University of Alberta

Mechanisms of Recovery in Acquired Alexia

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Speech-Language Pathology

Department of Speech Pathology and Audiology

Fall 2012
Edmonton, Alberta

Abstract

Reading impairment, known as alexia, frequently co-occurs with damage to the language areas of the brain in aphasia. Text-based reading treatments have been shown to improve reading fluency, but the mechanisms behind such improvement remain unclear. This study investigates the efficacy of Multiple Oral Rereading and Oral Reading for Language in Aphasia as a combined treatment for an individual with surface alexia, and examines whether eye-movements change as a result of treatment.

Following treatment, reading rate and accuracy significantly improved on practiced passages, and improved reading rate generalized to novel passages. Generalization was also observed on a measure of spoken/written language. Eye-movements (number of fixations, regressions, and fixation durations) differed from pre-treatment to post-treatment and follow-up, although in the opposite direction of what was expected. Initial fixation position shifted towards that of more proficient readers after the completion of treatment, suggesting treatment resulted in a change in reading strategy.

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Kim for her continuous support and guidance throughout this process. She was always willing to troubleshoot any issues that I encountered, and was extremely patient when it came down to crunch time. Thank you Dr. Kim for putting up with my last minute questions, all the thesis drafts sent your way at 2 am, and for inspiring me to try my hand at research. I truly appreciate the wisdom you were always willing to share, your belief that I would succeed, and am grateful that I was able to work with you.

I would also like to thank my thesis committee for the time they spent reviewing my thesis, and for offering their comments and suggestions. Your insights and constant support were greatly appreciated.

In addition, I must thank J.M. for his willingness to participate in this study, and the good humour he brought to each session. It was a pleasure to work and learn alongside you.

Last but not least, I would like to thank my wonderful family for always cheering me on and believing in me, my friends for reminding me of life outside of work, and my husband for his constant support, patience and convenient computer skills. I am one lucky girl to have such an amazing support system.

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Introduction and Literature Review

The ability to read is an integral part of daily life, allowing us to function effectively in a society where the demands for processing written communication are increasing. The efficiency with which we can comprehend, analyze, and respond to a task is of critical importance in both work and social settings, and in many situations, is anchored by our ability to read. Our reading aptitude is tested in countless daily situations, and is a seemingly natural skill that many of us take for granted. However, for those with impaired reading as a result of neurological damage, participation in a large number of daily tasks may become limited or increasingly difficult, and quality of life may decrease. Such restricted abilities make it extremely challenging to function effectively, prompting us to investigate how we might rehabilitate reading impairments, what the underlying causes of such changes are, and how daily living can be improved for these people.

Prevalence of Aphasia

The language dominant hemisphere (left hemisphere for a majority of people) of the brain is responsible for many acts of language, including comprehension, word production, and the ability to read (Miller, 2010). Aphasia is a communication disorder that results from damage to regions of the language dominant hemisphere, and may affect the production and comprehension of language in both spoken and written modalities. Aphasia can impact both personal and vocational domains, presenting a barrier to communication that is difficult to overcome.

Stroke is the most common cause of aphasia, and is reported to directly impact 50,000 individuals each year in Canada (Heart and Stroke Foundation of Canada, 2011). Roughly 35% of stroke victims present with aphasia, with greatly increasing incidence in those over 85 years of age (Dickey, Choy & Thompson, 2010). The Aphasia Institute (2012) reports similar statistics, stating that over 100,000 people in Canada are currently living with aphasia, although many more are impacted by both its direct and indirect effects.

Despite the high occurrence of aphasia in the stroke population, awareness of this condition in the general public is incredibly low. This is a significant concern, particularly when considering that with the aging of the baby boomer generation, the population over age 65 is set to double by the year 2030 (Knickman & Snell, 2002). Given that age is a risk factor for stroke and aphasia (Heart and Stroke Foundation, 2011) the number of people impacted by these conditions each year will continue to grow.

In addition to the challenges presented by the aging population, there has been rapid advancement of technology and electronic communication in our society (internet, email, social media, text messaging, etc.). We are coming to rely on these forms of communication, effectively based around the ability to read, to maintain relationships with family and friends, and to continue to learn about our community, culture and the world we live in. The fact that more people are being affected by aphasia in a society where the ability to read is becoming more essential requires that we understand the nature of reading impairments and develop ways to rehabilitate this condition.

What is Acquired Alexia?

Many persons with aphasia present with some degree of alexia, or reading impairment, due to the injured language centers of the brain (Beeson & Insalaco, 1998). Prevalence reports have varied widely, with some stating that alexia always occurs with aphasia (Webb & Love, 1983), whereas others indicate that roughly 80% of those with aphasia also have some form of reading impairment (Wilson, 2008). Acquired alexia may present in various forms following brain injury, and is commonly subdivided into two categories: peripheral alexia (historically called alexia without agraphia), and central alexia (alexia with agraphia; Leff & Behrmann, 2008). The former involves an isolated reading disorder, with many related abilities such as writing and speech production remaining relatively unimpaired. The difficulty with letter and word recognition is mainly limited to the visual modality, as the ability to spell words aloud and identify words spelled aloud to them, remains intact. On the other hand, alexia subtypes under the central category are characterized by difficulties in processing the semantic, lexical or phonological aspects of language. The deficit in this case does not involve the visual pathway utilized for reading, but is localized in areas of general language processing (Leff & Behrmann, 2008).

Reading requires a mastery of a number of complex, implicit rules that are specific to the language we speak. When reading single words, a normal reader has access to two routes in order to make sense of the visual information they encounter. The nonlexical or indirect route (as represented by letter 'A' in Figure 1) converts the written word to spoken word via grapheme-to-phoneme (letter-to-sound) correspondence rules. The lexical or direct route as shown by letter 'B', allows for the written word to be matched to its corresponding word in the visual-word store. Meaning is attached based on activation of the semantic processor, while the phonological processor acts to produce a reading of the word aloud (Cherney, 2004). In the process of normal reading, both pathways are accessible to the reader. That being said, the lexical route (B) is most often used to make sense of the written word, which increases efficiency, as long as the word is present in the visual word store. For proficient readers, the indirect route (A) tends only to be used when an unfamiliar word is presented (Cherney, 2004).

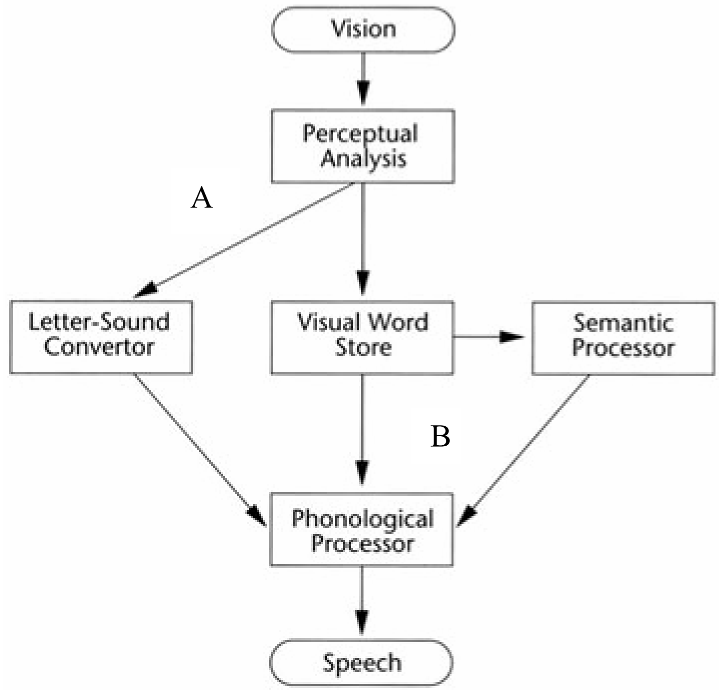

Figure 1: A model of the normal reading process (adapted from Cherney, 2004)

A number of central alexia profiles can be distinguished, reflecting damage to any of the component processes along the reading pathways delineated in Figure 1. In surface alexia, damage is typically found in brain regions that support reading via the direct route 'B', leaving only the nonlexical route 'A' intact and available to process written language (Cherney, 2004). Thus, non-words and regularly spelled words may be produced correctly (due to decoding in the letter-sound converter of route ‘A’), with difficulties encountered in reading irregularly spelled words, as access to the visual word store in path ‘B’ is effectively blocked (Cherney, 2004). Left temporal or temporo-parietal lesions have been frequently associated with surface alexia, although diffuse cortical atrophy has also been identified as a cause (Friedman, 1988).

Phonological alexia is encountered when the grapheme-to-phoneme rules of the language are no longer available to the reader, allowing them access only to the direct route in the reading process (‘B’ in Figure 1). As the letter-sound converter present in typical readers is not functioning, those with phonological alexia are unable to read by sounding out the letters of the word (Cherney, 2004). As such, they tend to read non-words as real words that contain many of the same letters (Leff & Behrmann, 2008). Phonological alexia typically results from damage to perisylvian cortical regions (Rapcsak et al., 2009).

Deep alexia presents with many of the same characteristics as phonological alexia, though in addition, a disturbance in the connection between the visual word store and the semantic processor as a component of the lexical reading pathway (‘B’ in Figure 1) is present. In this way, the letter-to-sound converter in route ‘A’ is unavailable, as is the visual word store of route ‘B’. The reader must rely on visual perception of the word and any semantic information accessible to make sense of the written word (Cherney, 2004). The reading of non-words and function words is inhibited, and semantic errors such as producing an antonym or synonym for the target word are frequent (Cherney, 2004). Lesions associated with deep alexia tend to involve a large area of the left fronto-temporo-parietal region, often including much of the left hemisphere (Lambon Ralph & Graham, 2000).

Although distinct alexia subtypes have been identified with common patterns of impairment and lesion location, a direct link between type of aphasia and alexia syndrome has not been documented (Beeson & Insalaco, 1998). Some studies have reported that certain alexias tend to accompany specific types of aphasia (i.e. surface alexia with fluent aphasia, Friedman & Hadley, 1992). However, more often than not, alexia when linked with aphasia involves numerous levels if impairment, producing a mixed type of alexia (Beeson & Insalaco, 1998).

Alexia Rehabilitation

The rehabilitation of acquired alexia has typically focused on single words, while often failing to address the reading of longer strings of text (Beeson & Insalaco, 1998; Cherney, 2004). Investigators have designed single-word reading treatments which involve matching different levels of information (picture-word, word-word, and letter matching), sentence completion tasks, or answering yes/ no questions. Variables such as the similarity between the target word and distractors, frequency, grammatical class, etc. are often manipulated to create various levels of difficulty (Cherney, 2004). Despite success in improving reading ability for single words, most of these studies have failed to report any generalization to longer strings of text (Cherney, 2004). This may limit the application of these studies to contexts of real life, as the reading of individually presented words is relatively rare.

The skills involved in reading single words when compared to reading longer strings of text may at first appear to be relatively similar. Both may incorporate the recognition of letters and/or words and require appropriate motor planning and the coordination of the vocal folds, air stream and articulators to eventually read the word aloud. However, text-based reading presents an additional challenge, as it entails repetition of this complex process to identify each component word, and making sense of syntax in order to derive meaning. This increased complexity presents little difficulty for a proficient reader; however, for someone with alexia, the reading of text may stress their system, requiring an alternative approach to rehabilitation.

On the other hand, some investigators have suggested that text may actually facilitate reading in individuals with acquired alexia (Silverberg, Vigliocco, Insalaco & Garrett, 1998; Mitchum, Haendiges & Berndt 2005). Contextual cues from reading words in text may provide an added benefit for individuals with acquired alexia, as the surrounding words and overall meaning of the sentence may cue a reader in recognizing and producing more difficult words. This finding has served as the rationale for text-based reading therapies. Several investigators have also argued that text based reading therapy provides a more practical skill for activities of daily living, and have successfully utilized these therapies to rehabilitate acquired alexia (see Cherney, 2004 for a review).

Multiple Oral Rereading. Multiple oral rereading (MOR; Moyer, 1982) is a text-based reading treatment that was developed to promote fluency when reading connected text. It involves repeated reading of selected texts, and has been shown to be effective in improving reading rate and accuracy of practiced and novel passages. The goal of such therapy is to provide practice at integrating all levels of reading, from letter features to syntactic units of sentences (Moyer, 1982). In this treatment approach, a text passage is chosen at a level that presents little challenge for the reader, and is read at a comfortable pace so as to ensure accuracy. A fluency goal (typically a reading rate around 100 wpm) is set, and the passage is then repeatedly read aloud on a daily basis until the goal is met. Expected treatment outcomes include faster reading rate and fewer errors, and the number of repetitions necessary to reach the fluency goal tends to decrease as MOR treatment continues. Although a reading rate of 100 wpm is noted to be well below what would be considered a normal reading speed (150-200 wpm), it is important to consider that reading even at this rate allows individuals to regain access to a number of functional daily activities that had been lost (e.g., reading the newspaper, mail, instructions) (Beeson, 1998).

A number of investigators have demonstrated the beneficial effects of Multiple Oral Rereading in helping individuals with acquired alexia increase their reading fluency. Beeson and Insalaco (1998) demonstrated the utility of MOR treatment in two individuals with mixed alexia profiles, in which both subjects improved their reading rate over the course of therapy. These individuals also significantly increased their *Western Aphasia Battery* (WAB; Kertesz, 1982) aphasia quotients, (5 point increase is considered to be clinically significant; Katz & Wertz, 1997), demonstrating generalization of reading treatment to the spoken language domain. Cherney (2004) also implemented MOR therapy for the treatment of an individual with phonological alexia who lived geographically far from the clinic. Although only a handful of therapy sessions with the clinician had been carried out, reading rate improved from 52 to 156 words/minute on practiced selections, and comprehension also improved. Others have presented supporting evidence for the fact that MOR treatment is effective in rehabilitating connected text reading, demonstrating significant improvement in letter-by-letter readers (pure alexics) (Beeson, Magloire & Robey, 2005; Moody, 1988; Beeson, 1998; Tuomainen & Laine, 1991).

Through the results of previous studies discussed above, MOR has provided benefit for improving the reading of those with alexia in a variety of ways. The applicability of MOR has been demonstrated for situations in which direct clinician-patient contact is not possible every week (Cherney, 2004), allowing for treatment to be provided for those in remote areas. It is also beneficial for those who are particularly driven to improve, as the amount of reading practice done between sessions will impact the performance on subsequent readings of the same passage. In addition, the strategies learned and practiced with this technique may be used even after treatment has been terminated, as direct clinician observation is not strictly required. This empowers those with alexia to play a direct role in their treatment and to guide their improvement.

Oral Reading for Language in Aphasia. Oral reading for language in aphasia (ORLA; Cherney, Merbitz & Grip, 1986) is another text-based reading treatment which focuses on repeated reading of a selected sentence or paragraph, moving along a continuum from supported reading to independence. Initially, the person with aphasia listens to the text as it is read by the clinician. They then progress towards choral reading with the clinician, pointing to and reading words within the passage, and finally to independent reading of the text. This treatment technique was initially designed to improve the reading comprehension of those with aphasia through repeated activation of the reading pathways (Cherney et al., 1986; Cherney, 2004). However, improvements have been observed across a variety of language domains, including verbal and written expression as well as auditory comprehension (Cherney et al., 1986; Cherney, 2004; Cherney, 2010a, 2010b).

A number of studies have reported positive results with regards to the effectiveness of ORLA. Cherney (2004) demonstrated that improvements in oral reading of trained sentences can be attained, even multiple years post-stroke. Cherney's subject made gains not only in reading comprehension, but also in auditory comprehension and oral expression, resulting in a nearly 5 point increase on the Aphasia Quotient (AQ) on the *WAB* (Kertesz, 1982). Other studies have shown that specific improvement may be mediated by the level of aphasia severity. Differential improvements may be observed in different language skills depending on the aphasia severity of the individual (Cherney, Babbitt, Oldani & Semik, 2005; Cherney, 2010a). Individuals with severe aphasia demonstrated the greatest improvement in reading abilities, whereas those with mild-moderate aphasia saw the largest improvement in writing and discourse production. These results point to the utility of ORLA as a method of reading rehabilitation, as it produces improvements across a wide variety of language areas. In addition, the steps involved are easily administered by a clinician, and are quickly learned by the patients due to the relative simplicity of the task (Cherney, 2004).

Mechanisms of Improvement

Single word reading treatments have been created based on cognitive models of reading. The mechanisms of improvement following single-word reading treatments appear to be the strengthening of damaged cognitive processes, together with continued use of intact processes (Hillis, 1993). For instance, individuals with phonological alexia have been trained to re-learn grapheme-phoneme correspondence rules (Kiran, Thompson & Hashimoto, 2001; Kendall, McNeil & Small, 1998). It is presumed that treatment directed toward restoring impaired sub-lexical processing contributes to improvement in reading words using this route. Similarly, individuals with surface alexia have shown improved single-word reading following whole-word recognition training, through strengthening of existing orthographic knowledge (Friedman & Lott, 2000). In this way, access to the lexical representations of words are restored or created anew in order to facilitate single-word reading (Hillis, 1993). Although cognitive models can illustrate the mechanisms responsible for single-word reading improvements, the mechanisms responsible for the benefits observed due to text reading treatments have been up for debate. Researchers have focused on either top-down or bottom-up explanations of reading in order to explain the impact of treatment on text reading.

Top-down processing. A number of investigators hypothesize that top-down processes facilitating the recognition of words in sentence form are responsible for improvement in text reading (Tuomainen & Laine, 1991; Beeson & Insalaco, 1998; Silverberg et al., 1998). Silverberg et al. (1998) proposed that reading of connected text allowed for support from context effects, stating that the activation of the sentence production system and syntactic constraints of text are responsible for improved recognition of certain word classes. Beeson & Insalaco (1998) furthered this argument by stating that their patients' improvement in reading closed-class words (i.e., functors) resulted from strengthened lexical access provided by repeated text reading. Similarly, Tuomainen & Laine (1991) argued that text-based treatment improved recognition of words in sentence form, as one of their patients did not increase his reading rate of single words, even though improvements were seen for longer strings of text. Thus, they argued that the text-based treatment MOR is effective because the semantic and syntactic constraints of text speeds up the recognition of words.

Bottom-up processing. Lacey, Lott, Snider, Sperling & Friedman (2010) present data that promote a mixed top-down/ bottom-up processing account to explain improvements that they observed. In their study, participants with alexia read novel passages that contained an overlap of content and function words with training passages, investigating the hypothesis that improvement would only be seen on novel passages with large amounts of overlap with training passages. The reading rate for control passages (containing few words practiced in training passages) did not improve in any of their subjects, and generalization to truly novel passages was not observed. However, improvement in the reading of function words was attained. To investigate this further, Lacey et al. controlled for the amount and type of functors in untrained passages, and found that reading rate improved only for novel passages that had a significant amount of function word overlap with training passages. The lack of improvement for passages without such overlap provided evidence against a top-down processing theory. However, the authors eventually concede that a mixed approach is likely, as either top-down or bottom-up theories are too simplistic to explain the amount of generalization observed.

All in all, a clear picture has not emerged as to why text-based reading therapy produces the effects that have been reported. The majority of studies cite the involvement of ‘context effects’ to explain the improvement observed as a result of text-based reading therapy. However, the fact that alexia rehabilitation has been examined using oral reading accuracy as the only measure of change is a limitation. These measures may not provide the micro-level analyses necessary to examine processing during text reading before and after a therapy program is provided. Such analyses may be necessary to understand and even recognize the changes after reading rehabilitation. In addition, oral reading can be quite taxing for those with alexia, which may additionally impact their reading ability. Thus, further research using alternative fine-grained methods of detecting change in reading ability is warranted.

Eye Movements in Reading and Aphasia

Eye-tracking may provide insight into mechanisms of recovery from acquired alexia, as moment-to-moment cognitive processes of reading can be measured, without the requirement of a verbal response. With significant advances in our knowledge of how eye-movements of normal readers function while reading, this tool has the potential to provide useful information on reading processes of individuals with acquired alexia. The following (summarized from Rayner, 1998), provides an overview of how eye-movements of non-brain injured individuals function during reading.

Eye movements in reading are comprised of three main components: saccades, fixations, and regressions. Saccades are defined as rapid eye movements that move forward along a line of text from left to right (when reading English). No visual information is processed during saccades as they are too quick for an environment to be perceived. In typical reading, saccades tend to be around 7-9 letter spaces. Fixations are periods with relatively no eye movement in which the words are registered, and can last anywhere between 200-250ms. In reading, landing position of fixations is a function of word length (in letter spaces), and lexical characteristics of the word. The longer a word is, the better chance of it being fixated upon. Content words tend to be fixated roughly 85% of the time, with function words being fixated only 35% of the time. Finally, regressive saccades are eye movements that backtrack over previously read text from right to left. They typically occur if a saccade has overshot its target, or when comprehension of the text is not attained. In the former case, the regression may backtrack over only a few letters, whereas in the latter case, a longer regression of 10 or more letters is necessary.

Eye movements differ depending on the proficiency of the reader. For instance, relative to typical adult readers, children or those with developmental/acquired reading disorders tend to have a higher frequency of short saccades, along with a higher number of regressions, making reading less efficient overall (Rayner, 1998; Rayner, Chace, Slattery & Ashby, 2006). However, no significant differences have been found in the eye movements of 'younger' adults when compared with 'older' adults (Kemper, McDowd & Kramer, 2006). Rayner (1998) stresses that eye movements are rarely the causal factor in reading inefficiency, but that they reflect difficulties encoding and comprehending the text read. In using eye-tracking methods, not only can the speed of reading be measured and recorded, but so can the quality of eye movements and changes in movement patterns as efficiency improves.

It is plausible to assume that since reading processes differ in those with aphasia as compared to typical readers, so will the quality of their eye movements. Few studies have been conducted on the eye movements of individuals with aphasia or acquired alexia while reading. Klingelhofer & Conrad (1984) describe general patterns of eye-movements of individuals with various types of aphasia. They demonstrated that the saccadic movements of those with aphasia differed from typical subjects and also differed according to aphasia type. Individuals with Broca's aphasia tended to have better preserved saccadic structures, while those with Wernicke's aphasia showed great difficulty in reading the text, making smaller leaps over the line without reference to the 'normal saccadic pattern'. Number of fixations, regressions, and reading times varied widely for these two types of aphasic patients, while those with anomic aphasia had relatively preserved values that tended to be within or close to the range of normal.

These findings of deviant eye movements in aphasia are supported by Schattka, Radach & Huber (2010). Their study represents the only investigation to date of how eye-movements of individuals with varying profiles of acquired alexia differ according to properties of the words they are reading. They examined oral reading of single words in individuals with surface alexia and phonological/deep alexia. Eye-movements were recorded while these individuals read words varying in length and frequency, and were compared to those of typical readers. They found that the eye movement parameter most indicative of type of alexia was the distribution of fixations into each word (i.e., spatial parameter). Individuals with surface alexia tended to use a segment-by-segment strategy, initially fixating near the beginning of the word, and using short saccades to move from left to right. On the other hand, those with phonological/deep alexia fixated close to the middle of a word at the 'preferred viewing position', just as the typical readers did. In this way, they were able to perceive the word holistically. Contrary to expectations, temporal parameters such as total reading time, number of fixations, and fixation duration did not aid in differentiating between the two types of alexia. However, temporal parameters for all individuals with aphasia were significantly different from controls.

In the aforementioned studies, researchers have used eye movements as a way of examining the cognitive processes of individuals with aphasia during reading, and have also examined the differences in eye movements between aphasia and alexia subtypes. However, the question of whether the eye movements of those with aphasia reflect more normal patterns following reading therapy is yet to be answered. In an effort to fill the gap in the current research, this study investigates the eye movements of an individual with aphasia before and following reading treatment, in order to identify eye-movement correlates that accompany behavioural reading changes.

Research Questions

The purpose of the present study is to examine fine-grained word processing abilities through the use of eye-tracking techniques, in response to text based reading rehabilitation in an individual with acquired alexia. Using an exploratory single-subject case study design, two main questions of interest will be examined and discussed.

1. Will text-based reading treatment (combining MOR and ORLA techniques) result in improved reading fluency and comprehension?
   i. Will improvements in reading generalize to novel reading passages and other language domains?

Hypothesis. It is anticipated with combined MOR and ORLA treatment we will find improvements in reading and other language domains, comparable to results of previous studies (Beeson & Insalaco, 1998; Cherney, 2004, 2010a, 2010b). Dependent measures include: rate of text reading (words per minute), accuracy of text reading (deviations per 100 words, including full or part-word insertions or deletions, semantic and phonemic paraphasias, word order changes, etc.), and comprehension of the text read (responses to multiple choice questions). Both direct and generalization effects will be investigated, pertaining to the repeated reading of practice passages, and novel passages respectively. In addition, two standardized reading assessments [the *Gray Oral Reading Test-4* (GORT-4; Wiederholt & Bryant, 2001), *Reading Comprehension Battery for Aphasia-2* (RCBA-2; LaPointe & Horner, 1998)], and an overall language battery [*Western Aphasia Battery- Revised* (Kertesz, 2006)] will be administered as additional generalization measures.

2. Will text-based reading treatment result in changes to eye-movements while reading?

Hypothesis. It is proposed that eye movements will change as a result of treatment to be more similar to eye-movements of typical readers. The extent to which text-based reading treatment promotes this result will be measured through fixation duration, number of fixations, number of regressions, and spatial parameters of reading. It is predicted that once therapy has been completed, each of these measures will shift towards that of typical readers, decreasing the number and length of fixations, and requiring fewer regressions.

Method

Participant

At the time of the study, J.M. was a 42-year-old right-handed male, who suffered a left hemisphere stroke at 33 years of age. He had no history of learning disabilities or neurological disorder prior to his stroke, spoke English as his primary language, and had no co-existing motor impairments that impacted his speech (i.e., apraxia). He had 12 years of education, and worked as a store manager prior to his stroke. JM did not undergo any form of additional treatment while this study was in progress. He stated during the initial interview that reading tended to be quite labour-intensive for him, but was a skill that he was motivated to improve.

As seen in Figure 2, MRI scans revealed a perisylvian lesion extending posteriorly into parietal regions, including the supramarginal gyrus. It covers much of the superior temporal lobe, extending into the inferior frontal lobe, intraparietal sulcus, anterior temporal lobe, and insula. The angular gyrus, considered an extrasylvian structure, has also been impacted by the lesion.

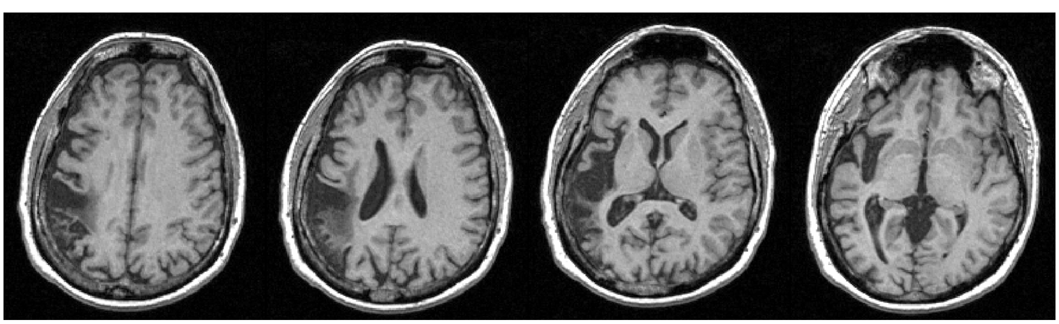

Figure 2: Representative axial slices illustrating J.M.'s lesion

Pre-Treatment Assessment

At the time of initial assessment, J.M. was nearly eight years post onset of stroke, avoiding the period of maximal recovery (Kwakkel, Kollen & Lindeman, 2004), which allowed us to attribute any gains made to the result of therapy and not to spontaneous recovery. Assessment of JM's spoken and written language was conducted over multiple sessions prior to treatment.

Spoken language. The Aphasia Quotient from the *Western Aphasia Battery- Revised* (WAB-R; Kertesz, 2006) was used as a measure of J.M.'s spoken language ability. He presented with an aphasia quotient of 83.2 (out of 100 possible points), and a profile of mild anomic aphasia, characterized by fluent speech, occasional word-finding difficulties, paraphasias (sound errors), and good auditory comprehension.

Single word reading. The *Arizona Battery for Reading and Spelling* (ABRS; Henry, Beeson, Stark & Rapcsak, 2007), a list of 40 regular and 40 exception words (balanced for frequency, length and imageability) as well as 20 pronounceable non-words, was used to examine single-word reading abilities. J.M. experienced the most difficulty in reading non-words and exception words, attaining only 60% correct for both word types. Reading of regular words was better preserved (88% correct), but not perfect.

Real word reading was characterized by effects of word frequency and spelling regularity. Although frequency effects are common across alexia subtypes (Beeson & Henry, 2008) spelling regularity effects are suggestive of a surface alexia profile (Cherney, 2004). J.M. demonstrated a regularity effect of

28%, illustrating the difference in reading accuracy for regular words vs. exception words. Although he also demonstrated a lexicality effect (his reading of words was 14% more accurate than his reading of nonwords), this was a small effect compared to the average lexicality effect size of 37% seen in individuals with phonological alexia (Rapcsak et al., 2009). Further, J.M. tended to make phonologically plausible errors in reading exception words ("prove" → /prov/), suggestive of a sublexical reading strategy. Thus, based on the size of the regularity effect, and when considering the phonologically plausible pronunciations for irregular words, the data suggests J.M.'s reading profile most closely resembled surface alexia.

Text reading. Reading of text was assessed using the RCBA-2 (LaPointe & Horner, 1998) and the GORT-4 (Wiederholt & Bryant, 2001). The RCBA-2 comprises 20 subtests, ranging from picture-word matching to answering multiple choice questions following paragraph reading. It investigates comprehension of single words, sentences and paragraphs, as well as functional reading passages. J.M. was highly accurate on this test, attaining 93 out of 100 total points, demonstrating good comprehension of the sentences and passages read.

The GORT-4 provides a measure of oral reading fluency, and contains 14 reading passages increasing in complexity and length. Two alternate forms of the GORT-4 are available, minimizing practice effects in reading. Comprehension questions are provided after each passage in order to determine how much of the story content was understood. J.M. read eight passages, and demonstrated decreasing accuracy and longer reading times as the difficulty of the passages increased. Reading of more difficult passages was characterized by a slow rate and multiple sound errors and word substitutions. Across the story subtests, he attained an average rate of 66.8 words per minute, with roughly 14 deviations per 100 words of text. However, despite slow reading rate and deviations from text, J.M. attained an average comprehension score of 80% on these passages (based on answering five multiple choice questions).

Eye-tracking. Eye tracking measures were also conducted before the onset of treatment, in order to examine J.M.'s eye movement patterns before any reading therapy had taken place. This provided us with quantitative measures to refer to for later data comparison. Eye movement data were gathered using the SR Research Eyelink 1000 with a remote/head free camera, which samples pupil location at a rate of 1000 Hz (i.e., temporal resolution = 2 ms) placed 60 cm from the participant. This eye tracker has a spatial resolution of less than 0.1 degree of visual angle. Eye movements were recorded only from the left eye, as is common for examining eye movements in individuals with left hemisphere lesions (Johnson & Rayner, 2007). The participant's head was stabilized using a chin/head rest during data collection

The eye tracking stimuli were comprised of a sub-set of sentences taken from another study (Kim & Bolger, 2012) investigating the effects of sentence context on eye movements of aphasic subjects. Stimuli used to assess JM's reading pre- and post-treatment included 40 active ("filler") sentences ranging between 7 and 12 words in length (See Appendix C for list of sentences used). These sentences were randomly distributed among 80 experimental sentences.

Ten practice sentences were given to familiarize the subject with the task at hand before the experimental and filler sentences were presented. Sentences were presented in sets of 30, with a calibration sequence preceding each set. For each trial, a fixation box appeared at the left-most part of the screen. J.M. was required to look at the fixation box to initiate the trial, and to press a button when finished reading each sentence. In addition to the silent reading of each sentence, J.M. answered a number of yes/no questions throughout the experiment in order to keep him engaged in the task. Analyses were carried out on the 40 filler sentences only.

Treatment

We chose to use a combined therapy approach as each component brought a different focus to the reading practice. With MOR, we incorporated the repeated reading of a practiced passage along with the vital component of homework to be completed between therapy sessions. On the other hand, ORLA techniques were used to guide and structure each of the treatment sessions.

Stimuli. Training passages were selected from the Scientific Research Associates (SRA; 1978) series, and chosen at a Flesch-Kincaid reading grade level of 4.5, as pre-determined from GORT-4 testing results (See Appendix E for sample training passage). This was the level at which J.M. read at least 65 words per minute with fewer than 15 deviations per 100 words, minimizing his frustration due to slow reading/inaccuracy, yet allowing for the possibility of improvement. J.M. was permitted to select each training passage, in order to allow for some personalization of the reading selection. Selected passages were divided into sections of 260 words on average, ranging between 220-313 words in length. Each passage selected had an average Flesch-Kincaid difficulty of 4.6, ranging between 2.4 and 5.9. New training passages were presented every week for J.M. to practice.

Generalization passages selected by the clinician were used each week to examine J.M.'s reading of novel texts. Each passage was roughly 115 words in length, ranging between 95 and 136, with an average Flesch-Kincaid difficulty of 4.6 (range of 4.2-5.0) to ensure an appropriate level of difficulty for probing (See Appendix F for sample generalization passage).

Procedures. Clinical sessions lasted roughly 1 hour in total, and involved the reading of a number of text passages to qualitatively and quantitatively assess J.M.'s reading ability. A generalization passage was read at the beginning of each session, and presented only once throughout the course of treatment. Reading of this passage was timed, and oral reading errors were noted, allowing the clinician to assess both reading fluency and comprehension. Combined, these passages were used to determine whether J.M.'s reading of novel texts was improving as a result of the therapy provided. J.M. was instructed to read each passage out loud, and to answer between 5 and 7 multiple choice comprehension questions afterwards.

Following this, the training passage to be read over the following week was given to J.M., and practiced within the session. The ORLA steps for providing reading rehabilitation were used as guidelines for the treatment sessions, allowing for repeated exposure and proper reading models to be given (see Appendix D for ORLA guidelines). J.M. completed his solo reading of the passage after each of the ORLA steps had been completed. In this way, J.M. had read the passage with the clinician multiple times before rate and accuracy measures were taken. Despite having previously read the passage both silently and aloud with the clinician, this solo reading was considered the first (baseline) of three time points to be collected.

A homework regimen, as a main component of this therapy, was given each week, emphasizing the reading and re-reading of the selected passage. A tracking form was provided with check boxes for J.M. to indicate that he had completed the allotted reading for each day. He was given the choice of either reading the selected passage for 30 minutes a day, or to read it in full a minimum of 3 to a maximum of 5 times each day. Although this homework component was of great importance to the success of this treatment, we encouraged J.M. to be honest about his weekly reading accomplishments, in order to attain an accurate reflection of his reading practice.

In order to provide a correct reading model for J.M. to practice with during the week, a DVD recording of the clinician reading the passage at a slow rate was provided. The video placed specific emphasis on irregular words that J.M. was likely to have trouble with, and provided a close-up of the correct articulation patterns to be produced. In addition, the words of the story were inserted at the bottom of the screen so that J.M. would be able to read in unison with the clinician.

At the mid point of each week, the clinician phoned J.M. to inquire how the reading practice was proceeding, and to take second measures of rate and accuracy for comparison to the original. The clinician answered any questions that J.M. had regarding the pronunciation of specific words, and addressed any major concerns.

At the following clinical session, J.M. formally read the training passage for the third and final rate and accuracy measurement. In total, three readings of the training passages were taken to attain these measurements, so that comparisons between each time point could be conducted.

Treatment frequency. Treatment was conducted over a twelve week period, in which J.M. attended weekly, one-hour, one-on-one treatment sessions with the clinician, and was phoned mid-week to check-in on his reading progress.

Post- Treatment Assessment

Post-treatment assessment measures were taken 2 weeks after completing the combined MOR/ORLA therapy regime. At this time, each of the pre-treatment language tests (WAB-R, RCBA-2, GORT-4 and ABRS) as well as eye tracking measures, were conducted once again in order to determine whether any improvement was made. With J.M.'s consent, we also conducted follow-up treatment at 6 months post-treatment. At this point in time we re-evaluated J.M.'s reading on the GORT-4 and the RCBA-2 as well as his eye movements while reading. These measures were chosen as they would indicate whether J.M. had maintained the reading rate and accuracy changes, and to determine whether his eye movements differed significantly from the post-treatment time point. As J.M.

was not enrolled in any additional reading treatment during this 6 month period, it was predicted that J.M. would maintain reading gains and there would be minimal change between post- and follow-up time points.

Results

Direct Treatment Effects: Trained Passages

The first experimental question examined whether combined MOR/ORLA treatment would be effective in improving the reading rate, accuracy and comprehension of our subject with surface alexia. The passages selected for practice each week are examined first.

Rate. For all training passages, J.M.'s rate increased from the first to the second reading period. In addition, for a majority of passages, his rate also increased from the 2nd to the 3rd time reading this passage (Figure 3). As expected, these results indicate that with repeated practice of selected texts, reading rate improved. Although we expected that overall reading rates of all practiced passages would improve over the course of treatment, they actually decreased.

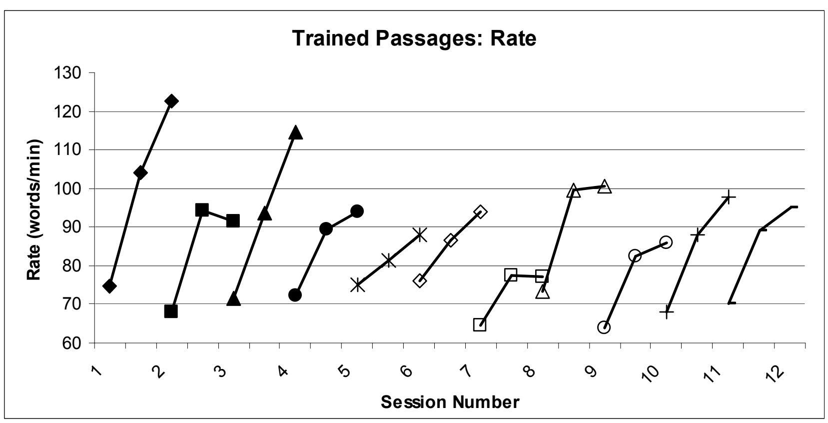

Figure 3: Reading rate in words per minute for each practiced passage.

A number of factors, including the difficulty or length of the passage, the amount practiced each week, or the content of the passage may have contributed to this result. In order to explore these factors further, a hierarchical regression was carried out on the rate change for trained passages, with the number of times a passage was practiced identified as the first predictor, and reading level (F-K level) and number of words as subsequent predictors. Both the number of times practiced and the number of words made a significant contribution to predicting the outcome (change in reading rate). More practice time resulted in an increase in reading rate (β= 0.85), while a larger number of words in the passage decreased JM's reading rate overall (β= -0.48); Table 1).

	B	SE B	β
Model 1			
Constant	-10.9	9.36	
# of times practiced	1.47	0.37	.80*
Model 2			
Constant	31.865	17.72	
# of times practiced	1.56	0.24	.85**
# of words	-0.20	0.05	-.48*
F-K reading level	1.56	1.58	.13

Note: R^2 = .64 for Model 1, R^2 = .90 for Model 2 ($p < .05$). * $p < .001$, ** $p < .0001$

Table 1: Regression analysis for change in rate of practiced passages

The *d* statistic (Busk & Serlin, 1992) was calculated as a measure of effect size, or change in reading rate as a result of treatment. Baseline measurement was represented by the single reading before repeated practice, with the mid-week check-in and final reading of the passage as the post-treatment data points. As there was only one baseline data point, d2 was calculated (Beeson & Robey, 2006). An average effect size of *d*=13.4 was calculated for change in rate in reading training passages, indicating that J.M. read more quickly as a result of his repeated reading homework. Robey, Schultz, Crawford and Sinner (1999) calculated average benchmarks for single-subject studies of aphasia treatment.

They reported average benchmarks of 2.6, 3.9 and 5.8 for small, medium and large effect sizes respectively. The average effect size of d=13.4 for change in reading rate represents a large effect.

Throughout the course of treatment, J.M. had been in-charge of recording the number of times he read each training passage between treatment sessions, as his diligence in practicing would likely affect his performance for the subsequent session. Not surprisingly, a positive Pearson's correlation [$r(9)=0.802$, $p<0.01$] was found when comparing the number of times a reading was practiced to the difference in reading rate between the first and third readings of each passage (Figure 4). This indicates that greater increases in reading rate were associated with more practice.

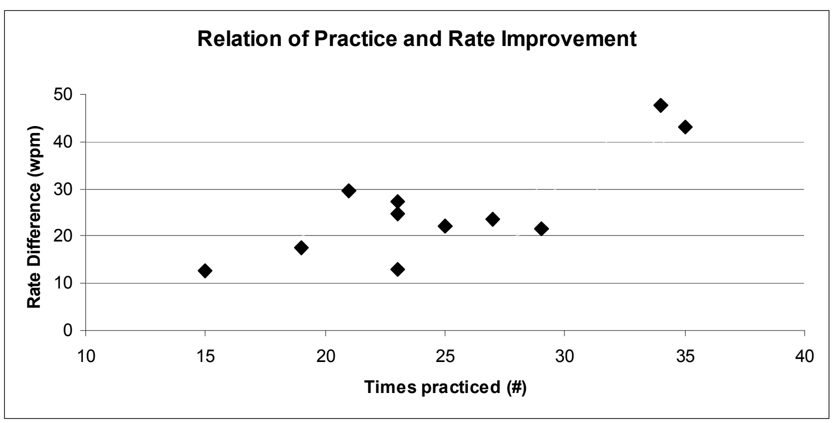

Figure 4: Correlation between number of times a passage was practiced and difference in reading rate from pre- to post-treatment

Accuracy. With regards to practiced passage reading accuracy, there was a general trend for total number of deviations per 100 words to decrease from the first reading to the second, and from the second reading to the third (Figure 5; note: increased accuracy is reflected as a *decrease* in the number of deviations/100 words). Despite small variations, accuracy at the third reading time point remained quite stable across all eleven passages. However, the improvements in accuracy are not as clear-cut as the reading rate values, as evidenced by the large amount of data overlap. Occasionally accuracy saw a large increase from 1st to 3rd reading (i.e. passage 1 and 7), while for other passages, accuracy did not improve or decreased overall (i.e. passages 4 and 9). However, for both of these passages, the decrease from reading one to reading three is less than 2 deviations per 100 words, so the scale must be considered.

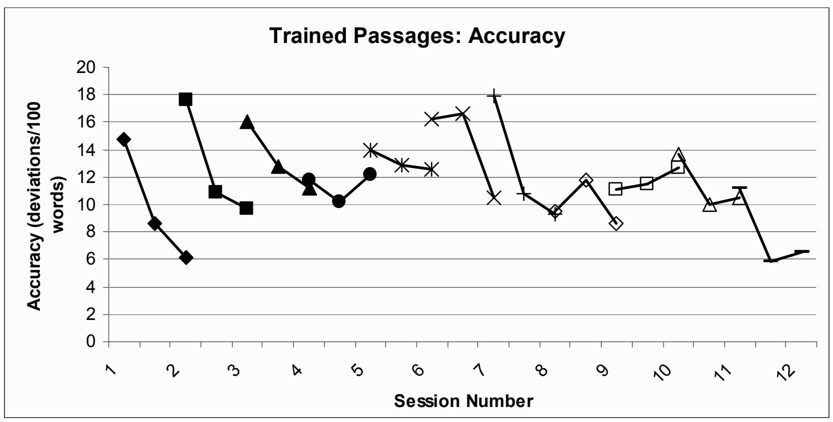

Figure 5: Reading accuracy in deviations per 100 words for each practiced passage.

Using the same methods as the rate effect size calculation, an average direct effect size of *d*=-4.45 was calculated for accuracy in the practiced passages, indicating that as J.M. read each passage more, he produced fewer errors. This is considered to be a medium-large effect size, according to Robey, et al. (1999), who reported medium and large effect sizes of 3.9, and 5.8, respectively.

When examining the number of times a passage was practiced and the accuracy J.M. was able to achieve at the following session, no correlation [$r(9)$=-0.016, p=0.963] is found between the two parameters (Figure 6). That is to say, the number of deviations that J.M. made between the first and last reading of a passage did not vary as a function of how much he had practiced the previous week.

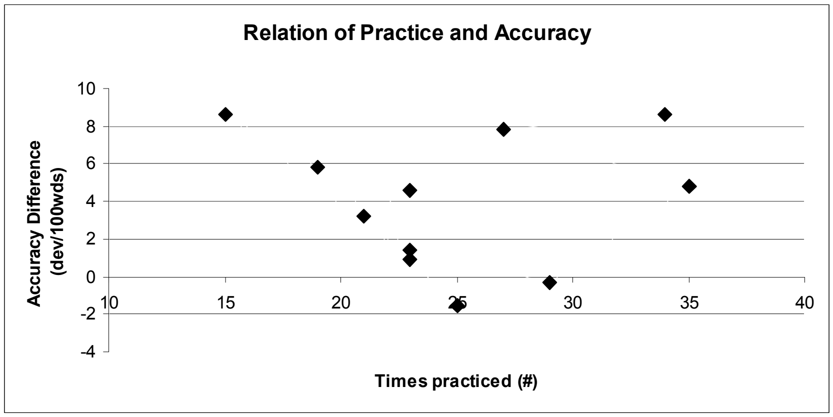

Figure 6: Correlation between the number of times a training passage was practiced and difference in reading accuracy (deviations per 100 words) between pre- and post-treatment.

Generalization Treatment Effects: Novel Passages

In addition to the training passages presented each week, generalization probes were introduced each week to examine the transfer of reading improvement to novel text.

Rate. When examining the generalization passages, some improvement in rate across passages can be observed, however these scores were highly variable (Figure 7). Although the slight upward trend reported is slim, it is in the anticipated direction.

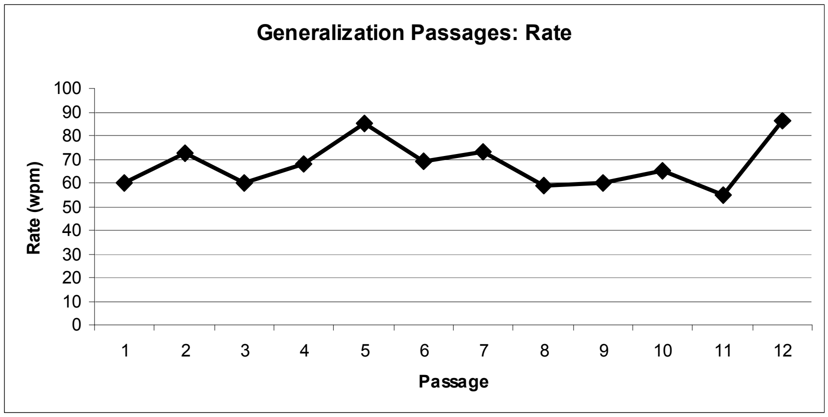

Figure 7: Reading rate in words per minute on novel passages

A generalization effect size was calculated for reading rate to examine the average change between the period before and after treatment (Beeson & Robey, 2006). In calculating d1, three baseline points were used, consisting of J.M.'s GORT-4 scores for stories 4 and 5 (as they represented the average reading rates prior to training), and the rate from the first probe passage. In addition, three post-treatment scores were utilized, consisting of GORT-4 stories 4 and 5 calculated after the completion of treatment, as well as the final generalization probe passage. A generalization effect size of *d*=0.91 was obtained for rate, indicating that there was a slight positive increase in reading rate of novel passages after treatment. When comparing this result to the Robey et al. (1999) benchmarks (2.6, 3.9, 6.8 for small, medium, large effects, respectively), treatment produced a very small generalization effect of reading rate to untrained passages.

Accuracy. When examining the generalization passages for accuracy, once again, a slight improvement is observed despite the high degree of variability in the data (Figure 8). Therefore, there is a decrease in the number of deviations per

100 words, or improvement in accuracy across generalization passages. Although this result is very small, it is also in the anticipated direction.

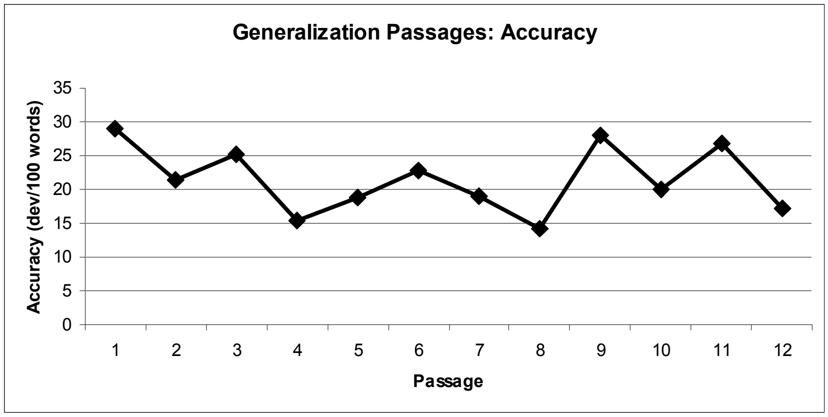

Figure 8: Reading accuracy as deviations per 100 words on novel passages

A generalization effect size of *d*=-0.26 was calculated, signifying a very small improvement in accuracy between pre-treatment and post-treatment for novel reading passages. However, these calculations identify that improvements were made in the direction predicted. In relation to the Robey et al. (1999) benchmarks, the effect size for reading accuracy is very small for this single subject report.

In addition to the above analyses, the types of deviations made were analyzed according to which word category (function or content) they occurred on, in order to examine the impact of word type on overall reading efficiency. As reading efficiency improves, our saccades tend to become longer, enabling us to pass over certain words to facilitate a higher reading rate. However, this may detrimentally impact reading aloud, as shorter (function) words tend not to be fixated on, and as a result may garner a larger number of reading errors.

In calculating the number of deviations according to word type, the total number of deviations on functors and the number of remaining deviations (on content words) were noted. Words that J.M. inserted into the reading passage were not included in this analysis, as they were not originally included in the body of the text. For each passage, the total number of deviations on function words was divided by the deviations on content words, providing the percentage of deviations that occurred on function words. Although very small, an overall increase is noted in the proportion of function word deviations to content word deviations (Figure 9).

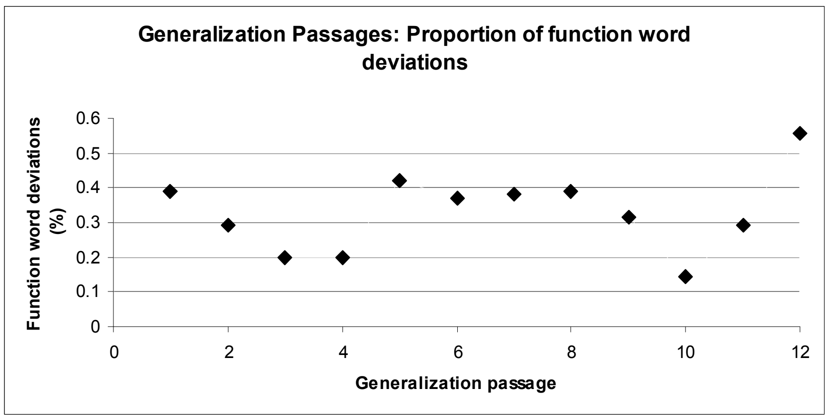

Figure 9: Proportion of function word deviations in generalization passages

Comprehension. After the reading of each probe passage, comprehension questions were presented to determine J.M.'s understanding of the new text (Figure 10). It can be seen that comprehension decreases slightly across all passages, however the final comprehension score skews the data slightly.

The first 6 passages were obtained from the 4.5 SRA level of difficulty, while the last 6 passages were taken from the 5.0 SRA level of difficulty. This may explain some of the comprehension difficulties for the later passages, as more questions were asked with a higher level of language complexity.

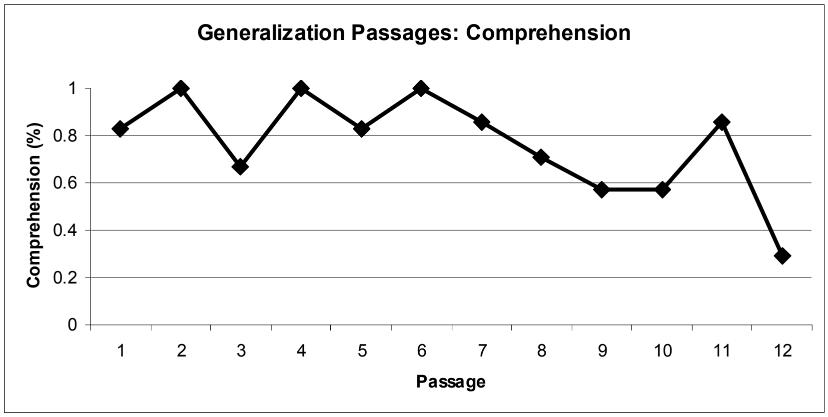

Figure 10: Reading comprehension on novel passages

A hierarchical regression was completed in order to determine whether the number of words in the passage, Flesch- Kincaid reading grade level, or the number of comprehension questions asked were predictive of the comprehension scores attained. The overall model was not significant (p= 0.13), indicating that comprehension accuracy performance could not be predicted by the above factors.

Generalization Treatment Effects: Standardized Measures

WAB-R. The WAB-R (Kertesz, 2006) was re-administered at post-treatment as an overall measure of language proficiency. J.M.'s Aphasia Quotient, measuring spoken language ability, increased 6.4 points from 83.2/100 to 89.6/100 after the completion of treatment. A 5-point increase in the AQ is considered to be clinically significant (Katz & Wertz, 1997), demonstrating that J.M. made some overall language improvements as a result of treatment. When examining the individual subtests, specific improvements were seen in JM's performance on auditory/verbal comprehension, repetition, as well as naming and word finding. In addition to these findings, J.M.'s Language Quotient (LQ), incorporating reading and writing abilities, increased from 82.5/100 at pre-treatment to 89.4/100 at post-treatment, demonstrating a 6.9 point increase. His reading score improved by 18 points as a result of the therapy provided, presumably leading to the significant improvement in LQ overall. The WAB-R (Kertesz, 2006) was not conducted a third time at follow-up assessment, as J.M.'s aphasia quotient was not anticipated to improve without treatment.

RCBA-2. The RCBA-2 (LaPointe & Horner, 1998) was once again administered at post- treatment and follow-up time points. A repeated measures ANOVA was computed using the sub-test raw scores on the RCBA across the three time points. No main effect of time was observed [$F(2,18)=0.759$, $p=0.483$], suggesting comprehension remained stable across each of the three testing periods (Figure 11). As J.M. had completed 93% of the tasks correctly before treatment was administered, his overall score was not anticipated to greatly improve.

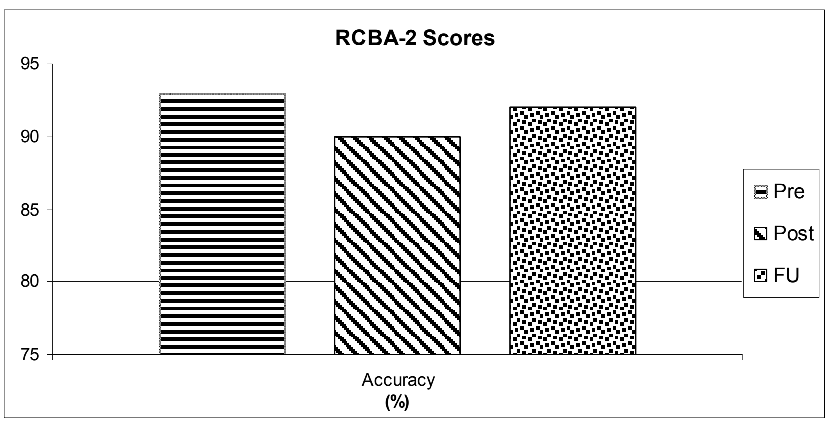

Figure 11: Reading comprehension as percentage on the RCBA-2

GORT-4. Finally, the GORT-4 (Wiederholt & Bryant, 2001) was administered at all three time points and examined with regards to changes across time points for rate, accuracy, and comprehension of the stories read. Table 2 provides ranges and average values for rate, accuracy and comprehension taken before treatment, after treatment, and at follow-up time points. Repeated measures

ANOVAs revealed only reading rate differed significantly at the three time points [$F(2,14)=4.371$, $p < .05$]. Pairwise comparisons revealed that a statistically significant change was present only between pre-treatment and follow-up reading rates, $p=0.011$.

	Levels	Rate (words per minute)		Accuracy (errors/100 wds)		Comprehension (out of 5)	
		average	range	average	range	average	range
Pre-treatment	1-8	67	50-90	14.4	11-25	4	2-5
Post-treatment	1-8	81.2	52-120	12.9	0-23	4	2-5
Follow-up	1-8	84.4	51-126	9.8	2-19	4	3-5

Table 2: Range and average scores for GORT-4 rate and accuracy

These data illustrate that J.M.'s reading rate for the novel passages within the GORT-4 increased, without sacrificing oral reading accuracy or comprehension. Thus, although a large improvement in weekly generalization passages was not observed, his results on the GORT-4 demonstrate that J.M. was able to transfer his reading rate improvement to novel sections of text. Although not statistically significant, J.M.'s reading accuracy improved from an average of 14.4 deviations per 100 words at pre-treatment, to 12.9 at post-treatment, and a further improvement to an average of 9.8 deviations/100 words at follow-up. This indicates that some quantitative change was observed in the accuracy of his reading, which may serve to impact his daily activities.

The passages were additionally examined with regards to the F-K reading grade level reported. Earlier passages of a level lower than the F-K level trained (4.5) were compared with passages of a higher level in order to determine whether any significant differences in improvement were apparent. Indeed, as seen in Figure 12, the improvement in rate on the level 1 GORT-4 passage was 36wpm between the two time points, compared to 16wpm on the level 4 reading passage (the level targeted for training and generalization passages), and less than 2 wpm on the most difficult passage tested (level 8) .

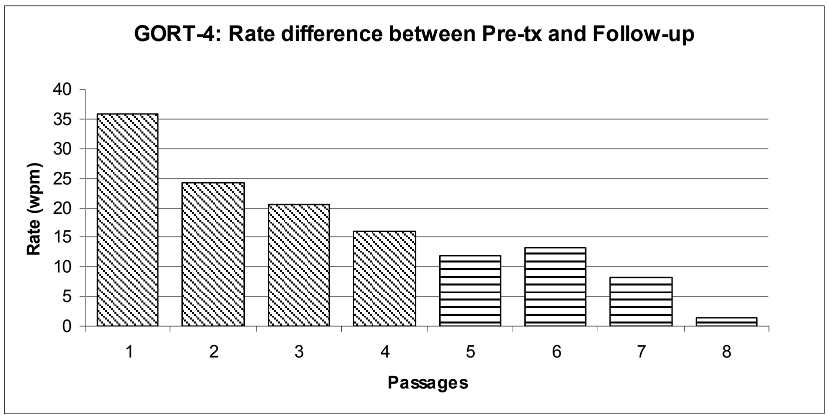

Figure 12: Difference in reading rate from pre-treatment to follow-up across passages on the GORT-4 (column lines differentiate passage difficulty into lower reading level [<F-K 4.5; diagonal lines] and higher reading level [>F-K 4.5; horizontal lines])

ABRS. In order to examine any changes in reading errors or the presence of word frequency and spelling regularity effects as reported before treatment, the ABRS (Henry et al., 2007) was re-administered at the post-treatment time point. J.M.'s reading accuracy overall did not change significantly from pre-treatment (74% vs. 70% post-treatment). Once again, J.M. experienced the most difficulty reading irregular words (57.5% accurate) and nonwords (50% accurate). Although the size of the regularity effect remained fairly stable from pre- to post-treatment (28% vs. 25%), the size of J.M.'s lexicality, frequency, and imageability effects all increased after the completion of treatment, as seen in Figure 13.

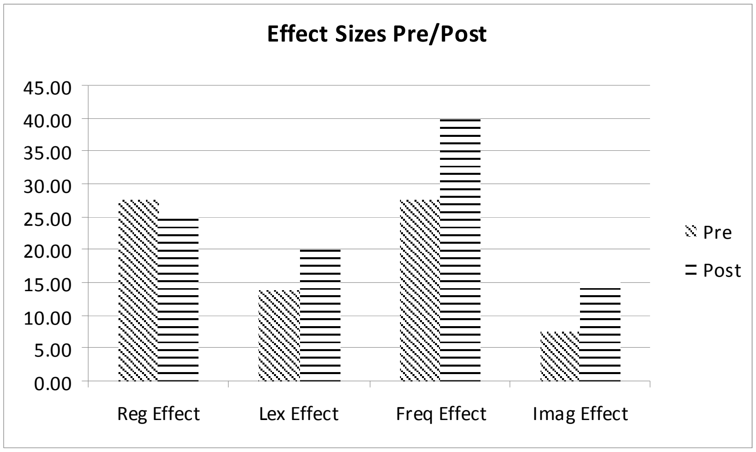

Figure 13: Pre- and post- treatment comparisons of reading effect sizes

In addition, the types of errors that J.M. made in reading these word lists were proportionately different between pre- and post-treatment (Figure 14). He made fewer phonologically plausible errors (PPE) post-treatment (29% vs. 13% pre-treatment), but had a greater percentage of phonologically implausible nonwords (PIN; 50% vs. 38% pre-treatment) and visually similar words (VSW; 29% vs. 24% pre-treatment).

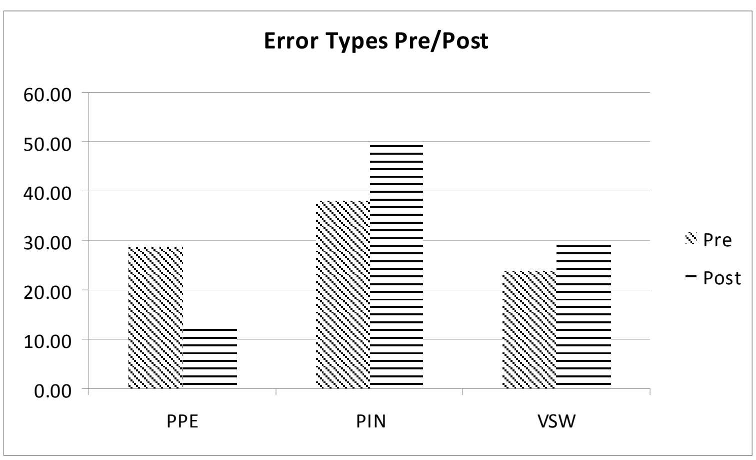

Figure 14: Pre- and post-treatment comparisons of reading error type

Eye-tracking Measures

Eye-tracking measures were conducted at three time points: pre-treatment, post-treatment, and at a follow-up session 6 months later. Specifically, we examined whether changes in number of fixations, fixation duration, and number of regressions were observed as a result of treatment (Table 3). Because the same set of stimuli were used at all three time-points, number of fixations and number of regressions were reported as raw values, while fixation duration was reported in milliseconds per sentence. In addition, we examined the position of the initial landing position for each word over four letters long to determine whether this value was impacted by treatment. Responses to the yes/no questions asked throughout the eye tracking procedure were also examined in order to determine whether J.M. was maintaining a good understanding of what was read.

	Fixations (#)	Fixation Duration (ms)	Regressions (#)
Pre-treatment	19.6	5545.0	2.9
Post-treatment	28.3	8622.6	6.0
Follow-up	27.1	7550.5	5.1

Table 3: Average values for saccades number of fixations, fixation duration, and number of regressions at pre-treatment, post-treatment and follow-up

Average fixation duration for each of the 40 sentence stimuli was analyzed via a repeated measures ANOVA. A significant main effect of time was observed [$F(2,70) = 18.604$, $p<0.001$]. Pairwise comparisons indicated that a significant difference was present between pre-treatment and post-treatment ($p<0.001$), as well as between pre-treatment and follow-up ($p<0.01$). No statistically significant difference was noted between post-treatment and follow-up time points (p=0. .213). However, it is noted that total fixation duration increased as a result of treatment, contrary to what we predicted.

With regards to the number of regressions noted for each sentence, a repeated measures ANOVA was conducted in order to compare each of the three time points. A significant main effect of time was detected on number of regressions made per sentence [$F(2,70)=12.821$, $p<0.001$]. Pairwise comparisons indicated that a difference was present between pre-treatment and post-treatment ($p<0.001$), as well as between pre-treatment and follow-up ($p<0.01$). As with the total fixation duration results, the number of regressions increased as a result of treatment as opposed to a decreasing as anticipated.

A repeated measures ANOVA was also calculated on the number of fixations made per sentence. A significant main effect of time was present [$F(2,70)= 14.682$, $p< 0.001$], revealing a significant difference between time points. Pairwise comparisons were computed, and revealed that there was a significant difference between pre-treatment and post-treatment ($p<0.001$), as well as between pre-treatment and follow-up ($p<0.01$). No significant difference was noted between post-treatment and follow-up time points ($p=1.000$). Again, like the other eye-movement measures, the number of fixations increased as a result of treatment, instead of decreasing as had been expected.

Finally, the first fixation position for each word over four letters in length was calculated as a percentage in order to account for the lengths of each word. A repeated measures ANOVA was conducted in order to compare the three time points, and a significant main effect of time was found [$F(2,306)=17.095$, $p<0.001$]. Pairwise comparisons revealed that the initial fixation position had significantly differed between each time point; pre-treatment and post-treatment ($p<0.05$), pre-treatment and follow-up ($p<0.001$), and post-treatment and follow-up ($p<0.05$) (Figure 15). Overall, the position of J.M.'s first fixation on each word increased, so that by follow-up, his initial fixation was slightly to the left of the centre of the word (i.e., the ‘preferred landing position’, Rayner, 1998).

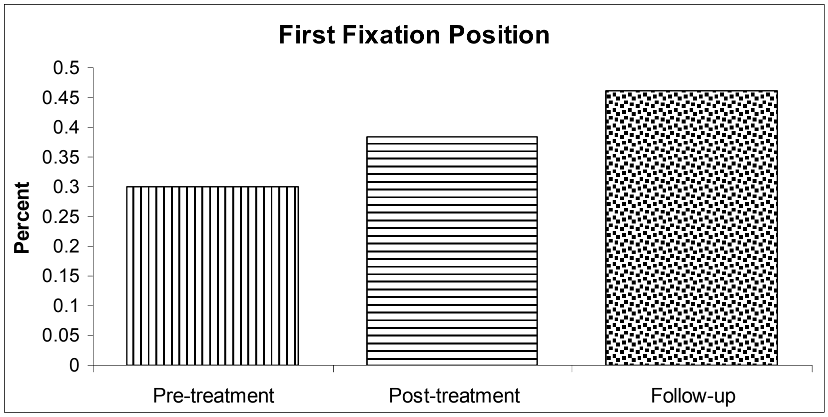

Figure 15: First fixation point expressed as percentage of word length for words over 4 letters

Examination of the comprehension questions inserted throughout the procedure indicated that J.M. understood a majority of the sentences he was reading. Response accuracy never fell below 80% at any of the three time points, demonstrating that he was reading the entire sentence and not sacrificing comprehension for faster reading rates.

Summary

As a result of the MOR/ORLA treatment provided, J.M. significantly improved both his reading rate and accuracy on practiced training passages, and demonstrated generalization of improved reading rate to novel passages on the GORT-4. J.M. also improved his overall language scores on the WAB-R (both Aphasia Quotient and Language Quotient) by clinically significant amounts, with the greatest improvement found for reading scores. Additionally, eye-movements (number of saccades, number of regressions, and fixation duration) differed from pre-treatment to post-treatment time points, although in the opposite direction of what was expected (all measures showed significant increase instead of the anticipated decrease). Notably, initial fixation position shifted towards that of more proficient readers after the completion of treatment, indicating a possible change in reading strategy overall.

Discussion and Conclusion

The two major goals of this study were to examine if text-based reading treatment would improve reading rate, accuracy and comprehension in an individual with acquired alexia, and to explore the mechanisms behind the improvements observed with such treatment using eye-tracking methodology. A reading treatment combining two established protocols that have produced beneficial results in a variety of alexia types (MOR/ORLA) was applied to this case. The use of eye tracking techniques allowed for examination of the minute on-line processes involved in reading, which were compared across three time points to investigate whether changes in eye movements resulted from this therapeutic method.

Treatment Effects

Trained passages. Similar to other studies implementing MOR and ORLA therapies, a major finding in our study was that a combined MOR/ORLA approach was successful in improving reading fluency in an individual with acquired alexia. J.M. demonstrated a moderately large effect size in reading accuracy for trained passages. Other studies have found similar improved reading accuracy for trained passages (Beeson et al., 2005; Lacey et al., 2010), although as with the present study, these changes tended to be less drastic than changes in reading rate. Beeson et al. (2005) reported a small effect size for accuracy, while Lacey et al (2010) reported that two of their subjects were able to significantly improve reading accuracy on trained passages, with between 90-95% correct productions. However, it is notable that Lacey et al. (2010) did not report on the reading rates of these individuals. They stated that the inability to read any passage at 90% or greater accuracy before treatment made measurements of reading speed inaccurate. Thus, although these individuals made gains in accuracy, such improvements may have come at a cost to reading rate.

J.M. improved his reading rate between the first and last reading for 100% of the practiced passages read. This study replicates results from other studies utilizing MOR or ORLA, but was different in that training passages were practiced for a maximum of one week, as opposed to meeting a rate criterion. Other investigators have reported significant post-treatment improvements in reading rate to greater than 100 wpm (Beeson & Insalaco, 1998), or even up to 150 wpm (Tuomainen & Laine, 1991; Cherney, 2004), rates similar to proficient readers. Even after practice, J.M. never attained a reading rate considered to be typical for proficient readers. However, like the two individuals with anomic aphasia described by Beeson and Insalaco (1998), J.M.'s reading rate improved to between 90-100 wpm after repeated practice for 8 of 11 passages. It is possible that J.M. could have attained faster reading rates had we used a rate criterion for progressing to a new passage, but in the interest of maintaining homework compliance and motivation, we chose to limit the time practicing each passage to one week.

The number of times that a passage was practiced best predicted the rate improvement across treatment. This result was expected, as J.M.'s familiarity with each passage would have increased each time he practiced, allowing him to read through the passage with greater speed. Although this was the strongest predictor, the number of words had a negative impact on the change in reading rate attained. This is not surprising, as more words in a passage would have required longer sustained attention to the task, and may have reduced the attention given to specific words while practicing. The fact that F-K reading level did not significantly predict the change in reading rate is curious, as a passage with shorter sentences and fewer multisyllabic words should have allowed for faster reading. In addition, the easiest passage J.M. read had one of the slowest initial reading rates when compared with all other trained passages, indicating that there was still room for significant improvement. It may be that J.M. unknowingly gave more effort when practicing the higher level passages, knowing that they demanded more attention and concentration than easier passages that did not present as much of a challenge.

Of note was that our baseline measurement of reading rate and accuracy was obtained after each of the ORLA steps had been completed. Thus, this recording was not his first time reading the text. Had J.M. read the training passage alone before each ORLA step was implemented larger effect sizes for training passages may have been produced.

Generalization measures. Despite the large effect sizes observed for trained passages, effect sizes for generalization of reading rate and accuracy improvements to novel passages were considerably smaller. In examining a case of surface alexia, Beeson et al. (2005), reported a small effect size of 2.18 for accuracy as a result of MOR, indicating greater generalization to novel texts than the current study produced. However, their subject produced very few errors per

100 words even before the completion of treatment (3-4.3 deviations), and read passages of lower Grade levels (F-K: 3-3.5) than J.M. Beeson et al.'s (2005) subject improved his reading accuracy to 1 deviation per 100 words of text, producing a small effect size, but allowing for little functional gain. In addition, they reported an effect size of 9.21 for reading rate, once again demonstrating a larger treatment effect than was observed with J.M. Lacey et al. (2010) on the other hand, reported that of four individuals, not one significantly improved on either rate or accuracy between pre- and post- treatment on generalization passages. Although subjects had either phonological alexia or pure alexia (not surface alexia like J.M.), there were a wide variety of aphasia types, and lesion locations. Similarly, limited generalization of rate and accuracy gains were observed for the present study. Although our reading rate and accuracy effect sizes were smaller for weekly generalization passages, we were able to observe improvement on other measures of generalization as noted later on.

With regards to the reading level of both training and generalization passages, future studies should consider manipulating the training difficulty in order to determine whether this may lead to greater improvements. Should training of text reading be conducted at higher levels than the generalization passages, it is possible that greater improvement may result. Practicing a more difficult text may allow for greater word exposure and practice with more complex sentence structures, leading to greater improvements and more efficient reading of novel text passages. This hypothesis follows along the lines of the 'complexity account of treatment efficacy' (i.e., CATE) proposed by Thompson, Shapiro, Kiran and Sobecks (2003). These authors reported that when sentences of higher complexity were trained, not only did improvement occur for linguistically related sentences, but gains were enhanced for those of lesser complexity.

As demonstrated in the present study, proportionately greater improvements were observed for texts of a lesser difficulty than the level that was trained, indicating that training passages of a higher complexity may result in greater generalization to easier passages. Conversely, it is possible that some individuals may become more easily frustrated when practicing a passage of greater difficulty than they are comfortable with. Thus, participants for such research would have to be carefully chosen, having a strong motivation to improve, and the stamina to work through difficult reading passages. Alternatively, the clinician may modify the level of support necessary to scaffold the client's learning and improvement.

Despite the lack of rate and accuracy generalization to novel passages presented each week, greater gains overall were observed for rate on novel readings of the GORT-4. A significant improvement in reading rate on the GORT-4 between pre-treatment and follow-up time points was produced, indicating that J.M. was able to generalize some rate improvements to novel texts. Overall improvement in reading rate did occur between pre- and post-treatment testing (14.2 wpm increase), however, it was not enough to attain significance. Although we would have anticipated J.M.'s reading gains to decrease slightly between post-treatment and follow up testing, a number of factors may have contributed to the continued improvement. On the day of post- treatment assessment, it was noted that J.M. may not have given his full effort to the tasks provided. He seemed to give up prematurely on a number of tasks, and did not perform as well on tasks that he had succeeded in completing before the onset of treatment. Although gains in a number of areas had been accomplished at post-treatment, this day of testing may have produced slightly atypical scores than would be expected. In part, this may have contributed to the lack of significance between pre-and post-treatment time points.

A number of factors may have differentially impacted J.M.'s performance on the generalization passages vs. GORT-4 reading passages, including the length and difficulty of the passages themselves. The weekly generalization passages tested J.M. at the reading grade level he trained at (Grade 4.5), as opposed to the GORT-4 which tested his reading at a variety of grade levels. Additionally, the weekly generalization passages were consistently around 100 words in length, whereas the GORT-4 passages began with less than 30 words, and slowly increased in overall length as the passages increased in difficulty. Thus, although improvements were observed for each GORT-4 passage between pre-treatment and follow-up, a proportionately greater improvement in rate was seen for simpler passages overall, accounting for the significant improvement in rate after treatment. These results indicate that reading rate improved the most for stories of a lesser difficulty level than those trained, potentially contributing to the significant improvement observed.

In addition to rate improvements on the GORT-4, J.M. made some progress in reading accuracy, despite the fact that these differences were not found to be statistically significant. As can be observed in Table 1, before treatment, deviations ranged from 11-25 per 100 words, while at the post-treatment session, J.M. read one passage without producing any deviations at all, and another producing only one deviation in total. Thus, a greater range of deviations was observed at post-treatment testing (0-24 deviations per 100 words), suggesting that, although minimal, some treatment generalization for accuracy was produced. As the two passages with few if any deviations at post-treatment were of a lower reading difficulty, the idea that proportionately greater improvements may be observed for passages of a lower difficulty level than for those that were trained is further supported. It can be assumed that as a result of treatment, J.M. was beginning to produce fewer errors overall in his reading of connected text.

Cross-modal generalization. Improvements in other language areas were observed as a result of treatment, in addition to improvement in skills necessary for efficient reading. J.M. increased his Aphasia Quotient (AQ) on the WAB-R by over 5 points, indicating that a clinically significant effect was produced in overall language proficiency (Katz & Wertz, 1997). This increase was not an improvement that was expected as a result of treatment, but indicates that MOR/ORLA impacted more aspects of language than just reading rate and accuracy. As previously discussed, within this study, improvements in AQ were observed in a variety of domains, including auditory comprehension as well as reading. Given the type of treatment provided, we would expect to observe treatment in these areas. However, the improvement in repetition, naming, and word finding subtests was of interest. Gains in these areas may be at least partially due to the extended focus on language and words contained within this treatment, and the emphasis on reading and identifying each word that is provided.

Other studies investigating MOR or ORLA have reported clinically significant increases in the WAB- AQ score as we have (7/25 subjects in Cherney, 2010a; 4 of 11 subjects in Cherney, 2010b, 2/2 in Beeson & Insalaco, 1998), similarly citing improvements in language areas of repetition, word naming, comprehension, and/or expression. Such ‘crossmodal generalization’ has not been fully explained in the literature, but Cherney (2010a) suggests that aphasia severity may differentially impact the domains in which gains are made as a result of ORLA therapy. Individuals with severe aphasia were found to have improved reading comprehension, and were the only subgroup to show increases on the reading scores of the WAB-R. Those with moderate and mild to moderate aphasia demonstrated discourse changes as a result of treatment, including the narrative discourse task and the picture description. Additionally, those within the mild to moderate aphasia severity group were the only individuals to show improvement in the written modality. Although J.M. had a relatively mild aphasia, improvements in his WAB-R scores were observed for discourse tasks (previously reported for those with moderate aphasia severity) instead of writing tasks as would be hypothesized given Cherney’s (2010a) results. Results from the present study differ from those reported by Cherney (2010a); however, many factors, including the variability within aphasia type and severity may be cited as a cause.

This study represents a novel approach to reading treatment, as a combination of MOR and ORLA components were involved. Each method was originally designed to target different areas of reading, with MOR utilized to improve reading fluency (Moyer, 1982), and ORLA initially used to improve reading comprehension of connected text (Cherney et al., 1986). Lacey et al. (2010) report findings of rate and accuracy improvement as a result of treatment on the trained passages, however, no generalization of these skills was noted. Beeson and Insalaco (1998) report similar findings for rate improvement on trained passages, also indicating that comprehension of their subjects was maintained throughout treatment. Although studies of ORLA regularly report improvements in comprehension, improvements in auditory comprehension, oral expression, picture description, and even writing have been detailed for a variety of aphasia types and severities (Cherney, 2004; 2010b). Thus, as a result of this combined treatment, J.M. demonstrated some improvement in a wide variety of areas discussed by each of the techniques separately. His rate and accuracy improved for trained passages, and selective generalization for rate also occurred as MOR treatment would predict. In addition, J.M. made cross-modal improvements in picture description, repetition, naming, word finding, as has been documented for ORLA treatment. Although comprehension did not improve as a result of treatment, it was maintained for generalization passages read, supporting both components of therapy.

Comprehension. In addition to determining that treatment was effective to some extent in improving reading rate and accuracy, this study found that J.M.'s comprehension of the generalization passages he read remained fairly stable, with no significant differences found between pre-treatment and post-treatment. His comprehension scores on the RCBA-2 also remained fairly stable, indicating that faster reading rates did not decrease his understanding of read text. It has been proposed that repeated reading of text leads to improved comprehension, as a result of greater attentional and cognitive resources that are no longer needed for decoding words (Beeson, 1998; Cherney et al., 1986). However, a number of studies have reported comprehension scores remaining stable after the completion of treatment (Lacey et al., 2010; Beeson & Insalaco, 1998; Beeson et al., 2005). Similar to the results of the current study, it is possible that because comprehension was already fairly high, there was little room for improvement at later time points. It is possible that had J.M.'s comprehension been lower at pre-treatment, we may have seen improvement in comprehension scores due to increased attention resulting from greater reading fluency.

Length of treatment. The length of treatment administered is consistently a topic of contention in research; what level of improvement signifies the completion of treatment, and what conditions warrant treatment continuation. J.M. attended 12 direct sessions with the clinician over the course of three months, and read eleven training passages in their entirety. Thus, this study represents a shorter span of treatment with significant improvements made, while others have continued treatment for much longer periods of time. Although reports from previous studies may not be directly compared due to the differences in treatment type and administration, they serve to indicate the differences observed as length of treatment is manipulated.

Studies investigating MOR have reported a wide variety of treatment lengths and improvements as a result. Beeson and Insalaco (1998) administered treatment for one subject over 10 months, with rate gains of roughly 25 wpm up to over 70 wpm on novel passages. Another subject received treatment for a total of three months, making rate gains from 50 to 60wpm on novel texts. Kim and Russo (2010) presented a case in which treatment was administered for 70 sessions over the course of nine months. Percentage of errors while reading novel connected text improved from roughly 23-12%, while reading rate improved from 4.7 to just 6.27wpm. However, this subject presented with mixed nonfluent aphasia, with a moderate apraxia of speech and mild cognitive deficit, which likely prevented greater gains from occurring.

With regard to studies of ORLA that have been conducted, Cherney (2010a) discussed 25 subjects with chronic aphasia and varying levels of severity. The average treatment period was over 12.5 weeks, ranging from 6-22 weeks in total, with 24 one hour ORLA sessions completed. Overall improvements on the WAB were not clinically significant (average increase of 2.38 on the AQ for all subjects), although 7 individuals did make clinically significant improvements. Cherney (2004) also reported on an individual with moderate Broca's aphasia who attended 24 one-hour sessions over 7 weeks. This subject's AQ improved nearly 5 points, with gains made in a number of cross-modal areas.

These studies indicate that treatment results are extremely variable, depending on a number of factors, including the length that treatment is administered. In our study, significant gains have been observed over just 3 months, though greater gains have been produced with longer treatment periods. Thus, it is possible that J.M. may have evidenced greater gains in his reading fluency for novel texts, as well as his WAB AQ, had treatment been continued. Of note is that these significant improvements were maintained six months following the completion of treatment.

Eye-Movements

Previous studies investigating the effects of MOR or ORLA reading treatments have reported a number of potentially causal factors for the improvements seen in component processes of reading however, the mechanisms behind such reports haven't been agreed upon. This study investigated eye movements involved in reading, as they are a more fine-grained judgment of the moment-to-moment cognitive processes involved in reading (Rayner, 1998).

Eye-tracking measures. Results for the eye tracking methodologies indicated that significant main effects were found in all four parameters examined between pre-treatment and post-treatment. Number of fixations, regressions, and total fixation duration were all significantly different as a result of treatment when comparing pre-treatment data to post-treatment and follow-up data. Additionally, the first fixation into the word differed significantly between all three time points, indicating that J.M.'s eye movements continued to change in the direction observed within this study 6 months after treatment had been completed.

However, despite these significant results, parameters of total fixation duration, saccades and regressions all changed in ways opposite to that which was anticipated. That is, total fixation duration became longer and more fixations and regressions were produced, indicating a step away from the typical eye movements observed in proficient readers. A study investigating the eye movements of individuals who had regained basic language functioning but continued to complain of comprehension issues following the diagnosis of aphasia, reported that longer fixations and a greater number of saccades and regressions were used when reading connected text (Chesneau, Joanette & Ska, 2007). These results indicate that those who have suffered neurological damage may continue to produce abnormal eye movements in reading when compared to controls, even after recovery. These abnormal eye movements may reflect the use of different reading strategies when comprehending written text. Thus, although we observed an increase in abnormal eye-movements after treatment, the fact that J.M. demonstrated behavioral improvements in his reading suggests a change in his efficiency in using this strategy.

First fixation position. J.M's first fixation into words shifted towards a position more typical for proficient readers. In essence, J.M. had fixated closer to the beginning of a word before treatment, but as a result of the therapy provided, this changed to approximate more closely the 'preferred viewing position', representing a conversion in the underlying reading strategy used (Schatka et al., 2010). Schattka et al. (2010) reported that saccadic landing positions in aphasic patients differed depending on the reading strategies used. They indicated that individuals with surface alexia tended to fixate much closer to the beginning of a word as they make use of a segmental reading strategy, while those with phonological/deep alexia fixated just to the left of the word centre in order to process the word as a whole. Taking the results from Schattka et al. (2010) into consideration, it appears as though J.M.'s initial fixation position, as a result of treatment, shifted from that more typical of surface alexia to those more in line with typical readers. Underlying this shift is an alteration in reading strategy, from segmental reading to a more holistic approach. Thus, his eye movements appear to suggest that his alexia type and overall reading strategy may have been altered as a result of MOR/ORLA therapy.

In order to investigate this claim further, data from the ABRS word lists were examined to see if J.M.'s reading errors supported an explanation of a shift in reading strategy. As reported from the pre-treatment data, J.M. presented with both a regularity effect and a frequency effect in his reading of real words, and produced a number of phonologically plausible errors. However, after treatment, an increase in the size of J.M.'s lexicality effect, frequency effect, and imageability effect was observed, each of which are considered more prevalent in phonological alexia (Beeson & Henry, 2008). To further corroborate this data, J.M. actually produced fewer phonologically plausible errors after the completion of treatment. When we consider the rationale behind text-based reading treatments, Besson and Insalaco (1998) suggest that the lexical-semantic associations are being strengthened due to the contextual associations made. Thus, it is logical that the reading strategy would become more lexical or holistic as a result of the treatment provided. Taken together, both eye tracking and behavioural measures support the conclusion that as a result of treatment, J.M. shifted his reading strategy from sub-lexical to a more lexical strategy frequently used by individuals with phonological or deep alexia.

Despite the apparent shift towards a more lexical reading strategy in which the whole word is perceived at once, this study found an increase in the number of saccades and regressions, and an increase in total fixation duration after treatment had been concluded. In their study, Schattka et al. (2010) reported that neither the frequency of fixations nor their duration aided in distinguishing between alexia types. In addition, they did not report on the frequency of regressions while reading connected text, so this is not a parameter that may be directly compared. As the Schattka et al. study is currently the only available research which has investigated eye movements in relation to different alexia types, no other data is accessible with which to compare our results. It is possible that with further research, additional temporal parameter distinctions between alexia types may be revealed, supporting the changes that we observed in J.M.'s saccades, regressions and total fixation duration.

Models of eye movement control. The eye tracking data above may implicate a number of changes in J.M.'s reading strategy, as his eye movements have become more efficient with regards to the initial landing position of a word, but include more regressions, indicating potential comprehension issues. However, in the behavioural testing data, no significant comprehension improvement or deterioration was identified. As a result, we are left to speculate on potential theories that may account for these contradictory changes observed.

Models of eye movements during reading have typically focused on the physical (ballistic) movements that the eyes make, with and without the incorporation of lexical processing. The following theoretical approaches to eye movements have been used to group reading models based on similar components, and vary according to their emphasis on occulomotor vs. cognitive aspects of reading. The Primary Occulomotor Control (POC; Reilly & O'Regan, 1998; McConkie, Kerr, Reddix & Zola, 1988) approach assumes that eye movements are driven by low-level factors without the influence of attentional processes. For example, fixations are produced a specific number of characters away from the previous fixation, regardless of higher-order processes. Sequential Attention Shift (SAS; Morrison, 1984; Reichle, Pollatsek, Fisher, and Rayner, 1998) models integrate the lexical processing of a word along with attentional shift in determining eye movements while reading, shifting attention from one word to the next sequentially. Alternatively, the Guidance by Attentional Gradient (GAG; Clark, 1999; Inhoff, Radach, Starr & Greenberg, 2000) approach proposes that eye movements are produced as a result of attentional processes and lexical processing (similar to the SAS models), but that the adjustment of attention may re-distribute future fixations according to gradient values given to subsequent words (Engbert, Longtin & Kliegl, 2002).

In examining the results obtained from J.M., it appears as though his ballistic control in reading has improved as a result of the treatment provided, as his initial fixation position in words has shifted towards that of typical readers. However, the increase in the number of eye movements (in particular, regressions) potentially indicates that J.M.'s cognitive component of reading has decreased in efficiency, as opposed to the increase that would be expected with improved ballistic eye movements. The E-Z Reader model (Reichle, Rayner & Pollatsek, 2003; included in the SAS category) accounts for this discrepancy in some ways, as it proposes that eye movements are produced efficiently in reading, and higher-order processes intervene in eye movements only when difficulty understanding the text is encountered. In this way, for J.M., his initial fixation position has moved towards that of typical readers as a result of treatment (efficient eye movements), but higher-order cognitive processes are intervening to produce additional regressions as a result of possible misperception.

A number of possibilities may account for the intervention of these higher cognitive processes producing an increased number of regressions. It is feasible that J.M. may have recognized the sentences he was reading on subsequent eye tracking procedures, as he read the same stimuli on all three occasions. However, this is unlikely due to the extended period of time between each eye movement tracking session. Alternatively, J.M. could have become a more efficient reader as a result of treatment, but may have become less sure of what he reads as a result. In this way, he may have lost confidence in his reading abilities, second guessing the meaning of what he has read, and producing more regressions in order to clarify the intended message. If the latter is true, this may account for the lack of clear rate and accuracy improvement for generalization passages, as J.M. was given only one chance to read and comprehend the material, as opposed to the trained passages which he had multiple opportunities to re-read. In this way, he has improved his ballistic eye movements, but has lost confidence in his comprehension abilities, and so, focuses increasingly on what he is reading, producing more regressions to ensure he has correctly understood the message.

A number of questions have been brought up as a result of this research, and few have resulted in clear-cut solutions. Similar testing with additional subjects may help to confirm which of these theories is at work, and will be addressed in the future directions section below. Thus, further research should be conducted in order to investigate whether this phenomenon occurs in other readers with aphasia, and what occurs in their reading process to produce these changes.

Qualitative Observations

Through qualitative examination of J.M.'s text-based oral reading, improvements were demonstrated in a number of areas as treatment progressed. Prior to the outset of treatment, it had been noted that J.M. read sentences and longer texts quite slowly, making a large number of errors and continually stumbling over irregular words. Additionally, he had a great deal of difficulty reading names, as he was unable to sound them out effectively, and thus spent a great deal of time attempting to produce the appropriate word. Overall, this prevented him from attaining a fluent pattern of reading, and slowed his rate down quite drastically.

At the completion of treatment, the quality of J.M.'s oral reading had improved, with fewer restarts and syllable repetitions, fewer disfluencies, and fewer phonemic and semantic paraphasias. He was observed to pause at appropriate intervals and before words that would usually cause him difficulty. Despite these pauses, his reading rate was faster than what it had been before treatment. The pauses and breaks served to organize his reading processes, so that fewer restarts and repetitions were necessary to read selections of text. J.M. reported that as a result of treatment, he will now read the paper in the mornings, and utilizes his computer more for reading. He indicated that reading is easier for him in the mornings, and finds that he is able to comprehend the material better than before. In addition, he attempts to maintain his use of strategies learned throughout treatment, and hopes to read more for enjoyment in the future.

Treatment Gains in the Chronic Phase

This research has further promoted the idea that improvements in various modalities can be attained even multiple years post-stroke. Moss and Nicholas (2006) conducted a comprehensive review of language treatments for chronic aphasia in order to examine the relation of time post-onset to treatment efficacy. Through this they found that there was no significant relation between time post-onset and response to treatment. Even subjects whose stroke had occurred 12 to 20 years ago showed significant improvement.

In relation to reading, it is important to consider the possibility that many subjects would not aim to improve this ability immediately after stroke. As reading is a higher-level skill and requires some language proficiency, it would be very difficult to target in the acute phase, unless language was not severely impacted. Thus, reading is an area that would most likely be targeted outside of the period of maximal recovery. Within this study, J.M. was nearly 8 years post-onset, and demonstrated the capacity to make significant gains in his language abilities. These positive results assert the idea that reading rehabilitation can be targeted years post-onset, and yet produce clinically significant improvement for patients.

Limitations and Future Directions

The results of this study are promising for future research and rehabilitation efforts, as the effectiveness of a combined MOR/ORLA approach has been validated in this subject, and the use of eye tracking measures in examining reading improvement has been supported. However, a few factors which may have impacted the results reported must be taken into careful consideration.

Single case study designs represent the majority of literature on the impacts of stroke, and have been shown to provide valuable information when designing and providing treatment for this population. However, this is also a limitation that should be discussed with reference to the present study. Due to the heterogeneity of individuals having suffered a stroke, it would be relatively impossible to control for the wide variety of factors that may impact the effectiveness of treatment in order to design a randomized control trial for reading rehabilitation. Thus, case studies allow for information to be shared regarding the impact of treatments for individuals without generalizing these results to the general public. However, this makes it difficult to determine whether a treatment would be effective for just one individual with a specific set of deficits, or if it may be effectively and ethically applied to a broader population. Overall, researchers must take the results of case studies with a grain of salt, and be cautious when applying the results to broader populations.

Eye tracking data was collected as sentences were read silently. However, treatment focused on the oral reading of paragraphs of text to investigate improvement, which may necessitate different eye movement patterns to effectively move through the text. Thus, it is possible that the eye movements observed while completing the eye tracking procedures may not completely account for what would be seen while reading longer passages. Continuity between trained and tested stimuli should be created in order to address this hypothesis. It is proposed that future studies investigate the eye movement patterns utilized while reading paragraph text in order to compare whether they differ from those produced while reading sentences.

The current study looked at the silent reading of sentences while eye tracking procedures were being completed, in order to account for any oral reading difficulties that may have impacted the individual's true reading potential. However, as treatment and homework centered on the oral reading of text passages, it may be useful to examine eye tracking data while reading passages aloud as well. Rayner (1998) reported that eye movements differ depending on whether material is being read aloud or silently, with longer total fixation durations and pauses in saccades present for oral reading as opposed to silent. A majority of eye movement data has been based on silent reading, however, future studies may also look to examine the eye movements while reading orally in order to determine any differential or distinguishing results.

With regards to the two possibilities for the paradoxical change in eye movements (ballistic vs. cognitive), the research methodology could be altered to potentially determine which is at work in this reading treatment. In order to rule out or confirm even slight recognition of eye-tracking stimuli, two sets of stimuli could be presented. One set would contain the exact same sentences from one eye-tracking session to the next, while the second set would consist of entirely different sentences for each of the three time points. In this way, the eye movements from both sets could be compared in order to determine whether more regressions were produced for one set over the other. Should both sets produce similar eye movements, the possibility of stimuli recognition could be ruled out, whereas different eye movements would indicate a differential underlying cognitive effect.

From this point, should the eye movements recorded be similar for both sets, the time taken to read the stimuli on the second, third (etc.) pass could be examined in order to determine if there were any changes. If the reading time on secondary passes increased, it is possible that comprehension of the passage was being confirmed. However, should there be no overall increase in time spent on second passes through the stimuli, it is possible that reading efficiency may not have translated to novel texts of this nature.

Reading homework was considered to be a main factor in the success of this treatment methodology, and produced significant changes in the reading of training passages. Within this study, we offered J.M. the option to read the text for 30 minutes each day or to read the entire passage between 3 to 5 times in one day, allowing for two days of no practice. Although clinically significant results were observed using this method, it is possible that varying the homework expectations may produce a greater impact on reading fluency. Requiring individuals to read the passage less each week may improve the motivation to reread the passage however, it may decrease the overall success of the treatment. Requiring more reading from individuals may indeed produce greater training effects, but may reduce the overall enjoyment of the treatment. J.M. reported that it was difficult to maintain his homework performance as the treatment progressed, as repeated reading of passages became quite tedious and required a great deal of stamina to complete. Homework compliance over time must be contemplated, as fewer daily readings may help to maintain homework performance over a longer period of time. Future studies investigating MOR/ORLA treatment should vary the homework constraints in order to determine whether modifying this variable may improve or reduce the impact on reading performance.

In addition to passage length, the content of what is being read should also be taken into consideration when investigating homework compliance. The practiced passages and probes chosen for use in this study were taken from a series designed for use in primary schools. Thus, although they were controlled for difficulty and length, their content was limited to stories and information that appealed to a younger age group. Although a majority of the time this did not greatly impact the success of treatment, it is possible that J.M. may have been more motivated to read a book of his own choosing, or a topic that was more in line with his interests or hobbies. In addition, the passages utilized did not accurately reflect the types of text that J.M. would be reading in every day contexts. Thus, generalization to more typical texts encountered daily may be less likely to occur. Although J.M. was initially given the option to bring in a selected text for use in treatment which would be altered for our purposes, he opted to read the texts that were already available. Future studies should investigate any difference in performance when the content of passages reflects more typical reading situations (i.e., content from the newspaper, information pamphlets, email, etc.).

The length of the training passages was selected for a variety of reasons, each of which may have impacted the overall improvements seen. Passage length averaged around 250 words, as this provided a good length of text to practice, with the hopes that it would not become tedious. Other studies having investigated the effectiveness of MOR, have reported using a variety of training passage lengths. Beeson et al. (2005) utilized passages with an average of 410 words each, while Lacey et al. (2010) shortened passages to 300 words each. Shorter texts may have become too repetitive to read, whereas longer texts may have presented too much challenge for significant improvement to be calculated. However, it is possible that the results attained may have been altered if the passage length was greater or lesser. Shorter passages may have allowed for greater concentration on a few specific areas of difficulty, whereas longer passages may have provided more content to maintain reading stamina. Future studies should look to systematically vary the length of passages practiced in order to determine an appropriate length that will produce the greatest changes observed.

This study has endorsed the use of eye tracking methodologies in examining the rehabilitation of reading, encouraging its use in rehabilitation studies of individuals with varying alexia profiles, and in the use of different treatment protocols. However, more research is necessary to determine whether changes in eye movements may produce improvements in reading across populations. Further case studies utilizing these methods with patients having different alexia types should be explored, as well as larger scale studies examining whether similar improvements may be observed across patients with the same types of impairments. This study has therefore provided the evidence necessary to allow for further, more generalized research along this line to continue.

Conclusion

This research has not only demonstrated the validity of using a combined Multiple Oral Rereading- Oral Reading for Language in Aphasia treatment in the rehabilitation of acquired alexia, but has for the first time recognized eye movements as a parameter of interest when determining mechanisms behind the effects of reading treatment. Results from our study suggest that text-based reading treatment not only results in improved reading fluency, but may also result in a shift from a sub-lexical to a lexical reading strategy in an individual with a surface alexia profile. Moreover, these changes are evident at the level of eye-movements, and seem to be maintained for at least six months following the completion of treatment. These results and the findings of other studies professing the validity of reading therapies for the rehabilitation of alexia may be utilized in the design of future treatment processes in order to better provide for those impacted by aphasia and alexia.

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Appendices

APPENDIX A

Participant Information Letter

Title of Research Study: Written Language Processing in Aphasia: Cognitive Mechanisms, Neural Substrates, and Evidence-Based Treatments

Principal Investigator: Esther Kim, Ph.D., R-SLP, CCC-SLP

Background: Individuals with aphasia (an acquired language disorder) often have difficulty understanding written language. Many factors, such as knowledge of spellings and meanings of words, attention, and memory contribute to reading. It is important to understand how these factors interact, and what brain regions support these processes.

Purpose: You are being asked to participate in a research study to understand: how people process written language, what brain regions are important for processing written language, and how best to treat people who have difficulty processing written language. The information learned from this study will help individuals who have language impairments.

Procedures: This study takes places in three phases. Information obtained in the prior phase will determine whether you continue on. Participation in Phase I of this study will involve:

a) An initial interview/visit at the Rehabilitation Medicine Satellite (RMS) clinic in College Plaza (Rm 6-04) lasting approximately 2 hrs. At this visit, we will get some background information and do some screening tasks to understand your ability to speak, read, write and understand language. Parts of the screening will be videotaped for scoring purposes.

b) Obtaining a copy of your medical records/clinical brain scan (if you have aphasia) to see what your brain looks like.

Participation in Phase II of the study will involve:

c) 3-5 additional assessment sessions lasting approximately 2 hrs. At these visits, we will do more extensive assessment of your ability to speak, read, write and understand language; and your ability to pay attention to and process items such as pictures, numbers, and letters. Parts of the assessment will be videotaped for scoring purposes.

d) Reading text while a special device measures your eye movements. This will take approximately 1 hour and will take place in Arts 1-04 on the U of A campus.

e) An MRI scan at the University of Alberta hospital (if appropriate). You will not be required to do anything but lay in the MRI machine while it takes a picture of your brain. This procedure should take approximately 1 hour.

Participation in Phase III of the study will involve:

f) Coming to the RMS clinic for hour-long therapy sessions, 1-2 times per week for approximately 6-12 weeks. If you do not qualify for therapy, you will be provided with information and resources, including a written report of your written language processing abilities.

Possible Benefits: The possible benefits to you for participating in this study are that you may learn about how individuals process written language, and what brain regions are important for doing this task. If you receive therapy, you may also benefit in that respect.

Possible Risks: You may feel fatigued during the language tasks, but you will be able to take rest breaks. You will not be eligible for the MRI if you have any metal implanted in you (such as a cardiac pacemaker, metal pins, rods, etc.). If you are eligible for the MRI you may feel claustrophobic or anxious, but you will have time to familiarize yourself with the equipment and the procedure before the actual scan.

Confidentiality: Any research data collected will identify you only by a numerical code. For this study, we will need to access your personal health records to obtain information about your aphasia. The health information collected as part of this study will be kept confidential unless release is required by law, and will be used only for the purpose of the research study. By signing the consent form you give permission to the study staff to access any personally identifiable health information which is under the custody of other health care professionals as deemed necessary for the conduct of the research.

Voluntary Participation: You are free to withdraw from the research study at any time, without any bad feelings. Your data collected in whatever part of the study you were currently participating in will be destroyed.

Reimbursement of Expenses: You will be provided with parking coupons for each visit. In addition, you will be compensated $10 for each visit.

Contact Names and Telephone Numbers:
If you have concerns about your rights as a study participant, you may contact the Human Research Ethics Board office at (780)-492-9724. This office has no affiliation with the study investigators.

Please contact the individual identified below if you have any questions or concerns:

Principal Investigator
Dr. Esther Kim, Assistant Professor, Department of Speech Pathology and Audiology
Phone: (780) 248-1542
Email: esther.kim@ualberta.ca

APPENDIX B

Participant Consent Form

CONSENT FORM (Phase III)

Part 1 (to be completed by the Principal Investigator):

Title of Project: Written Language Processing in Aphasia: Cognitive Mechanisms, Neural Substrates, and Evidence-Based Treatments

Principal Investigator: Dr. Esther Kim Phone Number(s): 780-248-1542

Part 2 (to be completed by the research subject):

	Yes	No
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to withdraw from the study at any time, without having to give a reason?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Do you understand who will have access to your records, including personally identifiable health information?	☐	☐
Do you give consent to be videotaped for scoring/research purposes?	☐	☐
Do you give consent to be videotaped for teaching/presentation purposes?	☐	☐

Who explained this study to you?

____

I agree to take part in this study: YES ☐ NO ☐

Signature of Research Subject

____

(Printed Name) ____ Date: ________________

Signature of Witness

____

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

Signature of Investigator or Designee ________________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH SUBJECT

APPENDIX C

Eye Tracking Stimuli- 40 Sentences

The party will last until the wee hours of the morning.
There was a brown bear blocking the road.
The boy kicked the ball over the fence.
I thought the dancers were very talented.
The little girl whispered in her mother's ear.
The young puppy dug up all of the flowers.
She could hear the music playing in the next room.
They waited over an hour for the rain to stop.
The man could not find his car keys anywhere.
The girl wore her helmet while riding her bike.
It was so hot that the candles melted.
The angry mob shouted outside city hall.
The shy boy was afraid to speak in front of the class.
She returned the dress to the store because it didn’t fit.
The girl in the choir sang at the top of her lungs.
The boy walked his dog around the block.
They decided it was finally time to sell their house.
The dog licked the boy all over his face.
The children walked down to the street for the festival.
The smell of her cookies made my mouth water.
The people complained that the train was too noisy.
He tried the new restaurant, despite the bad reviews.
The runners sprinted to the finish line.
The family went hiking in the mountains last week.
The baby clung to her mother while the stranger approached.
The sun shone through the open window.
The woman cracked the eggs into the frying pan.
Someday, I hope to sail around the world.
We are going to a family reunion this summer.
He waited for the nurse to give him his medicine.
The reporter asked a question about the case.
She will attend the brand new school in the fall.
The woman applied for the job at the last minute.
The fight broke out in the school yard.
I am taking a leave of absence from my job.
The student thought he failed the exam.
The severe storm caused the basement to flood.
The woman planted the seeds in her garden.
They visited their cabin at the lake every summer.
She kept reading the book until she was finished.

APPENDIX D

6-step ORLA Treatment Guide, taken from Cherney (2004)

Oral Reading for Language in Aphasia (ORLA)

1. The speech-language pathologist reads aloud to the patient, pointing to each word as he or she reads along. The length of the material may vary from 3 to 100 words, depending on the auditory comprehension skills of the patient.

2. The speech-language pathologist reads aloud to the patient again, pointing to each word as he or she reads along and encouraging the patient to also point to each word.

3. The speech-language pathologist reads the paragraph aloud together with the patient, while continuing to point to each word as he or she reads along. The patient also points to each word. The clinician adjusts the rate and volume of the oral reading according to the specific patient (e.g., reading a little ahead of the patient so he or she is able to hear the initial phonemes of the words; decreasing volume as he or she requires fewer cues).

4. For each line or sentence of the paragraph, the speech-language pathologist states a word that the patient must then identify. Words may be content words (e.g., nouns, verbs) or function words (e.g., pronouns, prepositions, conjunctions).

5. For each line or sentence of the paragraph, the speech-language pathologist points to a word for the patient to read aloud. Both content and function words are selected.

6. The patient reads the whole sentence aloud again in unison with the speech-language pathologist.

APPENDIX E

Sample Training Passage; 250 words, Flesch-Kincaid Grade 4.8

At your service

You may have seen them in shopping malls, restaurants, hospitals, movies, and schools. As a matter of fact, anywhere you go you may see them. They bark, wag their tails, and like to love and be loved. Plus, they do so much more. What are they? They are assistance dogs, or service dogs. These dogs help people with physical impairments. Service dogs go through very special training and are taught many important skills.

Dogs that will become service dogs must be smart, calm, and obedient. After all they will be responsible for their handler's safety and well-being. Some will be guide dogs that help people who are visually impaired. Others will be hearing dogs that alert handlers to sounds. Some, known as mobility assistance dogs, help their owners get around. They may pull wheelchairs or roll their owners over in bed. As you can see, service dogs are trained to help in many ways.

The first step in training a service dog begins with a volunteer known as a puppy raiser. Puppy raisers are dog lovers who are at least nine years old. Eight-week-old puppies are given to puppy raisers who will help them become confident, helpful dogs.

Puppy raisers teach basic commands such as *sit*, *down*, and *stay*. To get puppies to obey, puppy raisers use lots of praise. Food rewards are a no-no. Someday these dogs may have to help their handlers in restaurants. They need to be able to do this without being tempted by the food.

APPENDIX F

Sample Generalization Passage; 112 words, Flesch-Kincaid 4.6

Waves at the seashore are caused in part by wind and in part by tide. The wind gets a wave started by moving the water. Sometimes there is a wind when the tide is coming in. Then waves will be higher than they would be if there were the same wind and if the tide were going out. The wind and the tide push the wave.

Waves are also affected by the sea bottom. A smooth bottom that slopes gently will usually produce small, lapping waves. A rocky, hilly bottom with shallow water in one place and deep water in another will produce giant waves with the help of wind and tide.

APPENDIX G

Sample Generalization Passage Comprehension Questions

1. Waves at the seashore are caused by the
    a. wind
    b. tide
    c. both a and b
    d. neither a nor b

2. The article says that the wind
    a. starts waves by moving the water
    b. slows down the action of the waves
    c. has nothing to do with waves
    d. none of the above

3. When there is wind and the tide is coming in,
    a. both forces push the waves
    b. the two forces block each other
    c. the waves are terrible
    d. rain and thunder usually occur

4. The article says that waves are also affected by
    a. creatures living in the sea
    b. underwater plants
    c. the sea bottom
    d. the number of ships at sea

5. A smooth sea bottom that slopes gently will
    a. have a sandy floor
    b. have no wave action at all
    c. support many sea plants
    d. produce small, lapping waves

6. The article says that in part giant waves
    a. cause rocky, hilly seafloors
    b. are caused by rocky seafloors
    c. cause tides
    d. none of the above