TREATMENT OF DEVELOPMENTAL READING DISORDERS: A VISUAL
ATTENTION SPAN DEFICIT APPROACH

BY

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Abstract

A current theory of the cognitive underpinnings of developmental reading disorders supposes that two impairments contribute to the overall profile of disordered reading: one of phonological awareness and one of visual attention span. The severity of each impairment is different for each child. By identifying children that display a severe degree of one impairment, but a limited degree of the other, each impairment can be investigated. The current study identified one participant with a stronger phonological impairment, and one with a stronger impairment of visual attention span. They completed two training programs: one program tailored to improve phonology, and one tailored to improve visual span. Both treatments improved reading performance in both participants. It was expected that the treatment targeting each participant's particular cognitive impairment would prove more effective for that participant. However, both treatments were found to show similar levels of improvement with both participants.

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Chapter 1: Introduction

A significant number of children demonstrate unexpected difficulties while learning to read. These children are of typical intelligence and do not have general learning disabilities, and their reading difficulties cannot be explained by interfering factors, such as sensory acuity deficits, acquired brain damage or educational inequalities. These difficulties are important to address, as they are prevalent; occurring in 16% of school aged children; and they are persistent; as the performance of reading disordered patients does not recover to normal reading performance over their entire lifetimes (Valdois, 2010). Currently, the majority of treatments for reading disorders take a one-size-fits-all approach: they have a standard treatment which does not vary for each participant. A large number of these approaches are based on the premise that participants' abnormal reading performance is due to phonological difficulties. This is contrary to a large portion of the current cognitive literature. Dual route models of reading allow for the possibility that reading difficulties may have different cognitive origins in different individuals. Research has identified a form of reading disorder where phonological abilities appear intact, but reading is nonetheless abnormally slow, and individuals seem unable to acquire a sight vocabulary at the normal rate (Castles & Coltheart, 1996). If this is the case, then treatments aimed primarily at phonological awareness and phonological decoding skills may be inappropriate for these individuals; instead, an approach which attempts to address a visual impairment may be more appropriate. A recent branch of the literature indicates that the fundamental cognitive impairment in these cases may be one of visual attention. Based on these findings, the present study intends to: a) using a single-case methodology, identify individuals with qualitatively different reading profiles, and examine the extent to which these individuals differ in related cognitive skills, such as phonological awareness and visual attention; and b) design treatments differentially targeted to each of these contrasting profiles, and explore whether

these targeted treatments are more effective than treatments that are not targeted to the readers' specific profile.

The following literature review will consider the cognitive origins of developmental reading disorders, in particular the heterogeneity of the disorder, due to the combination of a phonological and visual attentional deficit. Firstly, the dual route models of reading aloud will be considered, then how these models transpose to the subtyping of reading disorders. Following this, the theories of a visual attention span deficit underlying reading disorders will be examined. Finally, previous treatments of reading disorders will be considered.

1. Models of Reading Aloud

One type of theoretical framework which has been highly influential in the field of reading and reading disorders is the dual route framework (Coltheart, 1978; 1985). Theoretical models based on this framework all share the premise that readers require two separate processes to read aloud – a *lexical* and a *nonlexical* procedure. The *lexical procedure* involves accessing information about the word from a mental lexicon or dictionary. When a person reads a familiar word, he or she first identifies the corresponding written word form (or *orthographic representation*) from their mental lexicon. Once this orthographic representation has been identified, associated information about the word's meaning and pronunciation can also be accessed. In many dual route models, this process is phrased in spreading activation terms (Coltheart, Curtis, Atkins & Haller, 1993). In these models information about a word's orthographic form, its meaning and its pronunciation are all interconnected within a network, so that once the orthographic representation is activated, activation then automatically spreads to representations of the word's sound and meaning.

This procedure alone fails to account for the ability to read words that are unfamiliar, and therefore not yet stored in the lexicon. This is the function of the *nonlexical procedure*,

which arrives at a pronunciation of an unfamiliar word by applying the spelling-sound correspondence rules of the language. In several influential dual route models, this is a three-stage procedure (Coltheart, 1978; 1985; Derouesné & Beauvois, 1985; Newcombe & Marshall, 1985). First, the word is first broken into its individual graphemes (letter combinations that correspond to individual phonemes). Each grapheme is then assigned its corresponding phoneme, based on a stored set of grapheme-to-phoneme correspondence rules (GPCs): rules that relate graphemes to phonemes. Then finally, each resultant phoneme is “blended” in the correct order to generate the entire pronunciation of the word. For example, if a reader was unfamiliar with the word “winter”, they would have to use the nonlexical route to read its printed form. First they would perform graphemic parsing, breaking the word into the graphemes of ‘w’, ‘i’ ‘n’ ‘t’ and ‘er’. Based on their knowledge of GPCs, they would assign these graphemes to their corresponding phonemes: /w/, /ɪ /, /n/, /t/ and /ɜ / . Finally blending would put these phonemes together to create the pronunciation of the full word: /wɪ nt ɜ /. (See Figure 1 for a visual representation of a dual route model).

Figure 1. The Dual Route Model of Reading

The Dual Route Cascaded (DRC) Model is a computational conceptualization of the dual route structure of reading (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). This model is illustrated in Figure 2. The GPC route applies the grapheme-to-phoneme rule system to achieve pronunciation of a word. It is analogous to the nonlexical procedure of the classic

dual route model. The lexical route accesses stored information about a word's form, meaning and pronunciation, and is analogous to the lexical procedure in the classic dual route model. It is conceptualized as a network consisting of various layers of units representing different types of knowledge about a word: each representation in the *orthographic input lexicon* (stored representation of a word's written form) is connected to the corresponding representation of that word's pronunciation in the *phonological output lexicon* and also its corresponding meaning representation in the *semantic system*. The corresponding units in each layer are connected to in the adjacent layers by activation pathways, which can be inhibitory or excitatory (except for the orthographic and phonological lexicons, which can only excite one another). In most cases, activation can spread between layers in both directions.

Figure 2. The Dual Route Cascaded Model of Reading (from Coltheart et al. 2001)

The DRC model operates as follows. First, the visual feature units determine the position of each orthographic unit (or letter) in the letter string (the word). The letter units determine the actual letters used. Then from this point on, processing diverges for the three routes. Within the GPC route, the individual graphemes are identified, and based on each grapheme's identity and position in the word, its corresponding pronunciation is retrieved

from the set of stored GPC rules. The corresponding phoneme units are then activated in the phoneme system, which allows the correct articulation of the word.

Within the lexical nonsemantic route, the activated letter units in turn activate representations of words containing those units in the orthographic input lexicon. Increased activity in this layer proceeds to activate the corresponding phonological representations in the phonological output lexicon, which thereby activate the phonological units in the phoneme system (and allows for the articulation of the word). This level effectively works as a ‘sight vocabulary’: a system of word-specific orthographic representations. Finally, the lexical semantic route involves a similar process to the nonsemantic route, except the letter string’s semantic representation is also activated through units in the semantic system.

The dual route models make a number of predictions about the type of words each route can process. Firstly, the nonlexical route is required to read nonwords. As nonwords are, by definition, always unfamiliar words (as a made up word cannot exist in one’s lexicon), they must be read by breaking down their graphemic components. Therefore, if an adult was to have a dysfunction specific to their nonlexical route, their performance on reading nonwords would be impaired, but their performance on familiar words would be unimpaired, as these words can still be processed by the lexical route. This pattern of performance has indeed been observed in patients suffering brain damage (Berndt, Haendiges, Mitchum, & Wayland, 1996; Coltheart, 1985; Deroiusné & Beauvois, 1985), and this deficit is known as acquired phonological dyslexia.

Secondly, the lexical route is required to read irregular words. Correct pronunciation of irregular words does not match their phonological profile dictated by GPCs. For example, the word “yacht” is irregular, as GPCs would indicate it is pronounced /jætʃ t/ (“ya-ch-t”). Only by accessing the information encoded in one’s lexicon, through the lexical route, is the

correct phonological information available. In the same example, yacht is only correctly read as /jɒ t/ by ‘looking up’ the pronunciation in one’s mental dictionary. It can therefore be predicted that a selective impairment in the lexical route in adult readers will lead to poor performance on irregular words, and a normal performance on regular and nonwords. Further, they might be expected to produce ‘regularization errors’, in which the word is pronounced as if it were regularly spelled - for example, “yacht” as /jætʃ t/. Again, this pattern has been observed in brain damage patients (Marshall & Newcombe, 1973; Newcombe and Marshall, 1981; Patterson, 1981; Shallice, 1981; Coltheart, 1981). The profile is known as acquired surface dyslexia.

2. *Subtyping of Reading Disorders*

Following the descriptions of the subtypes of acquired dyslexia, researchers made the natural progression to consider whether developmental forms of reading difficulty could be similarly subdivided. The following section considers these approaches.

An early, highly influential scheme for characterizing developmental reading disorders was proposed by Boder (1971). Boder’s study assessed trends within the recent literature on children with reading difficulties, and identified patterns of reading and spelling errors which would indicate different forms of cognitive impairment. She found three patterns of reading impairment. The first, termed *dysphonetic*, was a difficulty in integrating graphemes with their corresponding phonemes (a process she referred to as the auditory analytic function). The second, *dyseidetic*, was a difficulty in the development of a sight vocabulary (termed the visual gestalt function). The third, referred to as *mixed dysphonetic-dyseidetic*, showed both a weakness in phonological processing and in developing sight vocabulary.

These characterizations resemble the subtyping of acquired dyslexia into phonological and surface. Indeed, the dual route model provided a useful theoretical framework in which to conceptualize the idea of individual variation in language performance. Subsequent researchers therefore began to look in earnest for cases of developmental dyslexia that reflected the two major subtypes of acquired dyslexia.

Temple and Marshall's (1983) case study was the first of these. Their participant, HM, displayed a profile of developmental dyslexia that resembled acquired phonological dyslexia. HM was a 17 year old with a reading age of 12, but a normal intelligence for her age. When reading certain types of words, HM's errors matched those that would be expected of an acquired phonological dyslexic. Her reading of nonwords was severely impaired, and she was unable to read long nonwords or long regular words that she was unfamiliar with. On these kinds of materials, she frequently made *lexicalization* errors, which involve substituting a real word in place of the unfamiliar one. For example, HM read the nonword "fime" as the word "firm". This would be expected if the nonlexical route of the dual route model of reading was impaired, and HM only had the lexical route to rely on. In other words, HM could only read words by relying on the lexical route. These results led Temple and Marshall (1983) to conclude that the HM's dyslexia could be explained in terms of a dual route model, specifically as a selective deficit to the lexical route – a form of *developmental phonological dyslexia*.

Since this initial finding, a large number of cases of developmental phonological dyslexia have been described in neuropsychological literature (for example Campbell & Butterworth, 1985; Snowling & Hulme, 1989; Snowling, Stackhouse & Rack, 1986). A sample of these studies have demonstrated what researchers call 'pure' developmental phonological dyslexia. In these cases, the reading of nonwords is severely impaired, but the reading of irregular words is within normal levels - indicating that the nonlexical route is

selectively impaired. For example, Stothard, Snowling and Hulme (1996) studied a participant, LF, for 40 months. During this time, she demonstrated no impairment in reading, except for an inability to read nonwords. They concluded that LF had a severe phonological weakness (a nonlexical impairment), but was still able to read due to her lexical knowledge.

Evidence for the converse pattern of impairment that corresponds to acquired surface dyslexia also began to accrue around this time. Coltheart, Masterton, Byng, Prior and Riddoch (1983) were the first to describe such a case. Their participant, CD, had a chronological age of 16 and a reading age of 13. She performed more poorly on irregular words than regular. She also mostly produced regularization errors, whereby an irregular word is read as it is phonologically spelt, for example when “yacht” is read as /jætʃ t/. This would be expected if the lexical route was impaired, but the nonlexical route remained intact. Without access to the lexical store, CD would have to read the word according to its GPCs, leading to a regularization error. The study directly compared her to a second participant with acquired dyslexia, who made errors of a similar nature. Coltheart et al. (1983) concluded that developmental surface dyslexia also exists as a distinct clinical entity, mirroring acquired surface dyslexia (Further studies showing similar results include Seymour, 1990; Temple, 1997). Studies have also demonstrated ‘pure’ developmental surface dyslexia (for example, Bergmann & Wimmer, 2008; Castles & Coltheart, 1996).

However, case studies, on their own, do not provide any information about how prevalent these types of selective impairments are within developmental dyslexia as a whole. Castles and Coltheart (1993) addressed this question by examining a large sample of 56 children that displayed reading ages at least 18 months behind their chronological ages, whilst falling within normal IQ range for their age. These participants, along with 56 normal controls, were presented with a reading test involving 90 words presented individually, each on a separate card. Participants were required to read the word aloud. Three different types of

words were presented: 30 regular words, 30 irregular words and 30 nonwords. The results of the dyslexic sample were then compared to the controls. 85% of participants showed a dissociation between their performance on irregular words and their performance on nonwords. 55% of the participants showed disproportionately poor nonword reading, suggesting a selective difficulty with the phonological route, and 30% showed disproportionately poor irregular word reading, suggesting a selective difficulty with the lexical route. 34% showed a “pure” profile, that is, they performed within the normal range on one task but poor performance on the other. 15% of the participants showed a pure phonological profile, and 19% showed a pure surface profile. These results therefore confirmed that the subtypes of developmental dyslexia can be found in large samples of dyslexic participants. A study by Manis, Seidenberg, Doi, McBride-Chang and Peterson (1996) that also used a large sample has since confirmed these results.

However, not all researchers agreed on the usefulness of characterizing developmental reading disorders in dual route terms. Firstly, Bryant and Impey (1986) suggested that the pattern of reading performance observed in developmental surface dyslexia may simply reflect delayed reading and that characterizing it in terms of the dual route model might not be informative. They took the results of the original two case studies demonstrating the existence of developmental surface dyslexia (Coltheart et al., 1983; Temple & Marshall, 1983) and compared these cases to normal controls. These controls were matched to the original cases in reading age, not in chronological age. They found that Coltheart et al.’s (1983) surface dyslexic (CD) showed similar performance to the reading age matched controls. The ratio of irregular to regular words correct were similar, with both CD and the normal controls showing difficulty with irregular words. Also, both exhibited similar amounts of regularization errors, neologisms, and both showed impairment on a homophone task. This suggests that the pattern of performance that characterizes

developmental surface dyslexia might be better thought of as a reading delayed pattern. Manis et al. (1996) found similar results when directly comparing a large sample of participants with reading disorders and normal reading-age matched children: irregular and nonword performance was similar between the impaired and younger readers. These results suggest the profile specific to surface dyslexia is actually normal for a certain level of reading. This would therefore suggest that surface dyslexia is a reflection of delayed reading, rather than an inability to use the lexical route.

Secondly, a study by Murphy and Pollatsek (1994) suggests that developmental reading disorders are better conceptualized as a spectrum, rather than in terms of distinct categories such as surface and phonological. 65 participants with reading difficulties (as identified by their schools or reading clinics) performed a battery of reading and other cognitive tests, which include a number of “rapid word retrieval tasks” (rapid naming of letter strings and providing words in response to a definition), and a phonemic segmentation task. The phonemic segmentation task, which required participants to pronounce a series of words as their individual phonemes, is a measure of phonological awareness, and therein measures the proficiency of an individual’s nonlexical reading ability. Participants’ performance on the rapid word tasks was on a continuum, ranging from poor to moderate to good performance. A similar pattern was observed on phonological segmentation tasks. These authors concluded that there was no evidence for the existence of distinct categories of disorders corresponding to phonological and surface dyslexia respectively. Bryant and Impey (1986) also support this argument. During their comparison of developmental dyslexics and reading age matched normal readers, they concluded that the categories of phonological and surface dyslexia are too distinct, and do not reflect the spectral nature of developmental reading disorders.

In summary, there are two major criticisms with the dual route subtyping approach when applied to developmental dyslexia: firstly, the surface subtype's cognitive features are not satisfyingly accounted for, as some studies suggest that it may simply be an expression of delayed reading ability, and secondly, the categorical subtypes mask the continuous nature of reading disorders.

Wolf and Bowers' (1999) 'double deficit' theory attempts to overcome some these problems. These authors do not to classify reading disorders into two distinct groups, but rather consider them in terms of the respective contributions of two separate deficits, each of which can vary along a continuum: a phonological deficit, and a *naming speed* deficit. Naming speed refers to the rapid recognition and retrieval of linguistic stimuli. It is generally measured by serial rapid automatized naming tests, involving the rapid naming of an array of 50 stimuli. Stimuli are made up of five different stimuli (letters, numbers, colours or objects) presented 10 times in random order. Based on a review of previous literature, Wolf and Bowers concluded that the phonological deficit and the naming speed deficit are independent. Each impairment manifests at a different intensity in each child: one child may have a moderate amount of each, another may have mainly a phonological impairment, and another mainly a naming speed impairment.

Naming speed as an impairment is problematic, however, as its results may be influenced by many underlying cognitive mechanisms (Arnell, Klein, Joanisse & Busseri, 2009). In other words, while as a construct it can predict reading performance, this does not help elucidate the nature of the underlying cognitive impairment because poor performance on this task could reflect any number of impaired cognitive processes.

A range of recent studies suggests that a specific visual deficit may contribute to developmental reading disorders. The following sections consider this deficit, and explains

how it may be causing the poor performance in naming speed that Wolf and Bowers (1999) discuss.

3. Dyslexia as an Impairment in Visual Attention?

A number of recent group studies have shown that children with reading disorders, as a group, perform poorly during serial attentional searches. Iles, Walsh and Richardson (2000) examined a group of dyslexic children on a series of visual search tasks. Eight different tasks were used, each consisting of an array of objects. The first task consisted of a parallel search, in that the target object was immediately obvious, or 'popped out' amongst the distractors. The other seven tasks consisted of serial searches, in that each object had to be viewed one-at-a-time for the target to be identified amongst the distractors. Participants had to view each array and indicate whether the target object was present or not. They found that a group of dyslexic participants were impaired during the serial searches, but not during the parallel search. Normal controls were found to be unimpaired on both tasks, suggesting the dyslexic subgroup suffered an unidentified impairment of visual attention. Similar results were found by Valdois (1996) in a case study of a child with a two-year reading delay. This case showed no impairments in phonology, as demonstrated by his performance on a range of phonological awareness tests. However he was significantly impaired on a task requiring him to identify a target visual object amongst distractors.

Further studies investigating the direction of visual attention show that children with reading disorders have impairments involving attention to visual space. A study by Facoetti, Paganoni and Lorusso (2000) examined 11 participants who scored two standard deviations below the norm on a standardized reading test, without showing emotional or behavioural problems or impaired intelligence. Participants underwent a visual task, involving the identification of a target dot amongst distractor dots. A line of three dots were presented

above, below, and to each sides of a central fixation point. The target dot was filled, whereas the distractor dots were only outlined. The target dot appeared in all possible positions: above, below, to the left and to the right of the fixation point, and close to or further away from the fixation point. Participants had to indicate as soon as they identified the fixation point, and reaction times were measured. In this way, the study measured the participants' ability to orientate their visual attention to different locations in their visual field. Unlike non-dyslexic controls, who showed a normal increase of reaction time as the targets became more eccentric, the dyslexic participants showed no significant gradient.

A further study by Facoetti and Molteni (2001) shows that these results may reflect an impairment in attending to the left visual field. They performed a similar task to Facoetti, Paganoni and Lorusso (2000), with dot stimuli extending to the left and right of a fixation point. Again a filled dot was the target cue, and outlined dots the distractors. The target dot appeared at three different eccentricities from the fixation point in both the left and right visual field. They found that the same 11 dyslexic participants from the previous study (Facoetti, Paganoni & Lorusso, 2000) showed significantly slower reaction times to targets in their left visual field when compared to 10 control participants. This difference was not seen in the right visual field. This suggests that children with reading disorders show a deficit in visually attending to the left visual field (see also Facoetti et al., 2003; Facoetti, Turato, Lorusso & Mascetti, 2001; Valdois, 1996).

Studies of normal readers have helped to establish a link between this type of visual attentional impairment and reading difficulties. In Casco, Tressoldi and Dellantonio (1998) unimpaired readers performed a cancellation task, requiring them to strike out a target letter against a background of other random letters. Those participants who performed the poorest at this task had the slowest reading rate and the highest incident of reading errors (see also Williams, Brannan and Lartigue, 1987; Casco and Prunetti, 1996 for similar findings).

These results formed the basis of Hari and Renvall's (2001) 'sluggish attention shifting' (SAS) theory of dyslexia. According to this theory, reading difficulties are caused by sluggish attentional capture and prolonged attentional dwell time. In other words a dyslexic finds it difficult to disengage their attention from an attended object. The deficit occurs in all sensory modalities, and slows the processing of rapid stimulus sequences. The theory further postulates that these attentional deficits are the cause of the phonological difficulties often observed in developmental dyslexics: without normal attentional function, these individuals are unable to build stable phonological representations.

These studies all suggest that deficits in attentional processing contribute to reading impairment, at least when dyslexic children are considered as a group. However, these studies do not directly examine individual variability within the dyslexic group. Several more recent studies have proposed that visual attentional difficulties contribute to reading difficulties independently of phonological difficulties. One hypothesis, discussed in more detail in the next section, is that some – but not all – dyslexic readers may have an impaired *visual attention span*, or the number of orthographic units they can attend to in a single eye movement.

4. The Visual Attention Span Hypothesis

A number of studies have demonstrated that children with reading disorders may have an impaired *visual attention span* (or *VA span*) defined as the number of distinct visual elements which can be processed simultaneously in a multielement display. With respect to reading, the VA span corresponds to the number of orthographic units simultaneously processed in a letter string. (Valdois, 2010). For example, in an early study, Valdois et al. (2003) performed a case study of two French children with dyslexia. The first participant, Laurent, was found to fit the profile of phonological dyslexia. Laurent showed normal

performance when reading irregular words, with few regularizations but showed slow nonword reading and poor nonword spelling and high amount of lexicalization errors. Alternatively the other participant, Nicolas, fitted the profile of a surface dyslexic, showing the opposite pattern of errors to Laurent: nonword spelling and reading was normal, yet irregular words were impaired.

The two participants had to complete a battery of phonological tasks. These tasks included: an auditory rhyme judgment task (judging whether a pair of written words rhymed or not), a sound categorization task (determining which of four words started with a different sound); a phoneme and a syllable deletion task (removing the first phoneme or syllable from a word and the producing the resultant nonword); a phoneme segmentation task (pronouncing the individual phonemes in a word); and a spoonerism test, which required participants to exchange the first phonemes of two words. Laurent (phonological dyslexia profile), performed below the normal range on all of these tasks, when compared to both chronological age-and reading age matched controls, suggesting a significant phonological impairment in this case. However, Nicholas (surface dyslexia profile), performed above the norm when compared to chronological age-matched controls, suggesting normal phonological awareness.

The two participants also underwent two tasks that measured their visual attention span – specifically, the amount of letter information that is perceived during a single fixation. The first task, the *whole report task*, involved the brief (200ms) presentation of a string of five letters, and participants had to report as many of the letters as they could. The second task, the *partial report task* also involved a brief presentation of a random string of five letters, but this time a horizontal bar under one of the letters after it disappeared from view. Participants had to identify this cued letter. This provides a measure of how visual attention is balanced across the letter string, without the heavy short-term memory load imposed by the

whole report task (Bundensen, 1998). Laurent, the phonological dyslexic, performed as well as controls on both these tasks. In contrast, Nicholas was unable to report an entire string at all during the whole report task, and was particularly impaired on the last two letters of the string during the partial report.

Overall, these results suggest a dissociation between a phonological deficit and a visual attentional deficit contributing to reading disorders. They further suggest a very specific link between the nature of deficit and the nature of the reading disorder: specifically, the phonological deficit would appear to be linked to the phonological dyslexic reading pattern and the visual attentional deficit to the surface dyslexic reading pattern.

These results were supported by a study of a larger sample of reading disordered children by Bosse, Tainturier and Valdois (2007). The study consisted of the same reading, phonological awareness and visual attention span tasks as Valdois et al. (2003). The first experiment consisted of an undifferentiated sample of 68 French participants with significant reading difficulties. Correlation and factor analyses revealed that performance on the phonological awareness tests and the visual attention span tests were unrelated. It also found that the two tests were independent predictors of performance on the reading tasks. The second experiment, consisting of a sample of 29 British participants, used the same tasks whilst controlling a number of potentially confounding variables: IQ, verbal fluency, vocabulary and single letter identification skills. This experiment confirmed the results of the French sample. The study therefore supports the supposition that two separate cognitive impairments independently contribute to impaired reading development.

Bosse et al.'s (2007) results also had some other interesting implications. Their factor analyses indicated that the participants could be divided into four subgroups, determined by what impairments they displayed. The first subgroup consisted of those with a phonological

awareness impairment only, the second of those with a visual attention span impairment only, the third consisted of those with both impairments, and the fourth of those with no impairments (the controls). This is interesting because it indicates that a reading disorder can be caused by either one or a combination of both impairments.

A cross-sectional study by Bosse and Valdois (2009) performed the same tests with 417 children of normal reading ability. Participants from first, third and fifth grade were given a battery of reading tests, phonological awareness tests, and the whole and partial letter report tasks. Hierarchical regressions showed that visual attention span predicted reading performance independently of phonological awareness. Across all grades, visual attention span predicted irregular word reading, indicating that visual attention is an important cognitive mechanism for lexically mediated reading from a young age.

In a case study design, Peyrin et al. (2012) further confirmed the double dissociation observed between of these two hypothesized types of cognitive deficits in dyslexic readers, and also showed that each deficit was associated with distinct neurobiological counterparts. Case LL's performance indicated a marked phonological awareness impairment but a preserved visual attention span. Further, fMRI revealed reduced activation in the left inferior frontal gyrus during the performance on a phonological rhyme judgment task when compared to controls. Activation pattern during a visual categorization task, on the other hand, did not show a difference to that of controls. In contrast, FG's profile indicated a marked visual span impairment but normal phonological awareness. Further, during the visual task FG exhibited reduced activation of the parietal lobules when compared to controls, but no difference in activation was seen during the phonological task.

Eye tracking studies also provide further evidence in support of the visual attention span hypothesis. Research examining the eye movements of dyslexic children has

consistently observed longer fixation durations and shorter saccades for dyslexics when compared to normal readers, meaning dyslexic children fixate far more often whilst reading a word when compared to normal children (De Luca, Borrelli, Judica, Spinelli and Zoccolotti, 2002; Hawelka & Wimmer, 2005). Prado, Dubois and Valdois (2007) reported evidence to suggest that this pattern of eye movements may be associated with a visual attention span deficit. This study examined dyslexic participants who demonstrated the profile of a visual attention span impairment without evidence of a phonological awareness impairment. The study found that these dyslexics made significantly more rightward saccades than the normal controls. One interpretation of this result is that the dyslexics' reduced span causes them to process fewer letters of a word, therefore more fixations are required to perceive an entire word. The study also found that the number of rightward saccades performed whilst reading is related to performance on the whole report measure of visual attention. As saccades increased, performance decreased, indicating that dyslexics' increased fixations are related to the lessening of the visual attention span and therefore the number of letters they can attend to in one fixation.

5. Critique of the Visual Attention Span Hypothesis

It has been suggested that the whole and partial report tasks used by Valdois et al. (2003), Bosse et al. (2007) and Bosse and Valdois (2009) may not be measuring an impairment in visual attention, but rather an impairment in converting the visual information to a verbal response. In other words, the impairment is still fundamentally phonological in nature. If this supposition is correct, participants with reading disorders would demonstrate normal results on a visual attention task that no longer contains verbal components. A number of studies have obtained evidence consistent with this hypothesis. For example, a study by Hawelka and Wimmer (2008) used a modified visual attention span task that did not require a verbal letter response. The task involved the presentation of a target letter above a

five letter string. If the target letter was present in the string below it, the participant pressed the spacebar. When the verbal response was removed in this fashion, the dyslexic participants showed no difference from the normal controls. However, one problem with this study was that the stimulus was presented for an unlimited time, so may not be an accurate measure of parallel visual processing. Visual attention span encompasses the number of visual units processed simultaneously, and as the participant has time to perform eye movements across the letter string, they are no longer processing the visual elements simultaneously. Indeed, this hypothesis was supported in a study of a sample of dyslexic children by Lassus-Sangosse, N'guyen-Morel and Valdois (2008), who found these children to have a deficit in simultaneous visual processing, but not sequential.

An alternative methodology was used by Ziegler, Pech-Georgel, Dufau and Grainger (2010), who developed a task that removed both the verbal response and was based entirely on nonverbal stimuli. They used a symbol span task in which participants viewed a sequence of symbols then later had to select the matching sequence from two choices using a button press response. They found that, while their dyslexic participants performed significantly below the range of normal controls on standard visual span tasks involving verbal materials, they were within the normal range on this nonverbal task. However, this task makes heavy cognitive demands, and performance for the normal participants was also quite low, leading to the possibility of floor effects. This conclusion is supported by the findings of Pelli, Burns, Farell and Moore-Page (2006), who observed reduced memory spans for tasks involving non-alphabetic stimuli, when compared to more conventional letter or verbal stimuli.

Furthermore, several studies have found that, when verbal components are eliminated, participants with reading disorders still show a performance deficit. Rutkowski, Crewther and Crewther (2003) developed a visual attention task that removed the verbal response. This change detection task involved arrays of four letters positioned around a fixation point. In a

single trial, two arrays were presented, and participants had to press a button to indicate whether the second array was different to the first. Participants consisted of 19 children with a reading age two or more years below their chronological age, and of normal non-verbal intelligence for their age. These participants showed significantly poorer performance on the change detection task when compared to 44 controls. The study still retains verbal stimuli (letters) and so the detected impairment could still be explained as a reflection of a phonological process.

Further studies have found dyslexic participants show impairments on visual attention tasks that eliminate both verbal stimuli and verbal responses. Jones, Branigan and Kelly (2008) examined a population of 19 adult dyslexics, diagnosed by an educational psychologist, between 18 and 23 years old. They used a symbol search task and a visual-search task. In the symbol search task, strings consisting of five symbols were presented to participants, followed by two response options. The correct option was identical to the previously viewed symbol string, and the incorrect was a similar symbol string. Participants responded by pressing a key selecting an option. The visual-search task was similar, in that five target pictures created a visual string, following which two response options appeared, one identical to the target string, and one similar. A similar study by Pammer, Lavis, Hansen and Cornelissen (2004) examined 13 primary school aged children that had been diagnosed as dyslexic by a psychologist. They also used a symbol string task offering one of two responses. Both studies found that their dyslexic participants were more impaired than controls on these nonverbal tasks.

Finally, a study by Lobier, Zoubrinetzky and Valdois (in press) used a categorization task involving a mix of verbal and non-verbal stimuli (digits, letters, and three different types of nonverbal figures and shapes) as well as the whole report task of visual attention span. These stimuli were organized into strings of five items, each of which contained a mix of

verbal and nonverbal items. Following the presentation of a string, participants had to identify how many stimuli in the string came from a particular category (“1”, “2” or “3”, indicated by clicking the corresponding button). Participants consisted of 14 children with a reading age 18 months below their chronological age and an IQ normal for their age. When compared to controls, these participants performed poorly with both the verbal and non-verbal stimuli. High performance in the categorization task (regardless of the target search category) was associated with high performance in a conventional whole report task, indicating that the two tasks are likely to be measuring similar processes.

Therefore, the weight of evidence indicates that the impairments observed in visual attention span tasks are not merely a consequence of a more general verbal/phonological deficit, but rather reflect a distinct impairment in their own right. It also suggests that the whole and partial report tasks are valid tools for measuring visual attention span and are uncompromised by an underlying phonological processes (even though they still involve verbal components).

The serial position curves elicited during the partial report task also seem to refute visual attention span hypothesis. When considering letters briefly presented in an array, predictions can be made relating to the positions of the letters. Studies have demonstrated that participants without reading difficulties show a W-shaped function across a briefly presented array of five letters, with the best performance during the centre item, worst performance during the items at position 2 and 4 (to the left and right of the centre item) and intermediate performance during the furthest two items, position 1 and 5 (Mason, 1982; Tydgat and Grainger, 2009). If a participants’ visual attention span was narrowed, one would expect performance to be particularly high on the middle item, as this item is being fixated on, and lower the further the item is away from this. A study by Ziegler, Pech-Georgel, Dufau and Grainger (2010) generated the serial position curves of a sample of 28 children

that had been professionally diagnosed as dyslexic. These participants underwent the partial report task, and their performance on each item's serial position was graphed against their accuracy. It was found that their serial position curves closely resembled the W-shaped curves generated by a control sample of normal readers. However, the study did not differentiate between possible subtypes of dyslexia. As a result, their sample may have contained a confounding number of participants without the visual attention span deficit; their reading impairment being caused by a phonological deficit.

6. Theoretical Interpretation of the Visual Attention Span Deficit

The theories we have discussed so far do not address the visual perceptual aspects of word reading in any great detail. In order to understand how visual processing deficits may contribute to certain kinds of reading disorders, there is a need for a theory of reading that specifies the visual aspects of the reading process in greater detail. One theory designed to meet these conditions is Ans et al.'s (1998) connectionist multiple-trace memory (CMT) model. The CMT model has two main suppositions. The first is that reading involves a visual attentional window (VAW). This window extracts information from the orthographic input, in that letters within the window are activated the most, and processed simultaneously, whereas letters outside of the window receive either sparse or no activation. The second supposition is that reading involves two different analysis procedures: global and analytic. During the global procedure, one's VAW encompasses a whole letter string. Global processing therefore allows the analysis of the entire word form. If this processing fails, however, analytic processing begins. During the analytic procedure, one's VAW only spans a limited number of orthographic units. This narrow VAW begins at the first part of the orthographic input, proceeding left to right, attending to each part of the input independently. Analytic processing therefore involves reading words in small steps.

The two types of processing therefore access phonological information differently. As global processing attends to the entire word form, this type of processing facilitates the use of lexically-mediated reading strategies. It may therefore be particularly crucial for developing a “sight vocabulary” of familiar regular and irregular words. Alternatively, analytic processing generates phonological output in steps, so may encourage readers to rely more heavily on nonlexical, grapheme to phoneme conversion strategies. It may therefore be adequate – albeit inefficient - for reading regularly spelled words and nonwords, but may not maximally support the development of effective lexical reading strategies.

This model makes a number of suppositions in terms of reading acquisition. A new word memory trace can be created through either the global or analytical processing mechanism. To create a new word trace through global processing, the entire orthographic input and the entire phonological output would have to be presented at the same time. For example, a teacher presents a child an entire word and its full pronunciation. A new word trace would be created by analytical processing when the phonological output is generated step by step then held in the short term memory. For example, a child sounds out the phonology of a word, then puts it together to form the full word trace.

From this, a number of predictions about the phonological and visual attentional impairments seen in reading disorders can be made. Firstly, the phonological impairments should affect analytical processing the most. The analytical process relies on phonemic awareness to translate the limited orthographic input in each VAW into phonological output, and therefore build a full word. The model therefore predicts poor performance on the reading of nonwords, as the analytic process is required to read these. A phonological impairment could also indirectly influence the global processing mechanism as well. Without the analytic process building up new word traces from unfamiliar words, the lexicon of word forms will not be as strong. This would affect irregular word reading, as the global process is

required to read these. When these two effects are put together, the model predicts a phonological impairment will cause poor performance in nonword and irregular word reading.

Secondly, the visual attention span impairment will cause a reduction in the VAW. This, in turn, will mean that the global process will be severely affected, as the VAW will not be able to encompass whole words. Without the global process, irregular word reading will be impaired. If the visual span impairment is minor, the analytic process will be unaffected, as the VAW will still be large enough to process enough orthographic units to decode the phonological output. It can therefore be predicted that in this case, regular word and nonword reading performance would be unaffected. However, if the visual span impairment was very severe, the VAW would not be large enough to decode phonology, and regular and nonword reading performance would be diminished.

The CMT model offers an explanation for the features of developmental surface dyslexia. The global process can be seen as necessary for the effective operation of lexically mediated reading, and for the efficient development of a mental lexicon of orthographic word forms (a “sight vocabulary”). Therefore, any impairment to this process would be expected to result in a profile similar to surface dyslexia. At the same time, the CMT model can also accommodate the observations of Wolf and Bowers concerning the naming speed deficit. As tasks that measure naming speeds, serial rapid automatized naming, involve the presentation of symbols in a string, a smaller VAW would mean that less of the symbols are processed simultaneously, thereby the smaller the VAW, the longer the naming speed. Therefore, the cognitive mechanism underlying naming speed is one’s visual attention span. This is important, as it means the double deficit hypothesis could be seen as an impairment of phonological awareness and an impairment of visual attention span, rather than naming speeds, as the naming speed tasks may simply be measuring one’s visual attention span.

7. Reading Treatment Studies

A range of studies consider reading programs that are used to remediate children's reading difficulties. Two styles will be considered by this review. The first is phonologically based, and the second whole-word based. Treatment programs based on phonological instruction are designed to improve the child's phonological awareness and/or grapheme to phoneme conversion skills, teaching them how to break down words into their individual phonological units and/or how to convert letters and letter groupings into phonemes. Whole word training programs focus on the identification of words as a complete unit, without having to break the word down into its phonemic components.

Studies of undifferentiated groups of reading delayed children have demonstrated that either of these approaches can improve reading performance when compared to no treatment (Bradley & Bryant, 1985; Center, Wheldall, Freeman, Outhred & McNaught, 1995; Iversen & Tunmer, 1993; Joseph, 2000; Lalli & Shapiro, 1990; Lovett et al., 1994; O'Shaughnessy & Swanson, 2000; Shwartz, 2005; Wallach & Wallach, 1976). However, these studies only examine either a phonological or whole word approach, so provide no comparative information about which type of approach is more effective.

A range of studies have performed a phonological based program and a whole word based program side-by-side, allowing direct comparison of the two techniques. Some such studies have failed to find significant differences in treatment outcomes. For example, Olson, Foltz and Wise (1986) used a training procedure in which dyslexic children were provided with online feedback when they encountered a word in a text that they could not read. In the *whole word feedback* condition, the computer pronounced the entire word; in the *phonological feedback* condition, it pronounced and visually presented each syllable of the word separately. However, a post-treatment reading test involving the trained words failed to

demonstrated a significant difference between the two conditions. A similar result was obtained in a more recent study based on an expanded version of this computer-based feedback program (Olson and Wise, 1992). Schmidgall and Joseph (2007) used a more explicitly phonological program involving a word box procedure. Participants had to break words down into their individual phonemes, and then match these phonemes to their printed representations. They compared this program to whole word program involved the presentation of whole words on flash cards. Treatment outcomes were not significantly different from the two programs, nor did they differ from those of a traditional drill program involving rote learning (repeated reading of single words).

Other studies have found similar treatment outcomes for phonological and whole-word treatments when the treated words are examined, but significant benefits for phonological treatments when generalization to untrained words is considered. For example, O'Connor and Padeliadu (2000) used a phonological program, which trained participants to blend each individual phoneme of a word, one by one, eventually forming the entire word. They compared this to a whole word program, where participants read entire words from flash cards. Both programs significantly improved reading of the treated words, and no significant difference between the programs was found. However, after treatment, participants in the phonological program performed significantly better on words that were not part of the treatment, but were composed of the phonemes targeted during the phonological treatment.

Whilst these studies all directly compared at least two training approaches, they all used undifferentiated groups of reading delayed children. As a result, they provide no information as to whether different programs may suit some children more than others. One early study that attempt to tailored treatments to according to the individual's particular reading profile was conducted by Broom and Doctor (1995a). These researchers developed a

treatment program for a participant, SP, whose profile was indicative of developmental phonological dyslexia (disproportionately poor nonword reading). Broom and Doctor's treatment program was based around improving SP's knowledge of GPC's. Six GPCs were selected which SP had particular difficulty with. Each GPC was targeted for four training sessions, resulting in a total of 24 sessions. Each session involved the training of five different words that contained the targeted GPC. SP would suggest each of these words, and then would spell them using plastic letters. Following this, he would copy the word into an exercise book. The correspondence between the phoneme and graphemes was highlighted by the examiner during this process. At the end of the session, SP had to generate a sentence containing all five of the trained words. Each session would begin with a revision of the previous session's training words. Tests administered after the program indicated a significant improvement with the targeted words, untargeted words and nonwords containing the targeted GPCs, and also on words and nonwords that did not contain the target GPCs.

In a second study, these authors developed a tailored treatment for an individual with the converse reading profile, of developmental surface dyslexia (Broom & Doctor, 1995b). DF was found to be significantly better at reading regular than irregular words. The basis of the treatment program was to encourage visual reading strategies, including access to visual word information in the lexicon and access to semantic representations from this visual information. 66 irregular words were selected as the target words for the treatment. Each treatment session trained 11 of these words. The training procedure for each individual word involved DF reading the word aloud, hearing its definition, then writing it himself, whilst sounding out the word. Then after repeating this procedure several times, DF had to write the word from memory and suggest a sentence that contained the target word. At the start of each new session, the 11 words targeted in the previous session were retrained using 'flashcards', small cards displaying each target word in large letters. Testing following training reveal that

DF's reading accuracy for the trained irregular words improved significantly. However, it did not generalize to words outside of the treatment.

The lack of generalization found by Broom and Doctor (1995b) may be due to their particular choice of treatment for DF. They saw this disorder as a deficit in lexical processing, in that a word's lexical information cannot be correctly accessed. By training participants to read irregular words, it teaches them to rely less on a phonological strategy of reading, forcing them to use a lexical strategy instead. However, this strategy only worked when DF was reading words that he had been trained on. If the underlying problem in cases such as DF's is in fact, a visual attention span impairment, then a more visually-oriented treatment may produce better results – for example, one that encourages DF to attend to larger areas of the word at a time.

These studies suggest that treatment strategies which target the specific cognitive difficulties of the participant can lead to improvements in reading. However, neither of Broom and Doctor's studies examined whether the targeted treatment was more effective than an alternative treatment. A study by Rowse and Wilshire (2007) attempted to do this. They examined two children with reading disorders: one with a phonological dyslexic profile and one with a surface dyslexic profile. They administered two treatment programs to both participants – a phonological program and a whole-word program. The phonological program was similar to Broom and Doctor's (1995a): It was designed to target 10 families of words containing difficult GPCs, each of which was trained in a separate session, using a combination of reading each word aloud, spelling it, sounding it out, and identifying others with similar spelling. At the end of each session, the participant also wrote a sentence read by the examiner which contained at least five of the real words just trained. The whole word program used a range of techniques aimed at focusing on the target words as whole units. The training words were 200 irregular words, trained in groups of 20 over ten sessions. Two

different whole word techniques were used: visual mnemonic flashcards (10 sessions), and degraded images (10 sessions). Visual-mnemonic flash cards involved the presentation of a card displaying the target word with semantically related images superimposed on the word to highlight its full shape, and these visual and meaning relationships were highlighted by the examiner. The degraded image task involved presenting each word in a highly degraded form, and then re-presenting it in successively less degraded form until the participant was able to identify it. At the end of each both kinds of sessions, participants had to complete a sentence by using one of the target words.

Following each treatment program, both participants showed significant improvement on the words that had been trained. W.B., the phonological dyslexic, showed generalization of improvement to words that had not been trained, but only after the phonological training program and only on nonwords. Alternatively, N.S., the surface dyslexic, showed generalization to untrained words across all types of words and after both training programs. Rowse and Wilshire (2007) concluded that phonological dyslexics require the specific training of a program tailored to improve phonological awareness, whereas surface dyslexics can show improvement under a variety of treatment techniques.

These studies suggest that treatment tailored to an individual's specific subtype of reading disorder may have benefits over a more generalized treatment. However the literature has not yet considered a treatment program based on the theory of an underlying deficit of the visual attention span. Such treatment would use a visual process to widen the visual span, thereby allowing the reader to attend to more letters in each word.

8. The Present Study

These studies suggest that in general, treatment tailored to an individual's specific subtype of reading disorder may have benefits over a more generalized treatment. However,

the evidence in favor of this tailored approach is much stronger for individuals with a phonological dyslexia profile (where a phonologically-based program appears to have distinct advantages), than it is for those with a surface dyslexic profile (where whole word programs do not always show a significant advantage over than phonological ones). However, existing whole word programs have not always been based on strong theoretical grounds. Given the recent research suggesting that a visual span impairment may underlie this reading profile, it would be valuable to develop and evaluate the effectiveness of a whole word treatment program that is directly motivated by this framework – that is, one that focused on widening the visual span, thereby allowing the reader to attend to more letters in each word.

This study aims to do just this. The starting point for this work is the proposal that developmental reading disorders may be underpinned by two primary cognitive deficiencies: an impairment of phonological awareness, and an impairment of visual attention span. These two impairments interact to generate an overall reading deficiency. These deficits are reflected in two different reading profiles: the phonological deficit expresses itself as the pattern of phonological dyslexia, whereas the visual attention deficit expresses itself as the pattern of surface dyslexia. Participants with a reading profile of phonological dyslexia show an impairment reading nonwords, but no impairment reading irregular words. Alternatively, participants with a reading profile of surface dyslexia show an impairment reading irregular words, but no impairment reading nonwords. Surface dyslexics also show impaired reading latencies for all word types (Rowse & Wilshire, 2007; Seymour & Bunce, 1994). The study aims to develop two treatment programs: one tailored to treat the phonological impairment, and one tailored to treat the visual attention impairment. These programs will then be administered to two children who demonstrate relatively ‘pure’ forms of phonological

dyslexia, reflecting a phonological impairment, and surface dyslexia, reflecting a visual attention span impairment.

Firstly, participants with reading profiles expressing relatively ‘pure’ cases of phonological and surface dyslexia will be selected. Participants will complete an oral reading exercise containing regular, irregular and nonwords, developed by Coltheart and Leahy (1996). Performance on this exercise has been previously normed with a large sample, meaning performance can be classified into three bands: a normal band, a band of borderline deficiency, and a band of severe deficiency. Participants whose accuracy while reading nonwords falls at least a band below their accuracy while reading irregular words will be considered as fitting the profile of phonological dyslexia. Participants whose irregular word reading accuracy falls at least a band below their nonword reading accuracy and shows impaired reading latencies on all wordtypes will be considered as fitting the profile of surface dyslexia. In the second part of the study, evidence relating to each participant’s underlying cognitive profile will be examined. These include four phonological awareness tasks, as well as the whole and partial report tasks measuring visual attentions span. This is to assess the degree that the two theoretical cognitive impairments, a phonological deficit and a visual attention span deficit, associate with the profiles of phonological and surface dyslexia. If a phonological impairment underlies the profile of phonological dyslexia, we would expect these participants to perform poorly on the phonological tasks. Furthermore, if a visual attention span impairment underlies the profile of surface dyslexia, we would expect these participants to perform poorly on the visual attention tasks.

Finally, cases demonstrating relatively pure deficits of each type will be selected to undergo the two reading treatments. The phonological awareness program will target difficult GPCs, using a combination of traditional phonics-type exercises (repeated sounding out of specific difficult letter combinations), and through the training of word “families” (words that

share the target GPCs). This combined technique has previously been found to be effective with participants with a relatively pure phonological deficit (Broom & Doctor, 1995a; Rowse & Wilshire, 2007). In contrast, the visual attention program will attempt to increase the number of letters that can be simultaneously processed in a word, by training participants to recognize frequently occurring letter combinations as “letter chunks” (e.g., -ation, -ment). Previous studies that have used a ‘whole word’ approach to specifically treat participants with a surface dyslexic reading profile have failed to observed significant generalization to other, untrained words (Broom & Doctor, 1995b; Rowse & Wilshire, 2007). The current approach, which is based on letter chunks, rather than uniquely occurring combinations of words, may have greater potential to show generalization effects.

The hypotheses are:

1. That, during cognitive profiling, participants that fit the profile of phonological dyslexia will specifically show impairment during the phonological awareness tasks, with no impairment during the visual attention span tasks.
2. That, during cognitive profiling, participants that fit the profile of surface dyslexia will specifically show impairment during the visual attention span tasks, with no impairment during the phonological awareness tasks.
3. That, during cognitive profiling, participants that show a mixed profile of dyslexia (showing the same degree of impairment whilst reading both irregular words and nonwords) will show impairment during both the phonological awareness tasks and visual attention span tasks.
4. That the phonological treatment program will be more successful than the visual attention span program for the participant showing the phonological deficit, in that it will

elicit a significantly greater improvement on untreated words than the visual attention span program.

5. That the visual attention span treatment program will be more successful than the phonological program for the participant showing the visual attention deficit, in that it will elicit a significantly greater improvement on untreated words than the phonological program.

Chapter 2: Analysis of reading profiles and performance on key cognitive tasks for a selected group of reading-delayed children.

In the initial stage of the study, a cohort of 26 children, identified by their schools as having reading difficulties, were assessed on the BURT Word Reading test and the block design subtest of the Wechsler Intelligence Scale for Children. The purpose of these tests was to identify children with a reading age at least one year below their chronological age, and whose performance IQ is in a normal range for their age, in that they show a standardized score of eight or higher on the block design test.

Recruitment and Selection of Initial Participant Cohort

Participants

Seven schools in the greater Wellington region were approached to recruit participants. Of these, four declined, so participants were selected from three schools. Schools A and B both had a decile rating of 10, indicating the school is amongst the 10% of New Zealand schools with the lowest proportion of students from low socio-economic communities. School C had a decile rating of 6, indicating an average proportion of students from low socioeconomic communities.

School teachers, or other school staff such as remedial reading teachers were asked to identify children aged between 8 and 14 years old who were have particular difficulties with reading. Following this, teachers passed letters to participants' parents or guardians with a description of the study and an offer to express interest. Parents or guardians that expressed interest were then given full information; for those that chose to participate, both the child and parent provided written consent (See Appendix A and B). All participants were required to have English as their first spoken language. A total of 26 children (20 boys and 6 girls)

participated in the study, two from School A, 21 from School B, and three from School C. They were aged between 9.0 and 13.8 years old with a mean age of 11.3 years old.

Method

Materials

The BURT Word Reading Test (Gilmore, Croft & Reid, 1981) was used to assess the participants' reading ages. This test involves the presentation of 110 words and measures the participant's generalized word recognition ability (See Appendix C). It has been normed for New Zealand children and provides age norms between 6.0 and 12.11 years. Words were presented on two pages in rows of four, and participants were required to read across the page. Each column of words was 4.25cm wide, rows were 1.52cm high, and the words were Times font type, size 16 and bold. The test was administered according to standard instructions: they were told they would see a page with words on it, and they should try to read each one. If they could not read an item, they were encouraged to make an attempt. The test was terminated after a participant made ten consecutive errors. No time limit was enforced and accuracy was recorded.

The block design subtest of the Wechsler Intelligence Scale for Children – Fourth Edition (WISC IV; Wechsler, 2003) was used to obtain an estimate of performance IQ for each child. The test was administered as per standard procedure.

Procedure

Sessions were conducted one-on-one, in a quiet area at the participants' homes or schools. The sessions ran no longer than one hour. The BURT was administered first, followed by the block design test, with a five minute break between tests.

Results

Table 1 presents each participant's reading age score calculated from the BURT, and their scaled score for the WISC-IV block design subtest for each. Also shown are the participants' chronological ages, and the difference in years:months between their chronological and reading ages. Reading age scores on the BURT ranged from 6.11 to 13.6 years, with a mean of 9.9 years and a standard deviation of 1.77. Scaled scores on the WISC-IV Block design subtest ranged from 4 to 15, with a mean of 9.54 and a standard deviation of 2.86.

Table 1.

*Scores on the BURT Word Reading Test and the Block Design Test for the Initial 27**Participants*

Participant	Chronological age (CA)	BURT word reading test (reading age; RA)	Difference between RA and CA	WISC IV block design subtest (scaled scores)	Criteria fulfilled (RD = reading deficiency BD = block design)*
BL	9.11	7.6	-2.5	10	RD & BD
CB	9.0	8.10	-0.2	10	BD
DA	10.4	12.5	2.1	7	-
DD	9.9	9.6	-0.3	10	BD
FJ	10.3	8.6	-1.9	7	RD
HG	10.0	8.0	-2.0	12	RD & BD
HS	9.2	6.8	-2.4	14	RD & BD
JA	11.10	11.6	0.4	10	BD
KJ	13.8	10.9	-2.11	12	RD & BD
KM	10.5	9.6	1.5	5	-
LJ	11.1	11.7	0.6	13	BD
MC	11.9	11.11	0.2	6	-
MJ	12.2	13.6	1.4	7	-
MO	11.8	8.2	-3.6	11	RD & BD
MS	11.2	6.11	-4.8	9	RD & BD
MT	12.3	13.1	1.0	10	BD
MW	12.2	11.6	-0.8	9	BD
OS	11.4	10.4	-1.0	13	RD & BD
PJ	11.0	11.6	0.6	13	BD
RC	11.0	9.4	-2.8	8	RD & BD
SD	10.9	9.8	-1.1	7	RD
SZ	12.5	11.3	-1.2	11	RD & BD
TC	10.2	11.6	1.4	15	BD
TI	11.8	10.4	1.4	4	-

WJ	11.8	8.1	-3.7	7	RD
WJL	12.2	10.1	-2.1	8	RD & BD

*The criteria for a reading age deficiency was deemed a difference between reading age and chronological age of one year or more, the criteria for the block design test (deemed a level of normal intelligence) was eight or more.

Our criterion for selection of participants for the full cognitive screening was that their reading age should be at least one year below their chronological age, but their standard score on the WISC-IV Block designed subtest should be at least eight. Ten participants fulfilled both criteria, and so were invited to complete the full cognitive screening.

Full Cognitive Screening of Initial Participant Cohort

In this second stage of tests, the cohort of ten children identified by the previous stage of testing as having delayed reading and normal intelligence were administered a further collection of tests. This battery was designed to further assess the participants' reading and cognitive abilities, with the intention of classifying whether any participants fit the profiles of either phonological or surface dyslexia. The tests used included an oral reading task, consisting of wordlists devised by Coltheart and Leahy (1996): one of regular words, one of irregular words, and one of nonwords. Performance reading these wordlists has been normed with a large sample of normal readers, allowing performance to be categorized into three bands: a normal band, a band of borderline deficiency, and a band of severe deficiency. Response times were also measured. A study by Bosse and Valdois (2009) provide normative means for individual word reading response time, obtained from a large sample of normally reading children. Response times that were two standard deviation above this mean were considered abnormally slow (See Table 2). Participants were considered as fitting the profile of phonological dyslexia if their accuracy while reading nonwords fell at least a band below their accuracy while reading irregular words. Participants whose irregular word reading

accuracy fell at least a band below their nonword reading accuracy, as well as demonstrating abnormally long response latencies whilst reading all wordtypes, were considered as fitting the profile of surface dyslexia.

A battery of tests assessing phonological awareness and two tests measuring visual attention span were also administered. These tests were used to examine the underlying cognitive deficit(s) in each individual: participants fitting the profile of phonological dyslexia might be expected to perform particularly poorly in the phonological awareness tests, whereas those fitting the profile of surface dyslexia might be expected to perform poorly in the visual attention span test.

A study by Bosse and Valdois (2009) provides normative data for the visual attention span tasks, obtained from a large sample of children with normally developed reading. A score two standard deviations or more below the standard mean for a participants' age group was defined as deficient on this task (See Table 2).

Table 2.

Thresholds indicating abnormally low scores on the Visual Attention Span and Oral Reading Tasks. Scores equal to or below the visual attention thresholds indicate a deficiency on the task. Times equal to or above the reading latency thresholds indicate an abnormally slow latency. Thresholds are two standard deviations from normative means.

	Age Range		
	6-7	8-9	10-12
<i>Visual Attention Span Tasks</i>			
Whole Report: String (/20)	0	0	0
Whole Report: Letters (/100)	28	55	64
Partial Report (/50)	16	29	35

Reading Latencies (secs)	9.4	2.8	1.6
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Three of the four phonological awareness tests do not have previously collected normative data. For these three tests, the sample's mean will be used to assess abnormality: two standard deviations below the mean or less will be considered an abnormally low score (See Table 3). The phoneme deletion task has age specific standardized scores. Scores ranging from four to five are considered "poor", and scores ranging from one to three are considered "very poor". Therefore standard scores of five and under on this task are considered deficient (Hammill, Mather & Roberts, 2001).

Table 3.

Thresholds indicating abnormally low scores on three of the Phonological Awareness Tasks. Scores equal to or below thresholds indicate a deficiency on the task. Thresholds are two standard deviations below the sample means.

Task	Threshold Score
Rhyme Detection	5.96
Rhyme Production	1.88
Phoneme Identification	0.22

Participants

Participants of the cognitive screening series of tests were the ten participants that fit the criteria of the above reading age tests. This sample comprised of two girls and eight boys. Participants' chronological ages ranged from 9.2 to 13.8 years, with a mean of 10.94 years (SD=1.29). Reading ages (as measured by the BURT) ranged from 7.6 to 11.3 years, with a mean of 8.55 years (SD=1.76). Note that the mean chronological age is just over two years higher than the mean reading age. Their difference between chronological and reading ages

ranged from -1.0 to -3.6 years, with a mean difference of -2.15 (SD=0.90). Their standard scores on the block design subtest of the WISC-IV ranged from 8 to 14, with a mean of 10.80 (SD=2.04).

Method

Materials

Participants completed: four tasks designed to measure phonological awareness; two tasks designed to measure visual attention span; and one oral reading task designed to assess reading accuracy on a range of different word types. These various tests are described in further detail below.

Oral Reading Task. Oral reading of regular, irregular and nonwords was assessed using Coltheart and Leahy's (1996) wordlists. These wordlists consist of 30 regular-, 30 irregular-, and 30 non-words (see Appendix D). The lists are normed on 420 children without a reading disorder with ages ranging from 7 to 12 years. The norms enable each participant's scores on each wordlist to be classified into one of three bands: Normal (within two standard deviations of normal readers in the same age group); Band B (two standard deviations below the norms' mean, but still within the range) indicating borderline deficiency; and Band A (completely outside the range for normal readers) indicated severe deficiency. The wordlists are matched on word length, and the regular and irregular word lists were also matched on imageability and frequency.

For the purposes of the task, the words were randomized, with all three wordlists combined together. Five practice stimuli also preceded the 90 test items: two words and three nonwords. The words were individually presented to participants on an Apple laptop screen, using the PsyScope software.

Participants were informed that they would see a range of words and nonwords, or “made up words that sounded real”. They were told to read each word aloud when they saw it. If they could not read a word, they were encouraged to make an attempt.

A trial began with the presentation of a ready cue: “*****”, accompanied by a beep to alert participants of an upcoming presentation. The ready cue remained onscreen for 500 msec. Presentation of each stimuli followed 200 msec later, accompanied by a beep in a different tone. Both the ready cue and stimuli were centred in the middle of the presentation screen, were Times font type, size 70 and bold. Both were black against a white background. Stimuli remained on the screen until the participant made a response. Accuracy and response time were recorded.

Phonological Awareness Tasks. There were four phonological awareness tasks. These were Rhyme detection, Rhyme production, Phoneme identification and Phoneme deletion.

The *Rhyme detection task* was taken from Muter, Hulme, Snowling and Taylor (1998). Participants were presented with a target picture, and were asked which of three separate pictures rhymed with the target. For example, one item consisted of the target picture of a cat, and the pictures of a fish, a gun and a hat. The correct response to this item would be “Hat”. Three practice items preceded nine trial items. Each target picture and its three corresponding items were presented on one piece of A4 paper. The paper was halved by a vertical line. The target picture appeared above the line, and the three items below. See Appendix E for a list of items.

Each trial of the rhyme detection task consisted of the presentation of each item (the target picture and three corresponding pictures), followed by the participant’s verbal response. During each presentation, the examiner would say “Here is a picture of (target picture). Can you name these pictures?” The participant was then required to name the three

corresponding items. The examiner then asks, “Which of these three rhyme with or sounds like (target picture)?” Accuracy was recorded. Feedback was not given on the nine trial items.

The *Rhyme production task* was also taken from Muter et al. (1998). This task required participants to produce words that rhymed with a target word given by the examiner. The two target words used were day and bell. Each trial required the examiner to ask participants, “Can you tell me some words that rhyme with the word (target word)? You have 30 seconds to name as many words as you can think of.” Participants were then free to name words for 30 seconds. After this the examiner would stop the participant. Both words and nonwords that rhymed were accepted, and repeated words were not. Accuracy was recorded, and feedback was not given during the 30 seconds.

The *Phoneme identification task* was also taken from Muter et al. (1998). This task required participants to complete the last phoneme of incomplete words. Pictures of the target word were presented to participants. The experimenter then pronounced the target word out loud, minus its final phoneme. Participants had to produce the missing final fragment in isolation. Saying the full word counted as an incorrect response. For example, for the item “watch”, the participant was presented with an image of a watch, accompanied by the auditory fragment /wɒtʃ/. A correct response would be the missing phoneme /tʃ/. The task consisted of two practice trials followed by eight trials. Accuracy was recorded. No feedback was given on eight trial items. See Appendix F for a list of items.

The *Phoneme deletion task* was taken from the Illinois Test of Psycholinguistic Abilities Third Edition, subtest five (ITPA - 3; Hammill et al., 2001). This task required participants to delete phonemes from spoken words. The target word and the phoneme to be deleted were read aloud to the participant. The participant was then required to say the

correct response aloud. For example, if the target word was “jam”, and the phoneme to be removed was /j/, the correct response would be /æm/.

Up to three practice items preceded twenty test items. The first practice item began with the examiner saying the following: “I’m going to say a word and leave off one sound. If I say ‘man’ with /m/ it would be ‘an’. Now you do one. Say ‘sat’.” The participant would now respond, and the examiner would then say: “Now say ‘sat’ without /s/.” If the participant answers correctly (‘at’) the trial items begin. If the participant answers correctly, a second practice item is run. A third practice trial was run if the first two elicited incorrect responses. On each trial, the examiner says: “Say (item).” After the participant responds, the examiner then says: “Now say (item) without (phoneme).” For example, on the first trial, the examiner would say: “Say ‘jam’. Now say ‘jam’ without /j/”. The correct response for the participant to make would be ‘am’. No feedback was given after the response during the trial items. Accuracy was recorded. See Appendix G for a list of items.

Visual Attention Span Tasks. Participants completed two tasks designed to measure visual attention span: A Whole report task, and a Partial report task. Both were taken from Bosse et al. (2007). In the *Whole report task*, participants viewed strings of five random letters for a brief period, and were later required to report the letters that had appeared. In, the *Partial report task*, participants were presented with similar five-letter strings but this time had to report only the letter that appeared in the location specified by a post-stimulus cue (Bundensen, 1998). The whole report measures how many letters can be retained in visual short-term memory. The partial report is an indicator on how the attention span is distributed across the letters. The partial report task will be used as the primary criterion for assessing VA span as it is not confounded by limitations in short-term memory.

The stimuli of the *Whole report task* were twenty letter strings each made up of five letters, all selected from the following letter pool: B, P, T, F, L, M, D, S, R and H. Each string consisted of five of these letters chosen randomly, and no letter featured in a string more than once. Each letter appeared exactly ten times, twice in each position of the letter string. Items were presented in Arial font, size 24, and were separated by 1cm. Five practice trials began the condition, followed by the 20 trials. Two scores were recorded for this condition: the amount of strings that were correctly reported in their entirety, and the amount of letters correctly reported, regardless of whether the whole string was correct.

Each trial of the whole report condition required participants to report all the letters in each letter string. The condition began with the instructions: “This test measures how well you can view and read a line of letters quickly flashed onto the computer screen. First you will see a cross in the centre of the screen and hear a beep. Then a line of five letters will quickly appear on the screen. You should try and remember these letters. When they disappear, I will ask you to repeat as many as you can remember. The first five are for practice.”

Each trial began with the presentation of a cue “+”, in the centre of the screen, accompanied by a beeping noise to alert the participant of the upcoming presentation. The cue remained onscreen for 1000 msec. A blank screen then followed for 500 msec. The array then appeared for 200 msec. A second blank screen then followed, and remained visible until the participant responds and the examiner pushes a button on the keyboard.

Two sets of data were recorded: the number of items in which the participant reported the entire string correctly, and the number of letters reported correctly for each string (regardless of whether the full string was correct or not).

The *Partial report task* followed the whole report condition. This condition was similar to the whole report, except only one letter in each array was cued, and participants only needed to name this item. The stimuli for this task were fifty letter strings made up of five letters. The same 10 consonants were used to make up these strings. Again each string consisted of five of these letters chosen randomly, and no letter featured in a string more than once. Each letter appeared exactly 25 times, 5 times in each position. Items were again presented in Arial font, size 24, and were separated by 1cm. One letter in each string was selected randomly to be the cued target item. The cue indicating this letter was a vertical bar presented 1cm below the target letter after the offset of the letter string. The task began with the instructions, “This test measures how well you can view and read one letter, when a line of letters is quickly flashed onto the computer screen. Just like the last task, first you will see a cross, then a line of letters will quickly appear on the screen. A small line will then appear under ONLY ONE of the letters. You need to tell me what that ONE letter was. The first five are for practice.”

Just as in the whole report, each trial in the partial report task began with a 1000 msec appearance of a cue (“+”) in the middle of the screen, accompanied by a beep. Again a blank screen followed for 500 msec, then the array appeared for 200 msec. Following this, the line probe appeared under the space where the cued letter had just appeared, and remained visible for 50 ms. A blank screen then appeared again, and remained till the participants’ response. Accuracy was recorded.

Both tasks were run on an Apple laptop computer using the PsyScope software. All stimuli and instructions were presented on the computer monitor. Instructions were also read and explained aloud by the examiner. Following the practice trials, no feedback was given.

Procedure

Sessions were conducted one-on-one, and all occurred in a quiet area at the participants' schools. The sessions ran no longer than one hour, and it took two sessions to administer the entire battery of tests. The oral reading test was administered in the first session, and the phonological awareness tests and visual attention tests administered in the second session. The phonological awareness tests were administered in the following order: Rhyme detection, Rhyme production, Phoneme identification and Phoneme deletion. The whole report task was administered before the partial report task. A five minute break occurred between the phonological awareness tests and the visual attention tests.

Results

See Table 4 for summary of the results for each task.

Table 4.

Overall Performance on the Oral Reading, Phonological Awareness and Visual Attention Span Tasks.

Task	Scores			
<i>Oral Reading: Accuracy (/30)</i>	Min.	Max.	Mean	SD
Regular Words	12	30	24.80	5.18
Irregular Words	8	22	17.90	4.65
Nonwords	7	27	19.27	6.65
<i>Oral Reading: Response Time (sec)</i>				
Regular Words	0.71	3.69	1.25	0.88
Irregular Words	0.82	4.37	1.37	1.07
Nonwords	0.91	4.99	1.68	1.20
<i>Phonological Awareness</i>				
Rhyme Detection (/9)	5	9	8.50	1.27
Rhyme Production	5	16	8.50	3.31
Phoneme Identification (/8)	0	8	5.30	2.54
Phoneme Deletion (/20)	9	17	13.60	2.84
Overall	20	43	36.00	7.50
<i>Visual Attention Span</i>				
Whole Report: String (/20)	0	14	4.40	4.09
Whole Report: Letters (/100)	55	94	66.70	11.90
Partial Report (/50)	20	46	33.90	8.43

Oral Reading Tasks. Participants' individual accuracy scores, normalized rating of deficiency, z-score based on age dependent normalized means and mean response time for each of the three word types (regular, irregular and nonwords) are summarized in Table 5.

Also shown is each participant's band according to age norms: Band A indicates severe deficiency, and Band B indicates borderline deficiency.

Table 5.

Participants' Individual Accuracy Scores, Normalized Rating and Z-Scores on Coltheart and Leahy's (1996) Normed Wordlists

	<i>Participants</i>									
	BL	<i>HG*</i>	HS	<i>KJ*</i>	MO	<i>MS*</i>	OS	RC	SZ	WJL
<i>Regular Words</i>										
Total Correct /30	24	22	12	27	25	24	30	29	29	26
Band**	N	<i>B</i>	A	<i>B</i>	B	<i>B</i>	N	N	N	B
Z-Score	-1.23	-4.38	-5.23	-2.10	-1.95	-2.45	0.55	0.05	-0.10	-3.10
Mean Response Time (sec)	0.96	1.07	1.47	0.85	1.00	3.69	0.93	0.88	0.71	0.90
<i>Irregular Words</i>										
Total Correct /30	17	18	8	22	18	12	22	21	22	19
Band**	N	<i>N</i>	A	<i>N</i>	B	<i>A</i>	N	N	N	B
Z-Score	-1.36	-1.77	-3.86	-0.97	-2.23	-4.16	-0.94	-1.26	-0.97	-2.00
Mean Response Time (sec)	1.09	1.04	1.00	0.86	1.07	4.37	0.99	1.41	0.82	1.06
<i>Nonwords</i>										
Total Correct /30	18	14	7	17	17	13	25	24	27	21
Band**	N	<i>B</i>	A	<i>A</i>	B	<i>B</i>	N	N	N	B
Z-Score	-0.94	-2.88	-2.66	-3.68	-1.50	-2.21	-0.07	-0.25	-0.11	-2.25
Mean Response Time (sec)	1.27	1.48	1.80	1.04	1.27	4.99	1.17	1.77	0.91	1.12

*Participants in italics are the three identified as fitting the profile of either surface or phonological dyslexia

**N indicates performance within the normal band, B indicates Band B, almost deficient performance, A indicates Band A, severely deficient performance

***Bold response times indicate a response time two standard deviations above the normative mean

Participant MS fitted the defined profile of surface dyslexia. His score on irregular words (Band A) was a band below his score on nonwords (Band B). His reading times were all abnormally slow also. Participant KJ fitted the defined profile of phonological dyslexia. His score on nonwords (Band A) was two bands below his score on irregular words (normal band). He showed no reading latency deficiencies. Participant HG also showed the profile of a phonological dyslexic. His score on nonwords (Band B) was one band below his score on irregular words (normal band). He showed no reading latency deficiencies. Three participants, HS, MO and WJL, showed a ‘mixed’ profile of impairment: they demonstrated the same degree of impairment while reading both nonwords and irregular words. The remaining four participants, BL, OS, RC and SZ, showed normal performance on all three wordtypes.

Correlation analyses were performed on participants’ z-scores between the wordtypes (See Table 6). Significant correlations were found between all three wordtypes, showing positive r values. This indicates that as participants’ performance on one wordtype increased, their performance on the other types also increased. The correlation between irregular words and nonwords was of far less magnitude however ($r=0.40$). This may be due to the fact that these two wordtypes rely on separate reading routes (the lexical and nonlexical route). Correlation analyses were also performed between participants’ reading age delay behind their chronological age (as assessed by the BURT), and their z-scores on the three wordtypes (See Table 6). A significant negative correlation was found between reading age delay and irregular word performance, indicating that as the delay in reading age increased, irregular word performance became more deficient.

Table 6.

*Correlations Among Reading Performance, Phonemic Awareness and Visual Attention Span**Tasks (n=10)*

	RP	PI	PD	STR	LET	PR	RAD	RW	IW	NW
<i>Phoneme Awareness</i>										
Rhyme Detection (RD)	0.35	0.68*	0.30	0.21	0.23	0.40	-0.11	0.60	0.59	0.26
Rhyme Production (RP)		0.27	0.13	0.22	0.43	0.56	-0.61*	-0.05	0.48	-0.45
Phoneme Identification (PI)			0.19	0.25	0.35	0.18	0.08	0.14	0.18	-0.04
Phoneme Deletion (PD)				-0.03	0.14	0.26	-0.53	0.40	0.33	0.44
<i>Visual Attention Span</i>										
Whole Report: String (STR)					0.72*	0.59	-0.34	-0.14	0.10	0.06
Whole Report: Letters (LET)						0.77**	-0.55	-0.01	0.21	0.18
Partial Report (PR)							-0.60	0.12	0.45	0.04
<i>Reading Performance</i>										
Reading Age Delay (RAD)								-0.34	-0.71*	-0.41
Regular Words (RW)									0.65**	0.81**
Irregular Words (IW)										0.40*
Nonwords (NW)										

* $p < 0.05$ ** $p < 0.01$

Phonological Awareness Tasks. Table 7 presents a summary of each participant's results on the four phonological awareness tasks. On the rhyme detection task the majority of participants (8 out of 10) scored at ceiling. The other tasks revealed a greater range of scores across participants: indeed, the proportion of correct scores for the phoneme segmentation

task occupied the full range from 0 to 8. Only two participants showed impairments on any of the tasks: HS, who demonstrated impairment on rhyme detection and phoneme segmentation, and MO, who demonstrated impairment on phoneme deletion. Both these participants demonstrated ‘mixed’ reading profiles, in that their performance whilst reading both nonwords and irregular words showed the same degree of impairment. Surprisingly, neither participant who fulfilled the criteria of phonological dyslexia (KJ and HG) demonstrated an impairment during these tasks. A correlation analysis between rhyme production and phoneme identification did not generate a significant result, indicating these two tests may be measuring different constructs. These result suggests that these phonological test have been unreliable measures of phonological awareness.

Correlation analyses were performed between the age-related standardized scores of the phoneme deletion task and the z-scores of the three wordtypes (See Table 6). No significant correlations were found. Note that correlations between the other phonemic tasks and the wordtypes of the oral reading task are not informative, as the wordtype z-scores are relative to an age appropriate group, and the other three phonological tasks are raw scores collapsed across all age groups (as age-related normative data does not exist for these tasks).

Visual Attention Span Tasks. Table 7 presents a summary of each participant’s results on the visual attention span tasks. For the whole report task, two separate scores are given: the amount of letter strings correctly reported in their entirety (referred to as the string score) and the amount of letters correctly reported, regardless of their position or whether the entire string was reported correctly (referred to as the letters score). The partial report task only elicits one score: the amount of cued letters correctly reported.

A range of participants showed impairments during these tasks. Overall five participants showed impairment during the partial report task. As previously stated, this task

is considered the primary criterion for assessing VA span as it is not confounded by limitations in short-term memory. Participant MS, who fits the profile for surface dyslexia, showed an impairment in his score on the partial report and the letters score of the whole report. Participants KJ and HG, who both fit the profile of phonological dyslexia, also show impairments: HG during the partial report task, and KJ on both scores of the whole report task. Three other participants that did not fit the profile of either phonological or surface dyslexia also showed impairments during the partial report task: HS, MO and SZ. MO and SZ also showed impairment with the letters score of the whole report task. HS and MO both showed a mixed reading profile: they demonstrated the same degree of impairment during reading of both irregular words and nonwords. Alternatively, SZ showed normal reading performance across all three wordtypes.

Correlation analyses were performed between the two scores of the whole report task and accuracy during the partial report task (See Table 6). A high positive significant correlation was found between the two scores of the whole report task, and between the letters score for the whole report task and accuracy during the partial report task. This indicates that the letters score is the appropriate score to use during the whole report task, as it appears to be measuring the same construct as the partial report task.

Table 7.

Participants' Individual Performance on the Four Phonological Awareness Tasks and the Two Visual Attention Span Tasks

	<i>Participants</i>									
	BL	<i>HG*</i>	HS	<i>KJ*</i>	MO	<i>MS*</i>	OS	RC	SZ	WJL
<i>Phonological Awareness Tasks</i>										
Rhyme Detection (/9)	9	9	5	9	8	9	9	9	9	9
Rhyme Production	6	12	6	15	5	6	11	7	7	10
Phoneme Segmentation (/8)	5	7	0	5	7	7	7	2	5	8
Phoneme Deletion (Standard score)	10	8	7	7	5	8	11	6	10	7
<i>Visual Attention Span Tasks</i>										
Whole Report: String (/20)	2	7	3	0	1	2	3	6	6	14
Whole Report: Letters (/100)	75	68	61	53	63	55	73	65	60	94
Partial Report (/50)	37	35	28	39	20	26	42	40	26	46

*Participants in italics are the three identified as fitting the profile of either surface or phonological dyslexia

**Scores in bold are two standard deviations or more below the normative mean

Serial position curves. To provide an indication of how participants' visual attention was balanced across letter position, the serial position curves of the three participants' visual attention span results were generated by plotting accuracy against letter position for MS, KJ and HG (Figures 3 & 4). During the whole report task, both MS and HG show the classic W-shaped function that is typically displayed by normal readers: best performance on the centre item, intermediate performance on the far items, and worst performance on the items in the second and fourth positions. Conversely, KJ's accuracy steadily decreases from the far left item to the far right. The partial report task is a better measure for analyzing serial position

effects, as it measures how visual attention is balanced across the letter string. HG again shows the W-shaped function. MS' function almost resembles this as well, however the item in the fourth position shows intermediate performance. KJ again shows an unexpected result, however this time his serial position curve shows a U shaped function, with the best performance on the outer two items, with performance becoming steadily worse towards the centre item.

Figure 3. Serial position curve of responses to the whole report visual attention span task, showing the number of correct responses in each of the letter positions. The centre position refers to the letter in the position the fixation cross cued, and the other positions refer to the letters to the left or right of this centre position.

Figure 4. Serial position curve of responses to the partial report visual attention span task, showing the number of correct responses in each of the letter positions. The centre position refers to the letter in the position the fixation cross cued, and the other positions refer to the letters to the left or right of this centre position.

Discussion

This preliminary assessment of reading and related cognitive skills for our small initial participant cohort yielded a number of interesting findings. First of all, it is perhaps worth noting that the gender ratio in this small reading disorder group conforms to previous literature, in that boys significantly outnumber girls (Rutter et al., 2004).

Three participants were identified as fitting the profile of surface or phonological dyslexia. KJ exhibited a profile consistent with phonological dyslexia. He displayed scores within a normal range while reading irregular words, and severely impaired performance reading nonwords. HG also fitted the profile of phonological dyslexia. He showed a performance within the normal range for irregular words, and a borderline performance for nonwords. MS showed a borderline performance on nonwords and a severe deficiency on irregular words, and was shown to have impaired reading latencies on all three wordtypes, so was profiled as having surface dyslexia.

Coltheart and Leahy's (1996) profiles of 'pure' phonological and surface dyslexia require participants to have severely impaired performance (within Band A) reading nonwords and irregular words respectively, while showing a performance within the normal range while reading irregular words and nonwords respectively. The current study was required to mitigate these criteria, as none of the participants fit the profile of 'pure' surface dyslexia. Accordingly, KJ was the only participant who showed truly 'pure' phonological dyslexia, in that he showed severe impairments while reading nonwords, and performance within the normal range while reading irregular words. This indicates that KJ displays a specific impairment of the nonlexical route of reading. Conversely, HG demonstrated a less 'pure' profile of phonological dyslexia. His accuracy while reading irregular words indicates that he has an unimpaired lexical route, and his borderline performance while reading nonwords indicates he only has a borderline impairment of the nonlexical route. Finally MS displays a 'mixed' profile, in that he shows deficiencies while reading both wordtypes. However he shows particularly impaired performance reading irregular words, indicating his lexical route is more impaired than his nonlexical route. This indication is strengthened by his abnormally slow reading latencies. Previous research has shown that slow reading latencies are an indication of surface dyslexia (Seymour, 1987). Seymour suggests that this

occurs due to the surface dyslexic's overreliance on the nonlexical route. As a result, words have to be broken down into their individual GPCs in order to be processed, which takes far longer than lexical reading.

The finding that only one of the 11 participants showed a 'pure' profile of dyslexia is inconsistent with previous research. Castles and Coltheart (1993) found that approximately one in every three of their 56 reading disordered participants showed 'pure' profiles.

The current study's hypotheses with regards to cognitive profiling were: a) that participants fitting the profile of phonological dyslexia would show specific impairment of the phonological tasks, b) that participants fitting the profile of surface dyslexia would show specific impairment of the visual attention tasks, and c) that participants showing a mixed profile would show impairment of both styles of tasks. Only the second hypothesis was supported by the results.

Firstly, the phonological dyslexics KJ and HG did not show specific impairment of the phonological tasks. In fact, neither participant showed any impairment on any of the phonological tasks, and both showed impairments during the visual attention span tasks. These results could lead one to conclude that phonological awareness is unrelated to the reading profile of phonological dyslexia. However, there is an alternative explanation for these findings. The lack of impairment seen during the phonological tasks may be a reflection of the unreliability of these tasks at measuring phonological awareness. As for the impairments during the visual attention tasks, KJ only showed an impairment on whole report task. This task measures how many letters can be retained in short-term memory. KJ's performance may therefore be confounded by limitations in his short-term memory, and therefore his unimpaired performance during the partial report task may be a more accurate indicator of his visual attention span. KJ's serial position curve on the whole report task

(shown in Figure 3) is also consistent with this conclusion. Unlike normal participants, whose performance shows a W-shaped function (Hawelka, Huber & Wimmer, 2006), KJ's reveals steadily decreasing accuracy from the left to the right of the visual field, a pattern more indicative of a limitation in verbal short-term memory. Additionally, HG's performance during the partial report task was at the borderline of impairment. HG's score was exactly at the threshold of impaired performance for his age range (35), and he was at the bottom limit of this age range.

Secondly, the surface dyslexic MS did show specific impairment of the visual attention tasks, as predicted. This finding is unusual however, as MS' reading profile is not 'pure', rather, he shows a stronger impairment while reading irregular words than nonwords. It could therefore be expected that he would show some degree of impairment during the phonological awareness tasks. However, the fact that this impairment was not seen may simply be the reflection of the lack of sensitivity of the phonological tasks.

Thirdly, one case displaying a 'mixed' profile did not show impairments during both the phonological and visual attention tasks. Three cases showed a mixed profile: HS, MO, and WJL. HS and MO showed results confirming this hypothesis: impairments on both the phonological and visual attention span tasks. Conversely, WJL did not show impairment on either. Again, this may be due to the unreliability of the phonological tasks, however, given his cognitive profile, it would be expected that WJL would show impairment during the visual attention tasks also. It must be noted however that WJL showed borderline performance on irregular- and non-words, and is the only refuting case.

As noted in the introduction, the serial position curves generated by performance on the partial report task can provide information about the nature of a participants' visual deficit. Normal readers display a W-shaped curve. As participants displaying a profile of

‘pure’ phonological dyslexia theoretically do not have an impairment of visual attention span, they should also display this curve. HG, who fitted the profile of phonological dyslexia, appears to confirm this, as he demonstrated a W-shaped curve. However KJ, who also fitted the profile of phonological dyslexia, showed refuting evidence, a U-shaped function. This function is difficult to explain theoretically, but may be an expression of a crowding effect: adjacent letters in the periphery are causing interference in attending to the cued letter. Participants’ with impaired visual attention span would be expected to show particularly high performance on the middle item, as this item is being fixated on, and lower the further the item is away from this. MS’ serial position curve appears to show this trend, except for the item in the second position, which showed the worst performance.

Ultimately, the cognitive screening provided little evidence for the framework that a deficit in phonological awareness is associated with the reading profile of phonological dyslexia and a deficit in visual attention span is associated with the reading profile of surface dyslexia. This framework should not be rejected however, as more participants and more observations may be required before reliable trends will emerge. In particular, a wider variety of participants with ‘pure’ phonological and surface profiles are required, as well as more reliable measures of phonological awareness.

Chapter 3: General Method: Treatment Programs

Two treatment programs were designed; one specifically addressing phonological processing and one attempting to broaden the participants' visual attention span. A large number of previous studies have shown that increasing a participant's grapheme to phoneme conversion skills, teaching them how to break down words into their individual phonological units and to convert letters and letter groupings into to phonemes, is an effective way to treat reading disorders (e.g. Bradley and Bryant, 1985; Lovett et al., 1994; O'Shaughnessy & Swanson, 2000). Furthermore, two studies have shown that this technique is particularly effective when the participant has been diagnosed as having a phonological deficiency (Broom & Doctor, 1995a; Rowse & Wilshire, 2007). The phonological treatment program used here is adapted from these two studies. It involves the selection of grapheme to phoneme correspondences (GPCs) that the participant is particularly poor with. Words containing these GPCs are then generated, and these words are targeted during training. The particular training strategy is an adapted version of a teaching method developed by Bradley and Bryant (1985). The participant spells out the word a number of times whilst being encouraged to think about the GPCs contained in the word, in particular the target GPC. Also, multiple words sharing the same key GPC (GPC "families") are trained at the same time and the participant is oriented to their similarities.

Alternatively, the reading strategies developed for the visual attention span-based treatment were designed to increase the number of letters participants can encompass within their visual attention span. The main basis of this training was the breakdown of words into 'visual clusters', letter combinations that commonly occur in words and that are bigger than GPCs. By making participants familiar with these clusters, our aim was to encourage them to process the clusters as individual "chunks", thereby increasing their effective visual attention

span when processing words containing these clusters. This kind of training, if effective, would also be expected to generalize to other, untrained words containing the same clusters. Training also included a ‘whole word’ strategy, the degraded images task. This strategy encourages participants to visually attend to the shape of the entire word.

Both treatment programs were given to both participants. To be effective, the treatment programs would not only have to improve participants’ ability to read the words being trained, but also words that had not been trained. This would suggest that the program’s treatment methods had generalized to all of the participants’ reading. A series of tests that comprised of words not targeted during treatment was used to assess each program’s improvement.

Participants

As KJ withdrew from the study prior to the treatment phase, the two final participants were MS and HG. MS fit the profile of a surface dyslexic, and HG fit the profile of a phonological dyslexic.

Before participant selection was finalized, both participants undertook the full WISC-IV intelligence test (Wechsler, 2003). Both participants were found to be within the normal range of intelligence for their age group. MS attained a scaled composite score of 86 across the full scale, and HG attained a scaled composite score of 106 across the full scale.

Method

Design

Treatment sessions began approximately one month after the end of the cognitive screening phase. A total of 12 sessions were conducted.

To counterbalance the two treatment programs, an ABBA design was used. HG received one block of the phonological program followed by two blocks of the visual program, followed by a final block of the phonological program. Conversely, MS received one block of the visual program, followed by two blocks of the phonological program, followed by a final block of the visual attention span treatment. This design meant that both participants received two blocks of each treatment program. Each block consisted of three sessions.

Assessment tests were conducted before and after each block. Before each block an assessment pre-test of 45 untrained words was conducted, and following each block an assessment post-test was conducted, containing the same 45 words for comparison. Pre-tests were given in the session immediately preceding commencement of a new block, and post-tests were conducted the session following the final session of a block (except for the final posttest, this had to take place following session 12; See Figure 5).

Figure 5. The design of the treatment programs. Each participant completed four blocks of treatment program, two of the visual program (VP) and two of the phonological program (PP). Each block consisted of three sessions. An assessment pretest preceded each block, and a corresponding posttest followed each block.

Participant MS											
Block 1 - VP			Block 2 - PP			Block 3 - PP			Block 4 - VP		
Assess. Pretest 1 – Session 1	Session 2	Session 3	Assess. Posttest 1 – Assess. Pretest 2 – Session 4	Session 5	Session 6	Assess. Posttest 2 – Assess. Pretest 3 – Session 7	Session 8	Session 9	Assess. Posttest 3 – Assess. Pretest 4 – Session 10	Session 11	Session 12 – Assess. Posttest 4
Participant HG											
Block 1 - PP			Block 2 - VP			Block 3 - VP			Block 4 - PP		
Assess. Pretest 1 – Session 1	Session 2	Session 3	Assess. Posttest 1 – Assess. Pretest 2 – Session 4	Session 5	Session 6	Assess. Posttest 2 – Assess. Pretest 3 – Session 7	Session 8	Session 9	Assess. Posttest 3 – Assess. Pretest 4 – Session 10	Session 11	Session 12 – Assess. Posttest 4

Following the final assessment test (after all treatment programs had been administered) both participants again completed the whole and partial report visual attention span tasks. These materials are described in Chapter 2.

Materials

Assessment of Treatment Effects. Assessment tests were developed to measure the level of improvement following each treatment program. These tests consisted of words that were not tested during the treatment, to gauge the amount the treatment effect generalized to novel words. To assess the effectiveness of each of the four training blocks, four separate word reading tests were constructed, one for each training block. Each reading assessment was administered twice: once at the commencement of the training block, and once at the

end. Each reading assessment comprised 45 words: 15 regular, 15 irregular and 15 nonwords. To construct these four reading assessments, a pool of 180 words were constructed, comprising 60 regular, 60 irregular and 60 nonwords. 90 of these words were taken directly from Coltheart and Leahy's (1996) wordlists. These consisted of 30 regular-, 30 irregular- and 30 nonwords. A further 90 words were used. These words, developed by Rowse (2005), were matched to Coltheart and Leahy's wordlists with respect to word frequency (in the case of the real words), and length in letters and number of syllables (in the case of both real and nonwords).

These lists of regular-, irregular- and nonwords were then sorted into four separate lists, each containing an equal number of items of the three different types, and each matched for frequency (Lund & Burgess, 1996). These four lists comprised the words of the four assessment tests. See Appendix H for the full lists.

During the assessment tests, each test word was presented individually to the participant, who was required to read it aloud. Words were presented on an Apple laptop monitor. A trial began with the presentation of a ready cue: "*****", accompanied by a beep to alert participants of an upcoming presentation. The ready cue remained onscreen for 500 msec. Presentation of each stimuli followed 200 msec later, accompanied by a beep in a different tone. Both the ready cue and stimuli were centered in the middle of the presentation screen, were Times font type, size 70 and bold. Both were black against a white background. Stimuli remained on the screen until the participant made a response.

Phonological Training Program. To identify which grapheme – phoneme correspondences (GPCs) should be targeted in the treatment, a single word reading test, *the GPC Selection test*, was given prior to the commencement of treatment. The test consisted of five exemplars of the 20 most common GPCs (ai, au, ay, a-e, ch, ck, ea, ee, ie, i-e, le, ng, oa,

oo, ow, o-e, ph, qu, th and u-e; Berndt, Reggia and Mitchum, 1987; words were taken from Broom & Doctor, 1995a). Some of the words contained more than one of the key GPCs. For example, the real word “quaint” consists of both the GPC ‘ai’ and the GPC ‘qu’. These words were taken as representative of both GPCs. Because of this, the test contained 88 words. The words were randomized for presentation. See Appendix I for the full word list.

For each of the 20 key GPCs, the participants were given an accuracy score out of five. The 12 GPCs that scored the most poorly were targeted during the phonological program. These target GPCs and the participants’ score on each are listed in Table 8. For each of the targeted GPCs, 10 real words containing the GPC were compiled (see Appendix J).

Table 8.

Phonological Training Program. Number of words correctly read for each of the 12 key GPCs.

HG		MS	
GPCs	Accuracy /5	GPCs	Accuracy /5
ie	1	ie	0
ng	2	ck	0
ow	2	au	0
ai	3	ai	0
ck	3	a-e	1
i-e	3	u-e	1
u-e	3	qu	1
au	3	ph	1
ch	3	ay	1
a-e	3	ng	1
ay	4	le	1

le	4	i-e	1
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Visual Training Program. Initially 15 letter clusters were constructed. These clusters were four or more letters long, and encompassed at least two GPCs. See Table 9 for the list of clusters.

Table 9.

List of Visual Clusters Used in the Visual Training Program

able	ation	audi	aught	auto
cess	ence	fore	inter	ment
ough	spect	port	tract	tude

105 words were assembled, seven for each cluster. These words had a maximum age of acquisition of 9.5 years old (aspect), minimum of 3.6 (winter) and a mean of 7.8 (Gilhooly & Logie, 1980). They had a mean log Hyperspace Analogue to Language frequency of 9.33 (Lund & Burgess, 1996).

An initial test assessing which clusters participants performed most poorly on was devised. This test included all 105 words. The 12 clusters that each participant performed the most poorly on were then calculated. These were the clusters that were used in that participant's training program. See Table 10 for a list of the 12 clusters selected for each participant, and their accuracy score for each.

Table 10.

Visual Training Program. Number of words correctly read for each of the 12 key letter clusters.

HG		MS	
Cluster	Accuracy /7	Cluster	Accuracy /7
ation	1	pect	0
audi	2	auto	0
tract	2	audi	0
tude	2	tract	1
ence	3	ough	2
aught	4	inter	2
cess	4	ence	2
ment	4	cess	2
ough	4	tude	3
pect	4	aught	3
fore	5	ation	3
inter	5	ment	4

Five of the each of the clusters' seven words were selected as the training words (See Appendix K). These words were printed on cards 3 x 13.5 cm for presentation. The words were black on the white cards, font type Times, size 36.

The clusters were represented visually on card as well. Each A4 piece of card contained two representations of the cluster. In the centre of the top half of the card, the cluster was printed in font type Arial, size 200, coloured blue on white background. In the

centre of in the bottom half of the card, the cluster was presented as a pictogram. These were pictures containing the cluster. The pictures were designed to accentuate the shape of the letters in the cluster, and thereby make the cluster more recognizable from memory. As the clusters were not full words, and therefore contained no semantic information, the objects in the pictures had no semantic relation to the clusters (See Figure 6).

Figure 6. Example of the pictogram for the letter cluster “aught”, used in the Visual Attention Span treatment program

Degraded representations of the words were also used for training exercises. These involved the presentation of each word in a highly degraded form, followed by successive, less degraded presentations of the word. See Figure 7 for an example. On each presentation, the participants was asked to identify the word, and as soon as they were able to, then no further displays of that word were given. These degraded images meant that a participant had to visually attend to the shape of the entire word.

Figure 7. The five degraded forms of the word “ancient”. An example of the degraded images stimuli used during the visual treatment program (from Rowse & Wilshire, 2007).

The degraded images were formed using the PsyScope software, and were displayed on an Apple laptop screen. Each word would proceed through five steps of degradation,

before finally revealing the full word without any form of degradation. The levels of degradation were: 0.99 (most degraded), 0.975, 0.95, 0.925, 0.9, 0 (no degradation; values are based on PsyScope degradation settings). Each level was preceded by a beeping tone to alert the participant, and was visible for 1500 msec. The words were centered on the screen, were black on a white background, and were Times font type, size 70. When the word appeared with no degradation, it remained onscreen until the participant responded. Following a response, the examiner pushed a button on the keyboard to move to the next degradation trial.

Procedure

The GPC selection test, cluster selection test and the full WISC-IV were run in two one-hour sessions that took place prior to the commencement of the treatment programs. During the first session, the 88 words of the GPC Selection test were presented to participants individually, according to the same procedure used for the treatment assessment tests. Following this, the 105 words of the cluster selection test were presented, again according to the same procedure used for the treatment assessment tests. The second session, which occurred during the same week as the first, consisted of the full WISC-IV, which was administered as per standard procedure.

Treatment sessions were run at least one week apart. Each session lasted up to an hour. The sessions took place in a quiet location at the participants' respective schools.

Phonological Training Program. Two blocks of the phonological treatment were given to each participant, each block consisting of three sessions, making six sessions of the program in total. Two different GPCs were targeted for improvement each session; consequently, 12 different GPCs were targeted in total. See Table 9 for the list of the 12 target GPCs for each participant.

Each training session proceeded as follows. First, the examiner presented the first training word for the first of the two GPCs targeted for that session and read it aloud. The participant then repeated the training word, and the examiner defined the word. Following this, the participant spelled the word using large felt letters, whilst sounding the word out. If the participant could not spell a word, the examiner assisted by pronouncing in isolation the phoneme the participant was encountering difficulty on. If the participant still could not spell the word, the examiner showed them the letters required, then asked the participant to try the exercise again. Following this spelling exercise, the participant wrote the word in a personal exercise book, again sounding out each phoneme. The participant was then asked to check his spelling by referring to, and sounding out, the felt letters. Throughout the process, the participant was encouraged to think of other words that sounded like the training word, and words that also contained the target GPC, thereby encouraging him to see the commonalities between words. Each of the ten training words for the session were trained in this fashion, one after the other. After completion of all ten words, the examiner then dictated a sentence containing at least five of the recently trained words, which the participant wrote in his exercise book. If the participant failed to spell any of the trained words correctly, he was asked to try once more using the foam letters. The entire procedure was then repeated for the second targeted GPC for that session.

Before each session began, a test was given of the words trained in the previous session. This was done to gauge performance on previously trained words session-by-session, and also served the purpose of refreshing the participants' memories of the words trained the previous week. These tests included the 20 words from the previous session (10 from each targeted GPC), as well as six untrained words, three containing one of the previously targeted GPCs and three containing the other GPC. These words were presented for testing according to the same procedure used for the treatment assessment tests.

Visual Training Program. As for the phonological program, the visual program was conducted across six different sessions, with two different clusters trained in each session (a total of 12 clusters trained overall). During a session, each of the two clusters targeted for that session was trained separately. Following this training, a full degraded images task was given featuring all the words trained during the session.

Each individual cluster was trained as follows. First, the cluster was presented on a card showing its pictogram (See Figure 6). This card remained visible during the entire training of the cluster's corresponding five words, so participants could refer back to it. The participants were required to sound out and discuss the shape of the cluster with the examiner. Next the first of the words representing that cluster was presented on a card. The participant then read and spelled the word aloud. The examiner then defined the word if necessary and discussed the location of the cluster within the word. The word card was then removed from view and the participant spelled the word using large foam letters, receiving feedback from the examiner if he experienced difficulty. He then wrote the word in his personal exercise book. If the participant failed to spell the word correctly, he had to spell it with the foam letters again, receiving help from the examiner if needed. This process was then repeated for the other four words representing that cluster.

At the end each cluster training phase, the participants underwent the degraded images task. The five training words were the degrading items, appearing in random order. Participants were instructed that they would see a broken down image of a word which would slowly become clearer, and they had to say the word aloud as soon as they could name it.

Following both cluster training phases, a further degraded images task would occur. This task contained all ten of the training items used in the session, in a randomized order. This task was run using the same procedure described above.

Similar to the phonological training program, at the commencement of each new visual training session, a test was given of the previous session's trained words. This was done to gauge improvement on previously trained words session-by-session, and also served the purpose of refreshing the participants' memories of the words trained the previous week. The test included the ten words from the previous session, as well as four more words, two containing one of the previous session's clusters, and two containing the other cluster. These words were presented for testing according to the same procedure used for the treatment assessment tests.

Chapter 4: Results of Treatment Programs

Initially, the results from the tests that were run at the beginning of each session were calculated. During the phonological program, these tests contained the 20 words from the previous session, as well as six untrained words. During the visual program, the tests contained 10 words from the previous session, as well as four untrained words. The results of both participants are summarized in Table 11.

Table 11.

Participants' mean performance when tested on the words trained the previous session.

These tests were conducted at the beginning of sessions, and consisted of the words treated during the previous session and further words that were not trained, but contained one of the previous sessions' target GPCs or target clusters

	Participants	
	MS	HG
<i>Phonological Program</i>		
Treated (/20)	13.50	15.67
Untreated (/6)	3.17	4.67
Overall (/26)	16.67	20.34
<i>Visual Program</i>		
Treated (/10)	5.83	6.83
Untreated (/4)	2.16	2.17
Overall (/14)	7.99	9.00

The assessment tests measured the extent the treatment programs generalized to untrained words. Figure 8 summarizes the performance of MS in the pre- and post-treatment assessment tests. The data for MS is plotted as a function of treatment phase, treatment type and word type (regular words, irregular words and nonwords).

Figure 8. Participant MS's reading performance during the assessment tests before (pretests) and after (posttests) the phonological and visual treatment programs, on regular, irregular and nonwords.

A series of simultaneous logistic regression analyses were performed, with MS's accuracy as the dependent measure, and incorporating stimulus identify as a repeated measure. The regression model was built using a method known as GEEs, or Generalized Estimating Equations, which enables the researcher to model the effect of a repeated measure – in this case, stimulus identity, which was tested both in the pre-test and in the post-treatment assessment (see Liang & Zeger, 1986). The values reported are the Chi Square Score statistics associated with each predictor variable based on empirical standard error estimates. First, the two treatment programs were analyzed separately, to determine if each was effective overall, and if so, whether improvement was general or whether it was specific

to particular word types (regular, irregular or nonwords). Independent variables included testing phase (pre-treatment/post-treatment) and word type (regular/irregular/nonwords). The analysis of the phonological treatment showed two significant main effects: one for testing phase, $\chi^2(1)=7.85$, $p<0.01$, indicating that MS performed more accurately overall after treatment, and one for word type, $\chi^2(2)=19.15$, $p<0.01$, indicating that MS was generally not equally accurate at reading the three word types (a visual inspection of Figure 8 would suggest regular words in particular were more accurately read than irregular or nonwords). However, no significant interaction was found between testing phase and word type, suggesting that the treatments were not specific with respect to the type of words they targeted. Results of the analysis of the visual treatment also yielded similar results: there was a main effect of testing phase, $\chi^2(1)=1.49$, $p<0.01$, indicating an overall improvement in reading after treatment, and a main effect of word type, $\chi^2(2)=6.64$, $p<0.05$. Again, no significant interaction was found, suggesting that the different word types did not show differential responsiveness to treatment.

In order to examine whether the two different treatment – phonological and visual – varied in their effectiveness, a combined logistic regression analysis was performed on the assessment test data from both treatments. The independent variables included treatment type (phonological/visual), testing phase (pre-treatment/post-treatment) and word type (regular/irregular/nonwords). If there was a difference in the effectiveness of the phonological and visual attention span treatments, a significant interaction between treatment type and testing phase would be evident. This analysis also showed main effects for testing phase, $\chi^2(1)=21.46$, $p<0.01$, and word type, $\chi^2(2)=22.65$, $p<0.01$. No significant interaction was found however.

Figure 9 illustrates HG's performance in the assessment tests. The data is plotted as a function of treatment phase, treatment type and word type (regular words, irregular words and nonwords).

Figure 9. Participant HG's reading performance during the assessment tests before (pretests) and after (posttests) the phonological and visual treatment programs, on regular, irregular and nonwords.

A series of logistic regression analyses were performed, with HG's accuracy as the dependent measure. Again, the two treatment programs were first analyzed separately, using the same procedure as for MS. The analysis of the phonological treatment showed two significant main effects: one for testing phase, $\chi^2(1)=7.92$, $p<0.01$, and one for word type, $\chi^2(2)=12.02$, $p<0.01$. No significant interaction was found, suggesting there were not different treatment effects for the different word types. The analysis of the visual attention

span treatment only showed one significant main effect for word type, $\chi^2(2)=13.16, p<0.01$. The main effect of testing phase (pre- or post-) failed to reach significant ($p=0.22$), indicating that there was no statistically reliable improvement for HG following this type of treatment. Again, there was no significant interaction between testing phase and word type.

Following this a further logistic regression analysis was performed, combining the data from both treatments. If there was a difference in treatment effect between the phonological and visual treatments, a significant interaction between treatment type and testing phase would be evident. This analysis also showed main effects for testing phase, $\chi^2(1)=8.69, p<0.01$, and word type, $\chi^2(2)=24.96, p<0.01$. However, no significant interaction was found ($p=0.16$).

Each participant's performance on the visual attention span tasks administered before the treatment programs (during the cognitive testing phase) was compared to their performance on the same tests administered after the program. See Table 12 for a summary of both participants' results. A McNemar chi-squared test was performed on each participant's performance. No significant differences were found on any of the tasks for either of the participants. HG's score on the partial report task was no longer impaired following treatment. However, his score before treatment was on the border of impaired performance (35), and only improved by one following treatment

Table 12.

Performance on the two visual attention span tasks before treatment, during the cognitive testing phase, and after treatment, at the end of Session 12

	<i>Participants</i>	
	MS	HG
<i>Whole Report (Letter Score /100)</i>		
Before treatment	55	68
After treatment	58	65
<i>Partial Report (/50)</i>		
Before treatment	26	35
After treatment	28	36

Discussion

The analysis of participants' performance on the pre- and post- treatment assessment tests indicate that overall, our treatments were effective, in that improvement generalized to untrained words. This was the case for both MS and HG when considered separately. However, there was no evidence for any difference in the effectiveness of the phonological or visual treatments for either MS or HG. Although HG's improvement following the visual treatment was not in itself statistically significant, a combined analysis directly comparing the phonological and the visual treatments failed to reveal an overall reliable difference in the effectiveness of the two. There was also no evidence of specificity in the types of words that were most effectively treated by each program: for neither MS nor HG was there any evidence for a differential improvement across the three different word types, not overall nor in either of the treatment programs considered alone.

The current study's hypotheses with regards to the treatment programs were: a) the participant showing the phonological deficit (HG) would show greater improvement during the phonological treatment than the visual, and b) the participants showing the visual attention span deficit (MS) would show greater improvement during the visual treatment than the phonological. The results of the assessment tests did not support either hypothesis. While the treatments did increase both participants' reading performance, neither treatment showed a specifically greater increase. There are a number of possible methodological flaws that these findings could be attributed to. Firstly, the assessment tests may have lacked power. Each of the four pre- and post- tests comprised of only 45 words. This was due to time constraints during a session: some sessions required two tests (the previous treatment phases' post-test, and the next phases' pre-test) as well as the treatment program. If each test had an entire dedicated session, the number of items could be increased, increasing the statistical power.

Secondly, the use of the generalization tests may have been a poor choice as the outcome measure. The test words used were unlikely to include any of the targeted clusters or GPCs. The basis of the visual treatment's effect relied on making the participants' familiar with visual clusters that commonly appear in words. This effect would therefore generalize only to unfamiliar words that contained one of the targeted clusters. This oversight was due to the current study's assessment tests remaining consistent with Rowse and Wilshire's (2007). This study, however, did not use the visual cluster treatment that the current study implemented. It is therefore more reasonable for Rowse and Wilshire to expect a generalization effect with unrelated words. The current study should have included a second assessment test, analyzing the participants' performance on untrained words that contained one of the targeted clusters or GPCs.

No significant improvement in either participant's visual attention span was seen following treatment. This result is not surprising, when one considers how the visual treatment was constructed. The purpose of the visual treatment was not to extend the visual attention span, rather increase the numbers of letters it can encompass within particular words. The actual size of the visual attentional window remains the same, but the participant is able to take advantage of the redundancy in the letters of the clusters.

Chapter 5: General Discussion

The current research investigated whether two treatments of developmental reading disorders that targeted different cognitive impairments would differentially improve two participants' word reading accuracy. One treatment was aimed at improving phonologically-based reading skills, and the other was aimed at widening the effective "span" of visual attention during reading. Each participant was identified as conforming to an established profile of developmental dyslexia: phonological or surface. We hypothesized that the former profile was a reflection of a cognitive impairment in phonological awareness, and the latter an impairment in visual attention span. The results of the cognitive profiling phase of the study did not support this framework, however.

As regards the treatment program, our hypotheses were as follows: a) that the phonological treatment would show greater generalized improvement of reading than the visual treatment for the participant showing the profile of phonological dyslexia, and b) that the visual treatment would show greater generalized improvement of reading than the phonological treatment for the participant showing the profile of surface dyslexia. Neither of these hypotheses were confirmed. Participant HG was identified as fitting the profile of phonological dyslexia. However, there was no significant difference in the effectiveness of the two different treatment programs, at least not that was measurable on our pre- and post-treatment tests on words not treated during the sessions. Participant MS was identified as fitting the profile of surface dyslexia. However, there was no significant difference in MS's reading improvement on the two programs. Although the treatment programs did result in generalized improvement in both participants' reading accuracy, this improvement was not differentiated between the two programs.

The present results would lead us to conclude that there are no particular benefits associated with targeting a reading treatment program towards a particular individual's reading deficit, at least not when each type of deficit and its preferred treatment is operationalized in the way we did here. However, this does not imply that tailoring treatments to a reader's cognitive profile is never useful. The current study made a number of assumptions about the diagnoses of the dyslexia subtypes, and the cognitive framework that underlie these. We assumed that an impairment in nonword reading indicates a deficiency in phonological awareness, and an impairment in irregular word reading indicates a deficiency in visual attention span. As discussed in Chapter 2, our results did not conform to this framework. In particular the two participants (HG and KJ) who showed impaired reading performance on nonwords and normal reading performance on irregular words did not show impaired performance during a range of phonological awareness tests, but did show impaired performance during two visual attention span tasks. Also, one participant (WJL) who showed impaired reading of both nonwords and irregular words did not show impairment on either the phonological awareness or the visual attention span tasks. Furthermore, the framework predicts that performance during nonword reading and on the phonological awareness tests would be positively correlated, and performance during irregular word reading and on the visual attention span tasks would be positively correlated. Significant correlations of this nature were not found; however it is likely this is because the sample size of 11 did not lend enough statistical power. While there are a number of methodological explanations for these results, they suggest that the basic theoretical framework on which the treatment programs are based are flawed.

If we therefore consider HG and MS' performances during the cognitive tests rather than their reading profiles, we come to different conclusions about their underlying cognitive impairments. This reassessment still does not explain the unexpected results found during the

treatment programs. According to the cognitive tests, both participants demonstrated impaired visual attention span without an impairment in phonological awareness. We would therefore expect both participants to show a greater improvement during the visual treatment. As discussed in Chapter 2, the phonological tests may not have been a reliable measure of phonological awareness. If this was the case, both participants may have had an undetected impairment in phonological awareness (note that this is supported by MS' reading profile: he showed borderline deficiency during nonword reading and a severe deficiency during irregular word reading). This would explain the results: as both participants had a degree of both impairments, both treatment styles showed similar levels of improvement.

A number of additional assumptions about the best methods of treating the impairments were made during the construction of the treatment programs. Firstly, it was assumed that the visual treatment's use of clusters, or commonly occurring 'chunks' of words, would specifically target the visual attention span deficit. However, the treatment may have had a broader effect than intended. The clusters were meant to enable the participants to attend to more visual units in a word at a time. However, they could also have been used as cues to facilitate a phonological strategy of reading. Rather than associate the clusters with their visual form, participants may have been associating them with their comprising GPCs. Alternatively, this use of clusters may have emphasized the GPCs of a word not included within the target cluster. For example, one of the training words for the cluster "fore" was "before". Targeting "fore" may have emphasized the GPC "be" that attaches to the cluster to form the whole word. Therefore, the program may have actually been improving reading performance through alleviating the phonological impairment.

Secondly, it was assumed that GPC training would effectively target the phonological awareness deficit. The treatment trained participants on families of words containing the same GPCs. This approach was selected as it had been shown to have specifically improved

reading performance of participants demonstrating developmental phonological dyslexia (Broom & Doctor, 1995a; Rowse & Wilshire, 2007). However other approaches may have been more suitable for specifically targeting phonological awareness. A range of studies have demonstrated that treatment studies that target the participants' ability to identify and/or manipulate sublexical units in words, but do not involve reading and writing, have been effective in improving both reading ability and phonological awareness (for example Bradley & Bryant, 1985; Joseph, 2000; O'Shaughnessy and Swanson, 2000) .

As discussed in Chapter 4, the unexpected results during the treatment programs may also be due to the measures used to assess improvement. The assessment tests consisted of words that were unrelated to the trained items. Generalization effects may have been stronger if the assessment tests also consisted of untrained words that contained the trained GPCs and clusters.

The study produced a number of suggestions for future research. Firstly, the classification of phonological and surface developmental dyslexia may not align with the proposed underlying cognitive impairments of phonological awareness and visual attention span. This suggests that the use of reading profiles to diagnose the subtypes of reading disorders is not effective when considering programs targeting the cognitive impairments. Future studies should use performance on phonological awareness and visual attention span to classify their 'pure' participants. Further comparisons of reading profiles and performance during the cognitive tests are also necessary before any definitive conclusion on the relationship between reading profiles and cognitive impairments can be drawn. Research could focus on the serial position curves of performance during the partial report task for participants with the 'pure' subtypes. As discussed in Chapter 2, unusual functions are expected if a participant has a visual attention span impairment.

Secondly, future studies should investigate how to effectively treat the proposed impairments. Rather than compare two different styles of treatment as in the present study, tasks treating the same impairment could be directly compared. For example, a range of treatments explicitly targeting phonological awareness, such as phonemic segmentation, phonemic blending and rhyming, could be compared to GPC rule-based training to see which is most effective at treating the phonological awareness impairment, and whether one style specifically targets the phonological over the visual impairment. Treatments using whole word and cluster based techniques to target the visual impairment could also be compared.

Thirdly, future studies should consider the measures used to assess improvement. The assessment tests should measure the level of generalization of the treatment to untrained words containing trained GPCs and clusters, as well as words unrelated to the training. Furthermore, phonological awareness tasks could explicitly assess whether phonology was improving, and, if so, whether this improvement is specific to the phonological treatment.

Finally, it is possible that tailoring treatment programs to an individual's specific impairment is too difficult to be practical. The impairments may not be 'pure' enough in enough individuals, and the treatments may never specifically target their intended impairment. If this is the case, a "one size fits all" treatment would be effective, one that includes both phonological and visual elements.

In conclusion, the current study developed treatment programs based on the visual attention span theory of developmental reading disorders. This theory supposes that reading disorders in children are the cause of two underlying cognitive impairments: one of phonological awareness, and one of visual attention span. Visual attention span refers to how many letters a person can simultaneously attend to. When this is impaired, their attentional window is smaller, so they cannot attend to entire word forms. Participants' performance on

word accuracy can identify these impairments: poorer accuracy on irregular words compared to nonwords indicates a primary phonological impairment, and poorer accuracy on nonwords compared to irregular words indicates a primary visual attention span impairment. The current study's treatment programs involved two participants; each participant showed one of these profiles.

The phonological treatment was based on previously conducted treatment programs that had been shown to specifically improve phonological dyslexic's reading performances. This program involved familiarizing participants with a range of GPCs. The visual attention treatment was designed to require the participant to attend to larger portions of words, by both familiarizing them with large 'visual clusters'; letter combinations that regularly occur in words, and by using a degraded images task that required the participant to attend to the entire word form in order to process it.

Logistic regressions indicated that while the programs did improve reading of untrained words, thereby indicating that the increase in performance generalized to words not involved in the training program, neither program was more effective than the other for either participant. This result was unexpected, as it was hypothesized that the phonological program would prove more effective for the participant exhibiting a phonological deficit, and the visual program would prove more effective for the participant exhibiting a visual deficit. These results could indicate that both styles of treatment could be used to treat children exhibiting either profile of reading disorders, or may be an indication of incorrect assumptions about the cognitive profiles of participants, or the treatment.

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Appendix A: Consent Forms for Parents/Guardians

Consent to Participate in Research: Parents Form

Title of the project: **Treatment of developmental dyslexia using a visual attention span-based model**

I have been given a full explanation of this project and have had an opportunity to ask questions and have had them answered to my satisfaction. I understand that my child will be given a number of tasks to examine his or her reading and other related cognitive skills. Following this, my child may be chosen to take part in some further sessions designed to improve their reading skills, which we may also take part in if we so wish.

I understand that the data obtained may appear in graduate student reports, poster presentations, conference presentations and peer-reviewed publications, but that in all cases, my child will be referred to only by his or her reversed initials. The raw data will be kept by Dr. Carolyn Wilshire in a secure place. Summaries of the data will be kept by Ben Jones and Dr Wilshire and may be shared with other competent professionals.

I understand that I may withdraw my child (or any information we have provided) at any time up until the completion of the research without having to give reasons and without penalty of any sort.

I would/would not like to receive a summary of the results of this research when it is complete (please circle as necessary).

I agree that _____, who is under my guardianship, may take part in this research.

Signed: _____

Name: _____

Date: _____

If you would like us to share any information we obtain about your child with his or her classroom teacher, please tick here: ☐

(if you say yes, your child will also be asked if they agree to this)

READING PROJECT

You are invited to take part in Ben's special project

Ben is doing a special project to look at children's reading, and finding ways to help them learn to read better. If you want to help him with this project, he will do some reading and spelling activities with you. You can stop whenever you want to. These activities will be taped, then Ben will write down what you have said, and how well you have done in the activities. Ben will write a report about what you and other kids have told him. Nobody but Ben and his helper, Dr. Carolyn Wilshire, will be told your name.

Tick the boxes if these are true:

I know all about the project	☐
I know I can leave at any time	☐
I know what I say will be taped	☐

Yes, I'd like to take part ☐ No, I don't want to take part ☐

Name: _____

Appendix C: Burt Word Reading Test (Gilmore et al., 1981) items

to	is	up	for	big
he	at	one	my	sun
went	girl	boys	day	some
his	that	of	an	wet
love	water	no	just	pot
or	now	things	told	sad
carry	village	quickly	nurse	beware
return	scramble	twisted	journey	luncheon
known	shelves	explorer	tongue	projecting
terror	serious	belief	events	emergency
refrigerator	steadiness	obtain	overwhelmed	universal
nourishment	encyclopaedia	commenced	circumstances	fringe
formulate	motionless	trudging	theory	destiny
scarcely	exhausted	labourers	urge	atmosphere
apprehend	binocular	domineer	melodrama	economy
ultimate	reputation	humanity	excessively	philosopher
autobiography	contemptuous	terminology	mercenary	glycerine
unique	microscopical	perpetual	efficiency	influential
perambulating	renown	physician	champagne	exorbitant
hypocritical	atrocious	constitutionally	contagion	palpable
melancholy	eccentricity	fatigue	phlegmatic	fallacious
alienate	poignancy	phthisis	ingratiating	subtlety

Appendix D: Rhyme Detection Task (Muter et al., 1998) items

Target Word	Response Options (Correct response in brackets)		
Cat	Fish	Gun	(Hat)
Ball	(Wall)	Bell	Bag
Chip	Cup	(Ship)	Cheese
Boat	Foot	Bike	(Coat)
Key	Cow	(Tree)	Door
Chair	Car	Table	(Bear)
House	(Mouse)	Horse	Window
Head	Hand	(Bed)	Eye
Sock	Clown	(Clock)	Shoe
Train	(Rain)	Tractor	Spoon
Egg	Bag	Spoon	(Leg)
Car	(Star)	Bike	Cake

Note: First three items are practice trials

Appendix E: Phoneme Identification Task (Muter et al., 1998) items

Target Word	Word Segment	Correct Response
watch	wa-	-tch
cat	ca-	-t
horse	hor-	-se
fish	fi-	-sh
knife	kni-	-fe
ship	shi-	-p
bone	bo-	-ne
card	car-	-d
gate	ga-	-te
dog	do-	-g

Note: First two items are practice trials

Appendix F: Phoneme Deletion Task (Hammil et al., 2001) items

Target Word	Phoneme to be deleted	Correct Response
jam	/j/	am
shout	/sh/	out
dear	/d/	ear
ran	/r/	an
hold	/h/	old
take	/t/	ache
make	/k/	may
trade	/d/	tray
soap	/p/	so
house	/s/	how
shown	/n/	show
pine	/n/	pie
cart	/t/	car
spoon	/p/	soon
smell	/m/	sell
sting	/t/	sing
frame	/fr/	aim
blame	/b/	lame
raft	/f/	rat
splint	/n/	split

Appendix G: Coltheart and Leahy's (1996) wordlists (in randomized, presentation order)

mail	brinth	peril
cloud	tomb	drop
nuggle	soul	routine
frood	stendle	wolf
hattle	come	free
pite	curb	chance
boril	bleaner	flannel
mist	rint	cough
gop	wedding	good
lose	stench	pofe
delk	pump	check
borp	yacht	middle
work	long	pretty
need	grenty	ceiling
curve	seldent	brennet
break	trope	eye
bed	pint	bowl
norf	brandy	sure
drick	weasel	bouquet
choir	give	meringue
hest	luck	spatch
cord	marsh	blood
hand	tail	doash
ganten	shoe	crat
peng	baft	friend
navy	context	bick
brooch	take	nerve
chicken	aspy	tapple
farl	island	market
head	colonel	iron
plant	life	peef
framp	gauge	

Note: First five items are practice trials

Appendix H: Assessment Test Items

Test 1	Test 2	Test 3	Test 4
check	soul	stome	call
flannel	norf	display	acid
drop	pofe	debt	trang
grenty	mist	vock	cane
boril	yacht	mayor	engine
need	give	bomb	blares
chicken	free	reason	shove
pite	seldent	clinic	bine
tapple	meringue	trool	bruise
life	gurve	tribble	troat
good	choir	clue	maunch
break	market	jart	chike
wedding	peril	reetle	virth
spatch	navy	much	wool
island	gop	gone	prevent
context	brinth	dough	adopt
stench	framp	live	phurp
bowl	marsh	wait	please
cough	luck	sat	nurse
shoe	tail	greal	part
routine	trope	sister	ocean
peef	bouquet	text	hook
farl	colonel	feet	wist
doash	iron	sixteen	reep
weasel	middle	bield	prite
aspy	eye	moof	hain
pint	nerve	none	geyser
gauge	brooch	swull	cloam
bick	blood	rich	limb
hand	delk	liquid	scarf
sure	pump	boulder	war
friend	baft	foreign	once
lose	come	slont	sunten
take	drick	possum	side
bed	wolf	plug	high
pretty	curb	least	diesel
work	ceiling	soil	scarrow
head	bleaner	quist	despair
rint	brandy	name	minute
plant	tomb	prane	music
hest	cord	clemty	land

brennet	borp	know	lack
ganten	chance	circuit	snay
long	peng	north	villain
crat	stendle	buke	nine

Appendix I: GPC Selection Test Items

Item	Targetted GPC(s)	Item	Targetted GPC(s)	Item	Targetted GPC(s)
scream	ea	mow	ow	stripe	i-e
jingle	le/ng	jute	u-e	squash	qu
pier	ie	spray	ay	barrow	ow
wail	ai	groom	oo	quaint	ai/qu
fuse	u-e	foal	oa	phase	ph/a-e
cheat	ea/ch	deed	ee	spook	oo
fray	ay	shriek	ie	photo	ph
beetle	ee/le	vine	i-e	buckle	ck/le
leech	ch/ee	yeast	ea	croak	oa
raisin	ai	spade	a-e	crow	ow
sway	ay	poke	o-e	mumble	le
vulture	u-e	grape	a-e	haunt	au
boast	oa	frock	ck	fraud	au
rack	ck	stung	ng	spoon	oo
bellow	ow	aphid	ph	jeep	ee
lather	th	squeal	ea/qu	relay	ay
stole	o-e	munch	ch	cure	u-e
yield	ie	thatch	ch/th	flake	a-e
brood	oo	crane	a-e	haul	au
fable	le	foam	oa	keel	ee
quote	o-e/qu	siege	ie	duke	u-e
droop	oo	cope	o-e	theft	th
phantom	ph	cling	ng	hurray	ay
stain	ai	sauce	au	choke	ch/o-e
snack	ck	slime	i-e	preach	ea/ch
grief	ie	faith	ai/th	oath	oa/th
launch	au/ch	hanger	ng	linger	ng
willow	ow	slate	a-e	revise	i-e
missile	i-e	orphan	ph	bracket	ck

Appendix J: Training words used for the phonological awareness treatment program

Participant: HG						
Session	1	2	3	10	11	12
Target						
GPC	ie	ng	ow	ai	i-e	u-e
	priest	hanger	sorrow	frail	dine	cute
	grief	jingle	sparrow	maiden	limes	amuse
	niece	cling	harrowed	braid	hike	prune
	fiend	belong	swallow	hair	glide	mute
	thief	stung	stow	snail	stile	computer
	diesel	linger	marrow	raid	grime	fume
	siege	engine	burrow	bait	strife	flute
	shriek	angle	know	hail	crime	duke
	yield	bring	shadow	brain	smile	cure
	pier	finger	grow	stain	bride	fuse
Target						
GPC	ck	le	ay	a-e	ch	qu
	cricket	fable	crayfish	tame	charm	squawk
	sock	beetle	stray	rave	chatter	quail
	locker	mumble	haystack	crate	chill	squeeze
	stack	buckle	tray	shame	hunch	squeak
	packet	amulet	crayon	shave	chant	quit
	tickle	battle	delay	scrape	hutch	quarrel
	flock	castle	foray	mane	achieve	squirt
	pickle	clever	layer	spade	branch	quilt
	blacken	electric	holiday	flake	change	squash
	knock	table	away	grape	cheese	quote
Participant: MS						
Session	4	5	6	7	8	9
Target						
GPC	ie	ck	au	ai	a-e	u-e
	priest	cricket	naughty	frail	tame	cute
	grief	sock	daunt	maiden	rave	amuse
	niece	locker	gaunt	braid	crate	prune
	fiend	stack	laundry	hair	shame	mute
	thief	packet	taunt	snail	shave	computer
	diesel	tickle	haunt	raid	scrape	fume
	siege	flock	fraud	bait	mane	flute
	shriek	pickle	sauce	hail	spade	duke
	yield	blacken	haul	stain	flake	cure
	pier	knock	launch	brain	grape	fuse
Target						
GPC	a-e	le	ng	ay	ph	qu

tame	fable	hanger	crayfish	pharmacy	squawk
rave	beetle	jingle	stray	nephew	quail
crate	mumble	cling	haystack	physics	squeeze
shame	buckle	belong	tray	saxophone	squeak
shave	amulet	stung	crayon	pheasant	quit
scrape	battle	linger	delay	dolphin	quarrel
mane	castle	engine	foray	autograph	squirt
spade	clever	angle	layer	phantom	quilt
flake	electric	bring	holiday	orphan	squash
grape	table	finger	away	photo	quote

Appendix K: Training words used for the visual attention span treatment program

Participant: HG						
Session	4	5	6	7	8	9
Target Cluster	ation	audi	tract	tude	ence	aught
	imagination	audience	tractor	multitude	confidence	caught
	exploration	auditorium	subtract	student	difference	distraught
	communication	applauding	contract	altitude	evidence	taught
	combination	audition	extract	attitude	experience	daughter
	acceleration	audible	attract	gratitude	audience	naughty
Target Cluster	inter	fore	pect	ough	ment	cess
	winter	before	aspect	although	moment	excess
	painter	forecast	respect	enough	instrument	necessary
	interrupt	forehead	suspect	through	compliment	princess
	interior	foreign	inspect	rough	equipment	process
	interest	forest	spectre	dough	excitement	recess
Participant: MS						
Session	1	2	3	10	11	12
Target Cluster	spect	auto	audi	tract	ough	inter
	aspect	automobile	audience	tractor	although	winter
	respect	automatic	auditorium	subtract	enough	painter
	suspect	autograph	applauding	contract	through	interrupt
	inspect	autobiography	audition	extract	rough	interior
	spectre	autonomy	audible	attract	dough	interest
Target Cluster	ment	ation	aught	tude	cess	ence
	moment	imagination	caught	multitude	excess	confidence
	instrument	exploration	distraught	student	necessary	difference
	compliment	communication	taught	altitude	princess	evidence
	equipment	combination	daughter	attitude	process	experience
	excitement	acceleration	naughty	gratitude	recess	audience