes a link to a web app version is presented.

Rationale

The decoding intervention delivered by WordDriver-1 targets word reading, specifically decoding (use of grapheme-phoneme rules to sound out and blend to read a word). The focus on word reading is based on (a) the Simple View of Reading which highlights the essential role of word reading accuracy in reading comprehension (Gough and Tunmer, 1986); (b) studies showing that early word reading development is predictive of a range of skills such as later literacy, language, and general knowledge (García and Cain, 2014, Sparks et al., 2014, Botting et al., 2006); and (c) research showing that most children with reading disorders have word reading impairment, predominantly in the ability to use grapheme-phoneme translation to read unfamiliar words - decoding (Herrmann et al., 2006). Hence, the primary aim of WordDriver-1 is to teach accurate decoding skills assessed by measures of nonword reading - a direct test of decoding skill.

A range of evidence-based principles are incorporated into WordDriver-1. Firstly, it teaches accurate phonological recoding (sounding out and blending) and orthographic processing (paying attention to each letter in the item). Accurate phonological recoding has been shown to optimise the development of mental orthographic representations, *MORs* (Cunningham et al., 2002): a key component of sight word development (Ehri, 2005); and orthographic processing to contribute uniquely and significantly to word reading development (Cunningham, 2006). Secondly, it presents single items without story context as research suggests that MOR development is not significantly influenced by context (Cunningham, 2006). Third, the items are of similar grain size (i.e., all items require use of grapheme-phoneme correspondence so there is no switching of strategy to read items) as this type of presentation has been shown to optimise word reading performance for English readers (Goswami et al., 2003). Fourth, the items are organised according to orthotactic probability value (the frequency with which a word's graphemes and bigraphs appear in English). Although it was suggested that phonotactic probability (the frequency that the item's sound

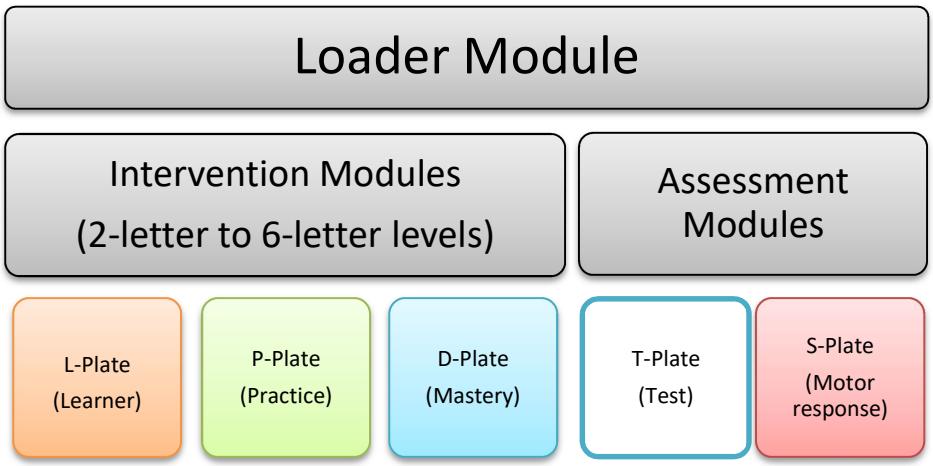
combination occurs in English) may influence the child's ability to phonologically recode, MOR development was found to be more efficient with words of high orthotactic probability (Apel et al., 2012). Fifth, WordDriver-1 provides repetition of key skills (phonological recoding) as repetition has been shown to optimise learning (Carmichael and Hempenstall, 2006) and MOR development (Bowey and Muller, 2005). Finally, intervention targets are chosen to match the decoding skill level of each user, as research has shown that prior orthographic knowledge predicts MOR development (Cunningham et al., 2002). WordDriver-1 targets items with 1:1 grapheme-phoneme correspondence because research has shown that children with reading delay in the early stages of reading acquisition are unable to accurately decode 3- and 4-letter words (McCandliss et al., 2003). The studies which piloted (Seiler et al., 2013) and evaluated WordDriver-1 found that group analyses (Seiler, 2015, Seiler et al., under review) showed significant gains in decoding (measured by nonword reading), while individual analyses (Seiler, 2015) suggested trends for improved word and text reading. The development of WordDriver-1 is now discussed.

WordDriver-1

Overview

WordDriver-1, a web app at the functional prototype stage, is written in HTML/Javascript/CSS with server support in Perl. It contains six modules which present all intervention stimuli and runs in a standard web browser. Five of the modules (the decoding intervention and the assessment modules) are used interactively with the child, and the sixth module (loader module) manages data and is used by the instructor/clinician (or researcher) to select the appropriate module for a specific child (see figure 1)

Figure 1: Diagram of Word Driver 1



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 decoding intervention: the L-Plate (learner), P-Plate (practice), and D-Plate (driver). The remaining two modules are used to deliver outcome measures: the T-Plate (test) and the S-Plate (speed).

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

- The L-Plate (learner) is used to teach 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 phoneme 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 phoneme 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 phoneme 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 child response, that is, an easier item is presented following an inaccurate response, and a more difficult item following an accurate response.

Each user begins the decoding intervention at a level that matches their decoding skill which is determined by a pre-intervention decoding assessment that measures accuracy of decoding (e.g., at the 2-letter, 3-letter, consonant blends etc.). For example a child who makes decoding errors on 3-letter items would 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 the remaining levels ensuring that the criterion of 90% accuracy is reached at each of the levels.

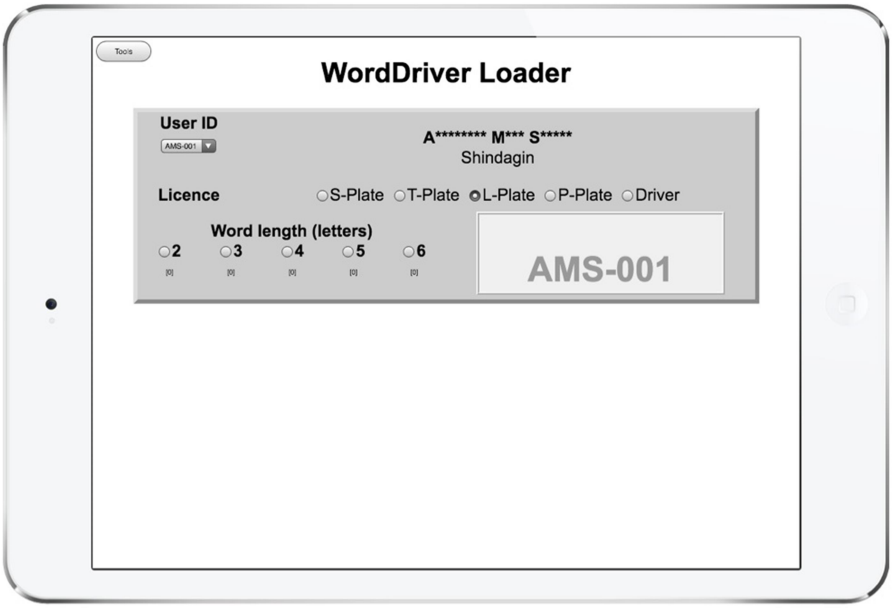
The remaining two components administer outcome measures.

- The T-Plate (test) delivers the *Assessment NW Lists* (researcher-developed nonword 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) measures the motor component of the task. This data allows an instructor to judge 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 children 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 instructor to select intervention modules. For example, to select a module for a specific child, the instructor firstly selects the User ID for the child user who is completing the session (e.g., AMS-001), then the module (e.g., L-Plate, P-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 computer programmes were written to manage these processes: the *StimulusMatcher*, and the *Nonword Assessment List Generator.*

Word and nonword requirements

The decoding intervention of WordDriver-1 requires words and nonwords with 1:1 letter sound correspondence in sets from 2- to 6-letter strings, and the T-Plate (Assessment NW Lists) requires 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.
- A phonetic representation of each sound in the item, so that a sound file could be linked to each grapheme 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 grapheme-phoneme 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 (e.g., brig, copt), obtain the phonetic transcription, and to calculate the orthotactic probability values. N-Watch is a freely available Windows programme (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 et al., 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 et al., 1995). N-Watch was employed in our research as the programme 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. The phonetic transcription for each word 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 programme called StimulusMatcher was written in Perl script using the N-Watch algorithm (Davis, 2005) to calculate the orthotactic probability values: in N-Watch called BF_TK (Bigram Frequency Token). This was necessary because N-Watch does not calculate statistics for nonwords. 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 bigram 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) and the BF_TK value (orthotactic 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 et al., 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 grapheme-phoneme 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 grapheme-phoneme 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 probability values, the output from the ARC database was processed using the same computer programme (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), with a phonetic transcription (DISC_PRON) and orthotactic probability value (BF_TK) for each nonword. The lists were ordered from highest to lowest BF_TK values, that is, according to orthotactic probability.

Preparation of audio files

The audio files are mp3 recordings (48,000 Hz: 128 kbps: mono) of each of the sounds used in the word and nonword stimuli. As the requirement for WordDriver-1 is for words and nonwords with 1:1 grapheme-phoneme correspondence, only twenty-two of the forty-four English phonemes are 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 is indexed to each grapheme, available to be presented within the decoding intervention as part of the corrective reinforcement, that is, following an error the child listens to phonological recoding of that item as each grapheme is “sounded out”.

Preparation of sentences

Sentences are used as reinforcement following the decoding of words. A sentence that matches each word is included in an interactive web page which indexes each word to its corresponding sentence. This enables the instructor to access the web page on a separate portable computer, and quickly retrieve the sentence which is then read to the child to

illustrate the meaning of the word. The criterion for sentence formulation is 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. The complete set of sentences for each level (i.e., 2-letter, 3-letter level etc.) is available in the (Seiler, 2015) thesis and the WordDriver website (ELRSoftware, 2017).

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 programming logic.

Procedures for stimuli organisation

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 changes. 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 that this sequence of presentation allows the instructor to train the child to pay attention to all letters in the letter string across a set. To achieve this order, the items were constructed 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 introduce the decoding intervention procedure and to teach 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 user number plate on the bottom right provides a visual check that the data is logged to the appropriate child. The road sign displays the stimuli. The Go Button is used to advance through the module, and the yellow buttons ("tick" for correct, "question mark" for help/incorrect) are used to provide feedback about accuracy of response. The dial provides visual feedback of progression through the task and the "LED indicators" show the level (i.e., 2-, 3-letter etc.). The Book and Bin buttons are used to sort stimuli: words into the Book and nonwords into the Bin. This screenshot shows the child 40% through the task at the second level (3-letter items).

Figure 3: Screenshot of WordDriver L-Plate interface

Organisation of stimuli

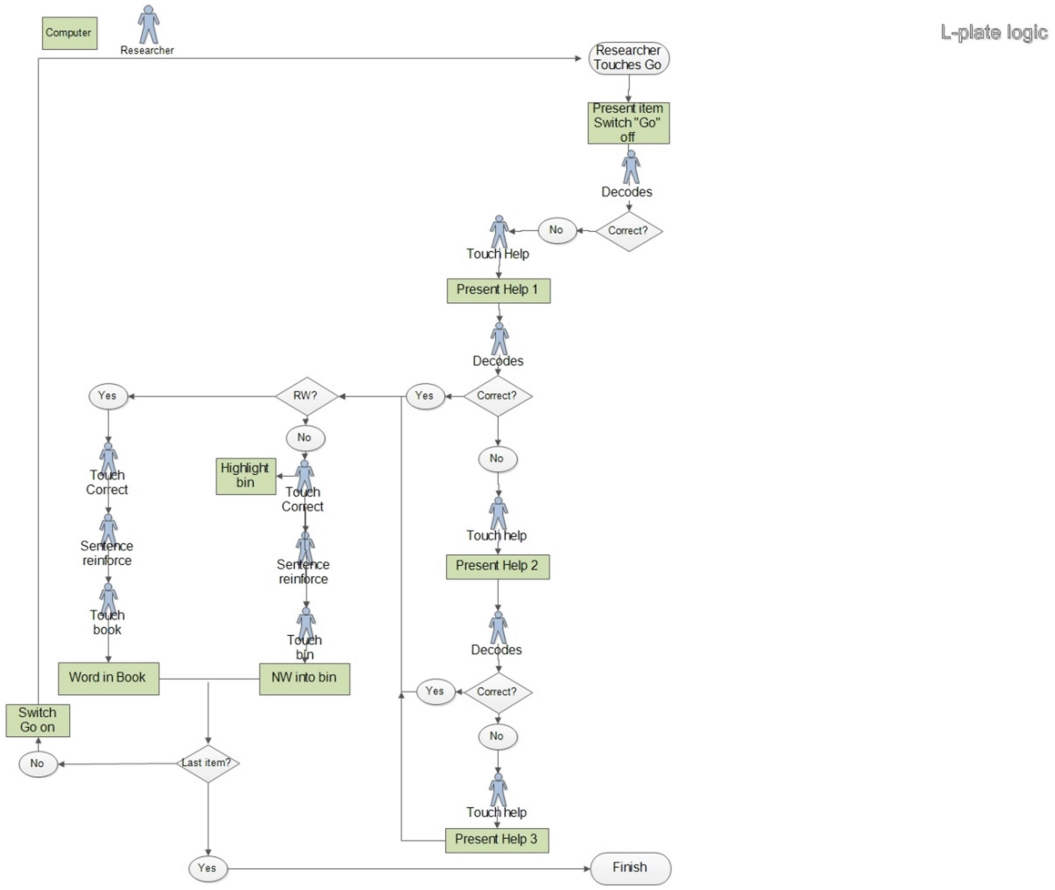
The L-Plate consists of 12 trials (because there are 12 stimuli), except for the 2-letter level where there are only five trials. Due to smaller numbers of available items for 2-letter and 6-

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. These letter changes are briefly highlighted in the initial display of the word to help draw attention to the importance of looking at each letter.

Programming logic

The primary aim of the L-Plate is to provide explicit teaching of phonological recoding. The instructor performs all of the interactions with WordDriver-1 which is programmed to display the procedure following an incorrect response on all items, thus providing the child with explicit teaching of the phonological recoding strategy on all items. Figure 4 illustrates the programming logic for the L-Plate.

Figure 4: Programming logic L-Plate



The instructor touches the Go button to display each item. After decoding the item with an inaccurate response, three levels of help are available: visual highlighting of letters to stimulate phonological recoding, visual plus auditory feedback to demonstrate phonological recoding, and finally the instructor touches each letter and verbally performed phonological recoding. Following each item the instructor models 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".

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 user number plate on the bottom right of the screen. The screenshot of a P-Plate illustrated in figure 5 shows that the child is 30% through the 4-letter level. The Correct and Help buttons are both active, ready for corrective feedback about accuracy of response to be provided to the child.

Figure 5: Screenshot of WordDriver P-Plate

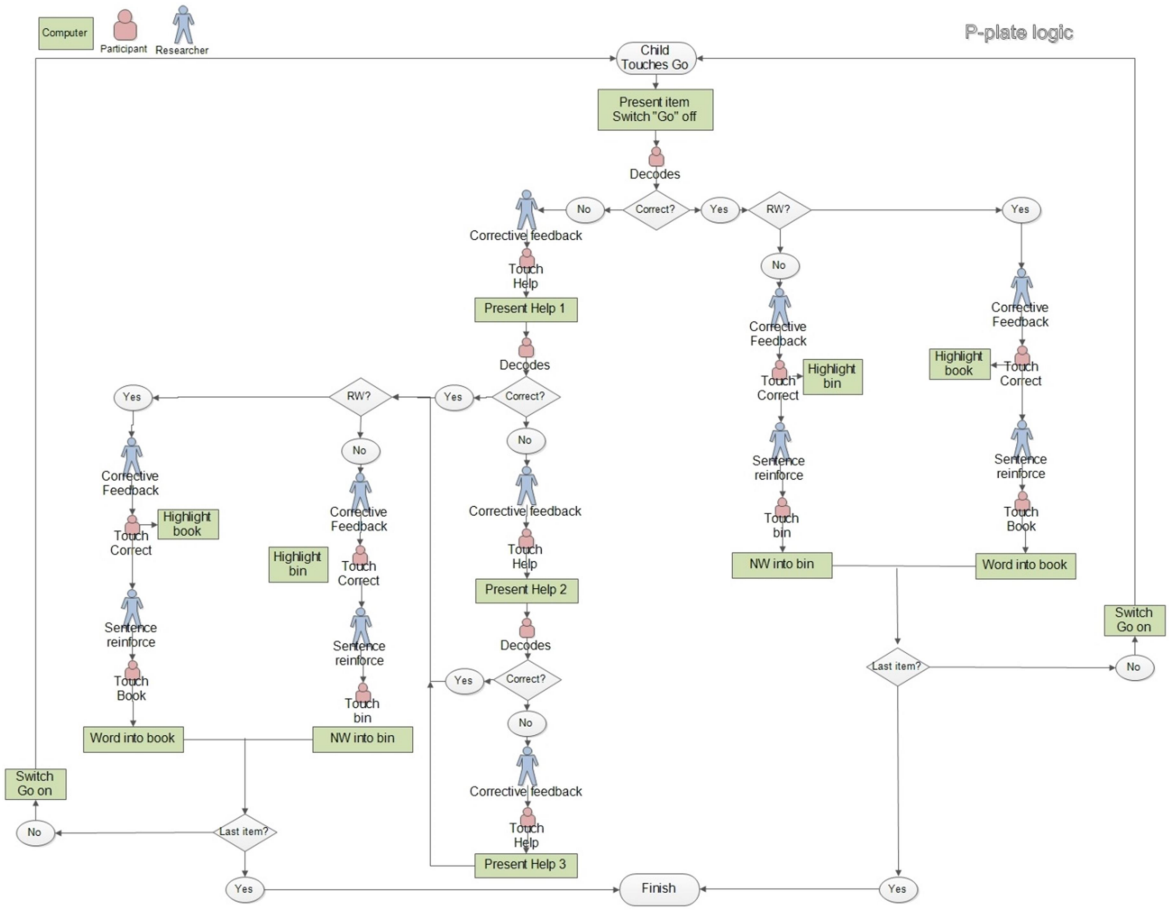
Organisation of stimuli

The items that remained after the L-Plate stimuli had been removed were then used to construct the P-Plate stimuli. The items are organised in a similar way to the L-Plate (i.e., first letter changing for the first few, then final letter and so on), and as with the L-Plate, these letter changes are briefly highlighted in the initial display of the word to help draw attention to the importance of looking at each letter. The difference between the L- and P-Plate is that the P-Plate contains more items at each level (i.e., more trials). The 3-letter, 4-letter and 5-letter levels each involve 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).

Programming logic

Figure 6 illustrates the programming logic for the P-Plate which is similar to the L-Plate: the difference being that the child performs more of the functions.

Figure 6: Programming logic P-Plate



The child touches the Go button and performs phonological recoding. The instructor provides corrective feedback about accuracy of response and touches the Correct or Help button which automatically enables the Book or Bin buttons as in the L-Plate. Following accurate phonological recoding words are reinforced by the instructor reading the scripted sentence accessed from a separate portable computer (or the child producing a sentence using the target word), and nonwords by a sentence explaining that the item is not a real word and has no meaning. Following an inaccurate response the Help procedure described in the L-Plate occurs. The child then 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.

D-Plate

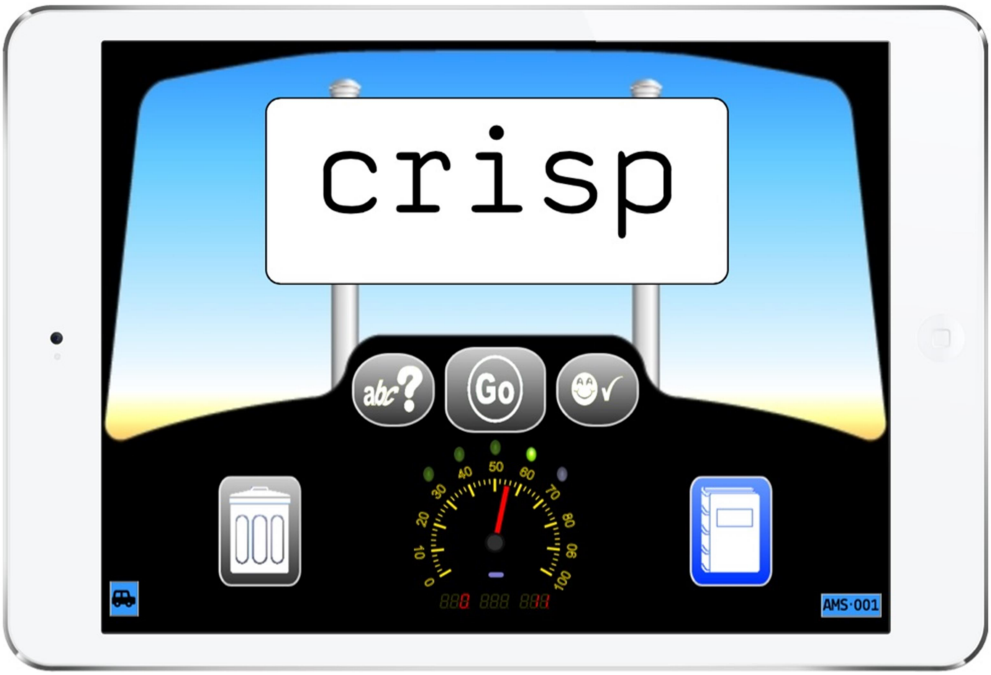
Goal

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 child 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 user 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

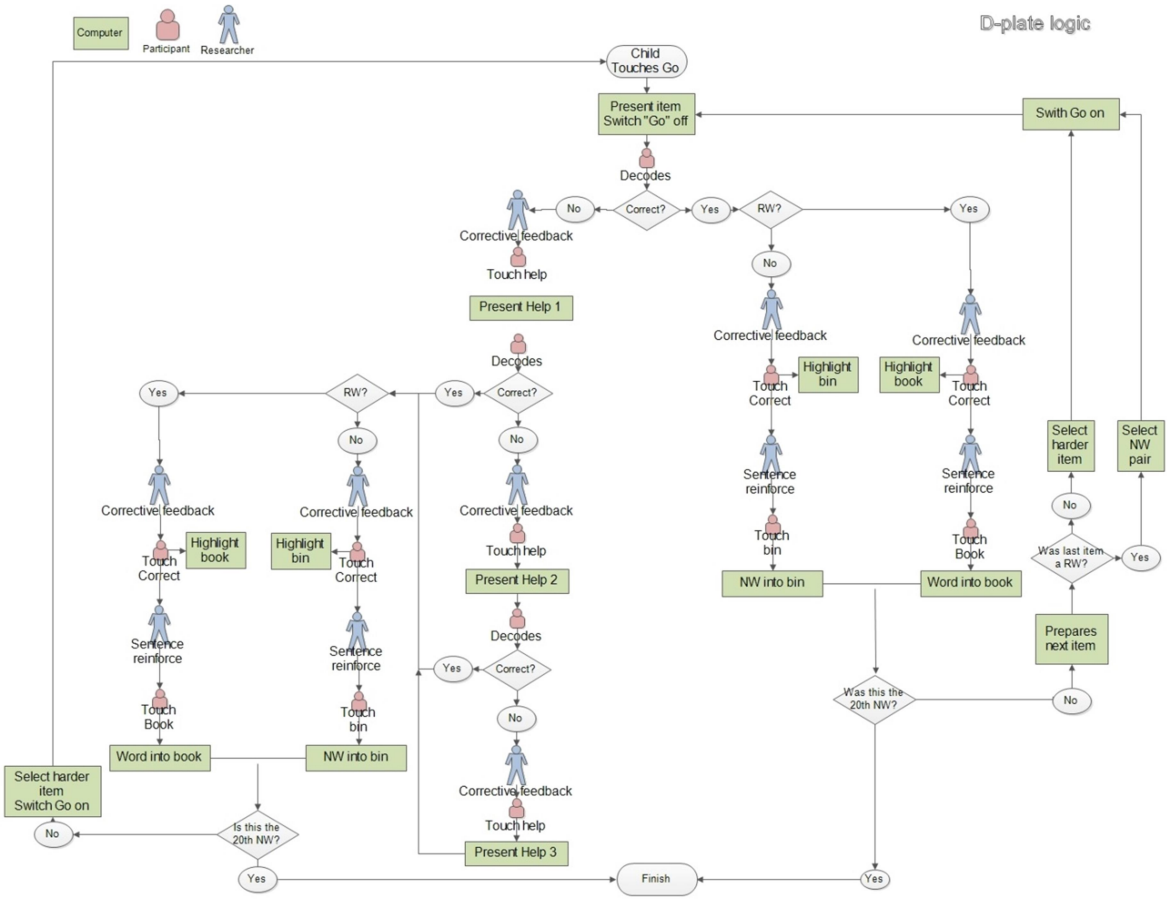
The items that remained after the L- and P-Plate stimuli had been removed were used to construct the D-Plate stimuli which consists of a series of paired items (word and nonword), closely matched for orthotactic value. This matching process was managed by StimulusMatcher - the computer programme that initially calculated the orthotactic probability values (described above). 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). The complete set of paired items (words and nonwords) for the D-Plates at each level are available in the Seiler (2015) thesis and on the WordDriver web site (ELRSoftware, 2017). 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).

Programming 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 user error, and (d) the session is

completed once the child has been presented with 20 nonwords. Figure 8 depicts the programming logic for the D-Plate.

Figure 8: Programming logic D-Plate



The interaction between the child, the instructor, and WordDriver-1 outlined in figure 8 is similar to the P-Plate, but an adapted PEST procedure (McArthur et al., 2008, Taylor and Creelman, 1967) was used 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. After the child reads the item out-loud, the instructor provides corrective feedback as described in the P-Plate, and then touches the Correct or Help button. Following an incorrect response an easier item (higher orthotactic probability) is automatically presented, and following a correct response, a harder item (lower

orthotactic probability). Additionally, to ensure the child isn't by chance presented with a series of words (for which they may have developed sight word knowledge); following a correct response on a word the matching nonword of the pair is automatically presented. The stimuli continue to be presented in this fashion until 20 nonwords have 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 is presented (i.e., from the easiest to the hardest item), the computer programme calculates 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 has a different number of items, the step size varies between levels. The step size is calculated by dividing the total number of items by 20. For example, the 155 items at the 3-letter word level is 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 is 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 – an outcome measure which assesses decoding accuracy.

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 user 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

Forty-two Assessment NW Lists were created last: 24 for the three baseline phases and 15 for the decoding intervention, and three spare lists (see ELRSoftware, 2017, Seiler, 2015). Each Assessment NW List is comprised of 70 items, as informal testing found that a skilled adult would take longer than one minute to read 70 nonwords, thus allowing measurement of the "number of nonwords read in 60 seconds" as an outcome measure. 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.

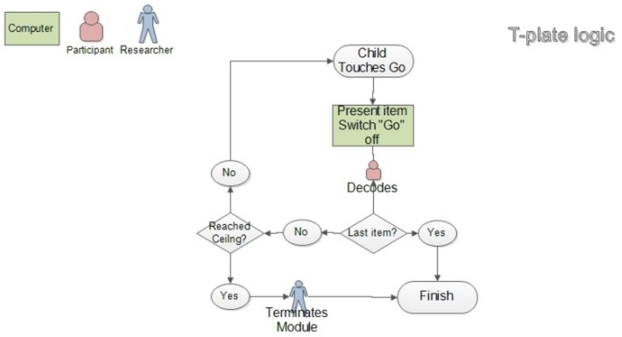
The 4-, 5-, and 6-letter items were similarly distributed using the method described above. The 2-letter items in each list were allocated using a different methodology as there were not enough 2-letter items for the requirement of two per list. The 36 available 2-letter nonwords were randomly assigned 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.

Programming 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 instructor. 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 instructor notes accuracy of response on a relevant response sheet (a printed version of the Assessment NW List) and 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 programming logic for the T-Plate.

Figure 10: Programming 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 is similar to the T-Plate except for the small red S-Plate at the bottom left and red user 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. Each time the road sign changes to black, the Go button becomes active (turns green).

Figure 11: Screenshot of WordDriver S-Plate

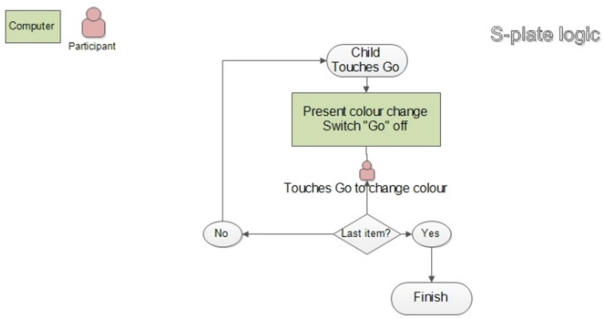
Organisation of stimuli

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

Programming 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 T-Plate is automatically concluded once 20 items are completed by displaying “All done!” on the road sign. Figure 12 depicts the programming logic for the S-Plate.

Figure 12: Programming logic S-Plate



Data logging

WordDriver-1 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 child progresses through a module, the data logged from that session is stored within the browser using HTML5 Local Web Storage. A range of data is logged for each module. For all modules this includes the unique identifier for each user, 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.

Summary

This programme of research developed a single component reading intervention, WordDriver-1, which enables examination of the effect of an intervention (which specifically targets phonological recoding and orthographic processing) on the reading skills of children with severe and persistent reading impairment. The design of the intervention is based on evidence pertaining to the essential skills required for word reading development and the results of intervention studies which have attempted to isolate the active ingredient/s. A functional

prototype of WordDriver-1 (which runs as a web app within a browser) and supporting documents are available for other researchers on the WordDriver website (ELRSoftware, 2017).

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