University of Alberta

Orthographic Learning in Adults with Reading Difficulties

by

Rickie Wai Kuen Hung

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Dedication

To my parents, whose love and support has helped me persevere on the path toward greater things.

To my friends in Edmonton, who made me feel at home away from home.

Abstract

This study examined the nature and cognitive predictors of orthographic learning in 20 adults with dyslexia and 27 controls. Orthographic learning was assessed with an orthographic choice task and with eye movements in reading a passage embedded with novel words. Participants also completed tasks measuring phonological awareness and rapid automatized naming (RAN). The results indicated that adults with dyslexia learned new words at a rate comparable to or even faster than that of typical readers, but were slower in recalling orthographic representations. Phonological awareness predicted orthographic learning, while RAN was not a significant predictor. These results confirm some previous findings on the predictors of orthographic learning, but also challenge claims that individuals with dyslexia exhibit impairment in orthographic learning.

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Chapter 1: Introduction

Reading is a skill that many children learn to do at an early age and one that is continuously applied throughout adulthood as new words and texts are encountered. Ehri (2005) proposed that reading develops in four phases. In the pre-alphabetic phase, spoken words are arbitrarily associated with symbols such as pictures, patterns or letters. In the partial alphabetic phase, knowledge of alphabet names and sounds is used to recognize words. In the full alphabetic phase, phonemic knowledge is applied in reading words from letter-sound correspondences. In this phase, phonological processing, or the ability to use sounds in processing language (Wagner & Torgesen, 1987), contributes to reading accuracy and fluency (Gottardo, Stanovich, & Siegel, 1996; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). With instruction and practice, words are eventually recognized automatically as chunks of familiar letter sequences called orthographic representations (Ehri, 2005). At this point, the reader has moved into the consolidated alphabetic phase, which allows for faster word recognition and ultimately improved literacy. Forming orthographic representations to aid automatic word recognition is termed orthographic learning (Castles & Nation, 2006).

The sequence of reading development phases outlined by Ehri (2005) has received empirical support for typical readers (e.g., Kerek & Niemi, 2009; Sprenger-Charolles, Siegel, Bechennec, & Serniclaes, 2003), but whether or not individuals with dyslexia follow a similar sequential reading development remains in question. Individuals with dyslexia have already been shown to display phonological processing deficits (e.g., Stanovich & Siegel, 1994; Vellutino, Scanlon, & Spearing, 1995; Wagner, Torgesen, & Rashotte, 1994), but the nature of orthographic learning deficits has been less clear.

There is support in the literature that readers with dyslexia are unable to form orthographic representations (e.g., Bruck, 1993; Reitsma, 1983), but there are also reports for individuals with dyslexia learning orthographically, albeit at a slower pace than typical readers (Ehri & Wilce, 1983; Share & Shalev, 2004). Most of these studies have focused on children. To extend models of reading development to adulthood, it is important to explore the nature of orthographic learning in adults. The goal of this study is to compare orthographic learning skills between typical adults and adults with dyslexia, and to see what cognitive factors may contribute towards orthographic learning. This study begins with a review of the literature on orthographic learning, followed by an outline of the steps taken to assess orthographic learning and reading-related factors in adults with and without dyslexia. Finally, the results are analyzed and discussed in light of existing research. Implications for reading models and future research directions are also presented.

Chapter 2: Literature Review

Orthographic learning involves acquiring word-specific representations as well as conventional orthographic patterns (e.g., Conners, Loveall, Moore, Hume, & Maddox, 2011; Nation, 2008; Siegel, Share, & Geva, 1995). The knowledge acquired from orthographic learning can speed up reading of words that have already been read, and of words that contain familiar letter patterns. Reitsma (1983) found in a sample of Dutch children that four exposures to a new word were sufficient for the formation of orthographic representations, as reflected in target words being read faster than words with slightly altered spelling but preserved pronunciation. However, there is also some evidence from a study with Hebrew children that representations may be formed after only one exposure in connected text, with lasting effects of up to a month (Share, 2004).

New words presented more times are more easily recognized than words presented fewer times (e.g., Bowey & Muller, 2005; Nation, Angell, & Castles, 2007). Additionally, initial exposure results in the strongest learning effect relative to learning that occurs after subsequent exposures (de Jong & Share, 2007); that is, when encountering a new word several times in print, the degree of increase in word-reading speed is greatest from the first to the second exposure.

To assess orthographic learning in experimental settings researchers have often utilized pseudowords, or pronounceable non-words. A widely used task is orthographic choice (Castles & Nation, 2008), where individuals are first presented with a pseudoword (e.g., zeet) and, after some time has elapsed, are presented with the same pseudoword alongside a homophone and a visually similar item (e.g., zeet, zeat, zeel). Individuals are then asked to select the pseudoword they had seen previously as quickly as possible. The number of times a target pseudoword is presented in the learning phase may also be manipulated. The assumption is that the pseudowords exposed more times will be more quickly recognized than those exposed fewer times (e.g., Bowey & Muller, 2005; Share, 2004).

Another method for assessing orthographic learning involves masked priming (McKague, David, Pratt, & Johnston, 2008). A priming letter combination is flashed briefly before the target pseudoword is presented. The prime item can be related or unrelated to the target pseudoword (e.g., relevant priming “zeet” with “zeet” versus irrelevant priming “zeet” with “kyle”). The assumption is that the relevant prime items are able to facilitate pseudoword recall, and the level of facilitation reflects the extent of orthographic learning.

The Self-Teaching Hypothesis

A prominent theoretical account explaining how orthographic learning occurs is the self-teaching hypothesis. According to the self-teaching hypothesis readers form orthographic representations of novel words by using a self-teaching mechanism which relies on successful phonological recoding of words (see Share, 1995). Share (1999) tested the self-teaching hypothesis by having Hebrew children read passages embedded with pseudowords and then asking them to identify, name, and spell these pseudowords a few days later. Most of the children were able to do so accurately, suggesting that orthographic learning took place. To demonstrate that phonological processing contributed to learning, Share introduced conditions that minimized children's phonological processing when viewing the pseudowords, and found orthographic learning to significantly decrease as a result. Kyte and Johnson (2006) also showed that English-speaking children who read aloud target pseudowords during learning trials recognized subsequently the targets quicker compared to individuals who were required to say distracter syllables during the initial learning phase.

Self-teaching has also been demonstrated in studies with adults. For example, Maloney, Risko, O'Malley, and Besner (2009) found that college students learned pseudowords varying from three to six letters in length. Naming latency was longer for longer items in the first exposure, but after four exposures to the same items, naming latencies were relatively equal for short and long pseudowords, suggesting that orthographic representations were formed. On learning trials in a subsequent experiment, Maloney et al. (2009) asked participants to identify whether pseudowords were written in lower or upper case letters rather than reading the items, thus attenuating phonological recoding. In this instance, naming latencies did not decrease with the number of exposures. These results suggest that orthographic learning was attenuated when phonological processing was hindered, a finding that is in line with the self-teaching hypothesis.

In another study, accuracy in spelling pseudowords was enhanced when phonological information was available as audio pronunciation recordings or as self-generated representations during learning trials, demonstrating the contribution of phonological information toward orthographic learning (Chalmers

& Burt, 2008). Utilizing variances in orthographic consistency, Burt and Blackwell (2008) found that pseudowords with only one pronunciation not shared with an alternate spelling (e.g., snobe) were learned much more easily than pseudowords whose pronunciation could be reproduced with an alternate spelling (e.g., yirth, yerth), again suggesting the presence of phonological influences on orthographic learning. This consistency effect was also found in young readers (Ricketts, Bishop, & Nation, 2008).

To summarize, the self-teaching hypothesis, which posits that phonological recoding serves as a self-teaching mechanism in orthographic learning, has received empirical support in studies with children and adults. Phonological recoding, when experimentally compromised, resulted in impaired orthographic learning.

Orthographic Learning and Dyslexia

Typical readers have been shown to form orthographic representations of newly learned words after four exposures, while poor readers were not able to do so (Reitsma, 1983). Poor readers were consistently slower than skilled readers in reading new words, despite receiving over ten practice trials (Ehri & Wilce, 1983; Manis, 1985). Bruck (1993) also reported that adults with a childhood diagnosis of dyslexia remained slow at recognizing novel words that were presented multiple times. Although Bruck (1993) concluded that individuals with dyslexia were not able to achieve orthographic reading of words, Ehri and Wilce (1983) suggested that they had the ability to do so, but only at a very slow pace. Recent studies have also reported the presence of orthographic learning, but with difficulties, in children (Ehri & Saltmarsh, 1995; Share & Shalev, 2004) and adults with dyslexia (Pitchford, Ledgeway, & Masterson, 2009). Results from Share and Shalev's (2004) study also suggested that orthographic learning in children with dyslexia was delayed, not absent.

Cognitive Predictors of Orthographic Learning

One may wonder how individuals with phonological recoding difficulties achieve orthographic learning. In addition to recoding, there may be other cognitive skills that facilitate the formation of orthographic representations. Phonological awareness has been shown to be a strong predictor of phonological recoding (e.g., Lenchner, Gerber, & Routh, 1990; Manis, Doi, & Bhadha, 2000; Torgesen et al., 1997). Phonological awareness is defined as an individual's sensitivity toward sounds in oral language (Wagner & Torgesen, 1987). If recoding is the self-teaching mechanism by which orthographic learning takes place and if phonological awareness is one of the best predictors of phonological recoding (e.g., Hulme, Hatcher, Nation, Brown, Adams, & Stuart, 2002; Parrila, Kirby, & McQuarrie, 2004) then phonological awareness should also predict orthographic learning.

According to Ehri (1996), orthographic learning in children is a product of phonological awareness, since reading development begins with awareness of sounds of spoken language, but others have suggested that orthographic learning can develop independent of phonological awareness (Masterson & Apel, 2000). Evidence in support of this argument came from studies with pre-school children who, even though they were at the very early stages of phonological awareness development, demonstrated sensitivity to orthographic patterns by recognizing easier pseudowords with legal consonant pairs than homophones with illegal consonant pairs (Cassar & Treiman, 1997; Wright & Ehri, 2007). Pre-school children have also been shown to spell newly learned pseudowords with high orthographic probabilities better than those with low orthographic probabilities, suggesting that the children were influenced by orthographic information in learning new letter combinations (Apel, Wolter, & Masterson, 2006). Summarizing the findings of these studies, Apel (2009) concluded that children at the early stages of reading development are capable of orthographic learning independent from phonological awareness. However, others maintained that without an awareness of sounds in spoken words, it is not possible to learn about the correspondences between written words and their sounds (e.g., Gough & Hillinger, 1980). Goswami (1993) suggested that awareness of speech sounds would help children to associate the sounds with letter clusters as individual units. The idea that phonological awareness is a prerequisite skill for higher order reading skills such as orthographic learning has been championed by various researchers (e.g., Ehri & Snowling, 2004; Hulme, Snowling, Caravolas, & Carroll, 2005) and has been the underlying assumption for the self-teaching hypothesis (Share, 1999). Given the conflicting evidence in the literature, additional work is required to help elucidate the relationship between phonological awareness and orthographic learning. Furthermore, as many of the existing studies involved children, whether phonological awareness is related to orthographic learning in adults deserves further examination.

Another cognitive component that may contribute to orthographic learning is rapid automatized naming (RAN), which is defined as the ability to name as fast as possible visually presented familiar symbols such as digits, letters, colors, and objects (Wolf & Bowers, 1999). Bowers and Wolf (1993) hypothesized that slow letter naming may disrupt orthographic learning, which then compromises reading development. Although RAN and orthographic learning deficits have been demonstrated in individuals with reading difficulties, few studies have specifically examined the relationship between them. Manis et al. (2000) reported that RAN was a unique predictor of orthographic processing. Children with RAN deficits have also been shown to be less accurate than typical children in a task requiring orthographic knowledge formation (Conrad & Levy, 2007). However, Bowey and Miller (2007), Cunningham, Perry, Stanovich, and Share (2002), and Cunningham (2006) all reported that RAN did not account for unique variance in orthographic learning in typically developing children. Given the conflicting evidence in the literature, more research is needed to clarify the nature of the relationship between RAN and orthographic learning.

Gaze Duration as an Orthographic Learning Measure

To date, orthographic choice and priming tasks have often been used as measures of orthographic learning, but they are post-learning tasks that measure the outcome of orthographic learning rather than the learning process itself. Orthographic choice tasks present distracter items that may cause confusion which normally does not arise in everyday reading (Castles & Nation, 2008). An alternative method is to capture orthographic learning as it happens during reading. One way of assessing on-line reading processes is by using the eye-tracking paradigm (Rayner, 1998).

The units of measurement in eye-tracking are fixations, or short pauses in eye movement, and saccades, the short eye movements between points of fixations. In reading, print is processed during fixations (Radach & Kennedy, 2004). Thus, by examining fixation frequencies and durations, one can infer ongoing cognitive processes during reading. For example, newly encountered words are fixated longer than familiar words (Rayner, 1998). Fixation duration is also influenced by word frequencies. Word frequency is usually reported as how often a word appears in a random sample of 1 million words from text – termed Kucera-Francis (KF) frequency (Juhasz & Rayner, 2003). Words that appear frequently in text are fixated shorter than infrequent words (Hyönä & Olson, 1995). White (2008) also observed the same frequency effect, as well as longer fixation durations, on words with lower orthographic familiarity.

Eye movement patterns also vary with reading ability. Less able readers have been shown to exhibit more and longer fixations than more able readers (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Everatt & Underwood, 1994; Hutzler & Wimmer, 2004; Rayner, 1998). Compared to typically reading adolescents who tended to fixate only once on words or skip words altogether, adolescents with dyslexia were found to fixate multiple times on a word more frequently and skip less often; and for words fixated on once, the fixation duration was longer (Hawelka, Gagl, & Wimmer, 2010). Hawelka et al. (2010) attributed these group differences to faulty recognition of whole-word orthographic representations, and an over-reliance on serial sub-lexical decoding.

In the context of orthographic learning, fixations on words for which orthographic representations are already formed are expected to be shorter than fixations on new words that are initially read through phonological recoding. Based on these assumptions, Barber (2009) conducted a study to track changes in fixation duration as a measure of orthographic learning in typical adults and adults with dyslexia. Individuals read a coherent passage embedded with pseudowords. Pseudowords appeared four, six, nine, or twelve times in the passage, and fixation durations on pseudowords were recorded. The decrease in fixation durations was sharpest from the first to second exposures, and became less pronounced across subsequent exposures until there was no significant change. Sharp initial decreases in fixation times appears to be in line with the finding that orthographic representations are formed after only one exposure to a new word (Share, 2004). When analyzing the rates of decrease in fixation duration, Barber (2009) found that the rate across pseudoword repetitions did not differ between typical adults and adults with dyslexia. This was an unexpected finding, given that adults with reading difficulties have been shown to display orthographic learning difficulties (Pitchford et al., 2009). At a first glance, the results may seem in conflict with Hawelka et al.'s (2010) findings that eye movement patterns of individuals with dyslexia contained more and longer fixations when compared to those of typical readers, but it should be noted that Hawelka et al. observed general eye movement patterns in reading rather than change in eye movement patterns across repeated target words. In fact, Barber (2009) found that fixation durations in readers with dyslexia were generally longer than those in typical readers, at both initial exposure to target words and at the plateau stage. In other words, typical readers and readers with dyslexia exhibited roughly parallel, as opposed to overlapping or intersecting, learning curves.

If adults with dyslexia are able to exercise orthographic learning at a rate comparable to that of typical adults as shown in eye movement data, then what cognitive factors may underlie the successful learning process when reading difficulties are present? Barber (2009) reported that phonological awareness was not a significant predictor of novel word learning as quantified by the rate of fixation duration decrease. The lack of a significant association was surprising in light of findings that phonological recoding was the best predictor of orthographic learning (e.g., Bowey & Miller, 2007; Conners et al., 2011; Chalmers & Burt, 2008; Cunningham et al., 2002; Maloney et al., 2009). Barber (2009) reported that this result may have been due to the reduced reliability of the phonological awareness task from the removal of inaccurate responses, which comprised 20% of the items. A replication study that utilizes more reliable phonological awareness tasks would help clarify the relationship between phonological awareness and orthographic learning.

In addition, the eye movement method may be assessing a cognitive factor of orthographic learning different from that of widely used orthographic learning measures, such as the orthographic choice task (Castles & Nation, 2008). Examining the relationship between this latter task and phonological awareness can provide information on possible differences between orthographic learning tasks. Finally, in light of reports of no significant relationship between RAN and orthographic learning in children (e.g., Cunningham, 2006), it is unclear if a similar pattern holds for adults with reading difficulties. Investigating the relationship between RAN and orthographic learning can help extend current findings.

The Present Study

The purpose of the current study is twofold: (a) to compare the performance of typical adults and adults with dyslexia in orthographic learning skills measured with an orthographic choice task and with eye movement patterns; and (b) to examine the role of phonological awareness and RAN on orthographic learning. The results of this study can shed light onto cognitive reading processes in adults with dyslexia. Even though many studies have suggested impaired orthographic learning skills in individuals with reading disabilities (e.g., Bruck, 1993; Pitchford et al., 2009), they examined post-learning performance rather than the learning process. Barber (2009) assessed the on-line learning process and reported similar rates of novel word learning in typical adults and adults with dyslexia. On the basis of the findings of previous studies, it is hypothesized that orthographic learning will occur at a similar rate in typical adults and adults with dyslexia when measured in eye movements, but post-learning performance on an orthographic choice task will be better in typical adults than in adults with dyslexia. In terms of the cognitive factors that may underlie orthographic learning, based on existing studies (e.g., Chalmers & Burt, 2008; Cunningham, 2006), it is hypothesized that phonological awareness will be a significant predictor, while RAN will be not be a significant predictor of orthographic learning.

Chapter 3: Method

Participants

Two groups of university students participated in the present study. The experimental group consisted of 20 adults (8 males, 12 females, mean age = 24.59, *SD* = 4.58) with a self-reported history of reading difficulties (RD) and with scores on the elementary education component of the Adult Reading History Questionnaire – Revised (ARHQ-R; adapted from Parrila, Georgiou, & Corkett, 2007) that indicated presence of reading difficulties in childhood. The RD participants also displayed low reading fluency as indicated in low scores on the Phonemic Decoding Efficiency (PDE) task (TOWRE; Torgesen, Wagner, & Rashotte, 1999) or low reading rate on Story 9 (Form A) of the Gray Oral Reading Test – Fourth Edition (GORT-4; Wiederholt & Bryant, 2001, see below for details). The RD participants were recruited through poster advertisements on campus or from the Specialized Support and Disability Services at the University of Alberta.

The control group consisted of 27 adults (9 males and 18 females, mean age = 21.52, *SD* = 2.54) with no self-reported history of reading difficulties, scores on the ARHQ-R that indicated absence of reading difficulties in childhood, and high reading fluency scores on PDE and GORT-4. The participants in the control group were recruited from a participant pool program in the Department of Educational Psychology at the University of Alberta. All participants in the control and RD groups reported English as their first language and had normal or corrected-to-normal vision.

Materials

Adult Reading History Questionnaire – Revised (Parrila et al., 2007). The purpose of administering this questionnaire was to assess the extent of developmental reading difficulties experienced by the participants. Hence, only items pertaining to difficulties displayed during the elementary school years were administered. The elementary education section of the ARHQ-R contained eight items, each requiring a response on a Likert scale from 0 to 4, with higher numbers signifying greater reading difficulty (see Appendix A). A participant's score was equal to the sum of his or her responses divided by the maximum sum of responses (32), and so scores ranged from 0 to 1. Cronbach's alpha reliability coefficient in our sample was .96. RD participants scored above .45 (mean = .68, *SD* = .13), and control participants scored below .28 (mean = .10, *SD* = .08).

Nonverbal IQ.

Matrix reasoning – Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). This paper-pencil task measures nonverbal fluid reasoning. It contains 35 incomplete visual patterns that individuals complete using one of five choices of visual pattern pieces. Participants were asked to point to or say the number of their choice. Following standardized administration procedures, testing began from item 7 for all participants and ended on the very last item or after four response errors on five consecutive items. The adult split-half reliability coefficient is .94 (Wechsler, 1999).

Orthographic learning.

Orthographic choice. Nine target pseudowords adopted from Bowey and Muller (2005) were incorporated into the list of pseudowords in a lexical decision task. These nine target pseudowords each contained four letters, with one-letter onset and three-letter rime (e.g., ferd, jume, wote), and were each randomly assigned to a one-, two-, or four-repetition condition corresponding to the number of trials the pseudoword was presented in a lexical decision task administered at the beginning of the testing session. Three pseudowords were assigned to each condition. Each item on the orthographic choice task contained one of the target pseudowords (e.g., wote), a visually similar foil (wute), and a homophone (woat) presented side by side on the computer screen. Participants were asked to respond as fast as possible to each item by pressing 1, 2, or 3 on the keypad corresponding to their choice of the pseudoword that had already appeared in the lexical decision task. Items were presented in random order. Reaction times and accuracy on each item were recorded.

Phonological awareness.

Phonological choice (Parrila et al., 2007). Pseudowords were presented two at a time juxtaposed on the computer screen. Only one pseudoword in each pair sounded like a real word when read aloud (e.g., klass – cliss, fite – fipe). Participants were asked to respond to each item as fast as possible by pressing the button corresponding to their choice of which word in each pair sounded like a real word. The task contained 20 pairs of pseudowords presented in random order.

Reaction times and accuracy on each item were recorded. Cronbach's alpha reliability coefficient in our sample was .75.

Elision. This task was adopted from the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999). In this task words were presented through the computer speakers and participants were required to remove a specific phoneme from the presented word and say the newly formed word (e.g., say *bold* without saying /b/ → old). There were a total of 13 items. Reaction times and accuracy on each item were recorded. Wagner et al. (1999) reported Cronbach's alpha reliability coefficient to be .89 for adults.

Rapid automatized naming (RAN).

RAN Digits. This task was adopted from RAN/RAS test battery (Wolf & Denckla, 2005) and required participants to name as fast as possible five digits (2, 4, 6, 7, 9) that were repeated ten times and arranged semi-randomly in five rows of ten. Participants were instructed to name as fast as possible all the digits from left to right starting at the top row, and their response times were recorded. Prior to the timed item, participants named the same five digits on a practice trial to ensure familiarity. Wolf and Denckla (2005) reported test-retest reliability to be .92 across ages.

RAN Objects. Administration format and procedures were identical to those of RAN Digits except that the stimuli were five objects (book, chair, dog, hand, and star). Wolf and Denckla (2005) reported test-retest reliability to be .84 across ages.

Reading fluency.

Sight Word Efficiency – Test of Word Reading Efficiency (TOWRE; Torgesen et al., 1999). This test measures word reading efficiency and consists of a list of 104 words that are arranged in four columns of 26 words. Participants were presented with the list and asked to read the words out loud as fast as possible. The number of words read correctly within 45 seconds was recorded. The test-retest reliability coefficients range from .82 to .87 (Torgesen et al., 1999).

Phonemic Decoding Efficiency – Test of Word Reading Efficiency (TOWRE; Torgesen et al., 1999). Participants were shown a list of 63 pseudowords and asked to read them out loud as fast as possible. The participant's score was the number of pseudowords read correctly within 45 seconds. The test-retest reliability coefficients range from .91 to .94 (Torgesen et al., 1999).

Gray Oral Reading Tests – Fourth Edition (GORT-4; Wiederholt & Bryant, 2001). The GORT-4 is a test of oral reading rate, accuracy, fluency, and comprehension. It has two parallel forms (A and B), each consisting of 14 stories of increasing length and difficulty. Participants in this study were asked to read aloud Story 9 (Form A). The experimenter recorded the reading rate (in seconds). The internal consistency reliability coefficient for reading rate on Form A is .96 (Wiederholt & Bryant, 2001).

Eye movement reading.

Experimental passage**.** This 1870-word passage is an adaptation of the one designed by Barber (2009) based on a text about New Caledonia (see Appendix B). The passage was embedded with the same 16 pseudowords that

Barber derived from White (2008). These pseudowords had low Kucera Francis frequencies (< 20), low orthographic neighbourhoods (one to four neighbours), and high average naming times. These perimeters reflect relatively difficult pseudowords, which helped limit the likelihood of participants reading them by analogy. Pseudowords were randomly selected to be presented 4, 6, 9, or 12 times, followed by one extra presentation subsequently in the passage (4 – odder, rumus, wrate, huay; 6 – bress, neron, noch, ducca; 9 – lince, aboe, yager, vark; 12 – kyre, fyrrh, zyena, tolo). Four pseudowords were assigned to each condition. Each initial set of repeated presentations occurred within the same general proximity, and the extra repetition was situated 538 – 559 words from the last repetition of the initial set for 10 of the pseudowords. The extra repetition, termed "trailer repetition," served as an indicator of gaze duration stability.

Comprehension quiz. To ensure that participants read the experimental passage for understanding, a 10-item, paper-pencil multiple choice comprehension quiz was administered to assess participants' retention and comprehension of the passage. Participants completed the quiz by circling their preferred choice among three options.

Procedure

Tasks were administered across two separate sessions, each lasting approximately an hour. Session A comprised of the eye movement measures on experimental passage reading, matrix reasoning, TOWRE, GORT-4, comprehension quiz, and ARHQ-R. Session B comprised of RAN Digits, RAN Objects, phonological choice, elision, and orthographic choice. The order of administering Sessions A and B was counterbalanced. Participants read an information letter about the study and signed a consent form at the beginning of their first session. For their participation, undergraduate pool participants received course credit, and participants recruited through advertisement received a $20 honorarium.

Eye tracking method. Head-mounted infrared cameras (Eyelink II, SR Research Ltd.) were used to track vertical and horizontal binocular eye positions with a sampling rate of 500 Hz and average gaze position error of less than 5^{o}. Participants wore the head-mount securely on their heads and were requested to remain as still as possible while they read the experimental passage on the screen. The passage was displayed across 32 screens on a computer monitor with an 85 Hz refresh rate. The passage contained 34-point font, double-spaced lines, and two spaces between words in order to obtain clearer eye tracking data. A drift correction screen appeared between each text screen to correct for any head movements that occurred during reading. Participants were told to silently read a passage about a real geographical location, and that later in the session they would be tested on their comprehension of what they read. After the calibration procedures were completed, the participants read the passage screen by screen and pressed the spacebar to move on to the next screen of text. The system recorded saccades and fixation durations.

Data cleaning. Prior to conducting any data analyses, the data were cleaned from outliers. The data cleaning for computerized tasks was completed in six steps. First, the reaction times associated with incorrect responses were deleted. The incorrect responses consisted of 17.7% of the data. Second, the reaction times of extremely large or small values (i.e., below 100ms and above 10000ms) were removed, which consisted of 7.8% of the remaining reaction time data. Third, for each task and for each individual, a mean reaction time was calculated. Fourth, within each task for each individual, values exceeding 2.7 standard deviations from the calculated mean, which is a criterion for identifying extreme outliers in small samples (Glass & Hopkins, 1996), were adjusted according to procedures in Tabachnick and Fidell (2001) to reduce the influence of univariate outliers on data distributions. Outlier values were adjusted to one unit away from the next most extreme value in the distribution (e.g., in a distribution with highest value 500, the smallest outlier would be adjusted to 501, the second smallest outlier to 502, and so on). Approximately 3% of the data were adjusted. Fifth, adjusted scores were used to calculate new means for each participant. Sixth, the mean distribution of the control group and the mean distribution of the RD group were then scanned for outliers (i.e., 2.7 SD from their respective distribution means). Mean outliers were adjusted to one unit away from the next most extreme score in the respective mean distribution.

For the eye tracking data, the variable of interest was gaze duration on each pseudoword, which reflects initial processing times on the target words. The data cleaning for gaze durations was completed in four steps. First, all instances of skipping (i.e., not fixating on) pseudowords were counted as missing data, since assigning a zero-value gaze duration to these skipped words would erroneously lower gaze duration means. Approximately 7% of gaze duration data across all participants were counted as missing data and were removed. Second, a mean gaze duration across participants within each group (control and RD) was calculated for each pseudoword presentation occurrence. Third, if the gaze duration of an individual for that presentation occurrence was 2.7 standard deviations above or below the mean, it was adjusted according to procedures in Tabachnick and Fidell (2001). These outlier values were adjusted to one unit away from the next most extreme value in the gaze duration distribution across participants for each pseudoword presentation occurrence. Adjustment occurred for 2% of gaze duration data across all participants. Fourth, a new mean gaze duration across participants within each group was calculated for each pseudoword presentation occurrence. These new means were used in the final data analyses.

Chapter 4: Results

Group Descriptive and Reading Measures Statistics

Table 1 shows the means, standard deviations, and the results of one-way ANOVA on all the measures used in the study. There were significant group differences on Adult Reading History Questionnaire – Revised, Sight Word Efficiency, Phonemic Decoding Efficiency, and Gray Oral Reading Test. On phonological choice, elision, and orthographic choice tasks, the reaction times of the RD group were significantly longer than those of the control group. In terms of accuracy, the control group scored significantly higher than the RD group only on phonological choice. There were no significant group differences on RAN Digits, RAN Objects, matrix reasoning, and comprehension quiz.

Eye Movement Data

Figure 1 shows the mean gaze durations across pseudoword repetitions for all four conditions. Given that the pseudoword repetition conditions were nested within participants in two different groups, hierarchical linear modeling (HLM) was used to investigate the growth curves' rates of change. Visual inspection of the nine- and twelve-repetition condition graphs suggested the presence of an initial steep change in gaze durations from repetitions one to five followed by a more leveled rate of change from repetitions five to nine and five to twelve, respectively. The steep change from repetitions one to five was designated Phase I, and the leveled change from repetitions five to nine and five to twelve was designated Phase II. The four- and six-repetition conditions were not divided into phases in order to maintain more than three data points per model allowing the

Table 1

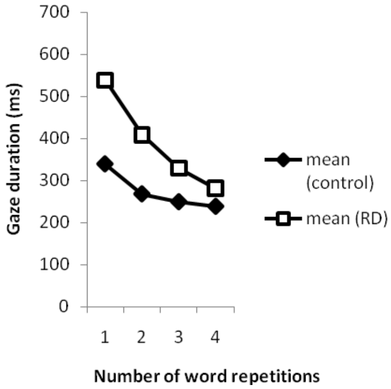
Descriptive Statistics of Control and RD Groups on Cognitive and Reading Measures

	Control (n = 27)		RD (n = 20)			
	M	*SD*	*M*	*SD*	*F*	η_p^2
WASI matrix reasoning	27.15	2.96	28.45	3.19	2.09	.04
TOWRE SWE	98.48	5.78	85.85	7.62	41.81**	.48
TOWRE PDE	59.15	3.98	41.95	9.20	75.69**	.63
GORT-4 reading rate	45.23	3.28	61.54	9.89	64.36**	.59
Phonological choice ac	18.15	0.91	16.10	3.31	9.46*	.17
Phonological choice rt	1549.57	319.05	2467.60	715.65	35.20**	.44
Elision ac	12.08	1.32	11.35	1.39	3.25	.07
Elision rt	837.88	225.00	1352.45	487.39	22.08**	.34
RAN Digits	18481.78	3655.05	20165.80	2608.57	3.08	.06
RAN Objects	30749.89	4913.42	30908.85	3270.72	0.02	.00
Orthographic choice ac	5.22	1.67	6.05	1.39	3.23	.07
Orthographic choice rt	1698.58	469.42	2593.13	1153.30	13.35**	.23
Comprehension quiz†	8.30	1.38	7.90	1.41	0.93	.02

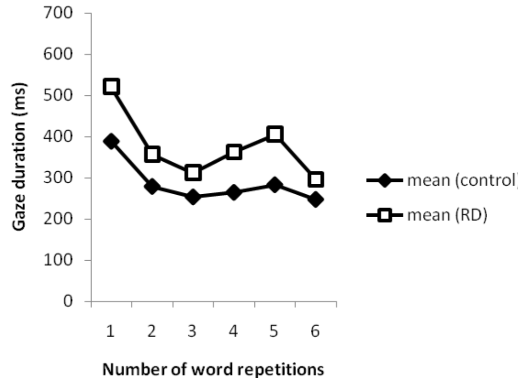
Note. WASI= Wechsler Abbreviated Scale of Intelligence; ARHQ-R=Adult Reading History Questionnaire; TOWRE=Test of Word Reading Efficiency; SWE=Sight Word Efficiency; PDE=Phonemic Decoding Efficiency GORT-4= Gray Oral Reading Test – Fourth Edition (reading rate in ms); ac=accuracy; rt=reaction time (ms); RAN = Rapid Automatized Naming; †Maximum score = 10.

* $p < .05$; ** $p < .001$.

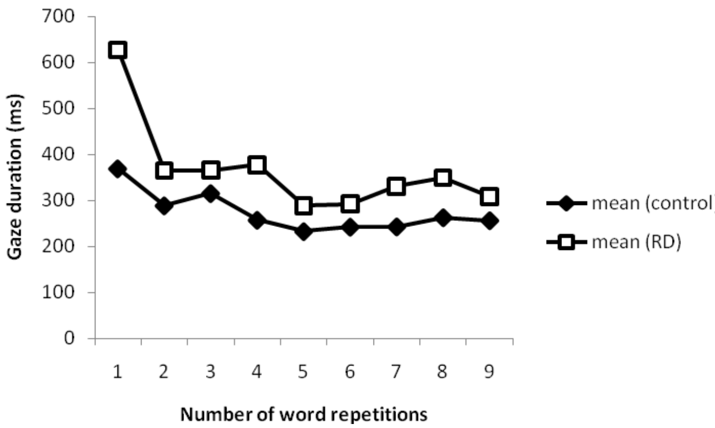
a. Four-repetition



b. Six-repetition



c. Nine-repetition



d. Twelve-repetition

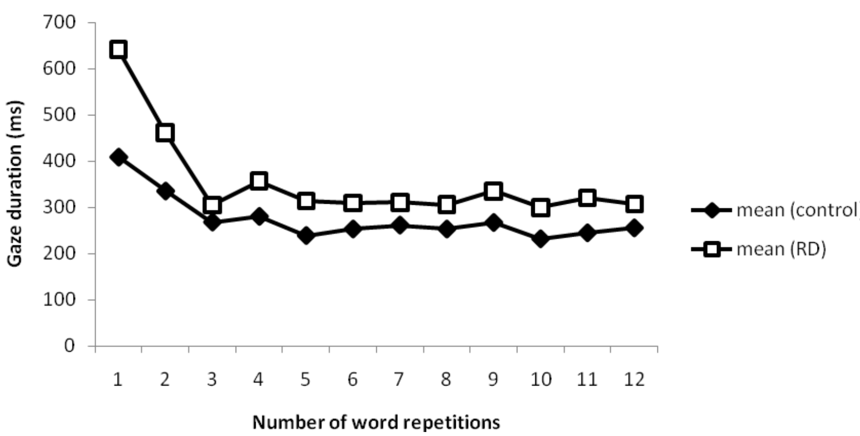


Figure 1. Mean adjusted gaze durations of control and RD groups in each repetition condition.

fitting of non-linear models. Hierarchical Linear and Nonlinear Modelling, Version 6.06 (HLM 6; Raudenbush, Bryk, & Congdon, 2004) was used to construct HLM models for four- and six-repetition conditions and Phases I and II for nine- and twelve-repetition conditions.

Four- and six-repetition conditions analysis. The data for the control and RD groups suggested that gaze durations decreased across repetitions in a linear or quadratic fashion. Baseline models ($y=b$, where b is the intercept), which assume no change in gaze durations across repetitions, were tested for each condition to see if adding linear (m_1x, where m_1 is the linear slope) and quadratic (m_2x^2, where m_2 is the quadratic slope) components would result in significantly better fitting models. Table 2 shows the deviance statistic differences between baseline and linear models ($y=b$ and $y=b+m_1x$), and between linear and linear-quadratic models ($y=b+m_1x$ and $y=b+m_1x+m_2x^2$). According to Raudenbush and Bryk (2002), the difference between two models' deviance statistics is approximately χ^2 distributed, with degrees of freedom equal to the difference in the number of estimated parameters. Comparisons were done using the full maximum likelihood estimation method. Addition of linear and quadratic components to the baseline model resulted in significantly better fitting models for four- and six-repetition conditions in the control group and six-repetition condition in the RD group. For the four-repetition condition in the RD group, adding a quadratic component did not result in a significant improvement in the model fit.

Table 2

Deviance Differences of Full Maximum Likelihood Ratio Tests for Models of Four- and Six-Repetition Conditions

	Group	
Condition	Control	RD
Four-repetition		
Linear	20.38**	48.55**
Linear-quadratic	4.20*	1.52
Six-repetition		
Linear	29.92**	17.07**
Linear-quadratic	19.15**	7.32*

Note. $df = 1$, * $p < .05$; ** $p < .01$.

The next step was to obtain the models' intercepts and slopes, which respectively reflect estimated initial gaze durations and estimated rates of change in gaze durations across repetitions. Prior to obtaining these values, it is important to ensure that the distributional assumptions are met. HLM models of continuous variables are valid when errors at each model level are normally distributed, and violation of this normality assumption can result in biases in standard errors of fixed effect estimates (Dedrick et al., 2009). Normality at level-1 (within-person model) was tested by examining normal Q-Q plots of level-1 expected residuals against estimated residuals. At level-2 (between-person model), normality was tested using the Mahalanobis distance, which is the distance between estimated and expected residuals. The normality assumption holds when the Mahalanobis distances are approximately distributed χ^2 (Raudenbush & Bryk, 2002), which can be shown on normal Q-Q plots of Mahalanobis distance against level-2 expected values of the order statistics for a sample size *J* from a population distributed χ^2. The normality assumption holds when the level-1 and level-2 Q-Q plots approximately resemble a 45^{o} line. Q-Q plots for data in the four- and six-repetition conditions revealed that the normality assumption was tenable.

To examine the extent of gaze duration changes across repetitions, the restricted estimated maximum likelihood estimation method was used because it accounts for uncertainty in fixed effects and adjusts for variance estimates (Dedrick et al., 2009). As for centering, no predictor variables in the current data set were centered because gaze duration values had a meaningful zero-point (i.e., 0ms gaze duration meant no fixation on a given word), and thus were appropriate for direct interpretation (Cheung, 2009; Raudenbush & Bryk, 2002). However, there were two missing data points in the RD four-repetition condition due to two participants skipping all pseudowords on one repetition point.

Table 3 shows the mean intercept and slope estimates of models for four- and six-repetition conditions. All estimates were significantly different from zero at the $p < .05$ level, except for the quadratic slope estimate in the RD four-repetition condition. This means that adding a quadratic component to the model for this condition did not result in a significantly better model fit, which is consistent with the results in Table 2.

Table 3

Final Estimate of Fixed Effects (with Robust Standard Errors) for Four- and Six-Repetition Conditions Predicted Models

Measure	Group					
	Control			RD		
	M	*SE*	*t*-ratio	*M*	*SE*	*t*-ratio
Four-Repetition						
Intercept	336.64	15.03	22.41**	502.10	35.08	14.31**
Linear slope	-77.23	21.82	-3.54**	-107.49	32.99	-3.26*
Quadratic slope	15.06	7.31	2.06*	11.17	9.30	1.20
Six-Repetition						
Intercept	367.27	18.64	19.70**	478.94	32.16	14.89**
Linear slope	-68.44	11.94	-5.73**	-82.18	19.48	-4.22**
Quadratic slope	9.78	1.98	4.93**	11.15	2.98	3.75**

Note. * $p < .05$; ** $p < .01$.

Independent samples t-tests were conducted to compare the mean intercepts and slopes between control and RD groups. Levene’s tests revealed unequal variances for four-repetition condition intercept and slopes, and so *t*-values based on assumption of unequal variances were reported. The mean intercept of the RD group was significantly higher than that of the control group, $t(20.15) = 5.54$, $p < .001$, indicating that the RD participants had longer initial gaze durations than the control participants. The difference in mean linear slopes between the control and RD groups approached significance, $t(20.35) = 1.71$, $p = .056$. Since the mean quadratic slope for the RD group did not differ significantly from zero given the large standard error relative to the mean, no further analysis was done for the quadratic slopes in the four-repetition condition. As for the six-repetition condition intercept and slopes, the equal variance assumption was met. Similar to the four-repetition condition, the six-repetition condition mean intercept of the RD group was significantly higher than that of the control group, $t(45) = 4.70$, $p < .001$, and there were no significant differences in linear slopes, $t(45) = 1.26$, $p > .214$, and quadratic slopes, $t(45) = -1.01$, $p = .32$.

Nine- and twelve-repetition conditions Phase I analyses. Similar to the four- and six-repetition condition analyses, baseline models were tested to see if adding linear and quadratic components would result in a significantly better fitting model. Table 4 shows the deviance statistic differences between baseline

Table 4

Deviance Differences of Full Maximum Likelihood Ratio Tests for Phase I Models of Nine- and Twelve-Repetition Conditions

	Group	
Condition	Control	RD
Nine-repetition		
Linear	35.05**	38.95**
Linear-quadratic	0.23	11.09**
Twelve-repetition		
Linear	48.89**	33.37**
Linear-quadratic	6.01*	12.86**

Note. $df = 1$, * $p < .05$; ** $p < .01$.

and linear models, and between linear and linear-quadratic models (approximately equal to χ^2 with degrees of freedom equal to the difference in the number of estimated parameters; Raudenbush & Bryk, 2002). Comparisons were done using the full maximum likelihood estimation method. The addition of only a linear component to the baseline model resulted in a significantly better model fit for the nine-repetition condition in the control group. Adding both the linear and quadratic components resulted in significantly better model fit for the nine-repetition condition in the RD group and for the twelve-repetition condition in both groups.

Prior to obtaining intercept and slope values, the normality assumption was tested using the same method as in the four- and six-repetition conditions. Q-Q plots of the residuals showed that the data were normally distributed. Intercept and slope values were calculated using the restricted estimated maximum likelihood estimation methods, and predictor variables were uncentered. There were no missing data. Table 5 shows the mean intercept and slope estimates of models for Phase I of nine- and twelve-repetition conditions. All estimates were significantly different from zero at the $p < .05$ level, except for the slope estimates in the control nine-repetition condition. However, it should be noted that the linear slope estimate was close to being significantly different from zero.

Independent samples t-tests were conducted to compare the mean intercepts and slopes between control and RD groups. Levene's tests revealed unequal variances for all mean estimates, and so *t*-values based on the assumption of unequal variances were reported. Only estimates that differed significantly

Table 5

Final Estimate of Fixed Effects (with Robust Standard Errors) for Nine- and Twelve-Repetition Conditions Phase I Predicted Models

Measure	Group					
	Control			RD		
	M	*SE*	*t*-ratio	*M*	*SE*	*t*-ratio
Nine-Repetition						
Intercept	357.35	20.44	17.48**	588.57	38.53	15.28**
Linear slope	-38.08	19.14	-1.99	-168.52	35.75	-4.71**
Quadratic slope	1.91	4.29	0.45	25.51	7.31	3.49**
Twelve-Repetition						
Intercept	405.89	25.15	16.14**	636.08	67.06	9.49**
Linear slope	-80.79	19.61	-4.12**	-213.53	52.75	-4.05**
Quadratic slope	10.29	4.15	2.48*	34.39	10.22	3.37**

Note. * $p < .05$; ** $p < .01$.

from zero were included in the mean comparison tests. The mean intercepts of the RD group were significantly higher than those of the control group in the nine-repetition condition, $t(29.07) = 7.85$, $p < .001$, and the twelve-repetition condition, $t(22.92) = 3.42$, $p < .005$. Since the mean linear and quadratic slopes of the control group in the nine-repetition condition were not significantly different from zero given the large standard errors relative to the mean, no further analysis was done for the slopes in this condition. In the twelve-repetition condition, both mean linear, $t(21.18) = -2.78$, $p < .05$, and quadratic slopes, $t(21.10) = 2.84$, $p < .05$, of the RD group were significantly steeper than those of the control group.

Nine- and twelve-repetition conditions Phase II analyses. Similar to the Phase I analyses, baseline models were tested to see if adding linear and quadratic components would result in a better fitting model. Table 6 shows the full maximum likelihood hypothesis test results reported as deviance statistic differences between baseline and linear models (approximately equal to χ^2 with degrees of freedom equal to the difference in the number of estimated parameters, Raudenbush & Bryk, 2002). A linear component to the baseline model did not result in a significantly better fitting model for either condition in both groups, indicating no change in gaze durations across repetitions in Phase II. For this reason, testing for model fit with quadratic components was no longer necessary.

Since Phase II slopes were not significantly different from zero in the predicted models, they were not analyzed further. Only intercept values were obtained. The normality assumption was tested using the same method for

Table 6

Deviance Differences of Full Maximum Likelihood Ratio Tests for Phase II Models of Nine- and Twelve-Repetition Conditions

	Group	
Condition	Control	RD
Nine-repetition		
Linear	3.46	3.12
Twelve-repetition		
Linear	0.00	0.00

Note. *df* = 1. None of the statistics were significantly different from zero.

Phase I and was found to be tenable based on Q-Q plots of the residuals. Restricted estimated maximum likelihood hypothesis tests with uncentered predictor variables were conducted. In the nine-repetition condition, one control participant did not fixate on all eight pseudowords across two repetition points, which resulted in two missing data points. Table 7 shows the mean intercept of Phase II models for nine- and twelve-repetition conditions.

Independent samples t-tests were conducted to compare the mean intercepts between control and RD groups. The equal variance assumption was met based on the results of Levene's tests. The mean intercepts of the RD group were significantly higher than those of the control group in the nine-repetition condition, $t(45) = 7.15$, $p < .001$, and the twelve-repetition condition, $t(45) = 5.40$, $p < .001$. This suggests that when gaze durations no longer changed significantly

Table 7

Final Estimate of Fixed Effects (with Robust Standard Errors) for Nine- and Twelve-Repetition Conditions Phase II Predicted Models

Measure	Group: Control			Group: RD		
	M	*SE*	*t*-ratio	*M*	*SE*	*t*-ratio
Nine-Repetition						
Intercept	232.06	11.52	20.15**	294.24	12.47	23.59**
Twelve-Repetition						
Intercept	250.34	9.03	27.71**	312.47	16.71	18.70**

Note. ** $p < .01$.

across repetitions, RD participants still exhibited longer gaze durations than control participants.

Trailer words. A 2 (group) x 2 (repetition) x 4 (condition) repeated-measures ANOVA was conducted to investigate gaze durations on the last planned pseudoword repetition and on trailer words as a way of seeing the extent to which automatic word recognition was maintained. Outliers were identified and adjusted following the aforementioned procedures (Glass & Hopkins, 1996; Tabachnick & Fidell, 2001), and mean gaze durations were calculated across trailer words of respective repetition-conditions.

There were significant main effects for group, $F(1, 17) = 16.70$, $p = .001$, and repetition, $F(1, 17) = 48.21$, $p < .001$, but not for condition, $F(1, 17) = 0.92$, $p = .35$. All interactions were not significant, but the group by repetition interaction approached significance, $F(1, 17) = 3.52$, $p = .078$. The control group displayed significantly shorter gaze durations than the RD group on the last planned repetitions in the six- and twelve-repetition conditions, as well as on trailer words in all repetition conditions. For both control and RD groups, mean gaze durations on trailer words were longer than those on the last planned repetitions for the four- and twelve-repetition conditions, and the respective differences in the six- and nine-repetition conditions were not significant. Table 8 shows the mean gaze durations on the last planned and trailer repetitions.

Correlational and Regression Analyses

Table 9 shows the correlations between the reading measures and the HLM mean intercepts and slopes for all participants. The correlations between

Table 8

Mean Gaze Durations and F-Values on Last Planned and Trailer Repetitions in Each Repetition Condition

	Group				
	Control		RD		
Measure	*M*	*SD*	*M*	*SD*	*F*
Four-repetition					
Last planned	238.25	85.34	283.54	74.29	3.61
Trailer	332.40	88.84	407.73	137.34	5.21*
F	15.77**		12.65**		
Six-repetition					
Last planned	247.08	61.91	296.15	71.67	6.31*
Trailer	252.20	76.93	335.93	104.61	9.80**
F	0.07		1.97		
Nine-repetition					
Last planned	256.45	61.09	308.44	122.61	3.55
Trailer	257.77	74.76	355.99	87.76	17.10**
F	0.01		1.99		
Twelve-repetition					
Last planned	255.07	56.82	307.05	89.04	5.96*
Trailer	313.95	107.50	394.75	102.91	6.63**
F	6.28*		8.31**		

Note. * $p < .05$; ** $p < .01$.

Table 9

Pearson Correlations for Reading and Eye Movement Measures Across the Whole Sample

	1.	2.	3.	4.	5.	6.	7.	8.
1. WASI matrix reasoning								
2. RAN Digits	.10							
3. RAN Objects	-.12	.20						
4. Phonological choice	.20	.47**	.01					
5. Elision	.23	.10	.20	.54**				
6. Orthographic choice	-.07	.08	.15	.46**	.18			
7. Intercept	.37**	.27	.07	.66**	.51**	.41**		
8. Phase I linear slope	-.37**	-.28	-.06	-.63**	-.46**	-.37*	-.94**	
9. Phase I quadratic slope	.34*	.27	.02	.59**	.40**	.34*	.85**	-.97**

Note. RAN= Rapid automatized naming. N = 47. * $p < .05$; ** $p < .01$.

Phase I intercept, Phase I slopes, phonological choice, elision, and orthographic choice performances were all significant, except the one between elision and orthographic choice. RAN Digits correlated significantly with phonological choice reaction times. RAN Objects did not correlate significantly with any measure. WASI matrix reasoning correlated significantly with the Phase I intercept and slopes.

Next, in order to investigate the predictors of orthographic learning, hierarchical regression analyses were performed. The order of the variables entered in the regression equations was as follows: Group (dummy coded variable) was entered at step 1, nonverbal IQ at step 2, phonological choice reaction time at step 3 and RAN Digits at step 4. An analysis was also conducted with phonological choice entered at step 4 and RAN Digits entered at step 3. RAN Digits instead of RAN Objects was used because the latter did not correlate with any reading measure. The results of the regression analyses are presented in Table 10. After controlling for group, nonverbal IQ accounted for a significant amount of variance in Phase I linear slope but not in orthographic choice, and approached significance as a predictor of Phase I quadratic slope (p = .06). After controlling for group and nonverbal IQ, phonological choice explained unique variance in Phase I linear and quadratic slopes, but not in orthographic choice. RAN Digits did not predict orthographic choice or Phase I slopes after controlling for all other predictors. When entered at step 3, RAN Digits was also not a significant predictor of all three outcome variables. When entered at step 4, phonological choice explained unique variance only in Phase I linear and quadratic slopes.

The regression model described above was also conducted with intercept as the outcome variable in order to examine the predictive value of cognitive factors on processing novel words at first exposure. After controlling for group, nonverbal IQ accounted for 5% of variance in the intercept. After controlling for group and nonverbal IQ, phonological choice accounted for 5% of additional variance. RAN Digits, entered either at step 3 or step 4 of the regression equation, did not account for any unique variance in the intercept. Phonological choice continued to account for unique variance in the intercept (5%), even when entered at step 4.

Table 10

Results of Hierarchical Regression Analyses With Group, Nonverbal IQ, Phonological Choice, and RAN Digits as Predictors of Orthographic Learning Measures

		Orthographic choice (rt)		Phase I linear slope		Phase I quadratic slope		Intercept	
Step	Variable	ß	ΔR^2	ß	ΔR^2	ß	ΔR^2	ß	ΔR^2
1.	Group	.48	.23**	-.59	.35**	.53	.28**	.71	.50**
2.	Nonverbal IQ	-.18	.03	-.26	.07*	.24	.06	.23	.05*
3.	Phonological choice	.28	.04	-.39	.09*	.41	.09*	.31	.05*
4.	RAN Digits	-.14	.02	.00	.00	.01	.00	-.01	.00
3.	RAN Digits	-.03	.00	-.13	.02	.13	.08	.09	.01
4.	Phonological choice	.35	.06	-.39	.07*	.40	.02*	.32	.05*
Total R^2			.32**		.50**		.43**		.60**

Note. RAN= Rapid automatized naming. * $p < .05$; ** $p < .01$.

Chapter 5: Discussion

Reading Processes in Adults with Reading Disabilities

The hypothesis that adults with dyslexia would display weaker orthographic learning was partially supported. Adults with dyslexia took longer than typical adults in responding to items on the orthographic choice task, but there was no group difference in the accuracy rate. In other words, the adults with dyslexia did not form orthographic representations of target pseudowords worse than typical adults, but they took longer in retrieving and/or processing these representations. These results suggest that adults with dyslexia have the ability for orthographic learning, but with delayed retrieval of orthographic representations. This finding is similar to those of previous studies (e.g., Bruck, 1993; Ehri & Wilce, 1983; Manis, 1985; Share & Shalev, 2004) in that individuals with dyslexia are slower in completing orthographic learning tasks, but challenges the claim that they require more exposures to new words in order to form orthographic representations (Reitsma, 1983).

Orthographic Learning Measured as Gaze Duration

Based on the slope values in the Phase I models (see Tables 3 and 5), typical adults and adults with dyslexia both exhibited shorter gaze durations on subsequent exposures of a given novel pseudoword. This is akin to the frequency effect in children, where gaze durations on a word shorten with successive viewing (see Hyönä & Olsen, 1995). This trend suggests that both typical adults and adults with dyslexia are capable of orthographic learning during silent reading of novel words in connected text.

It was hypothesized that the rates of orthographic learning, indexed as changes in gaze durations, would be similar between typical adults and adults with dyslexia. In other words, both groups were expected to display gaze duration decrease at similar rates. This hypothesis was partly confirmed in the current study. The slope values in Tables 3 and 5 indicate that the change was similar for both groups of readers in Phase I of the six-repetition condition. However, the slope values in Phase I of the nine- and twelve-repetition conditions indicate a sharper decline in gaze durations in adults with dyslexia. A similar trend was observed in the four-repetition condition, but the group difference in slopes only approached significance. In sum, in two conditions, the eye movement data indicated that adults with dyslexia learned faster than typical adults, as graphically shown in Figures 1c and 1d by the steeper initial drops in the learning curves. This finding is surprising in light of previous research that reported impaired orthographic learning in individuals with dyslexia (e.g., Bruck, 1993; Ehri & Wilce, 1983; Pitchford et al., 2009). This result also differed slightly from the similar learning rates between groups that were observed in Barber's (2009) study.

Despite learning faster, the adults with dyslexia exhibited longer gaze durations than typical readers, a finding that is in line with those of previous studies (e.g., Barber, 2009; De Luca et al., 2002). This was evident in the higher intercept values of growth curves in all conditions and phases. The adults with dyslexia had longer gaze durations at initial exposure to novel words as well as after a few exposures at the beginning of gaze duration stabilization. It can be seen in Figure 1 that the adults with dyslexia displayed longer gaze durations across most of the word exposures in all four conditions. These results suggest that although the adults with dyslexia may have learned at a faster rate than typical readers, they still took slightly longer to process words at every exposure. In addition, the adults with dyslexia not only took longer than typical readers to process pseudowords, but they used even more time when processing the pseudowords for the first time. As seen in Figures 1a, 1c and 1d, for the adults with dyslexia, short processing times on the second exposures of the pseudowords were preceded by much longer processing times at the initial exposures. The faster orthographic learning displayed by the adults with dyslexia appears to be an indirect result of the disproportionately prolonged initial processing of pseudowords. Although the adults with dyslexia took longer to decipher a newly seen pseudoword, they were able to somewhat “catch up” to typical adults in subsequent exposures.

In order to see how well orthographic learning was maintained after successive exposures to novel pseudowords, gaze durations on trailer words were observed. As seen in Table 8, the differences in gaze durations between the last planned repetition and trailer repetition were found not to be uniform across conditions. In the four-repetition condition, participants fixated longer on the trailer words than on the last planned repetitions. In the six- and nine-repetition conditions, participants fixated for a similar duration on trailer and last planned repetition words. In accordance to gaze duration stabilization being achieved after the fifth repetition, it makes sense that trailer words presented after the sixth and ninth repetition would be fixated with a similar duration. One would expect the same trend to be observed in the twelve-repetition condition due to the higher number of exposures, but surprisingly, the trailer gaze durations were longer than the last planned gaze durations in this condition.

Several factors may have accounted for this unexpected phenomenon. It is possible that pseudowords assigned to the twelve-repetition condition were more difficult than those in the other conditions. However, given that all pseudowords selected for the passage were controlled for KF frequencies, number of orthographic neighbours, and average naming times, it is unlikely that this factor played a role in the outcome. Another possible factor is the unequal number of words interspacing last planned repetitions and trailer words. A high number of interspacing words could have corresponded with a higher number of distracting stimuli and a longer delay between viewing the last planned repetition and the trailer word, which may have led to increased interference in forming and recalling of orthographic representations, subsequently resulting in longer gaze durations on the trailer words. Even though the number of interspacing words was controlled at 538 to 559 for only 10 of the target pseudowords, all of which were assigned to the six, nine, and twelve-repetition conditions, the four-repetition condition included three target pseudowords with 110 to 255 interspacing words, which were fewer than those in the other three conditions. Based on this observation, gaze durations on trailer words in the four-repetition condition should have been the most stable, while those in the other three conditions should have been similarly unstable. However, this was not observed, which suggests again that unequal number of interspacing words was unlikely to be a contributing factor toward gaze duration on trailer words. A replication study with the pseudowords reassigned to different conditions, or with a different set of pseudowords, would help elucidate if the prolonged gaze durations on trailer words in the twelve-repetition condition was specific to the current study. As for the retention of semantic knowledge of the pseudowords, the lack of significant group differences in the comprehension quiz (see Table 1) suggested that typical adults and adults with dyslexia were able to remember the meaning of the pseudowords to a similar degree.

When considered together, group differences in orthographic choice performance, slope values, and intercept values suggest that adults with dyslexia formed orthographic representations as well as typical readers, or possibly even faster than typical readers. This finding contradicts the lack of orthographic learning that Reitsma (1983) reported in individuals with dyslexia. It also differs from the slow learning exhibited by individuals with reading difficulties in the studies by Ehri and Wilce (1983) and Manis (1985). These three previous studies tested children learning novel words in isolation, while the current study tested adults learning words in context, so the discrepancy of results may be related to differences in methodology and participants' age. Because context has been shown to have no effect on orthographic learning (Nation et al., 2007), it is unlikely that context provided an advantage for better learning. The adults with dyslexia, given their age and educational level, may have had more reading practice and exposure to a wider range of orthographic patterns than the children, thus being able to use prior knowledge to aid in learning words orthographically.

However, a closer look at Manis’ (1985) results revealed that children with dyslexia read novel words with irregular orthography quicker in subsequent learning sessions, and the increase in speed appeared to be slightly greater than that in children without reading difficulties. This trend is in line with the eye movement data reported in the current study, and together suggest that adults with dyslexia may be slower than typical adults in orthographic processing, but not in orthographic learning.

Predictors of Orthographic Learning

It was hypothesized that phonological awareness would be a significant predictor, while RAN would not be a significant predictor of orthographic learning. None of the proposed factors contributed unique variance to orthographic learning as indexed by the orthographic choice task. This result is in contrast to the findings of Mesman and Kibby (2011). This may be attributed to four factors. First, the current orthographic choice task assessed orthographic learning of target pseudowords within the same experimental session, whereas the task in the past study assessed the ability to apply orthographic representations that had already been learned. Second, the orthographic choice performance in the past study was indexed by accuracy, not response times. Third, the past study included children in their samples. Finally, the task used in the current study had only nine items, which may have resulted in reduced variability.

It should be noted that the orthographic choice task mainly assessed the outcome of orthographic learning, while gaze durations reflected more the learning process in real time. When orthographic learning was indexed by gaze duration changes, the hypothesis that phonological awareness, and not RAN, would predict orthographic learning was confirmed (see Table 10). After controlling for other cognitive factors, phonological awareness accounted for unique variance in orthographic learning as measured by Phase I slope values, and also in intercept values corresponding to initial exposure to pseudowords. This suggests that phonological awareness is a significant factor in processing a new word for the first time. In contrast, RAN did not predict orthographic learning, a finding that is in line with those of previous studies (e.g., Bowey & Miller, 2007; Cunningham, 2006; Cunningham et al., 2002). There may be two explanations for this finding. First, it could be attributed to the use of RAN Digits and Objects instead of RAN Letters. Naturally, letters are more closely related to reading than digits or objects and are the components of orthographic learning. Second, previous studies have reported that children with slow RAN Digits performance had poor orthographic knowledge, as shown by deficits in recognizing illegal letter strings and inaccurate spelling (e.g., Bowers, Sunseth, & Golden, 1999; Sunseth & Bowers, 2002). The ability to quickly recall and apply orthographic knowledge is possibly reflected in the quick integration of information concerning digit symbols and their respective names. Whereas the rapid naming of digits measures the speed of recall, orthographic learning reflects the accuracy and ease of encoding new information. Conrad and Levy (2007) reported that readers, regardless of naming speed, were able to remember whole-word letter strings better than clusters of random letters, and so any orthographic learning deficits in slow namers may not be due to existing orthographic knowledge deficits.

Conclusion and Future Directions

Based on their performance in orthographic choice and reduced gaze durations, adults with dyslexia appear to be able to form and recall orthographic representations of newly learned words. The rate at which they learn can be as fast as or even faster than that of typical readers, but the speed of deciphering a new word and/or accessing orthographic representations is slower than that of typical readers. Phonological awareness predicted orthographic learning when measured with eye movements, but not when measured with an orthographic choice task. RAN did not predict orthographic learning at all. Altogether, the results confirmed previous eye movement findings that adults with dyslexia are capable of orthographic learning (Barber, 2009).

This study offered not only insights on the nature of orthographic learning in high-functioning adults with dyslexia, but also on the potential of using eye tracking as a means of measuring orthographic learning in reading connected text. However, the use of eye movement comes with limitations that need to be addressed in future studies. Gaze duration on target words may have been influenced by the words' physical position in the passage. For example, the first word on a line of text was often fixated once very briefly near the end of the word, followed by a longer fixation near the beginning. Rayner (1998) noted this to be a frequent ocular pattern when readers look from the end of a line of text to the beginning of the next line. Rayner also mentioned that the first and last fixations on a line are typically five to seven letter spaces from the ends, which meant that words located at the extreme positions will often be skipped. Future studies should try to format passages in such a way that target words are not placed either at the beginning or at the end of lines.

Based on the stabilization of gaze durations across word exposures and trailer word analyses, orthographic representations appeared to be formed locally within the reading of a text, but it remains to be seen whether or not these newly learned representations were stable enough to be recalled after a more prolonged period. One way to do this would be to have participants write the target words. Another way would be to administer an orthographic choice task whose items correspond to the target words in connected text. The accuracy rates and response times recorded from these additional tasks could provide more information on the extent of the stability of orthographic representations. Finally, future studies should re-examine the cognitive predictors of orthographic learning. The rather surprising finding of nonverbal IQ predicting orthographic learning would need further scrutiny in adults with dyslexia. RAN clearly did not predict orthographic learning, but the predictive value of phonological awareness was contingent upon the way orthographic learning was measured. These findings raise the need for further standardization of orthographic learning measures in research, as well as the need for further investigation on the orthographic learning of adults with and without dyslexia.

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APPENDIX A

Adult Reading History Questionnaire – Revised

1. Male _____ Female _____

2. Age ________

3. First language learned ____

4. Spoken language of preference ____________________________________

   Written language of preference ____________________________________

5. You prefer to use your: Right hand ___ Left hand ___ Ambidextrous ___

6. You have normal or corrected-to-normal vision Yes ____ No _____

7. Number of years of schooling (from elementary school to present) __________

8. To the best of your knowledge, did your parents ever report that either of them had a problem with reading or spelling?

________ Yes If **yes**, please give details: ______________________
________ No ____
________ Not Sure ____

9. To the best of your knowledge did your brother(s) and/or sister(s) ever have a problem with reading or spelling?

________ Yes If **yes**, please give details: ______________________
________ No ____
________ Not Sure ____

10. To the best of your knowledge, have any other members of your family (e.g., aunt, uncle, grandparents) ever had difficulties with reading?

________ Yes If **yes**, please give details: ______________________
________ No ____
________ Not Sure ____

Please circle the number of the response that most nearly describes your attitude or experience for each of the following questions or statements. If you think your response would be between numbers, place an "X" where you think it should be.

1. How much difficulty did you have learning to read in elementary school?

None				**A great deal**
0	1	2	3	4

---

2. How much extra help did you need when learning to read in elementary school?

No help	**Help from: Friends**	**Teachers/ parents**	**Tutors or special class 1 year**	**Tutors or special class 2 or more years**
0	1	2	3	4

---

3. How would you compare your reading skill to that of others in your elementary classes?

Above average		**Average**		**Below average**
0	1	2	3	4

---

4. Which of the following most nearly describes *your* attitude toward reading as a child?

Very positive				**Very negative**
0	1	2	3	4

---

5. When you were in elementary school, how much reading did you do for pleasure?

A great deal		**Some**		**None**
0	1	2	3	4

---

6. How would you compare your reading speed in elementary school with that of your classmates?

Above average		**Average**		**Below average**
0	1	2	3	4

---

7. How much difficulty did you have learning to spell in elementary school?

None		**Some**		**A great deal**
0	1	2	3	4

---

8. When you were in elementary school, how many books did you read for pleasure each *year*?

More than 10	**6-10**	**2-5**	**1-2**	**None**
0	1	2	3	4

APPENDIX B

EXPERIMENTAL PASSAGE

Screen 1

A Jewel in the Pacific: Geography and Economy

Screen 2

New Kyre is an overseas territory of France, located in the Pacific Ocean. It consists of one main island and several smaller island archipelagos. First discovered by James Cooke in 1774, New Kyre became annexed by France in 1853 in Napoleon's effort to rival the British Colonies. Many of the indigenous people in New Kyre are of Melanesian and Polynesian descent.

Screen 3

Like many colonies in the Pacific, the settlement of New Kyre was a mixed battle for religious and territorial supremacy. Today, however, there exists a relative harmony in New Kyre as traditional and modern cultures live side by side.

Bress is the capital city of New Kyre. It is located on a peninsula in the southwest area of New Kyre's main island, Grande Terre.

Screen 4

Bress is the only city in New Kyre. When you visit New Kyre, you must first come to Bress as it has the only airport big enough to accommodate transoceanic flights. Bress is home to the majority of New Kyre's population. There are only satellite towns on Grande Terre and small villages on the other islands. Although most of these settlements are relatively primitive, Bress is not.

Screen 5

Over the years, Bress has evolved into a modern city while still retaining its past. It is considered the 'garden city' and draws many tourists throughout the year.

The other major tourist attractions in New Kyre are the Neron Islands. These islands are renowned for their diverse beauty. The Neron Islands are considered a prime jewel of New Kyre. Their fertile grounds and pure waters allow for a rich agricultural economy.

Screen 6

The Neron Islands lie east of Grand Terre and stretch north to south. Fyrrh is the furthest south and is the highest of the Neron Islands. It is known for its wild beauty and diverse flora. Fyrrh also has many species of animals that cannot be found anywhere else in the area. The main economy of Fyrrh is gardening. Fyrrh gardening is the sole source of fruit for all of the Neron islands.

Screen 7

In particular, avocados from Fyrrh have such a reputation that there is festival devoted to them every year on the island.

A sight that visitors to Fyrrh will not want to miss is Noch. Located along the western coast of Fyrrh, Noch is a bay near the historic Neron Islands' grand chiefs area. Not only is Noch known for its gorgeous scenery, but it is also the site of the annual avocado festival.

Screen 8

Every year, Fyrrh islanders travel to Noch to celebrate this fruit. Although only approximately 800 people live on Fyrrh, people from all over the territory come to rest, relax and celebrate at Noch. With so many tourists, the avocado festival is also a significant source of income to those living in the Noch area.

Screen 9

Another particular site on the west coast of Fyrrh that should not be missed is the Ducca church and temple. This site has special significance for both native and European inhabitants of Fyrrh. For native inhabitants, Ducca is a sacred temple site where tribes came to worship their gods previous to colonization.

Screen 10

When the Europeans first came to Fyrrh, Ducca was selected as a site for one of the first churches. Although this was meant to prevent people from worshipping pagan gods, islanders continued to visit Ducca, often in secret, to carry on traditional beliefs and rituals. Today, Ducca represents the diverse beliefs on the island. Visitors often remark at how Ducca still exists in superb condition.

Screen 11

Zyena, the second main island, is one of the most beautiful in the Pacific with white sand beaches and water of varying shades of green and blue. Zyena is partly submerged and has a lagoon, which is not filled in, as on the other islands. The main industry on Zyena is finishing and is very popular with tourists and residents alike. Zyena's residents are mostly of Polynesian descent.

Screen 12

In fact, the name Zyena is of Polynesian origin. Ties with Polynesia are further demonstrated by the fact that, of two indigenous languages spoken on Zyena, one is of Polynesian origin.

One of the most spectacular things to do from Zyena is to visit the northern and southern Lince. The Lince are strings of islets that can be reached by boat from Zyena.

Screen 13

The northern Lince are accessible from the north end of Zyena and are known for their sand beaches. The northern Lince are popular with Bress residents and tourists looking for a day of rest. Though beachwear is allowed at the Lince, visitors are asked to dress modestly. The southern Lince are reachable from the southern tip of Zyena and are known for underwater diving.

Screen 14

In fact, the southern Lince are the most spectacular scuba diving sites in New Kyre. With so many things to do, Zyena is a popular destination. Anyone looking for relaxation should head to the northern Lince and those looking for adventure should head to the southern Lince.

Just north of Zyena is Tolo, the largest and most populated satellite island of the territory, with about 10,000 inhabitants.

Screen 15

Tolo is divided into three main tribal distrcts and has few urban centres. The town of ***Odder*** is the main economic hub on Tolo. ***Odder*** serves as the administrative and commercial centres of the island. However, ***Odder*** is not the largest town on Tolo. ***Odder*** is located on the rainy east coast while the larger centre, Chépénéhé, is located on the drier west coast.

Screen 16

Tolo's climate is moderate and sunny with two distinct seasons: warm and humid from December to March and cold and dry from April to November. Unlike the rest of Neron Islands, Tolo is a former coral atoll that was part of a submerged volcano. Nearly 2 million years ago, Tolo was uplifted to its present shape and elevation. There are no rivers on Tolo and the only source of freshwater is from ponds formed by the rain.

Screen 17

Geographically diverse, Tolo is known for its limestone caves, white sands and rich coral reefs. The island is flat like the Noch bay area, but has abundant vegetation, fertile soils and terraced cliffs. Although tourism is a large industry, Tolo is also known for its agriculture with many crops such as rubber, vanilla and sugarcane.

One of Tolo's chief exports is aboe, which is the dried inside of a coconut.

Screen 18

The aboe processing plants attract workers from both Fyrrh and Tolo and account for most employment on the island. Aboe is used to produce coconut oil. This is a process that requires many steps. The coconut shell must first be removed. The coconut is then broken up and dried, producing aboe. Coconut oil is extracted by first grating and grinding the aboe, then boiling it in water to obtain the oil.

Screen 19

The oil serves as food as well as medicines in Ducca temples. The South Seas and South Asia are the only places in which aboe can be made because production can only take place where coconut trees grow. The unique benefits of aboe have been researched and it seems that proteins in aboe increase milk production in animals. As such, aboe is a popular feed for horses, cattle and sheep.

Screen 20

A Jewel in the Pacific: People

Screen 21

There are two distinct cultures of people that live in the French territory: the Yagers and the Varks. The Yagers are the indigenous Melanesian people and the Varks are the European inhabitants. Yagers comprise 45% of the total population. The Yager identity is based on clan membership, a network of family alliances and specific land rights. Yager society has its own structure where everyone is expected to participate in tribal life.

Screen 22

The key person in Yager family life is the maternal uncle, often referred to as the "little chief". Any major decision related to the family requires the approval and blessing from the maternal uncle.

The Varks culture, on the other hand, is one based on supremacy over the Yagers. Settlers from Europe pushed the Yagers from dry to wet regions of land. These settlers were the first Varks.

Screen 23

Even today, the Varks consider themselves to be the superior culture. The Varks are very modern in comparison to their more traditional neighbours. In contrast to Yager culture, which is centred on Zyena and the northern and southern Lince, the Varks way of life is primarily based on a cash economy. The Varks actively try to stand out from other Europeans who come to this territory for temporary work or retirement. The Varks consider the islands their true home.

Screen 24

A Jewel in the Pacific: Language

Screen 25

With roughly 15,000 speakers, *Rumus* is the largest indigenous language on these islands. Unfortunately this language is endangered as large numbers of young people are no longer able to speak *Rumus* with confidence. The language spoken in schools is French and the native languages are being lost.

Screen 26

Over the summer school break, children are sent to their original home islands in hopes that the children will somehow acquire the language skills in *Rumus* that are lacking in schools. The results are far from satisfactory and the role of *Rumus* is being limited to customary greetings and exchanges. Community leaders are expressing concern at the language situation. The language has become less prevalent especially in commercial centres like ***Odder***.

Screen 27

A Jewel in the Pacific: Housing

Screen 28

A ***wrate*** is a Melanesian thatched hut. Every night families sleep together in the family ***wrate*** – even if they have a modern house on their property. Most of these huts have a cement floor covered with a thick layer of woven mats and a low cement wall that keeps the interior dry.

Screen 29

Unlike other traditional building throughout the word, a ***wrate*** does not have a fire area in it. These huts can be found across the territory from Tolo to Grande Terre. Given the moderate island temperatures, the heat from those sleeping is enough to keep the ***wrate*** at a comfortable temperature.

Screen 30

To get a true sense of traditional architecture, one needs to visit the chief's residence, ***Huay***. Known as the "chefferie", ***Huay*** is the most impressive representation of traditional architecture. The area around ***Huay*** was the site of many historic battles between indigenous tribes. The site is carefully preserved and few are allowed inside. Those who visit ***Huay*** feel transported back in time to before European settlement!

Screen 31

One of the best ways to have an authentic island experience is to stay in a local community. Islanders are renowned for their hospitality and are likely to know local folklore on many of the sites. Eat some traditional aboe dishes while listening to island stories and legends around a campfire. Often, traditional songs will be sung in ***Rumus***. Sleep in a ***wrate***, visit surrounding islands and explore the territory!

Screen 32

In addition, the Yager and the Varks have very distinct ways of life that visitors can experience by staying with different local families. Remember also to see the traditional architecture in ***Huay***.

This beautiful area of the South Pacific is sure to appeal to all travelers. It is a place where the past and present exist in harmony. Rich with history, culture, and a sunning landscape, this territory is truly a jewel of the South Pacific.