MANIPULATING TEMPORAL COMPONENTS DURING SINGLE-WORD PROCESSING TO FACILITATE ACCESS TO STORED ORTHOGRAPHIC REPRESENTATIONS IN LETTER-BY-LETTER READERS

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ABSTRACT

This study investigated the benefits of rapid presentation of written words as a treatment strategy to enhance reading speed and accuracy in two participants with acquired alexia who are letter-by-letter readers. Previous studies of pure alexia have shown that when words are rapidly presented, participants can accurately perform lexical decision and category judgment tasks, yet they are unable to read words aloud. These studies suggest that rapid presentation of words could be used as a treatment technique to promote whole-word reading. It was predicted that treatment utilizing rapid presentation (250/500 ms) will increase reading speed and accuracy of both trained and untrained words compared to the words trained in standard presentation (5000 ms). A single-subject ABACA/ACABA multiple baseline treatment design was used. Treatment was provided twice per week for four weeks for both rapid and standard presentation treatment. Each session comprised a spoken-to-written word decision task and semantic category judgment task. Stimuli included 80 trained words divided between the two treatments and 20 untrained controls. Weekly probes to assess reading accuracy were administered after every two treatment sessions. Based on effect sizes, results showed no consistent unambiguous benefit for rapid or standard presentation treatment. However, possible generalization to untrained words due to rapid presentation treatment was observed. Future research is warranted to investigate the effectiveness of rapid presentation treatment in letter-by-letter readers.

This thesis is dedicated to my advisory committee, family,

and friends who have supported me

throughout graduate school.

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CHAPTER 1

INTRODUCTION

Pure alexia, or "letter-by-letter reading" is an acquired neurogenic reading disorder that results in the degradation of the connections between written letter identification system and the orthographic lexicon (Lacey, Lott, Snider, Sperling, & Friedman, 2010). This is typically caused by a lesion to the left occipito-temporal area, which affects the communication between the visual information and the language processing areas of the brain (Cohen et al., 2004; Damasio & Damasio, 1983; Friedman & Lott, 2000). Individuals with pure alexia often employ a letter-by-letter reading strategy since “whole-word” reading is impaired. As a result, these individuals take a significantly longer amount of time to read words that contain more letters, which is known as the word-length effect (Bub, Black, & Howell, 1989; Hanley & Kay, 1996). Barton, Hanif, Björnström, and Hills (2014) concluded that individuals with pure alexia demonstrate a word-length effect that is “ten- to a hundred-fold larger” than normal readers.

Three common approaches to rehabilitation of pure alexia exist in the relevant literature, including letter identification, word reading, and text reading (Starrfelt, Ólafsdóttir, & Arendt, 2013). Tactile-kinesthetic treatment is a common bottom-up approach in which patients are instructed to trace the outline of letters to improve reading speed and accuracy (Lott, Friedman, & Linebaugh, 1994; Lott & Friedman, 1999; Starrfelt et al., 2013). Multiple Oral Rereading (MOR) is an example of an approach that arguably uses both bottom-up and top-down processing. In this type of therapy, the individual is instructed to orally reread a given text multiple times per day until a certain

criterion is reached (Kim & Russo, 2010). Results of MOR treatment have shown improvement in both reading speed and accuracy (Beeson, Magloire, & Robey, 2005). Though multiple treatment approaches have been found to be effective in increasing reading speed and accuracy in letter-by-letter readers, a gold standard approach does not exist. In a review article by Starrfelt et al. (2013), very few well-designed studies in rehabilitation of pure alexia were found that used control data and statistical analyses to evaluate their findings. The authors state that future research is warranted utilizing control data and statistical methods.

A number of case studies involving rehabilitation of pure alexia have shown that when words are rapidly presented, letter-by-letter readers are able to accurately perform lexical decision and category judgments tasks, but are unable to orally read or identify the word (Coslett & Saffran, 1989; Coslett, Saffran, Greenbaum, & Schwartz, 1993; Friedman & Lott, 2000; Lambon Ralph, Hesketh, & Sage, 2004; Gonzalez Rothi & Moss, 1992; Shallice & Saffran, 1986;Woodhead et al., 2013). Lambon Ralph, Hesketh, and Sage (2004) refer to this ability as the "Saffran Effect."

Previous studies have used lexical decision, semantic judgment, and oral naming tasks using rapid presentation to facilitate whole-word reading in individuals with pure alexia, or letter-by-letter readers. Results indicated that when given a brief exposure time, the participants were able to suppress the use of letter-by-letter reading and activate lexical representations (Lambon Ralph, Hesketh, & Sage, 2004). One of the earliest studies to demonstrate the effectiveness of rapid presentation was investigated by Shallice and Saffran (1986). They presented words at a brief duration of 2-seconds to a letter-by-letter reader. Patient ML performed above chance on lexical decision and word

categorization tasks, but was unable to explicitly identify the words. Coslett and Saffran (1989) repeated these tasks with four patients who presented with pure alexia. Results were similar to Shallice and Saffran (1986), as all four patients did not explicitly identify words presented at 50-2000 ms, but performed above chance on lexical decision and category judgment tasks. Coslett, Saffran, Greenbaum, and Schwartz (1993) also explored the use of brief presentation in one participant who used letter-by-letter reading They found that the participant performed better during the lexical decision and semantic category judgment tasks when words were presented at 249 ms, compared to an explicit naming task with words presented at 2000 ms. The authors believe this is due to the use of a letter-by-letter reading strategy during the naming task vs. a "whole word" reading strategy used during the categorization and lexical decision tasks.

Gonzalez Rothi and Moss (1992) investigated rapid presentation as a reading treatment to facilitate access to the semantic route in a patient with pure alexia, who utilized the letter-by-letter reading as a compensatory strategy. The patient completed three different treatment tasks with stimuli presented tachistoscopically: a homophone task, a semantic decision task and a lexical decision task. They found an increase in both speed and accuracy after 20 treatment sessions. However, the authors did not include control stimuli and therefore it was difficult to separate the effectiveness of the treatment to repeated exposure effects. Friedman and Lott (2000) employed a similar training program using rapid presentation of words with immediate feedback in a patient with pure alexia, or letter-by-letter reader. Tasks included category judgment and oral reading. Results showed improvement in both speed and accuracy of trained words, although generalization effects were not observed. The use of rapid whole-word training in pure

alexia was also explored by Ablinger and Domahs (2009) in a participant with impaired single-letter identification. The results of this study showed improvements in word reading speed and accuracy for trained and untrained words. The authors attributed the increase in word reading to strengthened lexical-semantic representations and letter identification. More recently, Woodhead et al. (2013) investigated the use of a whole-word training program to suppress letter-by-letter reading in nine patients with pure alexia. They used a brief exposure time of 500ms during a same/different discrimination task. Similarly, results showed improvements in trained items and generalization did not occur. In addition, patients demonstrated a reduced word-length effect resulting in faster reading times for longer words.

There is little consensus in the literature to explain how letter-by-letter readers are able to access lexical representations, but cannot identify the word. The first explanation proposes "two parallel reading systems" – one in each hemisphere – that support implicit and explicit processing (Saffran & Coslett, 1998; Lambon Ralph, Hesketh, & Sage, 2004). Saffran and Coslett (1998) suggest that patients with pure alexia utilize letter-by-letter reading as a compensatory strategy when the left hemisphere is damaged because of the inability to explicitly identify the word. They argue that patients with pure alexia can implicitly process whole words (i.e. "covert reading") when given a brief exposure time using the right-hemisphere. In other words, two separate reading systems exist; the left-hemisphere mediates explicit processing, while the right hemisphere is responsible for implicit recognition.

The alternative explanation is the "two processes theory" (Lambon Ralph, Hesketh, & Sage, 2004), which argues a single system that is responsible for two

processes: compensatory letter-by-letter reading and whole-word recognition (Behrmann, Plaut, & Nelson, 1998). The whole-word reading process and compensatory letter-by-letter strategy work together in one system to facilitate whole-word recognition. Friedman and Lott (2000) also believe there are two processes, but at the letter identification level. They used a cognitive model for single word reading to explain reading in pure alexia. In that model, letter identification is broken up into two routes: "automatic parallel" and "explicit serial." In the automatic parallel route, letters are processed simultaneously, which allows for whole-word reading, while the explicit serial route utilizes letter-by-letter reading. Both of these routes access the orthographic lexicon, or stored word system. In their study, Friedman and Lott concluded that the repeated presentation of rapidly presented words with feedback strengthened the link between the visual processing system and the stored orthographic lexicon. The increase in accuracy of oral reading did not generalize to untrained words. However, they found an increase in speed of reading for words that were not trained. The authors do not agree with Coslett and colleagues, who state that the rapid presentation of words engages the sematic reading route via the right hemisphere. Rather, they believe the rapid presentation of words facilitates the automatic parallel processing of letters, which strengthens the link to orthographic representations. While disagreement exists about the underlying processes in pure alexia, there is agreement that whole-word reading in letter-by-letter readers is possible when written words are rapidly presented.

The current study aims to investigate the benefits of rapid presentation as a treatment strategy to enhance reading speed and accuracy in letter-by-letter readers. Results from previous studies suggest that the use of rapid presentation of words could be

used as a treatment technique to promote whole word reading in letter-by-letter readers. To date, no study has compared the use of rapid presentation to standard presentation in rehabilitation of letter-by-letter reading. Due to the limited exposure time, the participants, both letter-by-letter readers, will be forced to utilize an implicit "whole-word" reading strategy and suppress the use of letter-by-letter reading. It is predicted that after treatment utilizing rapid presentation (RP), reading of both trained and untrained words will increase in both speed and accuracy compared to the items trained in the standard presentation (SP) treatment.

CHAPTER 2

METHODS

Participants

Two participants with acquired alexia were enrolled in this study. To be included in this study, participants had to 1) sustain a posterior left-hemisphere brain injury 2) acquire a reading deficit when previously literate 3) demonstrate diagnostic criteria for letter-by-letter reading as evidence by a clear word length effect (i.e. as the length of the word increases, reading time increases) and 4) show evidence of extremely slow reading time. In addition to having characteristics of letter-by-letter reading, both participants also presented with mild anomia.

Participant 1

At the time of the evaluation, Participant 1 (P1) was a 54-year old male who sustained a left intracerebral hemorrhage (ICH) involving the medial left temporal lobe and left basal ganglia in 2016. Following his stroke, Participant 1 presented with fluent aphasia, a right visual field deficit, and "alexia without agraphia." He received speech and language therapy at Magee Rehabilitation Hospital. Prior to his stroke, Participant 1 worked as a lawyer. At the time of the study, he presented with a mild ride side visual field deficit, though no hemiparesis, neglect, or limb praxis was present.

Participant 2

At the time of evaluation, Participant 2 (P2) was a 67-year old male who sustained a left temporal intracerebral hemorrhage (ICH) in 2008. Initially following his

accident, he presented with aphasia, visual perceptual deficits including a right field cut, and "alexia without agraphia". He received speech and language therapy at Magee Rehabilitation Hospital. Prior to his ICH, Participant 2 was a dance professor at Temple University. At the time of the study, he also presented with a mild ride side visual field deficit, though no hemiparesis, neglect, or limb praxis was present.

Pre- Treatment Assessment

Pre-treatment assessments were administered to confirm letter-by-letter reading and determine pretreatment reading abilities. Visual scanning and clock drawing tasks were administered to rule out neglect. Items from each of the following subtests from the *Psycholinguistic Assessments of Language Processing in Aphasia* (PALPA) (Kay, Lesser, & Coltheart, 1992) were administered: Letter Discrimination: Letters in Words & Nonwords, Letter Naming & Sounding, Letter Length Reading, Spoken Letter-Written Letter Matching, Spelling-Sound Regularity and Reading, Imageability & Frequency Visual Lexical Decision, Grammatical Class x Imageability Reading, Lexical Morphology and Reading, and Nonword Reading. The *Gray Oral Reading Task-Fifth Edition* (GORT-5) (Wiederholt & Bryant, 2012) was used to assess reading speed at the short passage level and was timed using a stopwatch (in seconds). Unrelated control tasks (i.e. Corsi block task, written word span task) were included to establish experimental control.

Results from the visual scanning and clock drawing tasks showed no evidence of right-side neglect for either participant. Other types of dyslexia, such as surface dyslexia and phonological dyslexia, were ruled out as both participants could read irregularly

spelled words (e.g. yacht) and functor words (e.g. though). The Letter Length Reading subtest was administered to determine the presence of letter-by-letter reading as evidenced by a word-length effect. This subtest requires the participant to read words increasing in length with 3-6 phonemes. Reading duration was timed using a stopwatch. Participant 1 demonstrated a clear word-length effect, as the average reading duration increased with the length of words (3-letters: 1.31 sec; 4-letters: 2.68 sec; 5-letters: 2.89 sec; 6-letters: 3.26 sec). Many of Participant 1's errors in Nonword Reading and Lexical Morphology and Reading subtests were at the end of the word (e.g. "cloud" for cloudy). Participant 2 exhibited a word length effect (3 letters = 2.11 sec; 4-letters = 2.47 sec; 5-letters = 2.29 sec; 6-letters = 4.22 sec). In the Lexical Morphology and Reading subtest, all of Participant 2's errors were noted at the end of words (e.g. "smile" for smiled).

Table 1

Pre- Treatment Testing

Test	P1	P2
Psycholinguistic Assessments of Language Processing in Aphasia (PALPA)		
Letter Length Reading	23/24	23/23
Letter Discrimination: Letters in Words & Nonwords	28/30	29/30
Spoken Letter-Written Letter Matching	26/26	26/26
Nonword Reading	14/24	21/24
Spelling-Sound Regularity and Reading	22/30	30/30
Imageability & Frequency Visual Lexical Decision	53/56	52/56
Lexical Morphology and Reading	26/45	42/45
Grammatical Class x Imageability Reading	32/40	38/40
Letter Naming & Sounding	26/26	25/26
Gray Oral Reading Task-Fifth Edition (GORT-5)		
17-word passage	28.0 sec	20.3 sec
41-word passage	89.9 sec	51.6 sec
52-word passage	97.0 sec	52.2 sec
81-word passage	197.2 sec	101.9 sec
Written Word Span Task	2.6	4.8
Corsi Block Task	3.67	5.67

Design

A single-subject ABACA/ACABA design with a multiple baseline across behaviors component was used to assess the effects of two treatment types: rapid vs. standard presentation treatment on reading speed and accuracy. An across-subjects counterbalancing design was used to control for order effects (Beeson & Robey, 2006; Goodwin & Goodwin, 2013). A pre-treatment assessment, baselines, weekly probes, post-treatment probes between treatment conditions, and maintenance probes were included. Selected post-treatment assessments were also administered. Each treatment was provided twice per week for two weeks. There were a total of four training sessions for each treatment type (rapid and standard presentation treatment). Figure 1 displays a schematic of treatment design.

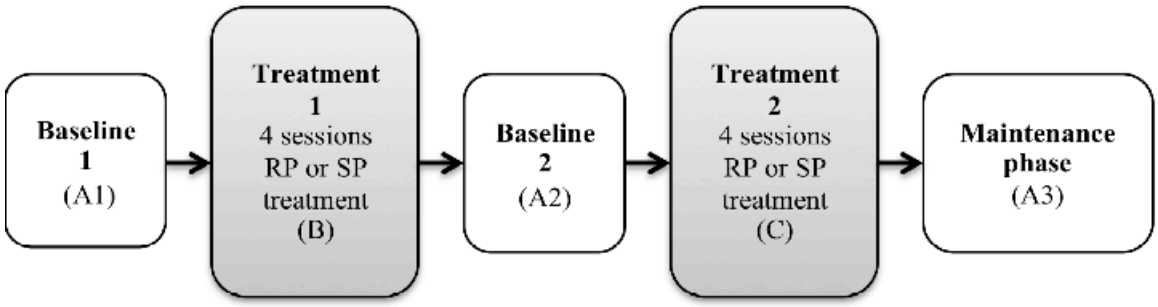

Figure 1. Schematic of treatment design.

Stimuli

A total of 80 training items (40 for the RP condition, 40 for the SP condition) and 20 control items were matched for word length, part of speech, morphology, frequency, imageability and orthographic neighborhood size. Stimuli varied between 5-6 graphemes in length. Stimuli were randomly assigned to the rapid presentation, standard presentation, or control conditions.

Procedures

Baselines/Probes Procedures

Before treatment, three baseline sessions were administered for each participant in order to compute effect sizes (Beeson & Robey, 2006). A total of 100 items were included in the baseline measures, including 40 words from the rapid presentation condition, 40 words from standard presentation condition, and 20 untrained control items. Once treatment was initiated, weekly probes after every two treatment sessions were administered using the 80 trained words and 20 untrained controls. Additional probes were administered between the two phases to confirm a stable baseline before beginning the second phase of treatment. The baselines and probe task consisted of oral reading of the trained and untrained words presented for 1000 ms. Each participant had 5000 ms to respond; if the participant did not respond within 5000 ms, the word was counted as incorrect. The participants' first complete response was scored (correct vs. incorrect); self-corrections were noted, but not counted as correct.

Treatment Procedures

Treatment sessions lasted approximately 1 hour and were conducted by a graduate student clinician in the Speech, Language, and Hearing Sciences program. Sessions took place in a quiet room and were recorded using a voice recorder. Each treatment session comprised two tasks: 1 – deciding whether written and spoken words were the same or different 2- making a semantic category judgment given a written word. All treatment tasks were conducted using E-prime software (Psychology Software Tools, Inc., Pittsburgh, PA; Schneider, Eschman, & Zuccolotto, 2002). During the rapid presentation treatment, words were presented at 500 ms for participant 1 and 250 ms for participant 2. In the standard presentation condition, words were presented at 5000 ms for both participants. Participant 1 received rapid presentation treatment first (Phase 1), followed by standard presentation treatment (Phase 2). This was counterbalanced for Participant 2, who received standard presentation treatment first, followed by rapid presentation treatment.

During the spoken-to-written word decision task, the participant was presented with a spoken and written word pair. The spoken word was presented 1000 ms before the written word. The participant responded yes/no to indicate if the two words matched. The response was recorded using a button-press on E-prime software to indicate a correct vs. incorrect response. The "non-match" pairs differed by 1-3 graphemes at the beginning, middle or end of the word. Half of the testing words were matched, while the other half was different. In other words, there were an equal number of "yes" and "no" responses.

During the category judgment task, the participant responded yes/no to indicate if the written word belonged to a given category. The category name was presented

auditorily 1000 ms before the written word. Half of the testing words belonged in the given category, while half of the words did not. The words that did not belong, or foils, differed by 1-2 graphemes at the beginning, middle, or end of the word. The response was recorded through the use of a button-press using E-prime software. Feedback was provided during both training tasks using E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA). Immediately after the participant's response, the word "Correct" in green or "Incorrect" in red were presented to the participant. Practice items were included to ensure the participant understood the task.

Data Analysis

Rapid presentation treatment and standard presentation treatment were compared based on the accuracy and speed of trained and untrained items obtained during pre-treatment and post-treatment data. Probes were scored by the treating graduate student clinician in the Speech, Language, and Hearing Sciences program. A certified speech-language pathologist double scored ~20-25% of the baseline and probes. To calculate inter-rater reliability, a blinded rater scored 3/22 (13.6%) of the probes using audio recordings. It is important to note that some of the probe items were removed for the blinded rater due to the inability to time after 5000 ms using the audio recording. The inter-rater reliability between the graduate student clinician and blinded rater was calculated to be 91.87%. Data were analyzed using visual analysis, as this is a standard way of analyzing single-subject design treatment study data (Kratochwill et al., 2010). In addition, standardized effect sizes were computed for each condition to quantify condition differences. Effect sizes were computed using the formula d = (mean POST –

mean PRE) / standard deviation PRE (Beeson & Robey, 2006; Busk & Serlin, 1992). Based on Maas and Farinella (2012), we considered an effect to be present when d >1, indicating that the post-treatment performance exceeded the standard deviation pre-treatment.

CHAPTER 4

RESULTS

Figure 2 and Figure 3 shown below display the participants' scores (percent correct) on the baselines, probes, and post-treatment assessment, which involved oral reading of the trained and untrained written words presented for 1000 ms. Table 2 and Table 3 show the effect sizes for each participant.

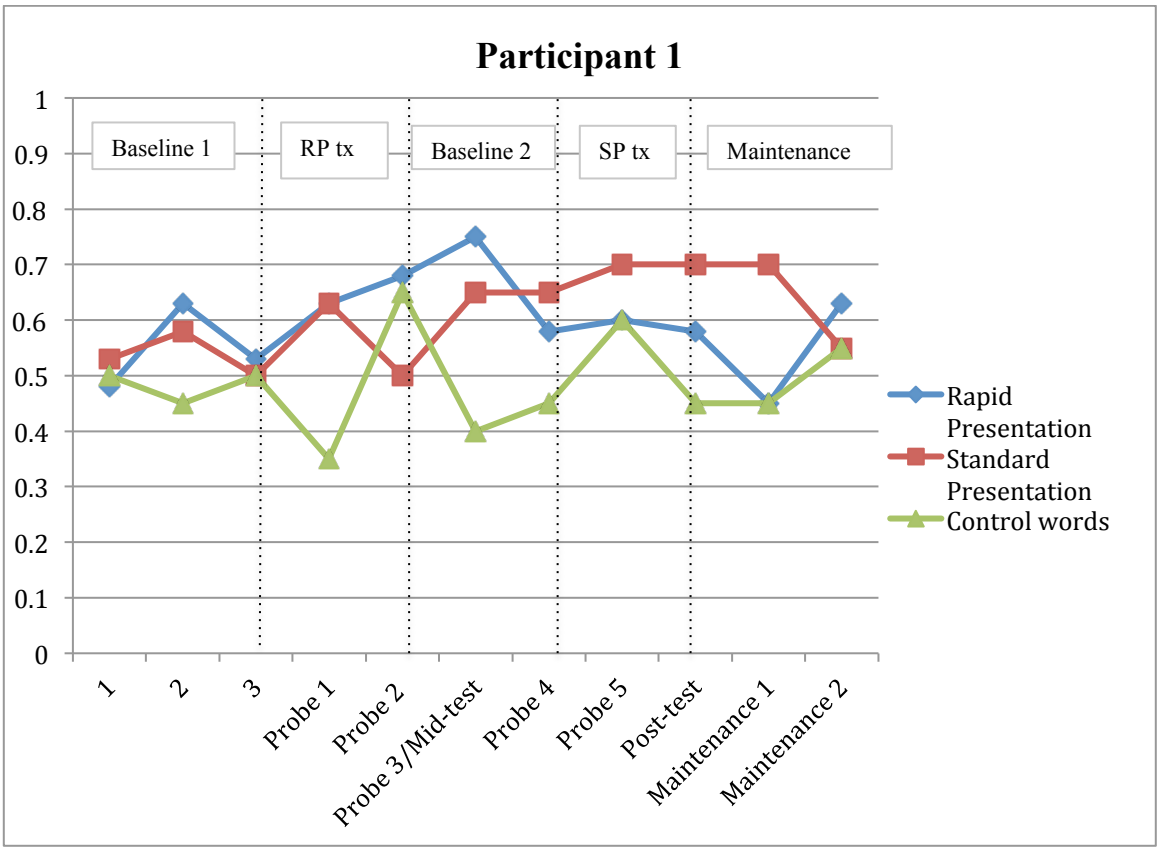

Figure 2. Graphical representation of Participant 1's scores.

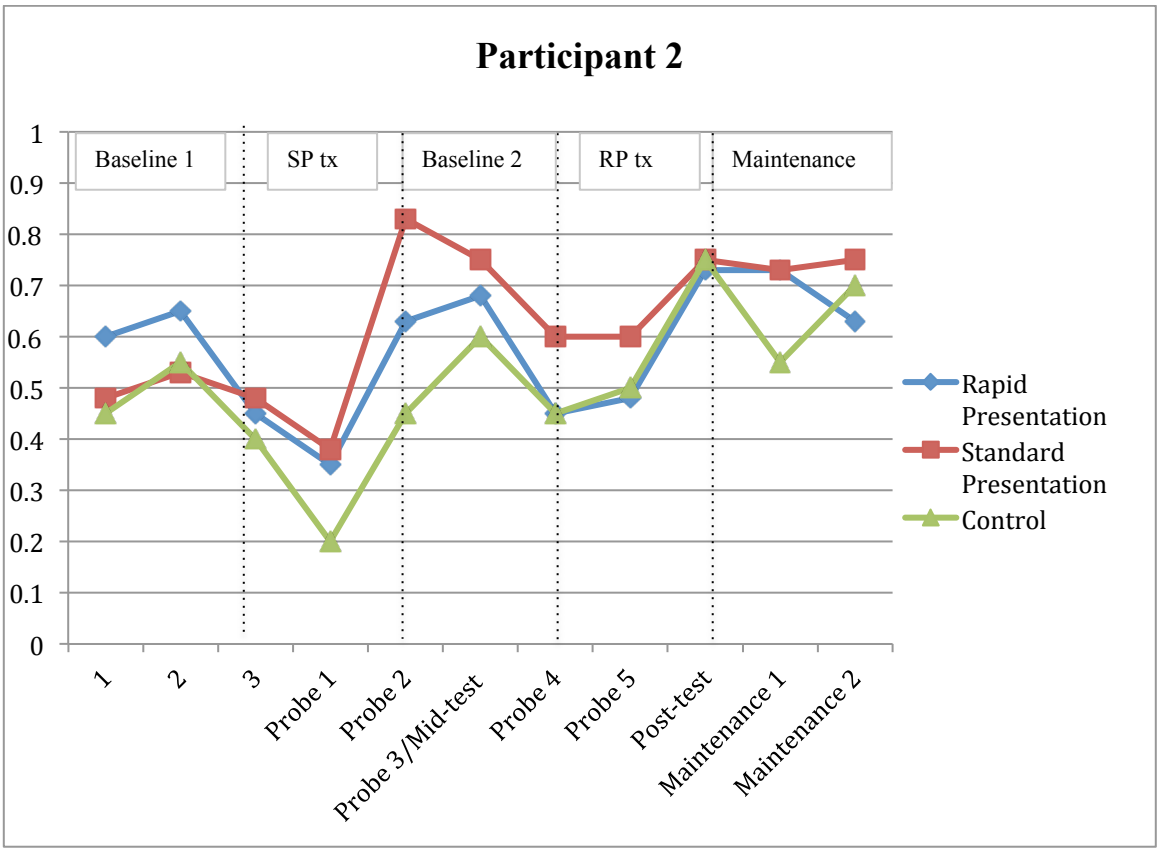

Figure 3. Graphical representation of Participant 2's scores.

Table 2

Effect sizes participant 1

	Phase 1 (RP tx)	Phase 2 (SP tx)
RP words	**1.5**	-1.33
SP words	1.5	**0.56**
Control	0.67	-0.15

Note. Bold = treated words

Table 3

Effect sizes participant 2

	Phase 1 (SP tx)	Phase 2 (RP tx)
RP words	0.20	**0.92**
SP words	**7.67**	0.08
Control	0.38	1.89

Note. Bold = treated words

Participant 1

Visual analysis (See Figure 2) of Participant 1's average scores shows that all word sets were relatively equal during baseline. Both rapid presentation and standard presentation word sets declined before the first treatment phase (RP treatment); the control words remained stable. During the RP treatment, the trained RP words steadily increased in accuracy, while the SP words remained constant and the control set was variable. During the second baseline phase, the RP words initially continued to increase, but then declined before initiating the second treatment phase (SP treatment). The SP words remained stable and the control set was variable before phase 2. During SP treatment, the SP words slightly increased, but then remained constant; the RP words and control set did not change. During the maintenance phase, the SP words declined, while the RP words and control set increased.

Based on effect sizes, the RP treatment (Phase 1) showed an effect (1.5) for both RP words and the (as-yet untrained) SP words, but not untrained control items (0.67). During SP treatment (Phase 2), the RP words declined (ES = -1.33) while untrained control words and the trained SP words did not change (ES = -0.15 and 0.56).

Participant 2

Visual analysis (See Figure 3) of Participant 2's average scores shows that all word sets declined before initiation of the first treatment phase (SP treatment). During the SP treatment, the SP words greatly increased in accuracy, while the RP words initially decreased and then increased. The control set remained relatively stable. During the second baseline phase, the RP words and control set initially increased, but then all treatment sets decreased before initiating the second treatment phase (RP treatment). However, the SP words were still greater in accuracy compared to RP and control sets. During RP treatment, the RP words and control set largely increased in accuracy, while the SP words initially remained constant and then improved.

Based on effect sizes, the SP treatment (Phase 1) showed an effect (7.67) for only the SP words; the untrained words (RP and control) did not show an effect (0.20 and 0.38). During RP treatment (Phase 2), the RP words and SP words did not show an effect (0.92 and 0.08) but untrained control words did improve (ES = 1.89).

Treatment Task Results

Results from the spoken-to-written word decision task and category judgment task are consistent with Coslett, Saffran and colleagues' prior studies, as both participants

exhibited the "Saffran Effect." That is, both participants performed above chance on these tasks when the words were rapidly presented at 250 ms and 500 ms. On average, Participant 1 was 80% accurate during the spoken-to-written word decision task, and 69% accurate during the category judgment task. Participant 2 was 86% accurate during the spoken-to-written word decision task, and 79% accurate during the category judgment task. It is also important to note that Participant 2 occasionally fatigued during treatment sessions and therefore, did not complete the total 320 trials for each task (i.e. 2 sets of 40 trials during each treatment session, or 80 trials multiplied by 4 treatment sessions). Generally, Participant 2 completed 240 trials per task prior to discontinuing the task.

Post- Treatment Assessment

Table 4 below shows a comparison of pre- and post-treatment testing results for both Participant 1 and Participant 2.

Table 4

Pre- and Post- Treatment Testing

Test	P1		P2	
	Pre	*Post*	*Pre*	*Post*
Written Word Span Task	2.6	2.8	4.8	6.2
Corsi Block Task	3.67	5.0	5.67	4.33
Gray Oral Reading Task-Fifth Edition (GORT-5)				
17-word passage	28.0s	26.7s	20.3s	17.6s
41-word passage	89.9s	132.0s	51.6s	46.4s
52-word passage	97.0s	120.0s	52.2s	71.4s
81-word passage	197.2s	210.2s	101.9s	100.0s

We posited that an increase in the Written Word Span task may indicate improvements in whole-word reading, as participants would be able to process greater amounts of verbal information given decreased effort to read the written words.

Participant 1's span slightly increased, while Participant 2 demonstrated a large increase in written word span. There was no significant change in reading duration at the passage level for both participants. In addition to these tasks, the Letter Length Reading subtest from the PALPA was re-administered to assess improvements in single word reading duration. Both Participant 1 and Participant 2's reading duration decreased from pre- to post-treatment for words containing 3-6 letters, which may suggest improved reading speed. However, it is difficult to discern if these improvements are due to the rapid presentation treatment.

CHAPTER 5

DISCUSSION

This study investigated the benefits of rapid presentation of written words as a treatment strategy to enhance reading speed and accuracy in letter-by-letter readers. Rapid presentation treatment (250/500 ms) was compared to a standard word presentation (5000 ms). We posited that the rapid presentation of words would force participants to read the words using an "implicit" or "automatic" processing system, whereas the standard presentation treatment allows the participants to use the laborious letter-by-letter reading strategy. It was predicted that treatment utilizing rapid presentation would increase reading speed and accuracy of both trained and untrained words compared to the standard presentation treatment.

The results of this study are a bit complicated. Based on effect sizes, no consistent unambiguous benefit was observed for rapid or standard word presentation treatment. In addition, visual analysis of the participants' results shows no significant treatment effect. Participant 1 demonstrated the same treatment effect for both RP and SP words during RP treatment (phase 1). Therefore, it is difficult to interpret this change as due to RP treatment, although this may suggest generalization for RP treatment to the untrained SP words. Visual inspection of P1's results shows a consistent improvement of RP words during phase 1. In addition, the RP words declined during the standard word presentation treatment, which may indicate the participant reverted back to using the letter-by-letter reading strategy, rather than using "whole-word" reading. Alternatively for Participant 2, SP treatment showed a large effect size for the trained SP words. RP treatment did not show an effect; however, untrained control words improved, which may suggest

generalization due to RP treatment. In addition, there appears to be an order of presentation effect, as both participants showed the largest effect size during phase 1. It is possible that both participants became accustomed to the task and stimuli during the first phase, which would affect the room for potential improvement in phase 2.

Overall, the results of this study do not show a significant treatment effect for rapid presentation treatment in letter-by-letter readers. However, the possibility of generalization from rapid presentation treatment to untrained words is promising for treatment in individuals who use letter-by-letter reading. One important research question to consider is whether the minor treatment effects observed were due to repeated exposure to the stimuli, rather than presentation time. The participants were exposed to the same set of words throughout the entire study. It is possible that both participants' reading speed and accuracy improved due to the repeated presentation of those words. The repeated exposure to a set of words is similar to the Multiple Oral Re-Reading (MOR) treatment used in rehabilitation of pure alexia, in which the participant re-reads a given passage multiple times per day until a certain criterion is met (Lacey et al., 2010). As stated in the literature review, MOR treatment has been shown to improve reading speed on trained and untrained passages. Lacey et al. (2010) suggest that the effects of MOR treatment is due to bottom-up processes, or ability to recognize single-words, rather than top-down processes. If this is the case, it is possible that the benefits of rapid presentation observed in previous studies is not due to the brief presentation, or forced "whole-word" reading, but rather due to repeated exposure to stimuli. It is possible that the re-reading at the single-word level increases the link between the letter-identification

system and stored orthographic representations, which in turn increases reading speed and accuracy for those words.

Limitations and Future Research

Several factors may account for the unclear findings in this study. One reason is that this was a facilitation study and the treatment duration was very short (i.e. four sessions for each treatment type). Previous studies that found positive effects using rapid presentation incorporated much longer treatment durations. For example, Gonzalez Rothi and Moss (1992) found an increase in reading speech and accuracy following 20 treatment sessions. Thus, it is unlikely that either participant would make significant gains during such a limited period of time. Another limiting factor in this study is the small number of participants that were included. It is difficult to hypothesize that rapid presentation treatment would be a beneficial treatment technique for other letter-by-letter readers for this reason. Additionally, the treatment design could be another limiting factor, given the order of presentation effect observed and the repeated exposure to the stimuli. If the goal is generalization, then future research should consider training a different set of words from those assessed during post-treatment to separate generalization vs. treatment effects. It may be beneficial to utilize words that vary in morphology, imageability, and frequency, to further understand the underlying impairments in letter-by-letter readers. It would also be interesting to evaluate the presence of error patterns. Finally, to make this treatment more functional, it would be advantageous to consider comprehension, as well as using rapid presentation with more difficult linguistic contexts (i.e. phrase or sentence level).

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